Project Number: 5-27858.01 10CAR

# Road Surface Noise Corrections

## Part 1: Large CPX Survey of Road Surfaces

Richard Jackett
WSP Research

15 October 2021

### Contact Details

*Richard Jackett*
WSP Research
33 The Esplanade
Petone
Lower Hutt 5012
+64 4 587 0600
+64 27 548 2451
richard.jackett@wsp.com

*Document Details:*

Date: 15/10/21
Reference: 5-27858.01 10CAR-1
Status: Issue 2

*Prepared by*
Richard Jackett

*Reviewed by*
Peter Cenek

*Client:*
Greg Haldane, *Waka Kotahi*
Stephen Chiles, *on behalf of Waka Kotahi*

## Document History and Status

| Revision | Date | Author | Reviewed by | Status |
|---|---|---|---|---|
| Issue 1 | 22/9/21 | R. Jackett | P. Cenek | Issued |
| Issue 2 | 15/10/21 | R. Jackett | | Issued |

## Revision Details

| Revision | Details |
|---|---|
| Issue 1 | Document issued to client |
| Issue 2 | Additional study on thickness effect in OGPA (section 3,4). Added thickness to Table 3-1 for OGPA 10 and SMA 10. Added summary sheets to Appendix B for nominal thicknesses of OGPA 10 and SMA 10. Changed order of sections in Chapter 3. Most sections have been edited for additional clarity. |

## Disclaimers and Limitations

This report ('Report') has been prepared by WSP exclusively for Waka Kotahi NZ Transport Agency ('Client') in relation to part 1 of using CPX data to refresh the passenger car data in the *NZ Road Surface Adjustments Table* ('Purpose') and in accordance with the Acoustics and Environmental Professional Services Contract Number 2290 dated 13 December 2019 (variation dated 11/11/20). The findings in this Report are based on and are subject to the assumptions specified in "WSP road surface noise research 2021 proposal - Surface corrections for cars - 20201021" provided by email on 21 October 2020 and the subsequent discussions and emails with Waka Kotahi, including after commencement of the work. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

In preparing the Report, WSP has relied upon data, surveys, analyses, designs, plans, reports and other information, including CPX data, road surface data, information in published and unpublished reports, and data sourced from RAMM, ('Client Data') provided by or on behalf of the Client. Except as otherwise stated in the Report, WSP has not verified the accuracy or completeness of the Client Data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in this Report are based in whole or part on the Client Data, those conclusions are contingent upon the accuracy and completeness of the Client Data. WSP will not be liable in relation to incorrect conclusions or findings in the Report should any Client Data be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP.

# Contents

## Abbreviations and Definitions

| | |
|---|---|
| A-weighting | Frequency weighting of noise that mimics human sensitivity to frequency |
| Chipseal | Road surface whose running surface is stones (chip) embedded in binder |
| CPX | Close-proximity Measurement of noise level (using the CPX trailer) |
| CPX:P1:80 | CPX using the P1 (car) tyre carried out at a nominal speed of 80 km/h |
| CRTN | Calculation of Road Traffic Noise (a noise model adopted by NZ) |
| Dual-chip | Chipseal specifications that include 2 distinct chip grades, e.g. RACK, 2CHIP |
| k | Statistical coverage factor for a desired level of confidence, e.g. k=2 is 95% |
| $L_{A10}$ | The A-weighted sound level exceeded for 10% of the measurement time |
| $L_{Aeq(t)}$ | A-weighted energy equivalent sound pressure level over time period, $t$ |
| $L_{Amax}$ | A-weighted maximum sound pressure level |
| Mobile Road | Web-based portal to RAMM surface data (https://mobileroad.org/) |
| NZ | New Zealand |
| NZ Adjustment | An adjustment to localise CRTN to NZ reference conditions (surface, fleet) |
| OGPA | Open-grade Porous Asphalt, a low noise NZ road surface |
| RAMM | Road Assessment and Maintenance Management (software and database) |
| sd | Standard deviation |
| SEL | Sound Exposure Level (measured in dB $L_{AE}$) |
| SLM | Sound Level Meter |
| SH | NZ State Highway |
| Surface Correction | An addition to CRTN noise level to account for surface characteristics |
| Surface Specification | The nominal materials, processes, and chip sizes for a surface (see below) |
| vkt | Vehicle Kilometres Travelled |
| Waka Kotahi | NZ Transport Agency (formerly NZTA) |

### Surface Specification

Each named road surface type in NZ has a published NZTA specification that dictates what materials, properties, and other construction parameters it can have. However, references to a "surface specification" in this report indicate a particular and distinct set of surface material, chip/aggregate size(s), construction process, and in some cases surface thickness. Generally, this is a subset of the published NZTA specification (each of which cover a range of aggregate sizes). The *surf_material*, *chip_size*, and *chip_2nd_size* parameters are readily available from Mobile Road for existing roads, and from project engineering teams for proposed roads, so are appropriate and accessible parameters for defining a road surface specification as it relates to noise. There is evidence that variation in void content and surface thickness [Bull et al, 2021] are relevant to the performance of porous asphalts, but RAMM does not hold void data and it includes thickness data inconsistently (and not via Mobile Road). In this report, when a porous asphalt specification also considers its thickness, that will be explicitly stated (in mm). If no thickness is stated then that specification is defined without consideration of thickness.

# 1 Introduction

## 1.1 Background

Road traffic noise is an inevitable by-product of traffic on NZ's state highway network. Most of this traffic noise is generated by the physical interaction between the tyres and the road surface, and it differs substantially between surface types: chipseals are infamously 'noisy', while asphalts have a reputation as 'quiet surfaces'. As a result, selecting the appropriate surface for new or upgraded state highway roads is the first form of noise mitigation that is considered because it means reducing the traffic noise 'at source' (as opposed to much more expensive barriers, which only block noise for specific receivers).

The opportunity to select the appropriate surface relies on knowing each candidate surface's noise properties in advance of consenting, so that practitioners can incorporate the information into their noise models. The road surface noise corrections (or just "surface corrections") are a set of noise level corrections (in dB) for each surface specification that fulfil exactly that role.

The surface corrections were last derived in the early 2000s [Dravitzki & Kvatch, 2007], and since then both tyre technology and NZ's surface specifications have evolved. Recent research indicated that some of the existing surface corrections may no longer be accurate [Jackett, 2019]. There are also new surfaces already in use on NZ state highways for which no corrections currently exist.

Separate surface corrections are required for cars and for trucks. Recent NZ research [Jackett et al, 2020] concluded that overall road traffic noise levels are far more sensitive to tyre/road emissions from cars than from trucks, and that new surface corrections for cars should be the priority.

## 1.2 Purpose

Waka Kotahi NZ Transport Agency requires that the noise corrections for road surfaces in table 2.1 of the *Guide to state highway road surface noise* [NZTA, 2014] are updated to reflect the surfaces currently laid on the state highway network [NZTA NV5, 2020]. The corrections were previously specified in relation to a reference surface, asphalt AC-10, but Waka Kotahi require that an alternative reference is found, in part because AC-10 is being phased out on state highways.

Waka Kotahi recognised that with the new corrections urgently required, and the budget and timeline constrained, an increased level of uncertainty and risk is expected. The corrections will initially be determined for cars only, with heavy vehicles to follow later. Waka Kotahi need the set of surface specifications to be complete (to the extent that a practitioner is not left to guess at a value to use in a noise assessment).

This project therefore establishes a methodology that uses available data sources and state-of-the-art instrumentation to efficiently determine a new set of draft surface corrections for cars.

## 1.3 Scope

The project consists of two parts, which are reported on separately:

**Part 1** determines the light vehicle tyre/road noise differences between 44 NZ road surface specifications using CPX noise data collected across state highways in 5 regions of NZ.

**Part 2** will aim to relate the CPX levels found in Part 1 back to the CRTN noise model. It will detail the replacement of the reference surface and recalibrate CRTN for the 2021 light vehicle fleet.

<u>This report covers Part 1 only</u>. It contains detail beyond that required to define the corrections and has additional findings on surface noise that will give more confidence in the final corrections.

The corrections for heavy vehicles will be determined separately, by a different method. A final review and ratification of the surface corrections is also likely to follow before they are published.

# 2 Methodology

The very large CPX survey of over 1000 km was conducted over the NZ state highway network and linked to validated data on surface type, condition and age. Average CPX levels for each different surface specification in the dataset were computed.

Full details of this process are provided in Appendix A. An outline of the methodology is provided below.

## 2.1 CPX measurements

CPX instrumentation was used to provide an efficient and accurate sampling of a vast number of road segments of different surface specifications.

CPX noise levels, $L_{CPX:P1,80}$ were measured in the left-wheel-path with the P1 tyre at 80 km/h on state highways across the Auckland, Waikato, Manawatū-Whanganui, Wellington, and Canterbury regions (see Table A-2). 33 contributing CPX surveys were conducted on 1100 km of highway between 2019 and 2021.

## 2.2 Surface types and validation

$L_{CPX:P1,80}$ levels are averages over 20-metre-long road segments, and each has been linked to its corresponding road surface specification using the RAMM state highway database. Each 20-metre segment of the 1100 km has been subject to a manual visual validation process (Appendix A.3), and about 12% were removed, with reasons including: suspect RAMM data; non-representative surface (e.g. it was on a bridge deck); extremely damaged surface. Further filtering by date resulted in a dataset of about 680 lane-km of road surface with valid CPX levels and that was between 6 months and 10 years old[1] at the time of measurement (Table 2-1).

*Table 2-1: CPX data available for analysis after validation and filtering*

| Description | Sample Size (number of 20 m segments) | Equivalent Distance (lane-km) | Percentage of Total |
|---|---|---|---|
| Total Survey Data | 55383 | 1107.7 | 100% |
| After Validation | 48492 | 969.84 | 87.6% |
| Data for Analysis | 34141 | 682.82 | 61.6% |

## 2.3 Characterise surfaces by CPX Level

For each distinct surface specification[2] in the resulting dataset, CPX levels and geographical information were extracted from the CPX database and summary statistics computed (see Chapter 3 and Appendix B), including measures of central tendency of CPX noise emission, age effects, geographic distribution of the sample, and 1/3$^{rd}$ octave spectra.

In total, 44 surface specifications were characterised (including 5 whose definition includes thickness). Of the current top 30 surface specifications on the state highway network by sealed length[3], 26 are represented with CPX level statistics. All of the top 15 surfaces are represented.

[1] This age range strikes a balance between maximising the size of the dataset while excluding surfaces that are not representative of 'typical' road surfaces. It was chosen in consultation with road surface specialists Laurence Harrow (WSP) and Phil Herrington (WSP), and considering fig. 4-7 in Chipsealing in NZ [NZTA, 2005]. Modern asphalts and chipseals have different reseal intervals, but most typically survive for at least 10 years.
[2] Here "surface specification" refers to a construction process and material properties, see Definitions.
[3] For reference, the 30$^{th}$ most common surface exists on 0.5% of the network, by length.

# 3 Results

The large CPX survey resulted in 683 km of useable CPX data from across 5 regions, covering 44 surface specifications. Analysis of this data has provided new insights on the differences between surface specifications, indications on their aging effects, and ways that surface specifications can be meaningfully grouped for the purpose of noise prediction.

When interpreting these results, the reader is reminded that the levels quoted are CPX levels, not wayside levels.

## 3.1 Result Tables

Table 3-1 summarises the results for asphalts, and Table 3-2 summarises the results for chipseals. The information in these two tables is the primary output of this report in terms of contribution to the overall goal of the project. These data form the basis for the difference between road surface corrections that will be computed in Part 2.

In these tables, the code for the surface specification includes the surface type and aggregate size information (refer to B.1.1 for a full explanation and list of full surface specification names). Each surface's rank (by length) within the NZ network is given in the second column. The next two columns give sample size, *n*, and equivalent distance in lane-km. The next two columns give the average age of the sample and its standard deviation. The three columns starting with "distinct…" give an indication of how geographically diverse the sample is. The six columns whose units are decibels (dB) are estimates of either central tendency or spread of the CPX levels in dB $L_{CPX:P1,80}$. The final two columns report the statistical significance of any surface aging effect with respect to noise, and its magnitude. If they are in grey, then no statistically significant aging effect was found.

For OGPA 10 and SMA 10, the surface specification definitions have been expanded to include the nominal surface thickness. The initial OGPA 10 entry in Table 3-1 contains all available OGPA 10 data without regard to thickness, and the following three entries introduce filtering by the stated thickness. Similarly, for SMA 10, the initial entry is all the data, and the following two entries are the same starting data but filtered by nominal thickness.

Further information for interpretation of columns is provided in Appendix B.1.

*Table 3-1: Summary of Results from a Large CPX Survey of Asphalt*

| Surface Code | Rank in network | n | Distance (km) | Avg Age (yr) | SD Age (yr) | Distinct Sites | Distinct Regions | Distinct Councils | Average Level (dB) | SD Level (dB) | Mode (dB) | Median (dB) | Lower Quartile (dB) | Upper Quartile (dB) | Slope with age (dB/yr)* | 95% CI on slope (± dB/yr)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AC 10 | 27 | 66 | 1.32 | 5.3 | 1.6 | 6 | 2 | 3 | 98.26 | 0.84 | 98.00 | 98.22 | 97.55 | 98.87 | -- | -- |
| UTA 10 | 34 | 141 | 2.82 | 4.7 | 2.3 | 12 | 3 | 5 | 97.53 | 1.55 | 97.50 | 97.69 | 96.72 | 98.62 | +0.38 | 0.22 |
| OGPA 10 ◊ | 6 | 8871 | 177.42 | 3.7 | 2.1 | 121 | 3 | 8 | 97.46 | 1.71 | 98.00 | 97.60 | 96.35 | 98.66 | -0.01 | 0.16 |
| 30 mm | -- | 3592 | 71.84 | 4.1 | 2.2 | 42 | 3 | 6 | 96.85 | 1.62 | 97.50 | 96.98 | 95.68 | 98.09 | +0.14 | 0.13 |
| 40 mm | -- | 16 | 0.32 | 6.0 | 0.0 | 1 | 1 | 1 | 97.80 | 0.84 | 97.50 | 97.71 | 97.31 | 98.44 | -- | -- |
| 50 mm | -- | 159 | 3.18 | 4.6 | 0.9 | 2 | 1 | 1 | 95.48 | 1.73 | 95.50 | 95.15 | 94.38 | 95.84 | -- | -- |
| OGPA 14 | 21 | 453 | 9.06 | 6.8 | 3.0 | 14 | 4 | 7 | 98.11 | 1.73 | 97.50 | 97.93 | 96.90 | 99.34 | 0.07 | 0.34 |
| OGPA 15 | 41 | 457 | 9.14 | 7.3 | 1.7 | 5 | 3 | 4 | 98.02 | 1.21 | 98.00 | 98.01 | 97.17 | 98.87 | -- | -- |
| OGPAH 10 | 30 | 55 | 1.1 | 5.2 | 3.2 | 6 | 2 | 3 | 98.71 | 1.61 | 99.50 | 99.09 | 98.35 | 99.74 | -- | -- |
| EPA 10 § | 24 | 1493 | 29.86 | 2.2 | 0.8 | 17 | 2 | 2 | 97.91 | 2.21 § | 98.00 | 97.77 | 96.44 | 99.22 | -- | -- |
| EPA 14 | 70 | 109 | 2.18 | 4.0 | 1.2 | 4 | 2 | 2 | 97.97 | 1.30 | 97.50 | 97.89 | 97.12 | 98.80 | -- | -- |
| EPA 7 | 54 | 1206 | 24.12 | 1.2 | 0.5 | 9 | 1 | 1 | 92.90 | 1.28 | 93.00 | 92.89 | 92.03 | 93.81 | -- | -- |
| EPAHV 10 | 148 | 42 | 0.84 | 2.3 | 0.2 | 2 | 1 | 1 | 95.67 | 0.53 | 95.50 | 95.60 | 95.30 | 95.99 | -- | -- |
| SMA 8 | 48 | 12 | 0.24 | 4.8 | 0.0 | 1 | 1 | 1 | 98.76 | 0.38 | 98.50 | 98.64 | 98.52 | 98.97 | -- | -- |
| SMA 10 ◊ | 11 | 4312 | 86.24 | 0.9 | 0.7 | 28 | 4 | 7 | 97.42 ‡ | 0.82 | 98.00 | 97.54 | 96.92 | 98.03 | +0.20 | 0.17 |
| 40 mm | -- | 356 | 7.12 | 1.6 | 0.9 | 12 | 2 | 3 | 97.15 | 0.90 | 97.00 | 97.18 | 96.64 | 97.84 | -- | -- |
| 50 mm | -- | 3798 | 75.96 | 0.8 | 0.0 | 6 | 1 | 1 | 97.45 | 0.77 | 98.00 | 97.57 | 96.97 | 98.04 | -- | -- |
| SMA 11 | 25 | 40 | 0.8 | 5.2 | 2.4 | 4 | 2 | 3 | 97.57 | 2.99 | 99.50 | 99.22 | 93.92 | 99.77 | -- | -- |
| SMA 12 | 65 | 19 | 0.38 | 6.5 | 0.8 | 2 | 1 | 1 | 99.43 | 0.30 | 99.50 | 99.44 | 99.24 | 99.60 | -- | -- |
| SMA 14 | 47 | 19 | 0.38 | 5.0 | 0.1 | 2 | 1 | 1 | 98.57 | 0.42 | 98.50 | 98.64 | 98.51 | 98.73 | -- | -- |
| SMA 15 | 37 | 71 | 1.42 | 6.5 | 2.1 | 5 | 3 | 3 | 98.85 | 0.68 | 99.00 | 98.91 | 98.43 | 99.32 | -- | -- |
| ENRAC† | 29 | 1267 | 25.34 | 1.9 | 1.1 | 9 | 2 | 4 | 98.27 | 1.41 | 99.50 | 98.65 | 97.46 | 99.30 | -- | -- |

* The slope of the age effect is shown in black if statistically significant at 95%, otherwise grey. The slope is only given where it was appropriate to calculate it.
◊ The main entry contains all records regardless of thickness. The rows below are filtered by the nominal thickness shown. 58% of PA-10 records had no thickness data.
† ENRAC is an asphalt rejuvenation treatment rather than a surface specification. It is included only for interest.
‡ 97.42 dB is the true arithmetic average of the SMA 10 levels. After correcting for sample age, a value of 97.9 dB is obtained (see section 3.3.4).
§ Incorrectly coded EPA 10 sections were removed through the validation process (see A.2) but some segment levels still appear suspiciously high and variable.

*Table 3-2: Summary of Results from a Large CPX Survey of Chipseal*

| Surface Code | Rank in network | n | Distance (km) | Avg Age (yr) | SD Age (yr) | Distinct Sites | Distinct Regions | Distinct Councils | Average Level (dB) | SD Level (dB) | Mode (dB) | Median (dB) | Lower Quartile (dB) | Upper Quartile (dB) | Slope with age (dB/yr)* | 95% CI on slope (± dB/yr)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1CHIP 2 | 10 | 655 | 13.1 | 4.3 | 3.3 | 18 | 2 | 4 | 101.58 | 0.68 | 101.50 | 101.57 | 101.23 | 101.98 | -0.05 | 0.14 |
| 1CHIP 3 | 3 | 1717 | 34.34 | 7.2 | 2.8 | 24 | 3 | 6 | 101.40 | 0.57 | 101.50 | 101.40 | 101.05 | 101.81 | -0.03 | 0.16 |
| 1CHIP 4 | 20 | 551 | 11.02 | 5.6 | 1.1 | 7 | 2 | 4 | 100.38 | 0.72 | 100.50 | 100.50 | 100.14 | 100.78 | -- | -- |
| 1CHIP 5 | 9 | 1780 | 35.6 | 6.0 | 2.7 | 26 | 4 | 8 | 99.89 | 0.61 | 100.00 | 99.90 | 99.53 | 100.22 | -0.01 | 0.13 |
| 1CHIP 6 | 49 | 36 | 0.72 | 1.2 | 0.0 | 1 | 1 | 1 | 99.25 | 0.38 | 99.00 | 99.23 | 99.03 | 99.45 | -- | -- |
| 2CHIP 2/4 | 1 | 2004 | 40.08 | 4.3 | 2.5 | 47 | 4 | 13 | 101.09 | 0.81 | 101.00 | 101.04 | 100.50 | 101.64 | -0.09 | 0.11 |
| 2CHIP 2/5 | 5 | 280 | 5.6 | 2.2 | 0.8 | 16 | 2 | 5 | 101.26 | 0.68 | 101.50 | 101.33 | 100.88 | 101.73 | -- | -- |
| 2CHIP 3/5 | 2 | 2374 | 47.48 | 6.5 | 2.5 | 63 | 4 | 10 | 101.14 | 0.85 | 101.50 | 101.21 | 100.59 | 101.75 | 0.05 | 0.08 |
| 2CHIP 4/5 | 35 | 116 | 2.32 | 6.3 | 0.0 | 1 | 1 | 1 | 101.13 | 0.47 | 101.00 | 101.10 | 100.81 | 101.36 | -- | -- |
| 3CHIP 3/5/6 | 33 | 27 | 0.54 | 1.1 | 0.0 | 1 | 1 | 1 | 101.02 | 0.40 | 101.00 | 101.00 | 100.70 | 101.27 | -- | -- |
| BS 2/4 | 13 | 511 | 10.22 | 3.4 | 1.9 | 10 | 2 | 4 | 100.67 | 0.75 | 100.50 | 100.64 | 100.12 | 101.19 | -- | -- |
| BS 3/5 | 12 | 837 | 16.74 | 6.6 | 1.3 | 8 | 2 | 5 | 101.46 | 0.87 | 102.00 | 101.63 | 100.91 | 102.09 | -- | -- |
| COMB 2/4 | 23 | 46 | 0.92 | 0.8 | 0.0 | 1 | 1 | 1 | 101.92 | 0.38 | 102.00 | 101.99 | 101.81 | 102.12 | -- | -- |
| COMB 2/5 | 16 | 65 | 1.3 | 1.6 | 0.0 | 1 | 1 | 1 | 101.42 | 0.50 | 101.50 | 101.44 | 101.06 | 101.75 | -- | -- |
| COMB 3/5 | 17 | 146 | 2.92 | 2.8 | 3.0 | 3 | 2 | 3 | 100.95 | 0.93 | 101.50 | 101.21 | 100.21 | 101.69 | -- | -- |
| RACK 2/4 | 7 | 662 | 13.24 | 3.5 | 2.9 | 13 | 3 | 7 | 101.47 | 0.76 | 101.50 | 101.47 | 101.02 | 101.98 | -0.11 | 0.24 |
| RACK 2/5 | 15 | 396 | 7.92 | 2.9 | 1.2 | 9 | 1 | 2 | 101.60 | 0.52 | 101.50 | 101.64 | 101.31 | 101.93 | -- | -- |
| RACK 3/5 | 4 | 1676 | 33.52 | 6.1 | 1.9 | 17 | 4 | 9 | 101.15 | 0.89 | 101.50 | 101.28 | 100.83 | 101.71 | 0.00 | 0.20 |
| RACK 3/6 | 81 | 10 | 0.2 | 4.1 | 0.0 | 1 | 1 | 1 | 101.01 | 0.44 | 101.00 | 100.99 | 100.78 | 101.24 | -- | -- |
| RACK 4/6 | 18 | 408 | 8.16 | 3.0 | 0.1 | 6 | 2 | 3 | 99.97 | 0.75 | 100.00 | 100.05 | 99.41 | 100.53 | -- | -- |
| VFILL 5† | 8 | 727 | 14.54 | 5.4 | 2.5 | 13 | 3 | 6 | 99.88 | 0.87 | 100.00 | 99.89 | 99.29 | 100.42 | -0.04 | 0.31 |
| VFILL 6† | 31 | 303 | 6.06 | 2.4 | 1.9 | 5 | 2 | 3 | 99.30 | 0.77 | 99.00 | 99.19 | 98.75 | 99.74 | -- | -- |

* The slope of the age effect is shown in black if statistically significant at 95%, otherwise grey. The slope is only given where it was appropriate to calculate it.
† VFILL is a void fill treatment for chipseals rather than a 'standalone' surface specification.

## 3.2 Findings for Individual Surface Specifications

Individual summary sheets for each surface specification have been provided in Appendix B, which include additional summary statistics and frequency distributions of CPX levels, the aging effect, and the frequency spectrum. Findings and observations across surface specifications are given below, with additional detail on individual aging effects to be found in section 3.3.

### *3.2.1 Dense Asphalts (AC and UTA)*

The sample of Asphaltic Concrete AC-10 from state highways was tiny so it has been bolstered by two non-state highway surfaces. With just 3 distinct roads it remains small, but provides a link back to the incumbent reference surface for CRTN. Its variability was higher than ideal for a reference surface (sd = 0.8 dB), though this may be an artefact of the small sample.

Ultra-thin Asphalt (UTA) is used to solve very specific engineering requirements, and consequently appears in short lengths across the network. Its variability in CPX level within-sites was low (sd ≈ 0.4) but between-site variability[4] was very high (sd = 1.6 dB), reflecting the diverse range of situations the sample was drawn from.

### *3.2.2 Porous Asphalts (OGPA and EPA)*

The porous asphalts were strongly represented, making up over a third of the total sample, which is in large part due to their status as low noise road surfaces driving interest in having them surveyed by the CPX trailer. These specifications (and SMA) are commonly laid on urban dual-carriageways, across multiple lanes.

As has been seen previously [Lester et al, 2017; Bull, 2020] the variability of the porous asphalts was particularly high in relation to most other surface specifications: a standard deviation of 1.7 dB is representative. This undesirable attribute also applies to the newer epoxy-modified EPA surface specification, which has a representative standard deviation of 1.8 dB. The within-site component of variability was also very high for these surfaces, typically between 1 dB and 2 dB. The broad distributions for both OGPA and EPA will make selection of 'typical' road/tyre CPX levels for each specification difficult.

Surface thickness is relevant to the acoustic performance of porous asphalts, but was not recorded in RAMM for 58% of the OGPA 10 sample. The majority of OGPA 10 in the sample is assumed to be nominally 30 mm thick, but the records without a recorded thickness averaged 1 dB higher than the 30 mm specification, which is surprising.

No significant aging effect was found for PA-10 overall, within the very large sample of nearly 9000 road segments that represented all 10 possible surface ages. However, the 30 mm subset had a small aging effect of +0.14 dB/year ± 0.13 dB/year ($p<0.05$).

The epoxy-modified EPAs were much younger than the traditional OGPAs on average (2.8 years vs. 5.7 years), which reflects their recent introduction. In theory the EPA specifications are resilient and should outlast the OGPA specifications they are intended to replace [Bull et al, 2021]. There is insufficient data to indicate whether EPA has an aging effect.

### *3.2.3 Stone Mastic Asphalt (SMA)*

For the SMA across the state highway network, the 10 mm maximum aggregate size covers more kilometres than all the other aggregate sizes combined. In this study SMA-10 forms 96% of the SMA sample, due to long stretches laid recently on the Waikato Expressway (which itself represents about 90% of the SMA-10 sample).

[4] A definition for "within-site" and "between-site" variability is provided in section 3.6.1.

The overall variability of SMA-10 was low (sd = 0.8 dB) compared to the porous asphalts. In general, the within-site variability of all the SMAs was very low (sd in the range 0.3 dB to 0.7 dB).

SMA-10 has a statistically significant aging effect of +0.20 dB/year ± 0.17 dB/year ($p<0.05$). The mean age of the sample is 1 year old, so some adjustment to the mean may be desirable when determining the 'typical value' for CPX level for this specification (section 3.3.4).

There is no clear hierarchy in CPX level with maximum aggregate size. However, only SMA-10 and SMA-15 achieve more than 1 km of surface, so any patterns may be hidden by statistical variation.

SMA-15 showed remarkable consistency between regions and over time, but this may be an artefact of the small sample size.

### *3.2.4 Enrichment Seal Over Asphalt (ENRAC)*

ENRAC is not a surface specification, it is a surface enrichment, or rejuvenation, treatment that aims to counteract ravelling in asphalts and extend surface life.

The treatment involves coating an existing (usually OGPA) surface with a low viscosity bitumen that flows into voids to increase the binder content of the layer. The process has the potential to reduce surface texture [Austroads, 2019] and perhaps to reduce void content.

It is presumed that the resulting tyre/road noise emission will be strongly influenced by the underlying surface. This study has not investigated whether or not ENRAC contributes its own effect, but there may be sufficient data to do so (25 lane-km).

### *3.2.5 Single Coat Chipseal (1CHIP)*

The 1CHIP specifications all showed low overall variability within their grade (sd = 0.6 dB was typical) and the distributions were mostly symmetrical about the mean.

None showed a significant aging effect over the 10-year age range examined.

There is a general decline in noise emission with increasing grade (decreasing chip size) of roughly -0.5 dB/grade. This is examined further in section 3.5.

An indicative between-site variability of sd = 0.6 dB has been estimated for 1CHIP chipseals from specifications with a large number of sites: 1CHIP2 (sd=0.49 dB, n=18), 1CHIP 3 (sd=0.46 dB, n=24) and 1CHIP5 (sd=0.65 dB, n=26).

### *3.2.6 Dual-Chip Chipseals (2CHIP, RACK, COMB, B/S, 3CHIP)*

The dual-chip[5] chipseals covered by the CPX survey include the general specifications Two-coat (2CHIP), Racked-in (RACK), Combination (COMB), and Sandwich (B/S). All use two different grades of chip, but differ in how, where, or when the chip and bitumen are applied to the road [NZTA, 2005 §3]. 3CHIP is also included here, which includes one grade of large chip and two different small chip grades.

The effect of chip size is significant, and is addressed generally in section 3.5. Essentially there is a decline in noise emission with increasing grade of the largest chip of roughly -0.5 dB/grade.

Holding the grade of chip constant, the different specifications provide similar results in terms of CPX level. The average level of the 2/4 and 3/5 chip combinations for each of the four general specifications is shown in Figure 3-1. The error bars represent the error of the mean of distinct sites (rather than of 20-metre segments) at 95% confidence. Within our sample the differences between specifications aren't statistically significant, nor are they substantial, suggesting there is no particular advantage or disadvantage to using one general specification over another, in terms of noise level. Finding 4.2.4 in Chapter 4 contains further comment on this.

---

[5] Also known as multi-coat chipseals, and sometimes, ambiguously, as two-coat chipseals.

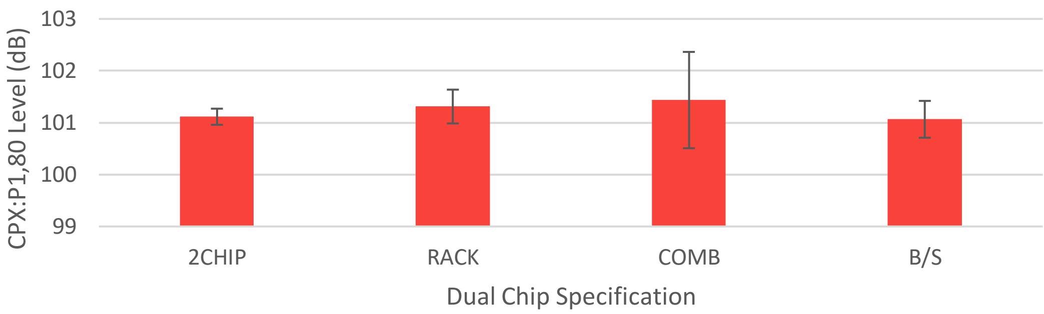



*Figure 3-1: Comparison of dual-chip CPX levels (average of 2/4 and 3/5)*

Out of the 15 different dual-chip specifications in the sample, none showed a statistically significant aging effect.

An indicative between-site variability of sd = 0.7 dB has been estimated for dual-chip chipseals from specifications with a large number of sites: 2CHIP 3/5 (sd=0.68 dB, n=63), 2CHIP 2/4 (sd=0.67 dB, n=47) and RACK 3/5 (sd=0.66 dB, n=17).

### *3.2.7 Voidfill (VFILL)*

A voidfill seal is a treatment for chipseal surfaces whose texture is too high (coarse) or that are starting to lose chip. It involves a single application of a small chip, typically grade 5 or 6, to fit into the macrotexture of the existing surface and reduce the texture.

It was expected that VFILL would behave similar to a dual-chip specification and be strongly influenced by the properties of the underlying coarse surface, but that was not what was found. Average levels for both VFILL 5 and VFILL 6 were indistinguishable from their 1CHIP 5 and 1CHIP 6 counterparts, respectively (within 0.05 dB). However, the variation amongst VFILL was about 50% higher than for 1CHIP. These four specifications, using the grade 5 and grade 6 chip, were the quietest chipseals in the dataset.

### *3.2.8 Surfaces Not Included in Sample*

Five specifications within the top thirty most common on the state highway network[3] were not in the final dataset, either because they weren't encountered on the survey or were excluded based on condition or date (section A.3).

- 2CHIP 4/6 would be expected to perform similarly to 2CHIP 4/5 and RACK 4/6, but these two specifications are separated by over 1 dB. For the time-being, an estimated level of 100.5 dB could be assumed.
- TEXT 5, is a texturizing treatment similar to VFILL, except that it can also add texture to isolated areas. Without additional data, it should be assumed that the acoustic properties of the underlying surface specification remain dominant.
- AC-14 was captured in the survey, but just 80-metres that were 12 years old at the time of measurement. The mean of 99.3 dB $L_{CPX:P1,80}$ is plausible, but higher than expected and may not be representative.
- COMB 4/5 would be expected to perform similarly to 2CHIP 4/5 and RACK 4/6, but these two specifications are separated by over 1 dB. For the time-being, an estimated level of 100.5 dB could be assumed.
- AC-15 was not captured. It's family members, AC-10 and AC-14, are also not well-defined.

Additionally, no slurry or cape seals were captured in the survey. These specifications are very uncommon, making up about 0.3% of the network in total. They are fundamentally different from the asphalt and chipseal surface types, making it difficult to extrapolate their performance.

## 3.3 Surface Age and Aging

Examining the aging effect was outside the core purpose of this project but is advantageous in determining a 'typical' CPX level for specifications, especially when their sample is skewed to either the young or old end of the age range. Ideally aging effects would be quantified by a longitudinal study of various specific surfaces over time, and accounting for traffic loading, but this data is not yet available in NZ. Instead, the slope of CPX level against surface age is found across *different* surfaces, which have been grouped by age. In many cases all the data of a particular age came from a single site, so these relationships should be treated as 'informative' and should not be accepted as definitive proof of an aging effect, nor proof of the lack of one[6].

In the current dataset, one third of the specifications captured had sufficiently diverse data across different surface ages to examine age effects.

### *3.3.1 Presence of an Aging Effect*

Statistically significant ($p<0.05$) aging effects were found for 3 surface specifications:

| | | |
|---|---|---|
| OGPA 10 30 mm | +0.14 dB/year ± 0.13 dB/year | (9 distinct ages) |
| SMA 10 (all) | +0.20 dB/year ± 0.17 dB/year | (9 distinct ages) |
| UTA 10 | +0.38 dB/year ± 0.22 dB/year | (6 distinct ages) |

OGPA 10 that was nominally 30 mm thick showed a small but statistically significant aging effect ($p=0.04$). This will be discussed below in section 3.3.2.

The aging effect of SMA 10 has a broad 95% confidence interval from essentially no aging effect up to +1 dB every two and a half years. Nevertheless, it is statistically significant, and could be helpful for correcting the current sample of SMA 10, which is particularly young.

The apparent aging effect of UTA is surprisingly large, and could be an anomaly – this surface was noted to have high variability between sites – or could be a cause of that variability.

### *3.3.2 Absence of an Aging Effect*

Determining where an aging effect is not present requires placing a tolerance around a slope of zero, and for this we have arbitrarily chosen a magnitude of 1 dB per 5 years. The following seven surfaces have slopes of $L_{CPX:P1,80}$ with age that are less than |±0.2 dB/year| at the 95% confidence level:

| | | |
|---|---|---|
| OGPA 10 (all) | -0.01 dB/year ± 0.16 dB/year | (10 distinct ages) |
| 1CHIP 2 | -0.05 dB/year ± 0.14 dB/year | (6 distinct ages) |
| 1CHIP 3 | -0.03 dB/year ± 0.16 dB/year | (7 distinct ages) |
| 1CHIP 5 | -0.01 dB/year ± 0.13 dB/year | (10 distinct ages) |
| 2CHIP 2/4 | -0.09 dB/year ± 0.11 dB/year | (10 distinct ages) |
| 2CHIP 3/5 | +0.05 dB/year ± 0.08 dB/year | (10 distinct ages) |
| RACK 3/5 | +0.00 dB/year ± 0.20 dB/year | (6 distinct ages) |

Together these surface specifications cover approximately 56% of the NZ state highway network.

Grouping all thicknesses of OGPA 10 together (incl. unspecified thickness) finds an aging effect of -0.01 dB/year ± 0.16 dB/year, whereas in the previous section nominally 30 mm thick OGPA 10

[6] Traffic loading is an important driver of surface deterioration, and was not considered in this analysis. A brief examination of the distribution of OGPA 10 levels against sites with different traffic loadings did not suggest that particular sample was biased by traffic loading differences. The 10-year window of this analysis is at the limit of some asphalts' design life. Caveat emptor.

increased by +0.14 dB/year ± 0.13 dB/year. As noted in section 3.2.2, the subset that is labelled as 30 mm thick appears to behave slightly differently from the average. The overall 'no substantial age effect' result for OGPA 10 echoes the general findings of the previous NZ study on long-term acoustic performance of OGPA [Lester et al, 2017], which used a similar methodology with a different CPX system. That study found approximately +0.2 dB/year aging effect, ignoring surface thickness. We note that the current brief analysis has not investigated whether there is any bias[6] in the sample that could affect the conclusion on aging.

The null-results for aging of the chipseals are particularly interesting. Generally, chipseals have a design life in the region of 10 years (subject to a number of considerations) and can fail prematurely in various ways, with the most common mode on state highways being flushing (loss of texture) [NZTA, 2005 §4]. Prior to the point of failure due to flushing[7], the contributing effects of binder rise and chip embedment, which generally accumulate over time, can reduce surface texture, as can the separate effect of chip rotation (although that often occurs soon after laying). Conversely, chip loss can increase surface texture. Given that surface texture generally reduces with surface age [NZTA, 2005 §4] and noise emission decreases with decreasing macrotexture [Jackett, 2019], it could be assumed that the noise emission of chipseals would reduce over their lifetimes. The data above suggest that on average the long-term acoustic performance of chipseal, beyond the first 6 months, is actually relatively stable, and if the hypothesised effect exists it is fairly weak after averaging across many surfaces. A more thorough examination of the data, incorporating the mean profile depth and a more rigorous assessment of the state of the road surface, would be required to gain further insight into why this is.

Notwithstanding the limitations of this study, these are important findings for OGPA and chipseal, and mean that the end users of road noise assessments can have reasonable confidence that noise level predictions apply to most of the lifetime of the road surface, not just to a particular time after it was laid.

### 3.3.3 Reference Age

Within the bounds of 6 months to 10 years old imposed on individual road segments (section 2.2), the average age of surface specification data in Table 3-1 and Table 3-2 ranges from 10-months-old (COMB 2/4) to 7.3-years-old (OGPA 15).

There is no pre-existing definition for a 'typical' or reference age of a road surface that road surface corrections (for example) should try to represent. Nor, judging by the results from section 3.3.2, is it likely to have great consequence from an acoustic point of view. However, it is preferable to have it defined for the outputs of this project, and so that some data can be corrected for age, where necessary, to achieve a like-for-like comparison across all specifications.

We have selected 4 years as the reference age, which should be in the first half of most surface specifications' design lives, while still allowing a lot of time for settling-in due to time and traffic. This is also the average age of surfaces within the current sample, which minimises error due to any undiscovered aging effects.

### 3.3.4 Correction for Surface Age

In general, corrections for surface age were not required for the data in Table 3-1 and Table 3-2. Only when the average age of a surface differed from the reference age by more than 2 years and had a known aging effect, was a correction considered.

Based on the findings of section 3.3.2, it was not necessary to correct any of the OGPA or chipseal specifications for surface age. There were either no aging effects, or the sample age was close to 4 years old, or both.

[7] About 1% of the chipseal surfaces surveyed for this study were excluded due to extreme flushing, but anything short of extreme remained, as we wished to capture the 'typical condition' of NZ chipseal.

The EPA surfaces in the dataset are young (averaging 2.5 years old) but, without evidence to suggest otherwise, were assumed to behave similarly to OGPA, and therefore no correction for age was applied.

SMA 10 has a significant age effect of +0.2 dB/year (section 3.3.1) and its sample of road segments averages less than one year old. With reference to its summary sheet (B.4), an age- corrected SMA 10 CPX level was taken from its regression line at age 4, giving 97.9 dB. The other SMA specifications have average ages around 5 years and no correction for age was applied.

Finally, the average ages of AC 10 and UTA 10 are both about 5 years old and did not require correction.

## 3.4 Thickness Effect in OGPA

A surface thickness effect for porous asphalts has been found overseas [Sandberg & Ejsmont, 2002] and there is evidence that the effect also exists in NZ porous asphalts [Bull et al, 2021]. The CPX dataset contains a field for the nominal surface thickness (RAMM's *ovlay_depth*) in millimetres, but it is only populated for about 50% of records. There is sufficient data to tentatively attempt[8] an analysis for the OGPA 10 specification, but not for any other porous asphalt types (due to lack of diversity in *ovlay_depth*). SMA 10 showed essentially no difference in noise level between 40 mm and 50 mm nominal thicknesses, so was not studied further.

### *3.4.1 Analysis of CPX Noise Level Data*

The full set of thickness data (n=4566) is shown in Figure 3-2 along with an indicative least squares linear fit to the 20-metre $L_{CPX:P1,80}$ levels (which is not statistically significant).

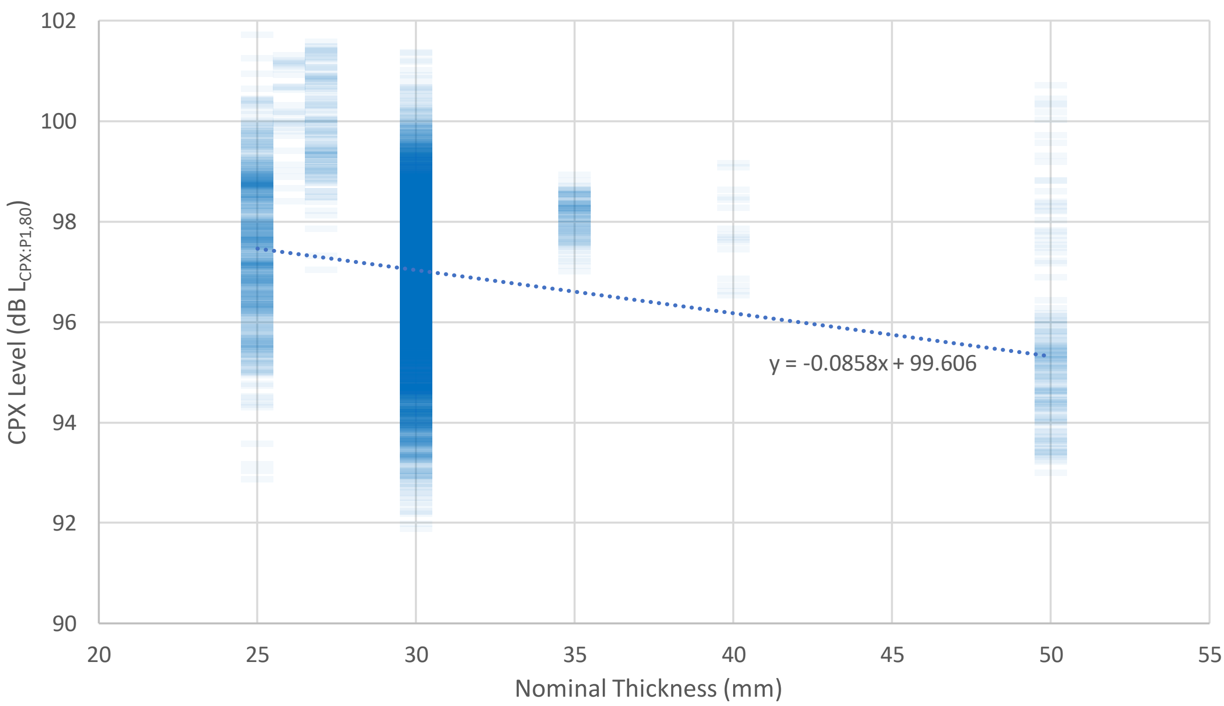



*Figure 3-2: 20-metre CPX levels for OGPA 10 by nominal thickness*

The 30 mm thickness accounts for more than three quarters of the OGPA 10 sample, and thicker surfaces are not well populated. The 50 mm data comes from just two sites, and has a very high variance.

[8] Ideally this analysis would take place as part of a broader consideration of factors thought to influence OGPA's acoustic performance, including surface texture, thickness, porosity, and tortuosity.

A weighted linear regression of the average level for each thickness has been attempted, noting that confidence in average $L_{CPX:P1,80}$ is not homogeneous between thicknesses. There is no uncertainty in the independent variable, as by definition it is the nominal thickness (not the actual thickness). Uncertainty in the dependent variable is estimated at the k=1 level from the CPX measurement uncertainty (assumed[9] ±0.5 dB) and the standard error of the mean calculated based on the number of distinct sites sampled under each thickness. The square of its inverse was used to weight the means in the linear regression.

Figure 3-3 shows the average $L_{CPX:P1,80}$ levels for OGPA 10 by surface thickness. The area of each dot indicates its share of the total number of sites. The error bars show the 95% interval of measurements contributing to the mean. The weighted least squares linear fit to the average CPX levels is shown, but is not statistically significant.

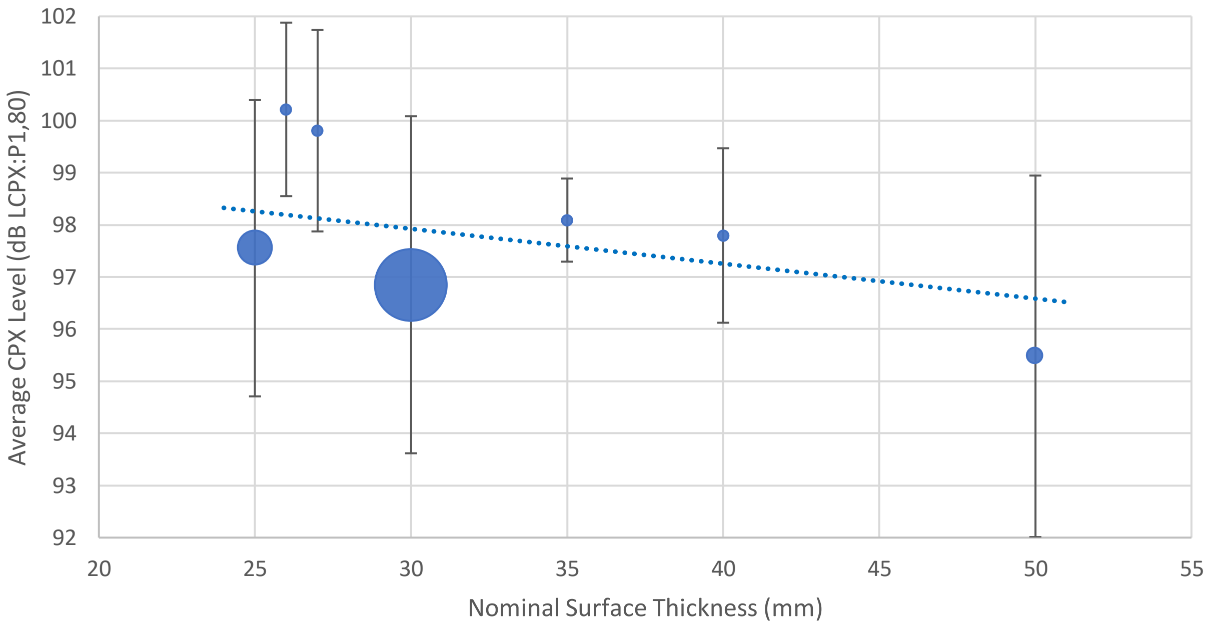



*Figure 3-3: Weighted regression of the mean CPX level of OGPA 10, grouped by thickness.*

The weighted linear regression of average $L_{CPX:P1,80}$ to nominal surface thickness found a least-squares fit of $L_{CPX:P1,80}$ = 100.3 – 0.079 * *nominal thickness* (mm), in dB, but this was not statistically significant ($r^2$=0.18, n=7, p=0.35).

A thickness effect of approximately -0.8 dB/cm of nominal surface thickness is tentatively indicated, but the 95% confidence interval on this effect is very large: (-2.7, 1.2) dB/cm. This is the best available estimate for the magnitude of the effect of nominal OGPA thickness on CPX level, but should be treated with a lot of caution.

For context, a recent study of actual (measured) thickness of EPA 7 [Bull et al, 2021] found an effect of -2.2 dB/cm (n=9). Unpublished data from a different NZ study of actual EPA 7 thickness provisionally indicates -0.3 dB/cm (n>1000).

### 3.4.2 Theoretical Absorption Frequency Band

Examination of the theory behind acoustic absorption of porous materials reveals that surface thickness should affect the magnitude of acoustic absorption of porous surfaces, and the frequency range over which it occurs. Acoustic absorption may therefore be an underlying mechanism for the thickness effect observed in NZ porous asphalts.

---

[9] No formal estimate of uncertainty for the Waka Kotahi CPX trailer was available

The theoretical effect of thickness on the frequency of peak absorption is a reduction of approximately one octave per doubling of thickness [Berengier et al, 1990]. The width of the peaks, and the amount of absorption between peaks, is influenced strongly by porosity. For the range of porosity expected in NZ, say 15%-25% voids, the absorption spectrum remains very 'peaky' – at most a few hundred Hz wide. Therefore, if absorption is to provide a noise benefit then it is important that its peak frequency aligns well with the frequencies of peak tyre/road noise emission. For cars on asphalt this is 800 Hz to 1000 Hz.

Acoustic absorption was shown to significantly reduce the magnitude of the horn effect[10] for overseas porous asphalts when its peak was well-aligned to the peak noise emission frequency [Peeters et al, 2016]. The horn effect is typically associated with noise directed to the fore and aft of the tyre, and it is not known how much of this effect is captured by the Waka Kotahi CPX trailer, which has microphones located laterally to the tyre, but also some reflection within the wheel bay.

Assuming 'usual' values for shape factor (*K*=3.5), porosity (Ω=0.20), and air flow resistance (*R*s=20 rayls/cm), approximate fundamental frequencies for peak absorption have been calculated following Berengier et al [1990] for surface thicknesses of 30 mm, 40 mm, and 50 mm. These are indicated by vertical bands (of arbitrary thickness) in Figure 3-4. The solid lines in the figure are the average measured CPX spectra of OGPA 10 for surfaces with those three nominal thicknesses.

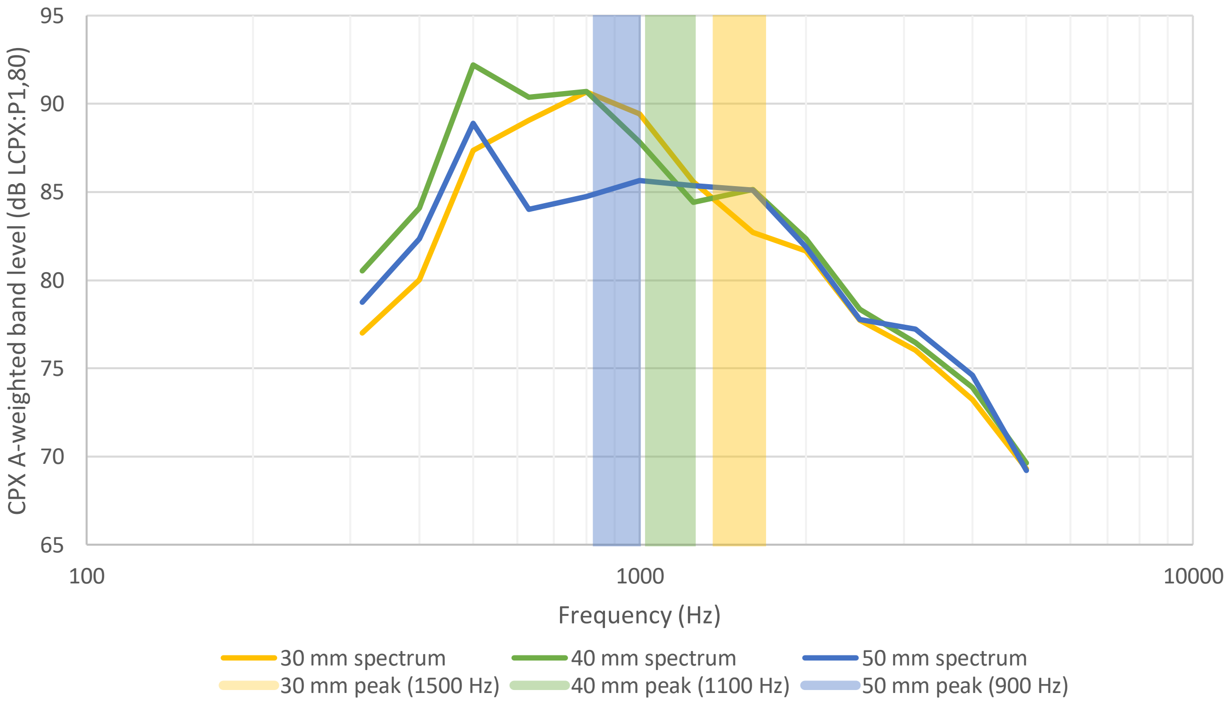



*Figure 3-4: Measured CPX:P1,80 OGPA 10 spectra by surface thickness (solid lines). Vertical bands estimate theoretical peak absorption frequency.*

Within the frequency range 630 Hz to 2000 Hz there is some indication that local minima in each average measured spectrum correspond with peaks in theoretical absorption. Particularly interesting is that the expected 800 Hz peak of OGPA is completely flattened at 50 mm (within this small sample), which aligns well with the theoretical peak absorption at approximately 900 Hz. The reasons for the high levels in the 500 Hz band are not known, but fall outside the main absorption frequency band.

In itself, this visual comparison is not evidence that absorption drives the thickness effect. However, it is consistent with that mechanism and it suggests that further investigation may be worthwhile.

[10] An amplifying effect arising from the horn-shaped geometry formed by the (front and rear) tread surface of the tyre and the road surface.

Particularly, should thickness be characterised as an additive reduction in dB/cm (as in section 3.4.1) or as a means of 'tuning' absorption to the optimal frequency band?

### *3.4.3 Specification of Asphalt Thickness*

Waka Kotahi are currently changing how asphalt thickness is specified when it is used for noise mitigation. Currently the specified thickness is notionally an average, but in future it is intended to be a minimum. It is yet to be seen what impact this will have on actual surface thickness, but it may affect the offset of the surface effect more than it affects the slope.

## 3.5 Dominance of Largest Chip Size

In the 2019 chipseal study [Jackett, 2019], two hypotheses were offered that could not be tested at that time:

> a) *on average, the noise emission of the dual-chip surfaces is dominated by the larger chip size; and more broadly,*
>
> b) *the noise emission of any chipseal surface (single- or dual-chip) is dictated by the largest chip size present.*

The large CPX survey conducted for the current project now allows for these hypotheses to be tested, as it contains 100 km of single-chip surfaces and 200 km of dual-chip surfaces, covering 20 distinct surface specifications in total.

### *3.5.1 Correlation*

As illustrated in Figure 3-5, there is a strong negative relationship between the largest chip size and the average CPX level of a chipseal surface specification (blue line). The single chip specifications are included in the graph (red dots), and obey a very similar linear relationship (red line), falling within the range of dual-chip specifications of the same grade. The voidfill specifications are also included because from an acoustic perspective they behave as the dominant chip size (section 3.2.7).

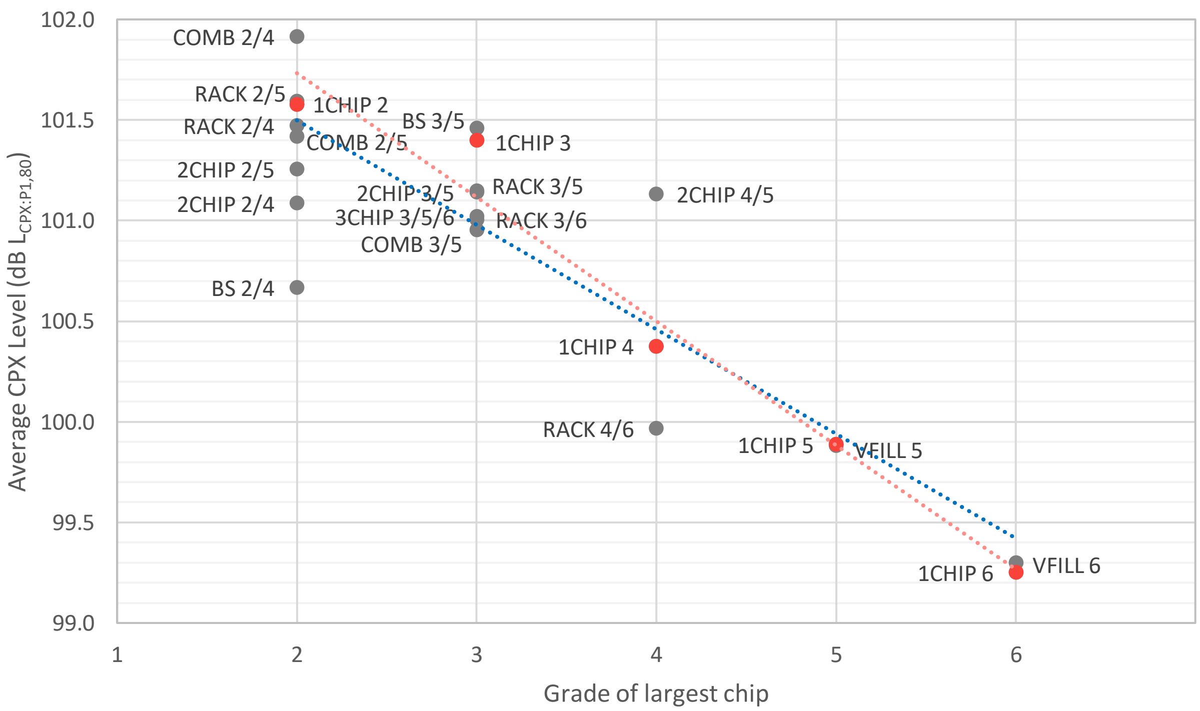



*Figure 3-5: Relationship between largest chip size and noise emission (1CHIP in red)*

Through a weighted linear regression, a strong relationship is found between CPX level and a chipseal's largest grade of chip ($r^2$=0.81, n=22, p<0.001):

$$L_{CPX:P1,80} \approx 102.5 - 0.52 * grade \quad \text{in dB} \qquad (3.1)$$

Based on this relationship, the prediction interval for the average $L_{CPX:P1,80}$ of an arbitrary single or dual-chip surface for which only the largest chip is specified has a width of 0.8 dB or less at 95% confidence. This is comparable to the between-site variation of the individual surface specifications, which are above 1 dB at k=2 (see Figure 3-7).

After controlling for largest chip size using equation 3.1, the residuals showed no statistically significant relationship between the smaller chip size and CPX level ($r^2$=0.01, p>0.05, n=15).

Both the null-hypotheses for (a) and (b) can therefore be disproven, which provides confidence that the hypotheses are valid. The noise emission of any chipseal surface (single- or dual-chip) appears to be dictated by the largest chip size present.

### 3.5.2 Applications

The equivalence of the single- and dual-chip specifications represents a significant departure from the existing surface corrections table (section 3.7). It introduces the possibility to consolidate the chipseals in the surface corrections table [NZTA, 2014] down to at most five entries, one for each grade. If, for example, the levels indicated by the dots in Figure 3-6 below were used, then grade 2 and grade 3 surfaces would be combined and all chipseal specifications could be described by just four values.

As another application, the survey does not include data for COMB 4/6, which is a member of the population of chipseals. Its average CPX level can be predicted based on its largest chip size, grade 4, as

$$102.5 - 0.52*4 = [100.4 \pm 0.8] \text{ dB } L_{CPX:P1,80}$$

In general it will be preferable to use an actual sampled average to characterise a particular surface specification, but if the sample size is very small, equation 3.1 may be more accurate. For example, COMB 2/5 has only been measured at one site, so its mean could be estimated as 101.4 dB ± 1.4 dB (see section 3.2.6) based on that one measurement, or as 101.5 dB ± 0.8 dB based on the knowledge that it belongs to the population of chipseals, and should therefore follow equation 3.1. The two estimates for the mean are very similar in this case, but the latter estimate has considerably lower associated uncertainty.

### 3.5.3 Observations

While unproven here, it is not a stretch to surmise that the key mechanism underlying the relationship between CPX level and chip grade is surface macrotexture. Macrotexture (measured as mean profile depth) correlates strongly to $L_{CPX:P1,80}$ when levels are averaged by surface specification ($r^2$=0.87) [Jackett, 2019]. Mean profile depth has a causal relationship with chip size, and is considered as part of the grade selection process [NZTA P17, 2002]. It was not within the scope of this study to examine macrotexture, but it could be an avenue for further investigation, and it may even provide a better prediction of CPX level than chip grade (though it would be more difficult to include in the noise modelling process).

Although a linear regression has demonstrated a general relationship between grade and CPX level, there is no fundamental reason that we know of that the underlying relationship must be linear. Also, while the production requirement for chip [NZTA M06, 2019] results in an approximately linear progression in size from grade 2 down to grade 6, there is some tolerance and overlap between each grade and the next. Deviations away from linear may therefore arise from either the dependent or the independent variable in equation 3.1, or both.

Following from that, it is noted that the specifications based on grade 2 and grade 3 chip have essentially the same average CPX levels. Figure 3-6 shows the weighted (by number of sites) average level by dominant chip grade. Equation 3.1 is plotted in red, and while it is a good overall representation, it does not describe the difference between grade 2 and grade 3 chipseals on that more local scale.

Previous studies have also shown mixed results for fleet and test vehicles on these two grades [Dravitzki et al, 2006; Dravitzki & Kvatch, 2007]. Analysis of macrotexture and measured chip size data might lead to a deeper understanding of why this is the case. As these two grades cover 66% of the highway network, that may be a worthwhile effort. Alternatively, if the P1 tyre has a sensitivity or insensitivity to a particular macrotexture wavelength it would aid future road surface noise research if that were understood.

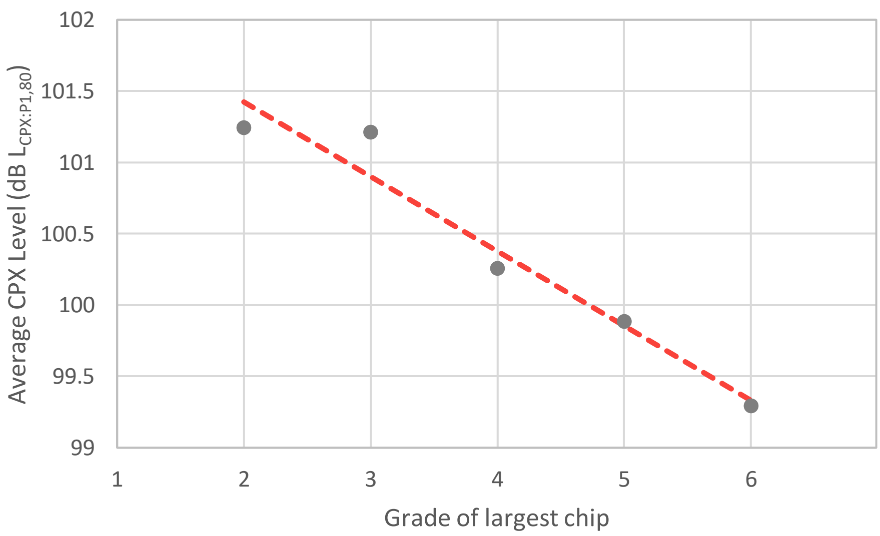



*Figure 3-6: Average CPX:P1,80 levels for each dominant chip size, weighted by number of sites*

## 3.6 Distribution of Levels

The distributions of CPX levels for each surface specification are illustrated by histograms in their summary sheets in Appendix B. This section takes a broader view of variability.

### *3.6.1 Variability within a Specification*

Within each surface specification, all records sharing a combination of *road_id* and *surface_date* are members of that distinct 'site'. This definition is the best available proxy for lengths of road that were sealed as part of a single resealing project, and should share some characteristics (for example, age, construction materials, construction crew, traffic, climate).

The variation in CPX levels within any given site, between the 20-metre road segments that are members of that site, is the "within-site" variance. This provides an indication of the inherent consistency of a surface with regards to tyre/road noise. Some of this variation will be associated with CPX measurement error.

In this analysis, site averages have been found by arithmetically averaging CPX levels over all 20-metre segments within those sites. Variation between the site averages is the "between-site" variance. This is an indication of the reproducibility of the acoustic properties of the surface specification, from one road project to another.

The overall variance encompasses the within-site and between-site variances, and describes the range of levels that any given road segment might produce, and, to an approximation, that a sensitive receiver positioned close to the road might receive.

Following those definitions, the typical within-site, between site, and overall standard deviations have been derived for each broad surface type (Figure 3-7), with the strong caveat these values are indicative only, and based only on the one to three best-populated specifications in each surface grouping. Each of the asphalts is primarily based on its 10 mm specification.

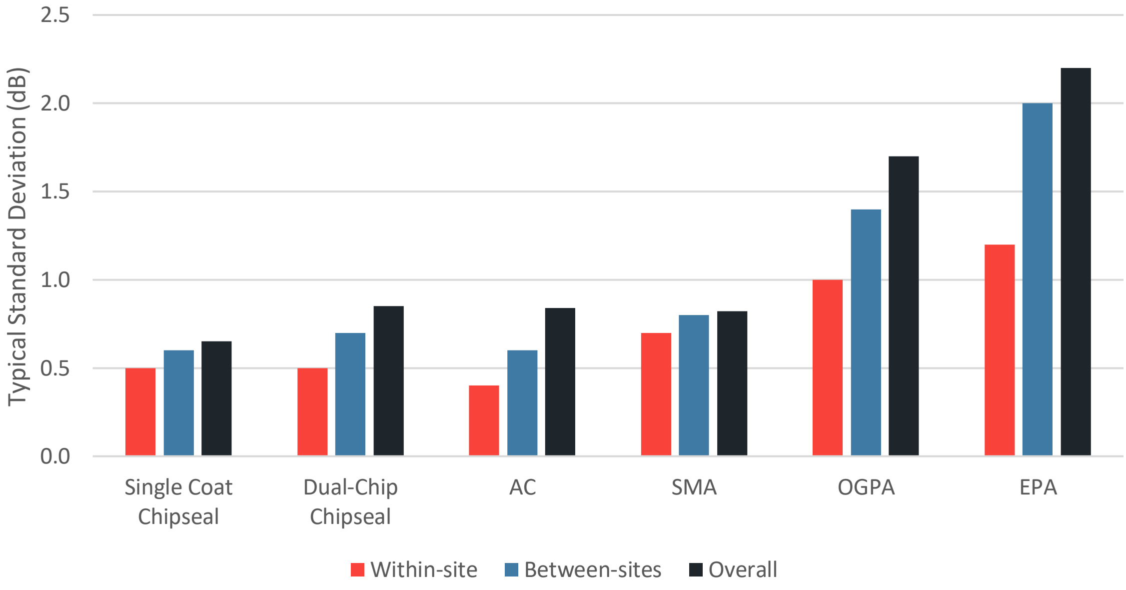



*Figure 3-7: Typical $L_{CPX:P1,80}$ standard deviations for different surface types (indicative values only)*

The key observation is that the porous asphalts, OGPA and EPA, have at least twice the overall standard deviation of any other surface type. This is driven by both the within-site and between-site variability. EPA appears more inherently variable than OGPA (within-site), but it is the large difference in average level between sites that helps it exceed an overall standard deviation of 2 dB (see also the note in Table 3-1).

Single-coat chipseals had the lowest overall standard deviation, and were slightly more consistent than both dual-chip chipseals and SMA between sites. SMA was more variable within-site than either of the chipseal specifications.

AC-10 had the lowest within-site standard deviation of any surface, but perhaps in part due to the small sample of only 4 sites, its variance between sites and overall was higher than expected from the incumbent reference surface. This finding will be helpful for putting the (unknown) uncertainty of the existing system of surface corrections in context for Part 2 of the project.

The 95% confidence interval for random selection of surface from any of these surface types is approximately (-2 sd, +2 sd) about the mean. Considering between-site variations as an example of how the data in Figure 3-7 can be used, site averages for single-coat chipseals vary across an interval of about 4 * 0.4 = 1.6 dB. Site averages for EPA 10, by contrast, vary across an interval of 4 * 2 = 8 dB.

### *3.6.2 Probability Density and Overlap Between Specifications*

To illustrate the implications of variability, the probability density of selected asphalt and chipseal specifications have been calculated and are plotted in Figure 3-8. The area under each curve is the same, and in general it is the position and spread along the horizontal axis that is of interest.

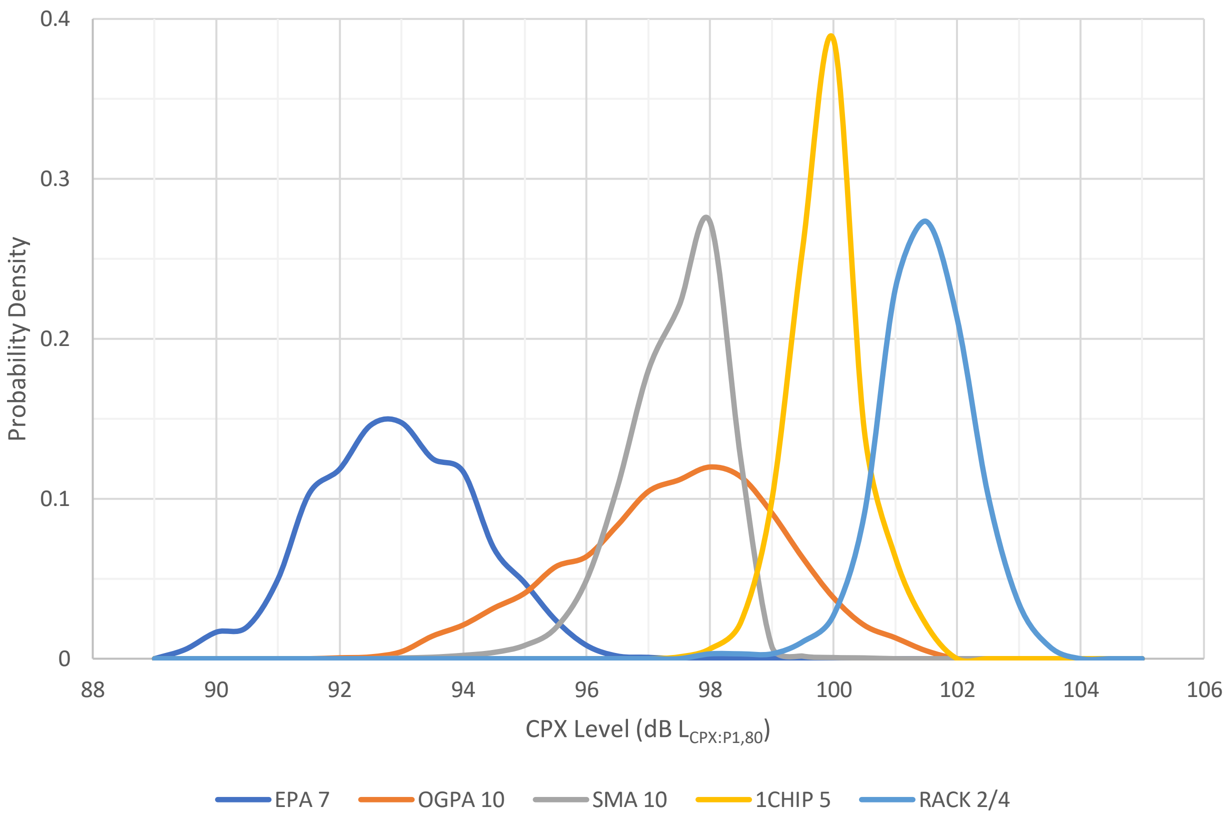



*Figure 3-8: Probability density of $L_{CPX:P1,80}$ for five different types of surface*

The very broad porous asphalt distributions (EPA 7 and OGPA 10) stand in contrast to the relatively narrow distributions of the other surfaces (SMA 10, 1CHIP 5, RACK 2/4). The implications for noise prediction are immediately clear: the CPX noise level from a randomly selected 1CHIP 5 surface can be predicted with confidence; the noise level from a randomly selected OGPA 10 surface cannot.

There is overlap in acoustic performance between NZ's most-common 'low noise' surface, OGPA 10, and one of the noisiest, RACK 2/4. It is common in roading projects for the former to be substituted for the latter for the purpose of noise mitigation. SMA 10 achieves the same average performance as OGPA 10 but appears to do so more reliably.

The small sample of EPA 7 sits at the low end of the CPX level scale, but its distribution is also broad, like that of OGPA, making it somewhat misleading to summarise its performance with a single value of central tendency. A high level goal of the Waka Kotahi surface noise research programme is to identify the causes of variability in porous asphalt, such that they might be controlled for and result in a higher level of confidence in its acoustic performance in future.

## 3.7 Comparison with *R*c Values

The existing set of surface corrections for cars (*R*c values) are defined relative to AC-10 in the *Guide to state highway road surface noise* [NZTA, 2014]. This project will not define road surface corrections relative to AC-10, but as a means of comparison with the existing *R*c values, equivalent corrections to AC-10 have been computed from the current CPX surface dataset. For surface specifications common to the guide and the current CPX dataset, Figure 3-9 plots both sets of *R*c values. Note that these CPX values should not be used as substitutes for the existing *R*c values.

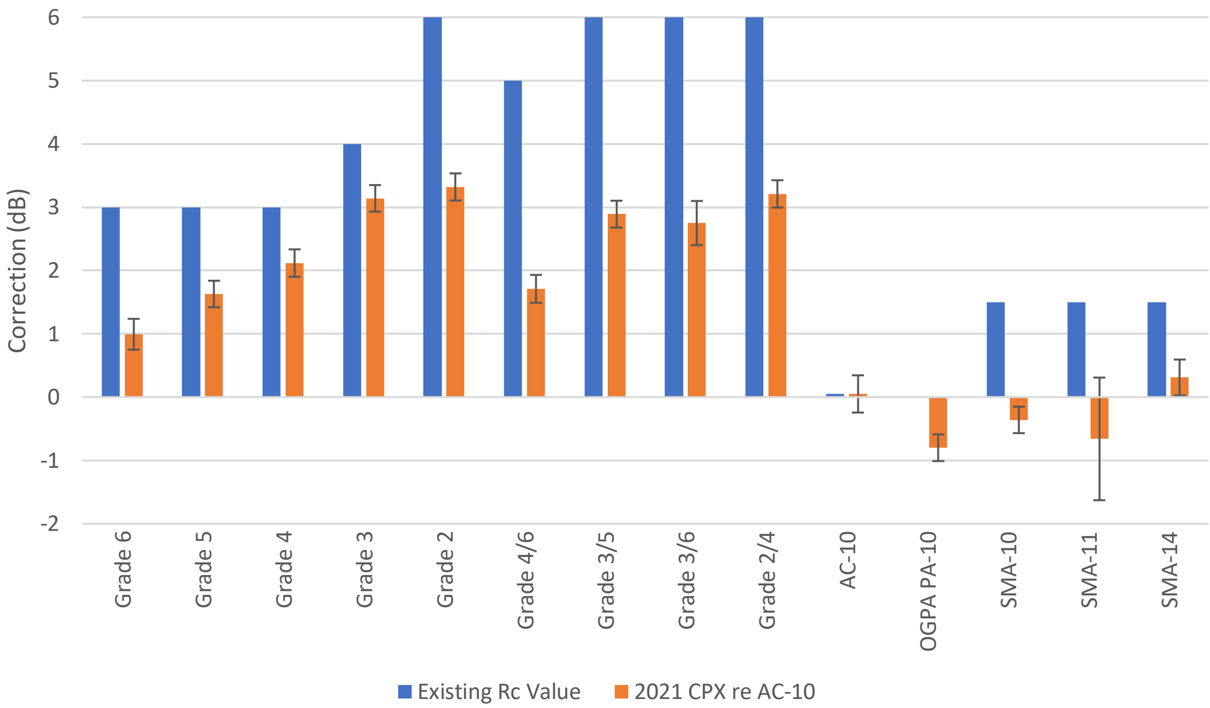



*Figure 3-9: Existing car surface corrections compared to latest CPX data (for illustration only)*

Both sets of corrections are dependent on AC-10 tyre/road emission as a reference, and the CPX dataset contained fewer AC-10 sites than would be optimal for this purpose. There is therefore some uncertainty in the absolute level of all the CPX corrections (shown as the uncertainty in the mean of all segments at 95% confidence, including the uncertainty in the evaluation of AC-10), but it is sufficient for this comparison.

In general the CPX-derived levels are well below their *R*c equivalents. While it is noted that the methods, speeds, vehicles, and tyres were different between the two measurement approaches, better agreement was expected. Poor alignment between the two sets of AC-10 measurements could explain some of the difference. No additional insight can be offered into why the large difference is observed at this time, but it is hoped that Part 2 will provide some clarity.

Several surfaces in the existing *R*c table have no equivalent surface in the CPX dataset: Slurry seal, Cape seal, Macadam, and some asphalt variants. It may be necessary to interpolate corrections for these surfaces from the final CPX-based corrections, and for any other missing surfaces that are in use on state highways (section 3.2.8).

## 3.8 Spectra

A detailed analysis of spectra by surface specification is outside of scope, but a comparison between selected surfaces is provided in Figure 3-10 as this represents the most comprehensive data currently available for NZ road surfaces. Note that these spectra are specific to CPX:P1,80 measurement of tyre/road noise and do not represent the general road traffic noise spectrum.

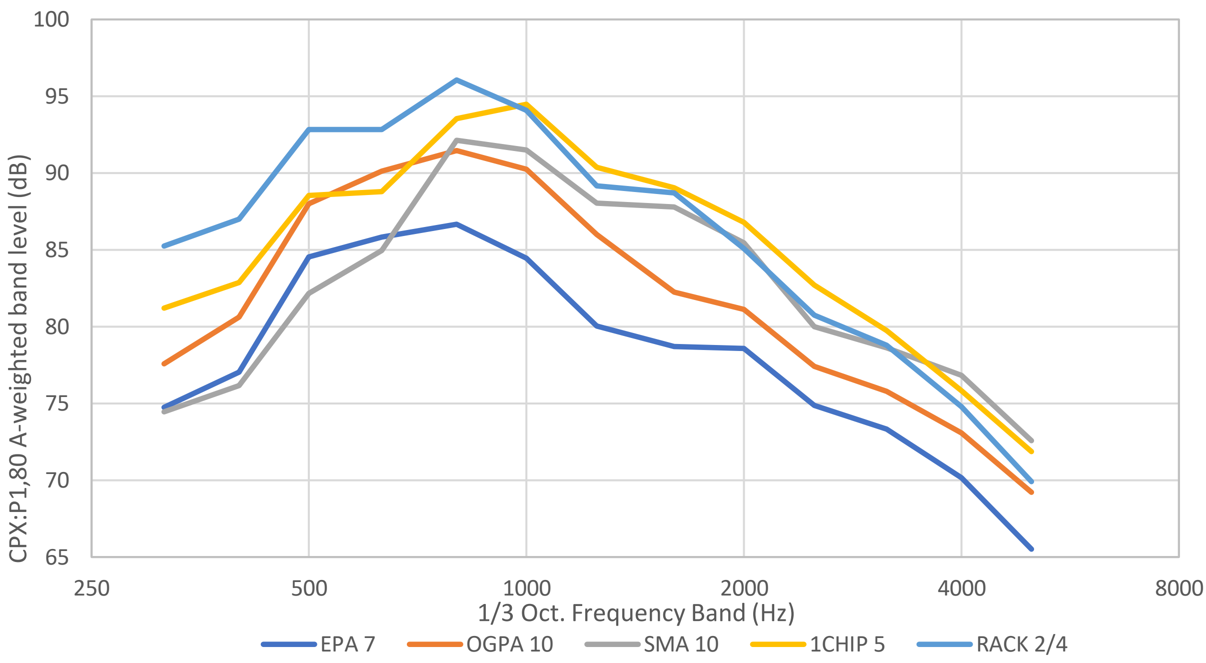



*Figure 3-10: Average spectra for five surface specifications*

The contrast of OGPA 10 and SMA 10 spectra, whose overall average CPX noise levels are almost identical (within 0.05 dB), is particularly interesting. Below 800 Hz OGPA is significantly louder by up to 5 dB; above 1250 Hz SMA is louder by up to 5 dB. This illustrates the potential for audible tonal differences between road surface types that would be masked by looking at level alone.

The very broad rounded peaks of the porous asphalts contain significant overall noise level contributions down to the 500 Hz band. The chipseals in the dataset all had sharper, higher frequency peaks across the 800 Hz and 1000 Hz bands, with neighbouring bands about 5 dB below (see also Figure 3-11). Chipseals based on grade 2 chip generally peaked by 1-2 dB in the 800 Hz band, grade 5 by 1-2 dB the 1000 Hz band, and those based on grade 3 (as in Figure 3-11) were very even between both bands on average.

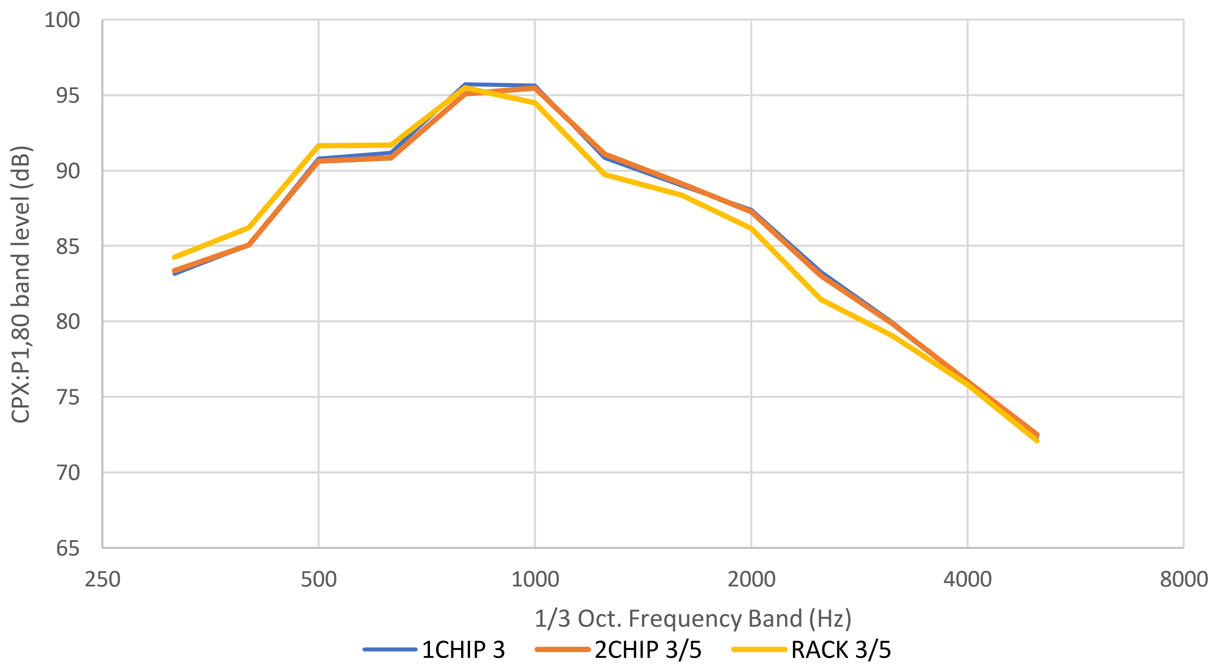



*Figure 3-11: Average spectra for three chipseal specifications that are based on grade 3 chip*

# 4 Outputs

## 4.1 Core Outputs

- 33 CPX surveys have captured CPX:P1,80 data from 1107 km of state highway across 5 regions. Validation and filtering have resulted in a dataset containing 683 km of 20-metre-long CPX measurements where the surface specification and surface age are known.
- 44 distinct surface specifications have been characterised, including 25 of the top 30 specifications on the NZ state highway network, representing 89% of the network by length.
- Table 3-1 and Table 3-2 summarise data for the CPX noise level, surface geographical and age distributions, and sample statistics for each of the 44 specifications.
- Each surface specification has a summary sheet in Appendix B that provides a more detailed view of its noise level distribution, difference in noise level with surface age, and frequency spectrum.
- A reference age of 4 years old has been selected as appropriate for the comparison of acoustic properties of surfaces. Surface age has not previously been explicitly considered in road surface corrections.
- The data in this Part 1 report is suitable for use as an input to the surface corrections methodology of Part 2.

## 4.2 Supplementary Findings

In deriving the core outputs above from the large quantity of CPX data, other relevant avenues of investigation were revealed. A series of ad-hoc studies have allowed previous research questions to be answered, provided additional confidence in the accuracy of the core outputs, and may be of value to future surface noise research or optimisation efforts in NZ.

### *4.2.1 Aging Effect*

Given the availability of age data, an opportunistic examination of noise level change with surface age was possible by grouping discrete surfaces within a specification by age.

Statistically significant effects were found for three surface specifications (section 3.3.1), including SMA 10 (+0.2 dB/year).

Conversely, six chipseal specifications for which a good quantity of data was available, showed no change in noise level with age (defined as less than ± 0.2 dB/year at the 95% confidence level; section 3.3.2).

The full set of OGPA 10 data showed no aging effect, but a subset of nominally 30 mm thick OGPA 10 showed a weak effect of +0.14 dB/year (section 3.3.2). These results are slightly lower than previous estimates for the aging effect of OGPA.

Whilst only indicative, these are encouraging findings for OGPA and chipseal, and imply that the end users of road noise assessments can have reasonable confidence that noise level predictions apply to most of the lifetime of the road surface, not just to a particular time after it was laid.

### *4.2.2 Thickness Effect*

There was sufficient nominal thickness data to tentatively study the effect of nominal thickness on the tyre/road noise emission of SMA 10 and OGPA 10 (section 3.4). The nominal thickness was based on values entered into RAMM, and should not be assumed to accurately reflect the actual surface thickness.

SMA 10 showed essentially no difference in noise level between 40 mm and 50 mm nominal thicknesses.

A weighted linear regression of CPX level on OGPA 10 nominal thickness indicated an effect of -0.8 dB/cm ± 1.9 dB/cm, which was not statistically significant ($r^2$=0.18, n=7, p=0.35). This is the best NZ estimate for the magnitude of the effect (*nominal* OGPA thickness on CPX level), but should be treated with extreme caution, and the analysis repeated when better samples are available.

The theory behind acoustic absorption of porous surfaces was reviewed (section 3.4.2). Surface thickness has a primary role in determining where the narrow frequency band of absorption falls, which could be the mechanism behind the observed surface effect in NZ porous asphalt. Peak absorption frequencies were estimated for 30 mm, 40 mm, and 50 mm and may align with dips in the spectra of those thicknesses of OGPA 10.

### *4.2.3 Dominance of Largest Chip Size in Chipseals*

A previous hypothesis that the largest chip size in a chipseal specification drives it noise emission [Jackett, 2019] has been confirmed. This extends to single-coat surfaces, effectively meaning that there is no significant distinction between single- and dual-chip surfaces in terms of either noise emission level (section 3.5.1) or tonality (e.g. Figure 3-11). The noise emission of any chipseal surface, therefore, appears to be dictated by the lowest grade (largest chip size) present.

The equivalence of the single- and dual-chip specifications represents a significant departure from the existing surface corrections table, and introduces the possibility of consolidating the table significantly.

A linear regression of CPX level against chip grade, across all chipseal specifications, resulted in a statistically significant relationship ($r^2$=0.81, n=22, p<0.001) with a prediction interval of ±0.8 dB or less:

$$L_{CPX:P1,80} \approx 102.5 - 0.52 * grade \quad \text{in dB} \qquad (3.1)$$

The linear relationship works well overall, but does not describe the local difference between grade 2 and grade 3 -based specifications, which have the same average level (Figure 3-6).

### *4.2.4 Racked-in versus Two-coat*

A research question about racked-in seals was previously raised [Chiles & Bull, 2018]:

> *Is there a basis for complaints that racked-in chipseals are noisier than two-coat seals?*

This can now be answered. Racked-in and two-coat chipseals were indistinguishable by level, based on CPX measurements from 140 distinct sites over 4 regions (Figure 3-1). Their tonality, compared in Figure 3-11 for grade 3/5, is also effectively identical. Neither specification showed any significant aging effect (section 3.3.2) after the first 6 months.

It is very likely that there is no significant audible difference between racked-in and two-coat chipseals over the long-term.

### *4.2.5 Variability within a Specification*

Indicative values for the within-site and between-site variability of surface types have been determined (Figure 3-7). This has reinforced previous findings that OGPA is extremely variable both between and within sites, and its epoxy-modified version, EPA, appears at least as variable. Chipseals, SMA, and the small sample of AC showed much more consistency, with the chipseals marginally (and against expectations) being the least variable.

The probability density of selected asphalt and chipseal specifications were plotted (Figure 3-8), again emphasising the broad porous asphalt distributions, and showing an overlap in performance between NZ's most-common 'low noise' surface, OGPA 10, and one of its noisiest, RACK 2/4. SMA 10 achieved the same average level as OGPA 10, but with half of its variability and no overlap with the coarse chipseals.

The width of some of the distributions poses a challenge for defining single-value surface corrections – should a central value like a mean be used, or a more conservative value such as an upper quartile? An element of subjectivity will inevitably be required during Part 2 and the review and ratification process.

#### 4.2.6 Comparison with Existing Corrections

For an informational comparison with the existing surface corrections, pseudo surface corrections were derived for the same surface specifications by subtraction of CPX AC-10 measurements (section 3.7). The CPX-derived corrections were all well below their equivalent existing corrections. It is hoped that Part 2 of this study will indicate why this is the case.

### 4.3 Areas for Further Study

#### 4.3.1 Surface Thickness of Porous Asphalts

Theory suggests that surface thickness may be less of an 'additive' effect, and more of a 'tuning' of the absorption band peak frequency (section 3.4.2). If further investigation finds this to be the case, then determining and specifying the shape factor and thickness for NZ porous asphalts could help optimise the acoustic absorption effect, which may be worth several decibels.

#### 4.3.2 Macrotexture and Chip Grade

Whilst examining the strong relationship between chip grade and CPX level (section 3.5), it was hypothesised that macrotexture may be the underlying cause. It was also noted that the linear relationship with grade seems to break down between grade 3 and grade 2, with the two sharing a very similar overall level (Figure 3-6) but showing some characteristic differences in their spectra (section 3.8). The key to understanding this behaviour within these two common chip sizes, which cover 66% of the state highway network, may be an examination of macrotexture, including its wavelength as well as its depth. If the reason is specific to the CPX P1 tyre used to conduct road surface noise research in NZ, that should be understood and accounted for.

#### 4.3.3 Capture "Missing" Surfaces

No slurry seals, cape seals, or Macadam surfaces were measured on the CPX survey, and it would be preferable to locate examples of these for a future targeted CPX survey rather than interpolate them from the existing corrections table. Similarly, more examples of un-grooved AC would be useful.

#### 4.3.4 Expand EPA 7 Sample

The EPA 7 surfaces included in this study have outstanding acoustic performance, but all are young, and all are within one region. Expanding the CPX dataset to other examples of EPA 7 should be a priority to ensure their performance can be reproduced elsewhere.

#### 4.3.5 Effect of Enrichment Seals

The effect of ENRAC, an enrichment seal sometimes used on OGPA, is assumed to be secondary to the characteristics of the underlying surface. There may be sufficient data within the CPX dataset produced in this project to examine whether ENRAC treatment has an effect on noise emission.

#### 4.3.6 Detailed Review of Surface Emission Spectra

Surface emission spectra have been captured, but not examined in detail within this report. Amongst other things, their analysis may suggest reasons why some sections of OGPA and EPA differ so markedly in overall level from other sections.

# References / Bibliography

Austroads (2019) *Guide to Pavement Technology Part 4K: Selection and Design of Sprayed Seals*, Ed. 1.3, Section 3.4.3.

Bagshaw S, Jackett R (2020) *Initial Review of Aggregates with Respect to Road Traffic Noise*, WSP report 5-27858.00 2AGGR for NZTA

Berengier M, Hamet JF, Bar P (1990) *Acoustical Properties of Porous Asphalts: Theoretical and Environmental Aspects*, Transportation Research Record 965, pp. 9-24

Bull J (2020) *Road surface noise research: Porous asphalt variability study – final report*, Altissimo Consulting Ltd report 18-103/R11/B for NZTA

Bull J, Wareing R, Chiles S, Jackett R (2021) *Investigating the effect of layer thickness on the variability of porous asphalt tyre/road noise*, PIARC International Seminar, Cluj-Napoca, Romania, 20-22 Oct. 2021

Chiles S, Bull J (2018) *Road surface noise research 2016-2018: CPX trailer development and initial measurement results*, NZTA

Delany ME, Harland DG, Hood RA, Scholes WE (1976) *The prediction of noise levels $L_{10}$ due to road traffic*, J. Sound Vib. 48(3), pp.305-25

Dravitzki V, Walton DK, Wood CWB (2006) *Road Traffic Noise – Determining the Influence of New Zealand Road Surfaces on Noise Levels and Community Annoyance*. Land Transport New Zealand Research Report 292

Dravitzki V, Kvatch I (2007) *Road surface effects on traffic noise: stage 3 – selected bituminious mixes*. Land Transport New Zealand Research Report 326.

Jackett R (2019) *Preliminary Chipseal Study*, NZTA Road Surface Noise Research Programme 2018/2019, WSP report 5-27854.00 CHIP9 for NZTA

Jackett R (2020) *Strategy for populating road surface noise corrections table*, unpublished advice document for NZTA, ref: 5-27858.00 9SURF

Jackett R, Lester T, McIver I (2020) *Tyre/Road Noise Contribution from Heavy Vehicles*, WSP report 5-27858.00 1TRUC for NZTA

Lester T, Dravitzki V, Carpenter P, McIver I, Jackett R (2017) *The long-term acoustic performance of New Zealand standard porous asphalt*, NZ Transport Agency Research Report 626

ISO 11819-1:1997 *Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method*

ISO 11819-2:2017 *Acoustics - Measurement of the influence of road surfaces on traffic noise – Part 2: The close-proximity method*

ISO/CD TS 13471-2 *Acoustics – Temperature influence on tyre/road noise measurement – Part 2: Correction for temperature when testing with the pass-by methods*

NZTA M06 (2019) *Specification for Sealing Chip*

NZTA M10 (2020) *Specification for Dense Graded Asphaltic Concretes*

NZTA NV5 (2020) *Technical Memorandum Noise and Vibration No. 5*, version 2

NZTA P17 (2012) *Performance Based Specification for Reseals*, Section 9.2

NZTA (2005) *Chipsealing in New Zealand*. Wellington, NZ

NZTA (2014) *Guide to state highway road surface noise*, version 1.0

Peeters B, Hirschberg M, Kuijpers A (2016) *Influence of Pore Structure on Sound Absorption in Porous Road Surfaces*, Conference paper DAGA 2016, Aachen, Germany

ROSANNE D2.3 (2015) *Analysis of methods for measuring noise properties of road pavement*

ROSANNE D2.5 (2016) *Compatibility of the proposed noise characterization procedure with CNOSSOS-EU and national calculation methods*

Sandberg U, Ejsmont JA (2002) *Tyre/Road Noise Reference Book*, Infomex ISBN 13: 9789163126109

# Acknowledgements

The author expresses their gratitude to Waka Kotahi NZ Transport Agency for supporting and funding this research, and to the other members of the Road Surface Noise research group for their support and assistance: John Bull, Stephen Chiles, Greg Haldane, and Robin Wareing. Additional thanks to John and Robin for collecting and providing the CPX data. Finally, the author acknowledges the various contributions of help and sharing of knowledge from their colleagues at WSP Research.

# Appendices

# Appendix A Derive CPX Levels for Surface Specifications

## A.1 Collection of CPX Data

CPX noise levels, $L_{CPX:P1,80}$, with the P1 tyre at 80 km/h in the left-wheel-path have been measured using the Waka Kotahi CPX Trailer. This trailer is described in detail elsewhere [Chiles & Bull, 2018] and is broadly compliant with ISO 11819-2.

Approximately 33 CPX surveys conducted between 2019 and 2021 on state highways across the Auckland, Waikato, Manawatū-Whanganui, Wellington, and Canterbury regions (Table A-2) have contributed to this project. Some recent long-distance surveys were conducted specifically to provide data for this project, whereas the majority were undertaken for other reasons but still contributed useful data. CPX operators were John Bull (Waka Kotahi), Robin Wareing (Altissimo), or Richard Jackett (WSP).

All the CPX data was stored in a dedicated CPX database that is administered by Waka Kotahi and was accessed remotely using SQL over TCP/IP.

## A.2 CPX Data Validation

Altissimo & Waka Kotahi have performed several tests to verify the acoustic measurement and GPS positioning systems of the Waka Kotahi CPX trailer [Chiles & Bull, 2018]. No additional validation of CPX data was performed as part of this project.

## A.3 Surface Specification Validation

The road surface information in the CPX database derives from the RAMM database and was retrieved by Waka Kotahi and Altissimo. The surface properties are taken from the Carriageway Surface table, and include the position of the surface (i.e. highway, RS, and start and end chainages), the surface specification (i.e. surface material, 1st chip size, 2nd chip size), and the age of the surface at the time of measurement (from the most recent surfacing date). Other fields that play a secondary role are the sealing length, sealing width, lateral offset, and the surface function.

The road surface tables in RAMM are intended to contain the full surfacing history of every carriageway on the SH network, but the history is often incomplete and errors in entries are common and can be difficult or impossible to spot retrospectively.

WSP has performed a manual desktop validation of approximately 1100 lane-kilometres of road surfacing data. For each CPX survey route, the validation process included:

1. Review, section-by-section, the current surface specifications and dates plotted along the SH centreline for each of the CPX survey routes[11].
2. Use the PC-based Argonaut Roadrunner[12] software to 'drive' along the survey route and visually examine the road surface to check[13]:

---

[11] On custom maps generated by John Bull (Waka Kotahi) or via spreadsheets generated in-house.

[12] Similar in function to Google Maps Street View, but with the camera directed towards the road, better image quality, georeferenced to RP, and available for each survey year. https://roadrunner.argonautltd.co.nz/

[13] to the extent possible from looking at photographs taken at high speed and some metres from the surface; for some parameters like chip size this is more of a plausibility test than a validation.

   a. that the surface type in the survey year was consistent with that in the CPX database;
   b. that the surface age was plausible;
   c. the condition of the road surface at the time of the survey.

3. The surface history in RAMM's Carriageway Surface table, especially:
   a. where the above two steps indicated a mismatch;
   b. where the surface had been resealed since the CPX survey (and therefore the surface information stored in the CPX database was not for the actual surface surveyed).

4. Modify the surface table in the CPX database
   a. with corrections from RAMM surface history, based on findings from steps 1-3;
   b. to record which entries have been validated, which have been modified, and which should be excluded from the analysis.

Common reasons for excluding a section of carriageway from the analysis included:

- Validation step 2 indicated that the CPX database surface type or age was incorrect, and could not be confidently corrected using the RAMM Carriageway Surface table.
- Validation step 2 showed its condition to be particularly poor; beyond a typical level of aging or deterioration. E.g. extreme flushing, or moderate stripping or cracking, etc within the left-hand wheel path.
- The surface would not be representative of its surface specification on the wider state highway network. E.g. because it was on a bridge or at a railway level crossing.
- There was evidence that the CPX level did not correspond to the specified surface. For example, AC on the state highway network often has transverse grooves milled into it, which are seldom visually detectable while driving or from Road Runner but can add several decibels to the noise emission.
- The CPX survey pre-dated the reseal date in the CPX surface table, and its properties at the time of the CPX survey could not be confidently determined from the RAMM Carriageway Surface table.
- Duplication: where multiple CPX surveys had been conducted over the same carriageway, all but one were excluded to avoid over-representation of those specific surfaces in the averaging process.

After removal of duplicates and sites where no surfacing data was recorded, there were 55-thousand 20-metre long segments of road surface remaining. The visual inspection process rejected an additional 12% of this data, resulting in a final surface dataset containing 48-thousand samples, or 970 lane-kilometres, of validated road surface[13] (see Table A-1).

*Table A-1: Summary of road surface data manual validation exercise*

| Description | Samples (20 m segments) | Equivalent distance (km) | Percentage of total distance |
|---|---|---|---|
| Total data checked | 55383 | 1107.7 | 100% |
| Accepted | 48492 | 969.8 | 87.6% |
| Rejected | 6891 | 137.8 | 12.4% |

The final surface dataset contained 53 surface specifications (distinct combinations of surface material, 1$^{st}$ chip size, and 2$^{nd}$ chip size, see Definitions).

## A.4 Link CPX and Surface Specification Data

The validated surface data was linked, by carriageway geometry parameters, to the CPX run data in MySQL and additional filtering was applied. Only records meeting the following criteria were retained:

- A valid CPX *left_level* noise level existed: numeric and between 85 dB and 110 dB.
- The *surface_date* in the surface dataset predated the CPX *measurement_date*.
- The surface was between 6 months and 10 years old the time of CPX measurement.
- The CPX measurements used the P1 tyre and the appropriate speed, temperature, and hardness corrections (coefficients of 30, -0.092, and 0.12, respectively).

After filtering, a minimum sample size of 10 records was set as a threshold for analysis (i.e. ten 20-metre road segments worth of CPX data for any given surface specification).

Following this process, the number of distinct surface specifications available for analysis reduced to 39, and the total number of samples available for analysis reduced to 34141 (70% of the validated surface data). The main reasons for records to be rejected at this stage were that the surface was too old (> 10 years) or had been resurfaced since the measurement and only the current surface was recorded in the data set.

For OGPA 10 and SMA 10, limited surface thickness data was also available, allowing for an additional 5 surface specifications linked to thickness (as a subset of the OGPA 10 and SMA 10 data).

## A.5 Derive CPX Levels for Surface Specifications

The linked CPX and road surface data was collated for each surface specification using MySQL, and exported to MS Excel for analysis.

For each surface specification a number of parameters and statistics were calculated for both the surface properties and the acoustic properties. Surface properties included information about the size, age, and geographic diversity of the sample. Acoustic properties included measures of central tendency and distribution of noise level, any aging effect, and an indicative spectrum.

The output of this analysis is presented in Appendix B in the form of a summary sheet for each of the surface specifications.

## A.6 Geographic Coverage

The final dataset consists of CPX levels measured on urban and rural state highways across 5 regions and 17 local authority areas (Table A-2).

*Table A-2: Geographical distribution of CPX measurements*

| Region | Local Authority Area | Percent of sample (%) |
|---|---|---|
| Auckland | Auckland City | 19 |
| Waikato | Hauraki District | 2 |
| | Waikato District | 19 |
| | Matamata-Piako District | 5 |
| Manawatū-Whanganui | Manawatu District | 2 |
| | Palmerston North City | 1 |
| | Horowhenua District | 4 |
| Wellington | Kapiti Coast District | 2 |
| | Porirua City | 2 |
| | Upper Hutt City | 3 |
| | Hutt City | 7 |
| | Wellington City | 3 |
| | Masterton District | 3 |
| Canterbury | Hurunui District | 2 |
| | Waimakariri District | 3 |
| | Christchurch City | 11 |
| | Selwyn District | 12 |

The 683 lane-kilometres of road surface used to derive CPX levels represents approximately 5% of the total state-highway network.

# Appendix B Surface Specification CPX Summary Sheets

Summary sheets for each road surface specification included in this project are presented on the following pages, referenced by their surface specification code.

## B.1 Interpretation of sheets

The information below will aid with interpretation of the data contained in the summary sheets.

### *B.1.1 Surface Code*

References field names from RAMM's *c_surface* table.

For asphalts the code is

*surf_material chip_size* *e.g. OGPA 10, SMA 14, UTA 10*

where *chip_size* is the nominal maximum aggregate size in millimetres.

For chipseals the code is

*surf_material chip_size / chip_2nd_size* *e.g. 1CHIP 5, RACK 3/5*

where *chip_size*, and optionally *chip_2$^{nd}$_size*, are the grade of chip (higher numbers = smaller).

Full names for each surface are given below

| Code *surf_material* | Full Surface Name | Category |
|---|---|---|
| 1CHIP | Single-Coat Seal | Chipseal |
| 2CHIP | Two-Coat Seal | Chipseal |
| RACK | Racked-In Seal | Chipseal |
| BS | Sandwich Seal | Chipseal |
| COMB | Combination Seal | Chipseal |
| 3CHIP | Three-Coat Seal | Chipseal |
| VFILL | Void-Fill Seal | Chipseal Treatment |
| OGPA | Open Graded Porous Asphalt | Asphalt |
| OGPAH | High Strength Open Graded Porous Asphalt | Asphalt |
| EPA | Epoxy-Modified Porous Asphalt (aka EMOGPA) | Asphalt |
| SMA | Stone Mastic Asphalt | Asphalt |
| AC | Asphaltic Concrete | Asphalt |
| UTA | Ultra-Thin Asphalt | Asphalt |
| ENRAC | Enrichment Seal Over Asphalt | Asphalt Treatment |

### *B.1.2 CPX Levels*

The top left box shows summary statistics for the CPX levels within this sample:

**n**, the size of the sample, given as the number of 20-metre-long road segments included.

**dist**, the equivalent distance in lane-kilometres (i.e. *n*20/1000*).

**mean**, the arithmetic mean CPX level for this surface specification (in dB $L_{CPX:P1,80}$).

**median**, the median $L_{CPX:P1,80}$ value for this surface specification (in dB $L_{CPX:P1,80}$).

**mode**, the most common $L_{CPX:P1,80}$ value (to the nearest 0.5 dB) within the sample (in dB $L_{CPX:P1,80}$).

**SD**, the standard deviation about the mean CPX level (in dB).

Percentile values, in dB $L_{CPX:P1,80}$, are given for the 25th, 50th, 75th, 85th, and 95th percentiles of the distribution of CPX levels.

### *B.1.3 Histogram of Levels*

The histogram shows the distribution of CPX levels of the sample of the current surface specification. The bins on the horizontal axis represent the CPX levels rounded to the nearest 0.5 dB $L_{CPX:P1,80}$, i.e. they are centred bins. The vertical axis is the number of 20-metre-long road segments contained in the sample for each bin.

### *B.1.4 Geographic Diversity*

Distinct road_id is the number of distinct values of road_id within the sample.

Distinct road region is the number of contributing NZ regions (of the 5 surveyed, see Table A-2).

Distinct road council is the number of contributing NZ local authorities (of 17, see Table A-2).

Distinct state highway is the number of distinct state highways included in the sample.

Distinct road_id & date is an estimate of the number of independent '**sites**' at which the surface specification was found. The definition is limited by what information is available in cpx_surface. For the purpose of this study, data that do not share both *road_id* and *surface_date* are considered to be different 'sites'.

Generally dual carriageways would be two sites, but both directions on a single carriageway would contribute to the same site. Note also that some RAMM operators set the *surface_date* field to a single date for all surface sections within a project, even if the surfaces were laid over several days.

### *B.1.5 Sample Age*

The mean age of surface segments within the sample, along with the standard deviation.

### *B.1.6 Sample Breakdown by Age*

This graph shows the number of road segments of each age (rounded to the nearest year) within the sample. It provides context for the estimates of central tendency and particularly for the aging effect graph and linear regression.

### *B.1.7 Aging Effect*

The graph shows the arithmetic mean of CPX level in dB $L_{CPX:P1,80}$ by age (rounded to the nearest year). A line of best fit is calculated through unweighted linear regression and the equation for the line is displayed above the graph. Note that the line and equation are computed whether or not the relationship with age is valid (or statistically significant). Refer to the notes on each sheet for further comments regarding any aging effect.

### *B.1.8 Spectrum*

The graph displays the average 1/3rd octave spectrum of the sample. The horizontal axis is nominal 1/3rd octave centre frequencies, in Hz. The vertical axis is arithmetically averaged A-weighted 1/3rd octave band levels, in dB.

### *B.1.9 Notes*

A brief commentary is provided for each sheet. This includes observations or calculations performed on data from or across individual sites, which would otherwise be hidden at this level of summary.

## B.2 Open Graded Porous Asphalt (OGPA)

### OGPA 10

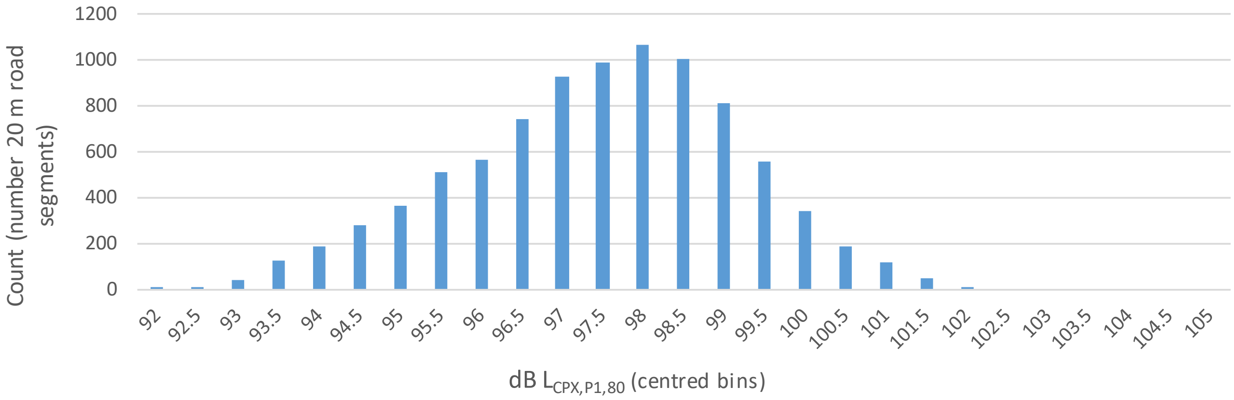
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 8871 | 25th | 96.35 |
| dist = | 177.42 km | 50th | 97.60 |
| mean = | 97.46 dB | 75th | 98.66 |
| median = | 97.60 dB | 85th | 99.19 |
| mode = | 98.00 dB | 95th | 100.08 |
| SD = | 1.71 dB | | |

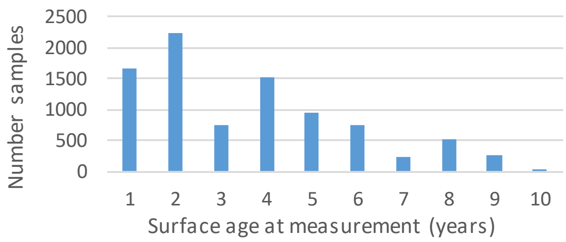
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 42 | n = | 8871 |
| Distinct road region: | 3 | mean = | 1349 days |
| Distinct road council: | 8 | mean = | 3.7 years |
| Distinct state highway: | 6 | SD = | 785 days |
| Distinct road_id & date: | 121 | SD = | 2.1 years |

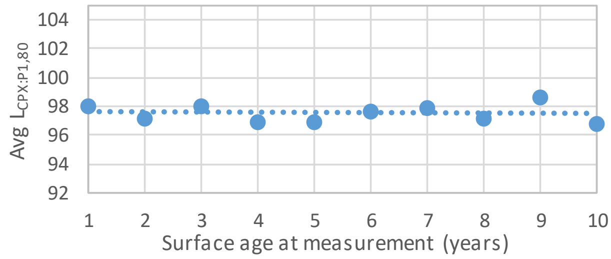
**Histogram of OGPA 10 levels (n=8871)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.01 * years + 97.58 dB**



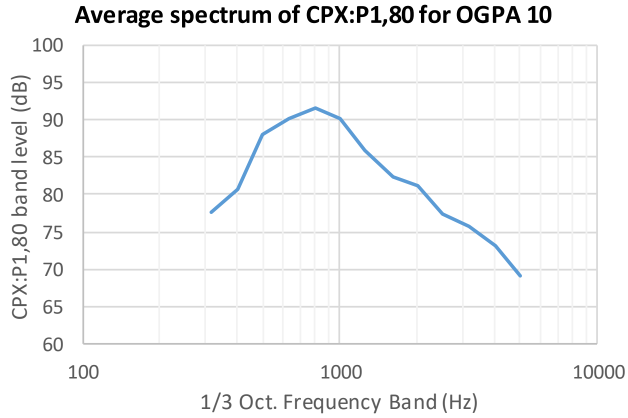

**Notes**

Very big sample size, distribution is skewed to left.
Average age of sample is 4 years old, well distributed.
Aging effect is not significant p>0.05 [-0.01 ± 0.16 dB/y]

Data from 3 regions: AKL, WGN, CHC

Additionally, variances have been analysed:
Within sites SD = 1.20 dB, [2 < n < 648, avg(n) = 114]
Between sites SD = 1.20 dB [n = 78 groups]
where "site" has distinct road_id AND age in years

**Average spectrum of CPX:P1,80 for OGPA 10**



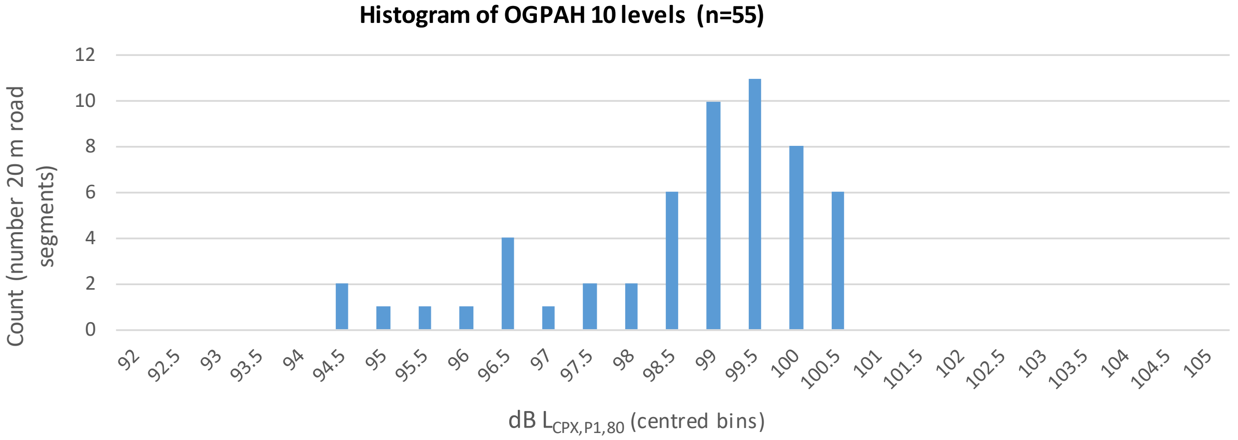
# OGPAH 10

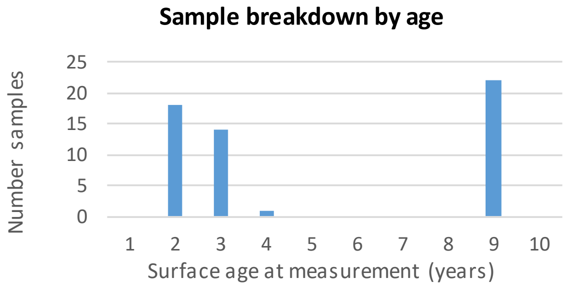
**CPX Levels**

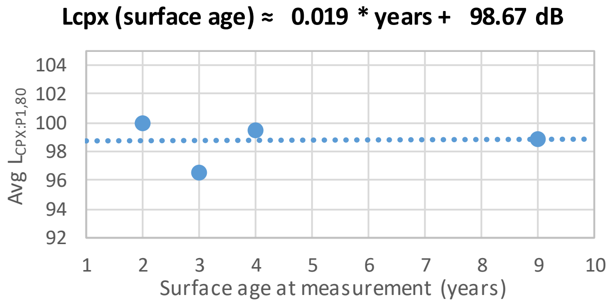
| | | Percentiles | |
|---|---|---|---|
| n = | 55 | 25th | 98.35 |
| dist = | 1.1 km | 50th | 99.09 |
| mean = | 98.71 dB | 75th | 99.74 |
| median = | 99.09 dB | 85th | 100.15 |
| mode = | 99.50 dB | 95th | 100.56 |
| SD = | 1.61 dB | | |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 6 | n = | 55 |
| Distinct road region: | 2 | mean = | 1906 days |
| Distinct road council: | 3 | mean = | 5.2 years |
| Distinct state highway: | 4 | SD = | 1180 days |
| Distinct road_id & date: | 6 | SD = | 3.2 years |



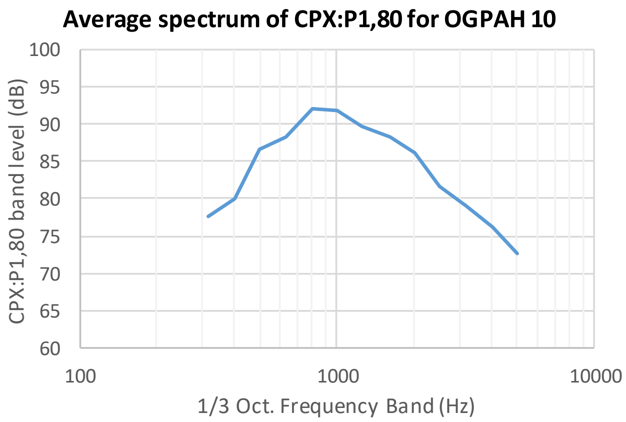




**Notes**

Small sample size, and not normally distributed.
Average age of sample is 5 years.
No evidence of significant aging effect.

6 distinct sites from 2 regions: AKL & WGN.
The average is not dominated by any one sample, there is at most 14 samples from any one site.
Variation within each site approx. SD=0.7 dB.



# OGPA 10 30 mm

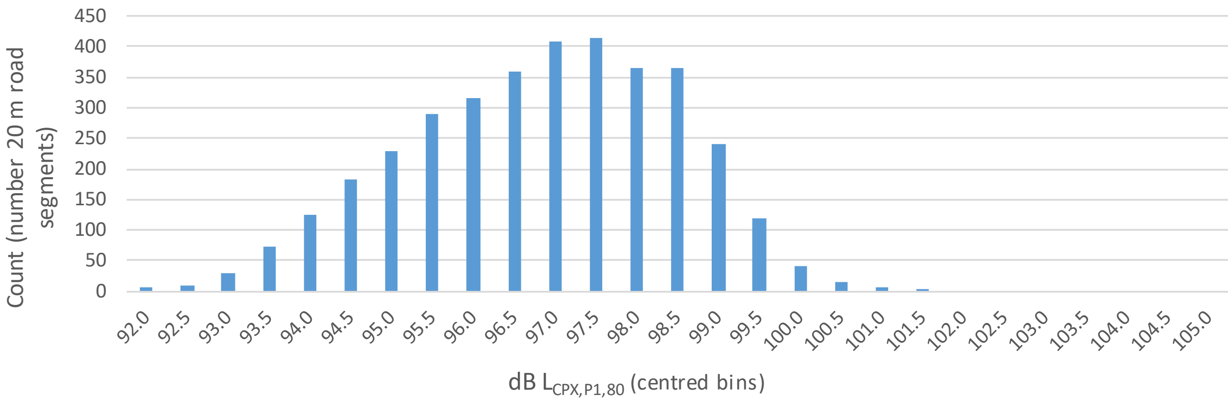
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 3592 | | |
| dist = | 71.84 km | 25th | 95.68 |
| mean = | 96.85 dB | 50th | 96.98 |
| median = | 96.98 dB | 75th | 98.09 |
| mode = | 97.50 dB | 85th | 98.59 |
| SD = | 1.62 dB | 95th | 99.27 |

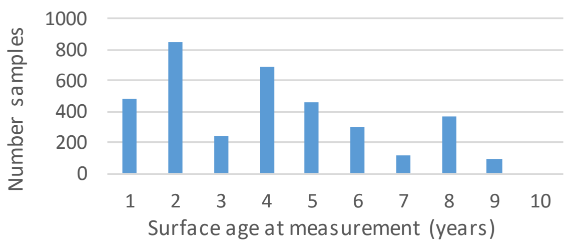
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 21 | n = | 3592 |
| Distinct road region: | 3 | mean = | 1509 days |
| Distinct road council: | 6 | mean = | 4.1 years |
| Distinct state highway: | 5 | SD = | 796 days |
| Distinct road_id & date: | 42 | SD = | 2.2 years |

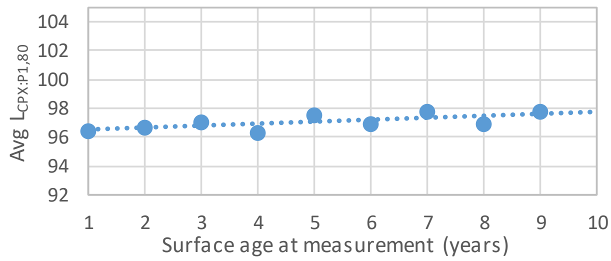
**Histogram of OGPA 10 30 mm levels (n=3592)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.14 * years + 96.39 dB**

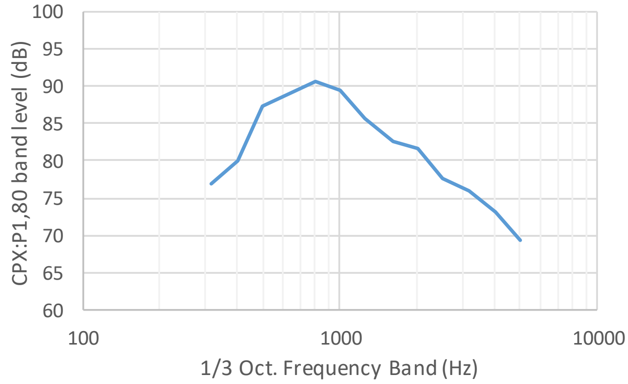



**Notes**

This large sample is a subset of the OGPA 10 set. Only records with *ovlay_depth = 30* have been included. That field is empty for 50% of the records in the broader OGPA 10 set.

The aging effect of +0.14 dB/year is significant at p<0.05 (+0.01,+0.27). This is in contrast to the broader OGPA 10 set which is significant at less than +/- 0.2 dB/year.
The mean of this set is also lower by 0.5 dB.

**Average spectrum of CPX:P1,80 for OGPA 10 30 mm**



# OGPA 10 40 mm

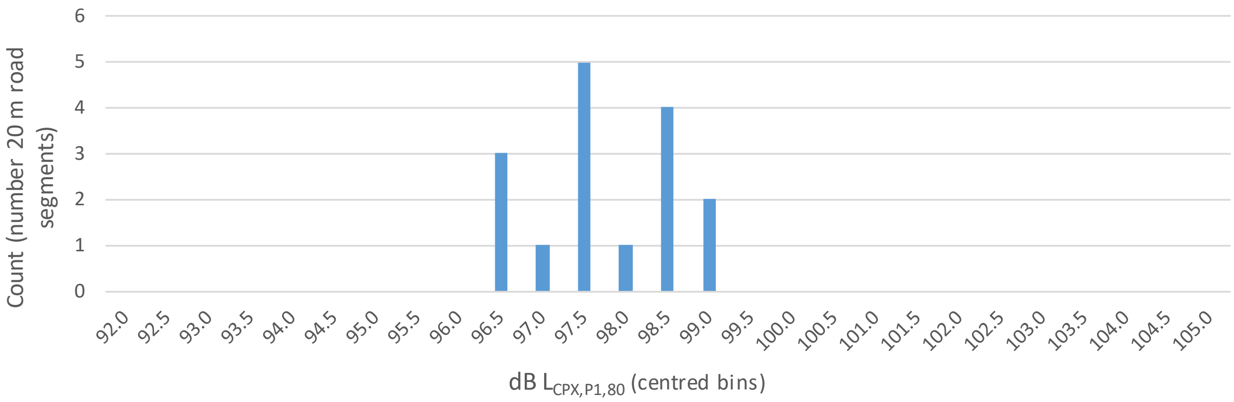
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 16 | 25th | 97.31 |
| dist = | 0.32 km | 50th | 97.71 |
| mean = | 97.80 dB | 75th | 98.44 |
| median = | 97.71 dB | 85th | 98.59 |
| mode = | 97.50 dB | 95th | 99.10 |
| SD = | 0.84 dB | | |

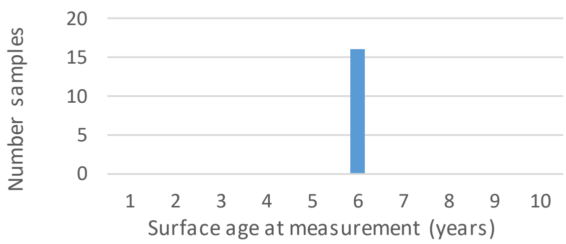
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 16 |
| Distinct road region: | 1 | mean = | 2191 days |
| Distinct road council: | 1 | mean = | 6.0 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

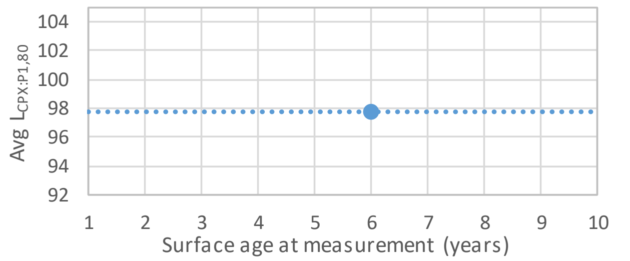
**Histogram of OGPA 10 40 mm levels (n=16)**




**Sample breakdown by age**



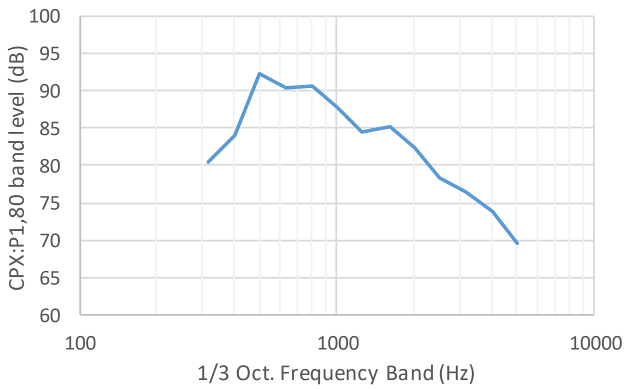

**Lcpx (surface age) ≈ 0 * years + 97.8 dB**




**Notes**

This tiny sample is a subset of the OGPA 10 set. Only records with *ovlay_depth = 40* have been included. That field is empty for 50% of the records in the broader OGPA 10 set.

**Average spectrum of CPX:P1,80 for OGPA 10 40 mm**



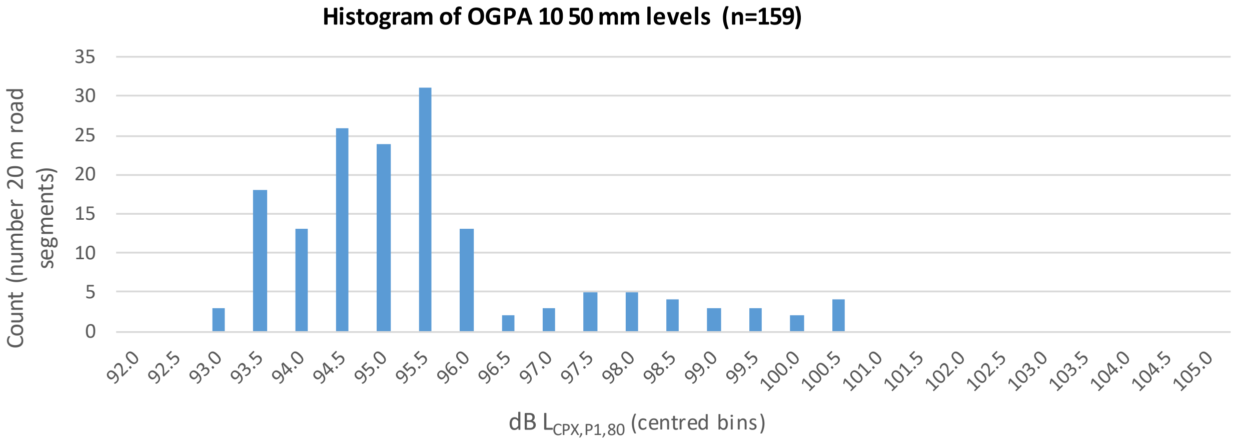
# OGPA 10 50 mm

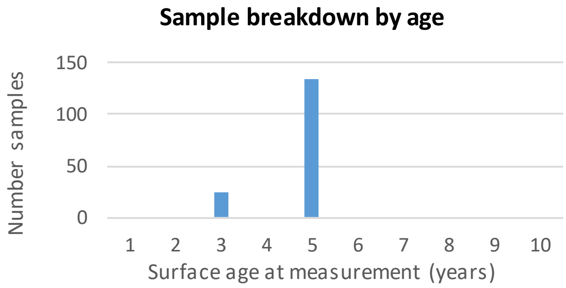
**CPX Levels**

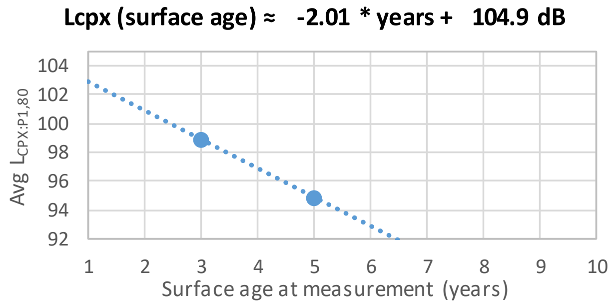
| | | Percentiles | |
|---|---|---|---|
| n = | 159 | | |
| dist = | 3.18 km | 25th | 94.38 |
| mean = | 95.48 dB | 50th | 95.15 |
| median = | 95.15 dB | 75th | 95.84 |
| mode = | 95.50 dB | 85th | 97.50 |
| SD = | 1.73 dB | 95th | 99.33 |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 2 | n = | 159 |
| Distinct road region: | 1 | mean = | 1690 days |
| Distinct road council: | 1 | mean = | 4.6 years |
| Distinct state highway: | 2 | SD = | 313 days |
| Distinct road_id & date: | 2 | SD = | 0.9 years |

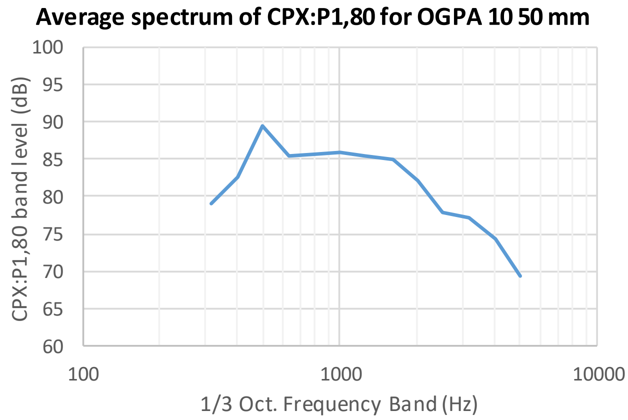



**Notes**

This small sample is a subset of the OGPA 10 set. Only records with *ovlay_depth = 50* have been included. That field is empty for 50% of the records in the broader OGPA 10 set.



# OGPA 14

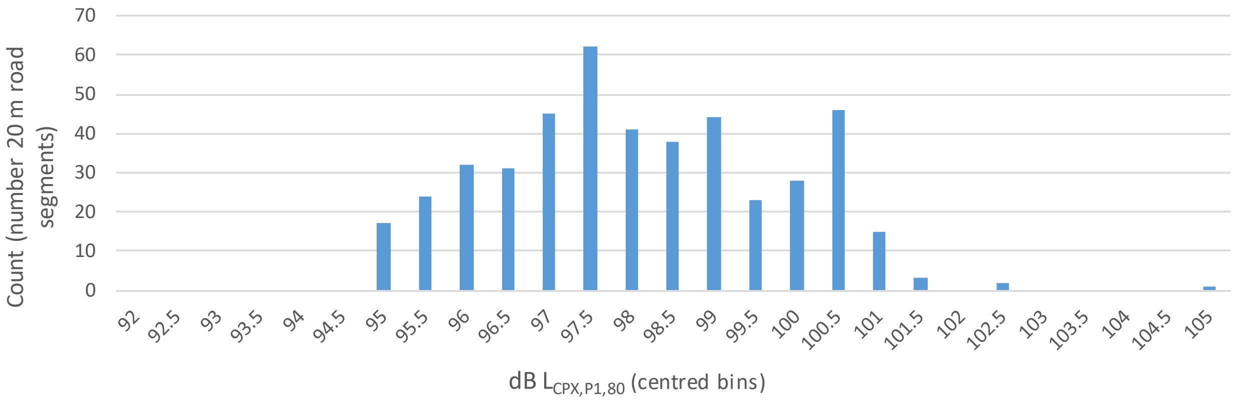
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 453 | | |
| dist = | 9.06 km | 25th | 96.90 |
| mean = | 98.11 dB | 50th | 97.93 |
| median = | 97.93 dB | 75th | 99.34 |
| mode = | 97.50 dB | 85th | 100.24 |
| SD = | 1.73 dB | 95th | 100.72 |

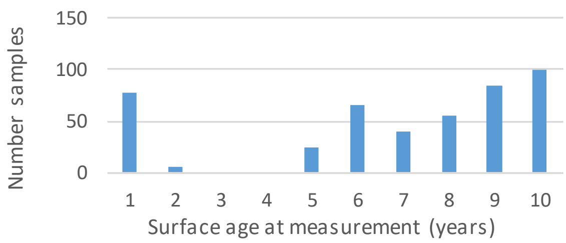
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 12 | n = | 453 |
| Distinct road region: | 4 | mean = | 2468 days |
| Distinct road council: | 7 | mean = | 6.8 years |
| Distinct state highway: | 4 | SD = | 1090 days |
| Distinct road_id & date: | 14 | SD = | 3.0 years |

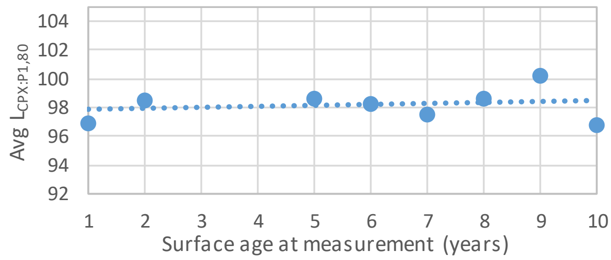
**Histogram of OGPA 14 levels (n=453)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.07 * years + 97.81 dB**

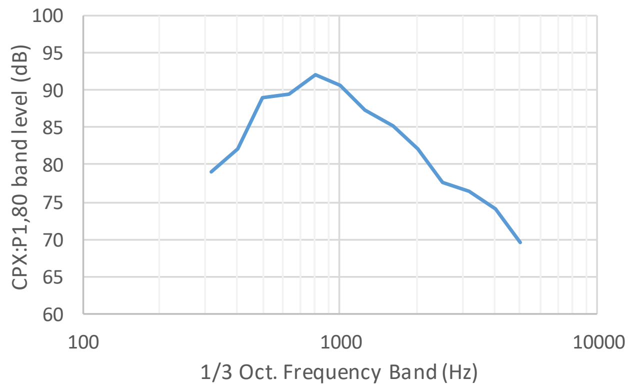



**Notes**

Sample includes a good range of ages.
Average age of sample is 7 years -- quite high.
Aging effect not significant p>0.05 [0.07 ± 0.34 dB/y]

14 distinct sites, across 4 regions, is a good sample.
The average is not dominated by any one sample,
the average sample size was about 40 from each site.
Variation within each site approx. SD=0.9 dB.

**Average spectrum of CPX:P1,80 for OGPA 14**



# OGPA 15

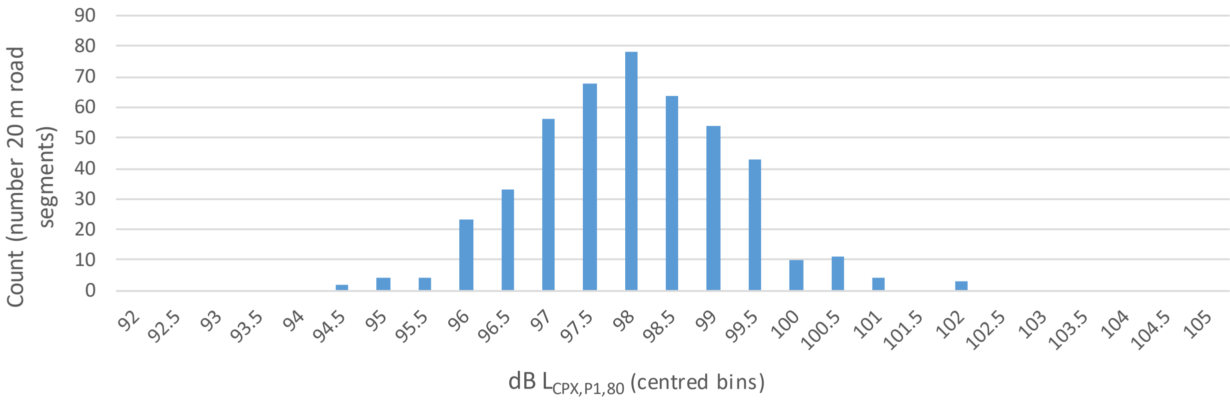
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 457 | 25th | 97.17 |
| dist = | 9.14 km | 50th | 98.01 |
| mean = | 98.02 dB | 75th | 98.87 |
| median = | 98.01 dB | 85th | 99.26 |
| mode = | 98.00 dB | 95th | 100.16 |
| SD = | 1.21 dB | | |

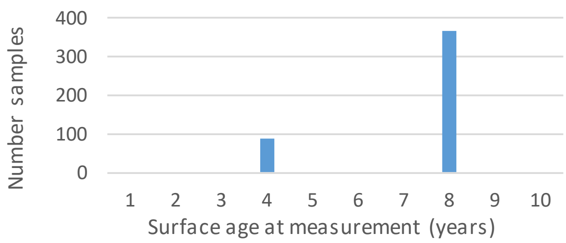
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 457 |
| Distinct road region: | 3 | mean = | 2677 days |
| Distinct road council: | 4 | mean = | 7.3 years |
| Distinct state highway: | 3 | SD = | 611 days |
| Distinct road_id & date: | 5 | SD = | 1.7 years |

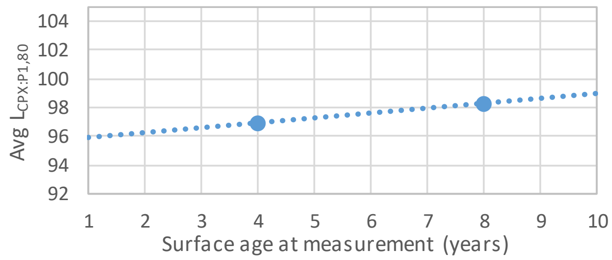
**Histogram of OGPA 15 levels (n=457)**




**Sample breakdown by age**



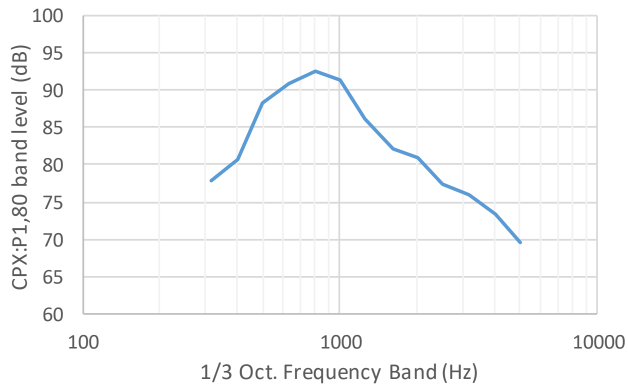

**Lcpx (surface age) ≈ 0.343 * years + 95.55 dB**




**Notes**

Sample only consists of 4yo and 8yo surfaces.
Average age of sample is 7 years -- quite high.
Upwards trend in noise with time, but not enough points to be confident that it is real.
Only 5 distinct sites had OGPA 15, across 3 regions.
2/3 of the sample comes from 018-0007, which was about 1 dB noisier on average than other sites.
Variation within each site was approximately 0.9 dB.

**Average spectrum of CPX:P1,80 for OGPA 15**



## B.3 Epoxy-Modified Porous Asphalt (EPA)

### EPA 7

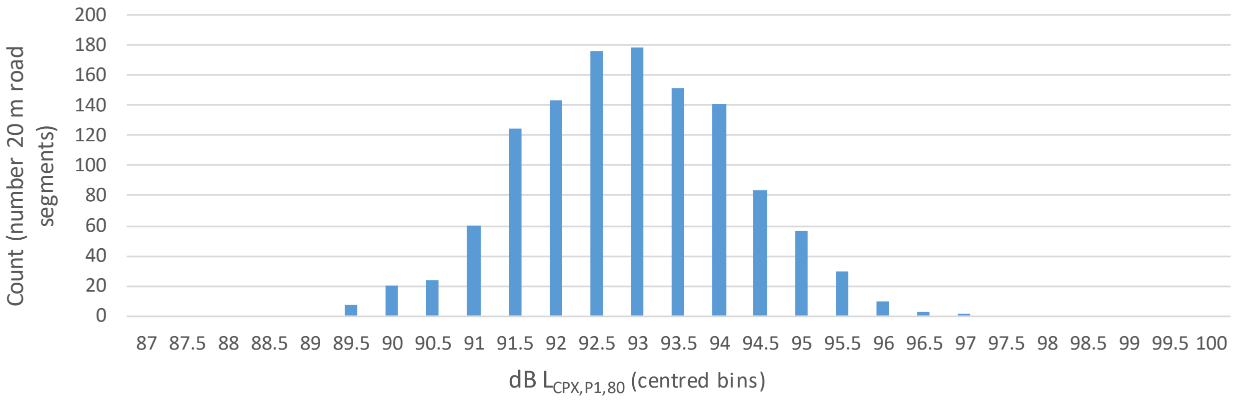
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1206 | | |
| dist = | 24.12 km | 25th | 92.03 |
| mean = | 92.90 dB | 50th | 92.89 |
| median = | 92.89 dB | 75th | 93.81 |
| mode = | 93.00 dB | 85th | 94.26 |
| SD = | 1.28 dB | 95th | 95.07 |

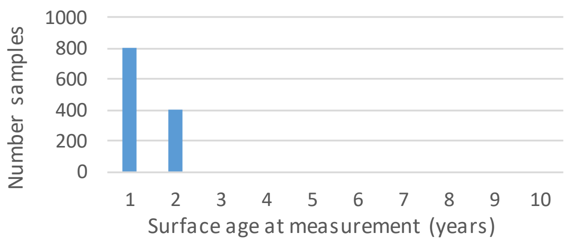
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 1206 |
| Distinct road region: | 1 | mean = | 437 days |
| Distinct road council: | 1 | mean = | 1.2 years |
| Distinct state highway: | 1 | SD = | 195 days |
| Distinct road_id & date: | 9 | SD = | 0.5 years |

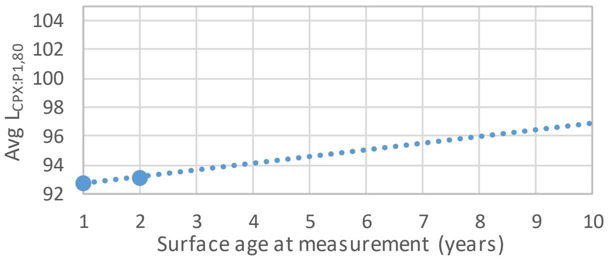
**Histogram of EPA 7 levels (n=1206)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.466 * years + 92.28 dB**

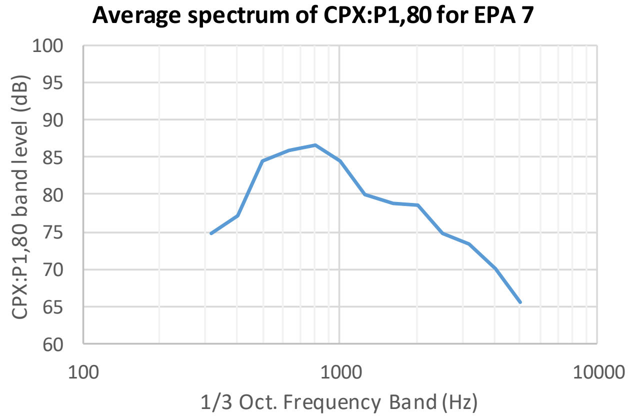



**Notes**

The sample was expanded from n=800 by including a later set of measurements of the same surfaces, primarily to get a broader range of ages. The age relationship shown is unlikely to be accurate. Reasonable sample size, notwithstanding duplication, but limited to two route stations, both in Chch: 01S-0333 and 01S-0327.

Variation within each site approx. SD=1.4 dB.

**Average spectrum of CPX:P1,80 for EPA 7**



# EPA 10

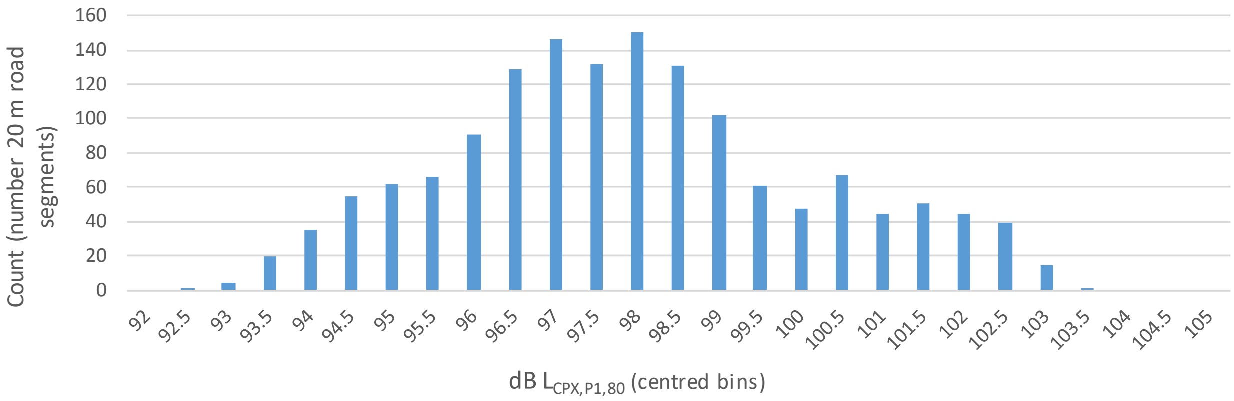
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1493 | | |
| dist = | 29.86 km | 25th | 96.44 |
| mean = | 97.91 dB | 50th | 97.77 |
| median = | 97.77 dB | 75th | 99.22 |
| mode = | 98.00 dB | 85th | 100.47 |
| SD = | 2.21 dB | 95th | 102.05 |

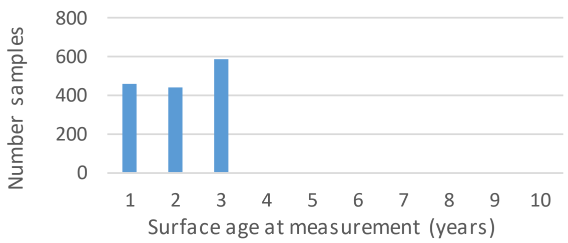
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 8 | n = | 1493 |
| Distinct road region: | 2 | mean = | 813 days |
| Distinct road council: | 2 | mean = | 2.2 years |
| Distinct state highway: | 4 | SD = | 291 days |
| Distinct road_id & date: | 17 | SD = | 0.8 years |

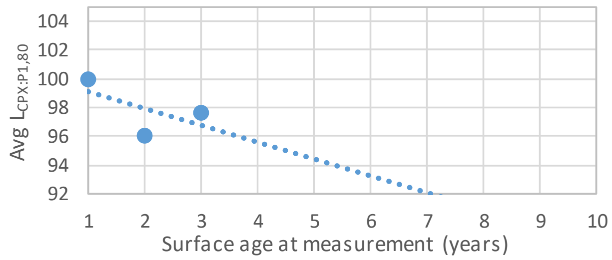
**Histogram of EPA 10 levels (n=1493)**




**Sample breakdown by age**



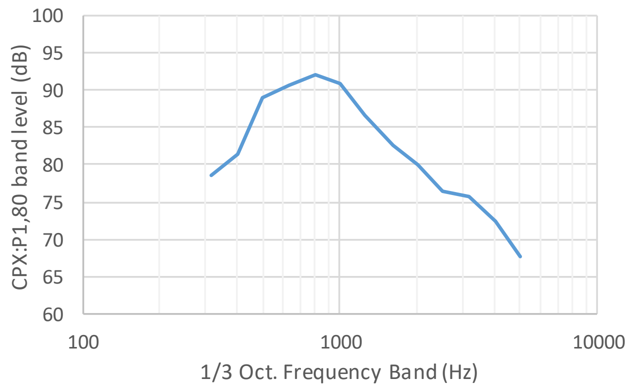

**Lcpx (surface age) ≈ -1.16 * years + 100.2 dB**




**Notes**

A decent sized, but very young sample. The downward trend in noise level is probably an abberation due to sample size and should be ignored. This surface has a particularly broad distribution, especially considering it only includes AKL and CHC surfaces of a similar age. The long extension above 100 dB is unusual. This sample had some surface data errors but care was taken during surface validation to remove them. There is no visible reason for 2 dB differences between lanes. Variation within the longer sites is also SD ≈ 2 dB

**Average spectrum of CPX:P1,80 for EPA 10**



# EPA 14

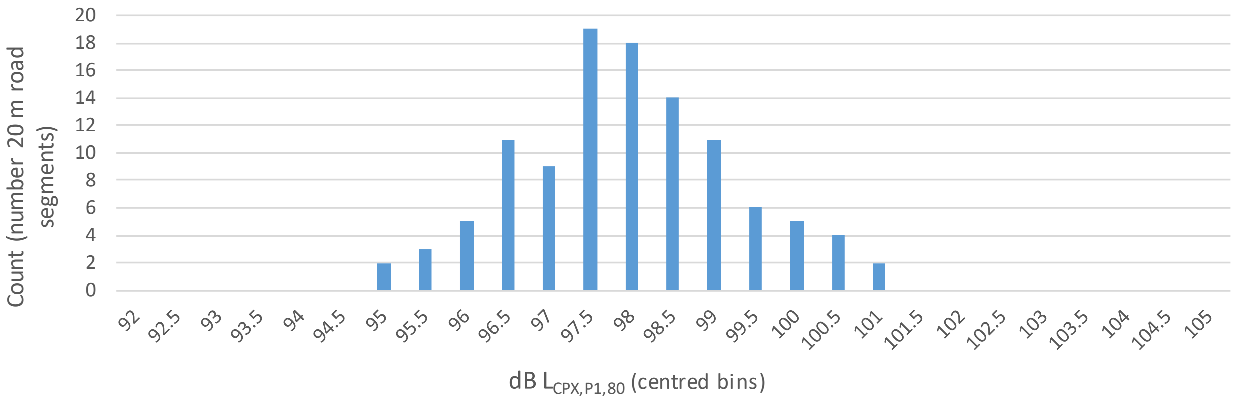
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 109 | | |
| dist = | 2.18 km | 25th | 97.12 |
| mean = | 97.97 dB | 50th | 97.89 |
| median = | 97.89 dB | 75th | 98.80 |
| mode = | 97.50 dB | 85th | 99.36 |
| SD = | 1.30 dB | 95th | 100.26 |

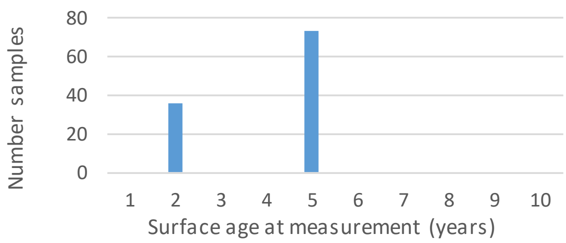
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 3 | n = | 109 |
| Distinct road region: | 2 | mean = | 1464 days |
| Distinct road council: | 2 | mean = | 4.0 years |
| Distinct state highway: | 3 | SD = | 445 days |
| Distinct road_id & date: | 4 | SD = | 1.2 years |

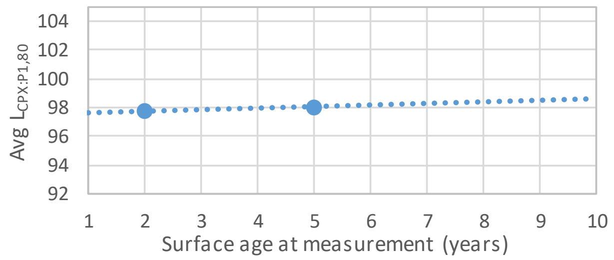
**Histogram of EPA 14 levels (n=109)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.098 * years + 97.58 dB**




**Notes**

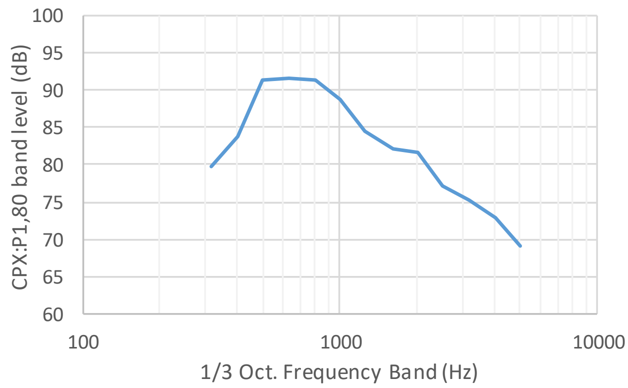
A fairly small sample, but normally distributed.

Only two ages measured, 2 yo and 5 yo EPA 14, but no indication of a strong trend over time.

Short lengths of road in WGN and CHC.

Variation within sites is approx. SD ≈ 1.0 dB

**Average spectrum of CPX:P1,80 for EPA 14**



# EPAHV 10

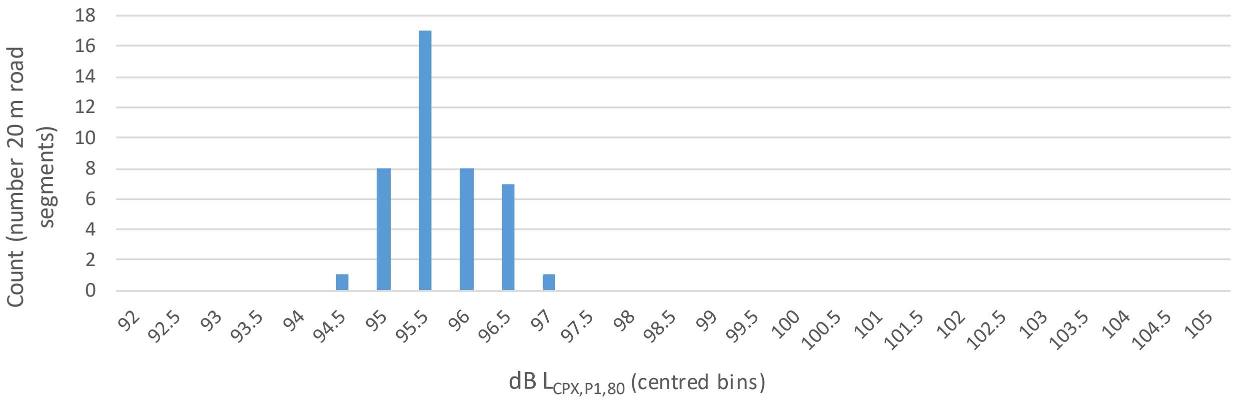
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 42 | | |
| dist = | 0.84 km | 25th | 95.30 |
| mean = | 95.67 dB | 50th | 95.60 |
| median = | 95.60 dB | 75th | 95.99 |
| mode = | 95.50 dB | 85th | 96.32 |
| SD = | 0.53 dB | 95th | 96.58 |

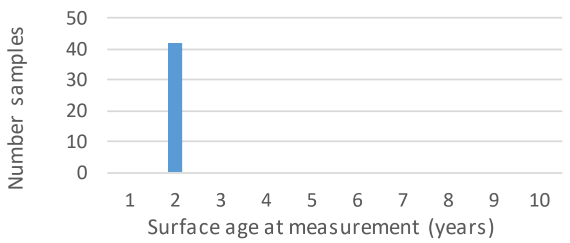
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 42 |
| Distinct road region: | 1 | mean = | 836 days |
| Distinct road council: | 1 | mean = | 2.3 years |
| Distinct state highway: | 1 | SD = | 83 days |
| Distinct road_id & date: | 2 | SD = | 0.2 years |

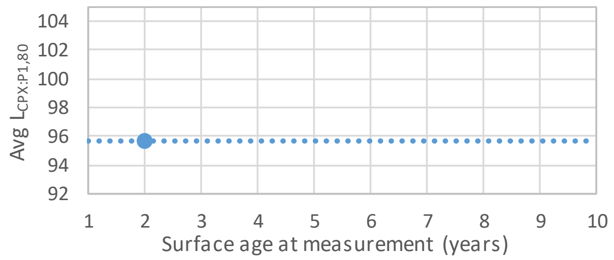
**Histogram of EPAHV 10 levels (n=42)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0 * years + 95.67 dB**

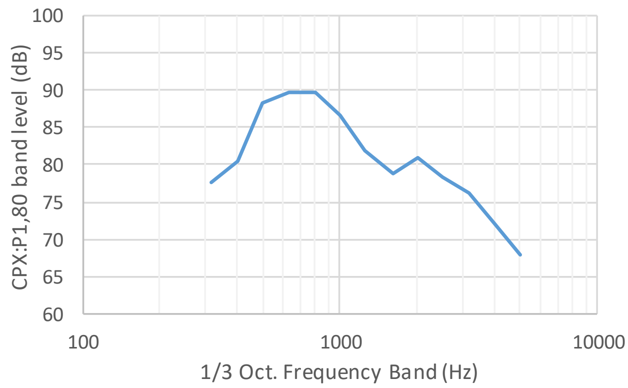



**Notes**

A single trial section (apparently laid over two days)

Useful only as an indicative result. More data would be required to determine if this result is typical of the EPAHV 10 surface specification, but unlikely that further examples will be laid in the near future.

**Average spectrum of CPX:P1,80 for EPAHV 10**



## B.4 Stone Mastic Asphalt (SMA)

### SMA 8

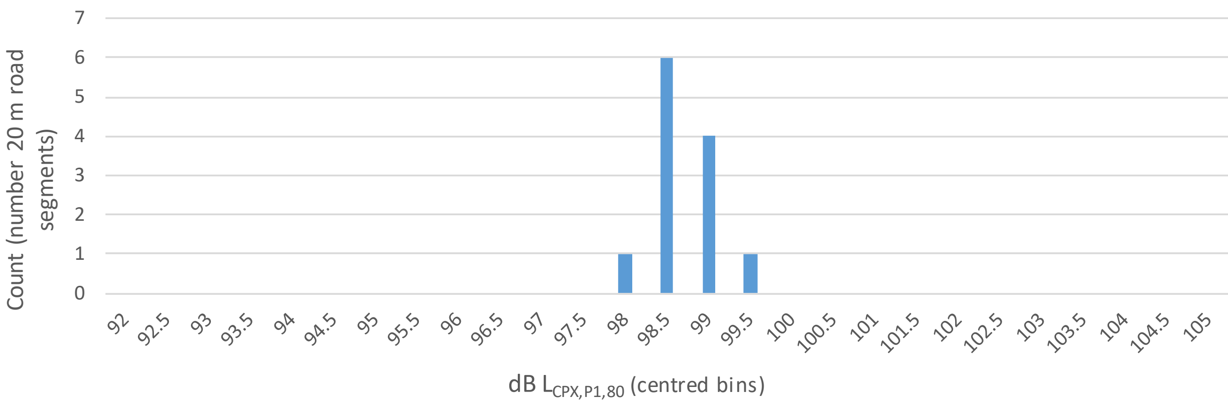
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 12 | | |
| dist = | 0.24 km | 25th | 98.52 |
| mean = | 98.76 dB | 50th | 98.64 |
| median = | 98.64 dB | 75th | 98.97 |
| mode = | 98.50 dB | 85th | 99.08 |
| SD = | 0.38 dB | 95th | 99.32 |

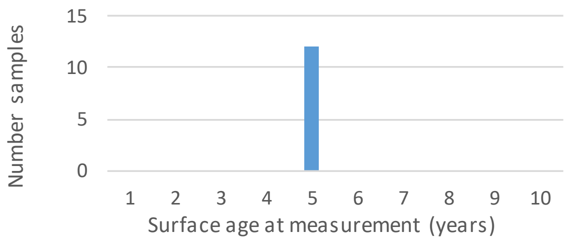
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 12 |
| Distinct road region: | 1 | mean = | 1740 days |
| Distinct road council: | 1 | mean = | 4.8 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

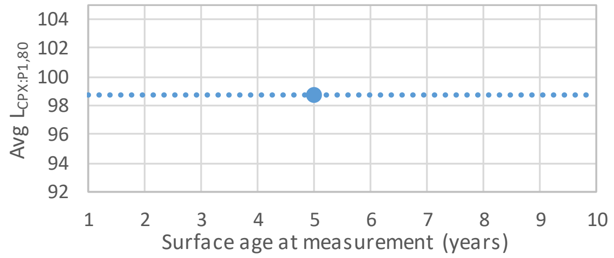
**Histogram of SMA 8 levels (n=12)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0 * years + 98.76 dB**

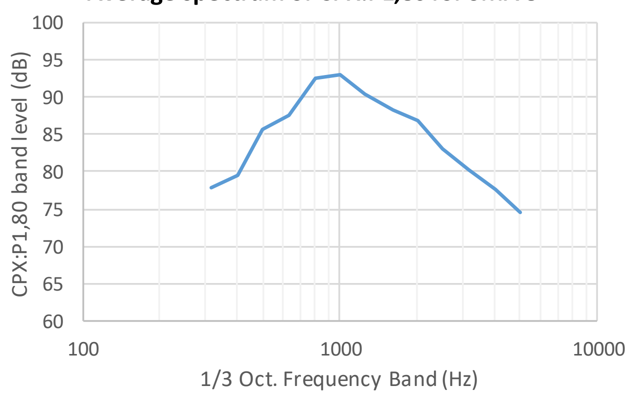



**Notes**

A very small sample from a single short stretch of road.

The average for SMA 8 shown here may not be representative of this surface specification.

**Average spectrum of CPX:P1,80 for SMA 8**



# SMA 10

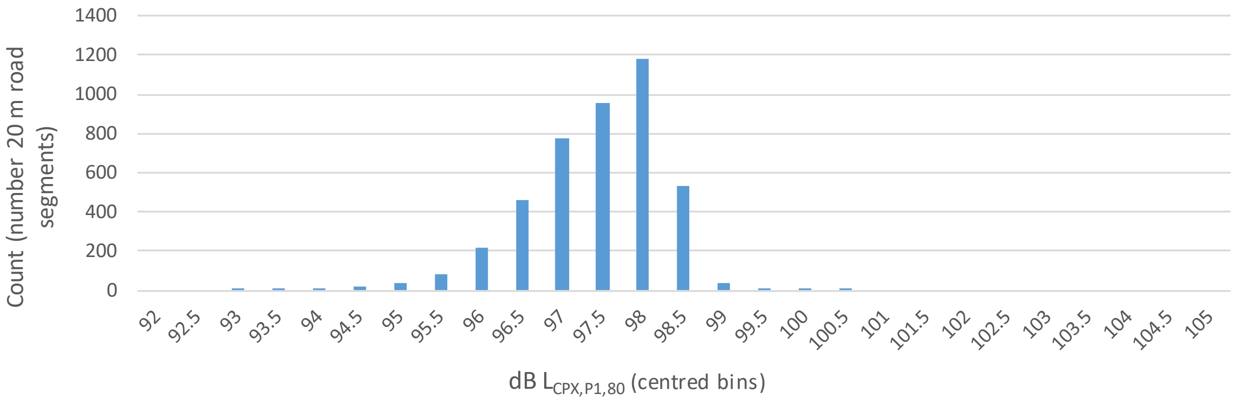
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 4312 | | |
| dist = | 86.24 km | 25th | 96.92 |
| mean = | 97.42 dB | 50th | 97.54 |
| median = | 97.54 dB | 75th | 98.03 |
| mode = | 98.00 dB | 85th | 98.22 |
| SD = | 0.82 dB | 95th | 98.47 |

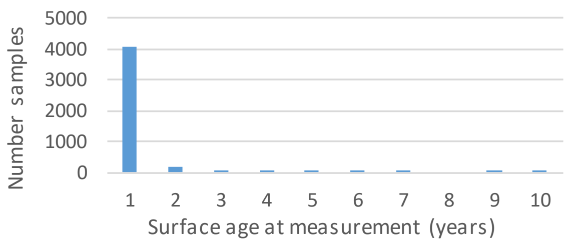
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 23 | n = | 4312 |
| Distinct road region: | 4 | mean = | 340 days |
| Distinct road council: | 7 | mean = | 0.9 years |
| Distinct state highway: | 5 | SD = | 253 days |
| Distinct road_id & date: | 28 | SD = | 0.7 years |

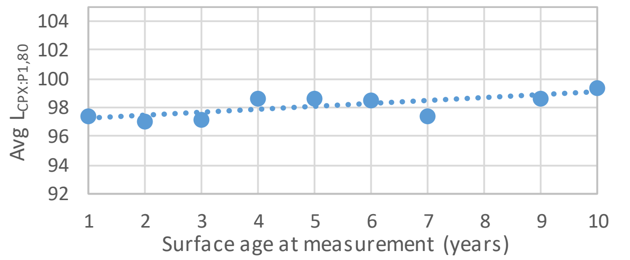
**Histogram of SMA 10 levels (n=4312)**




**Sample breakdown by age**



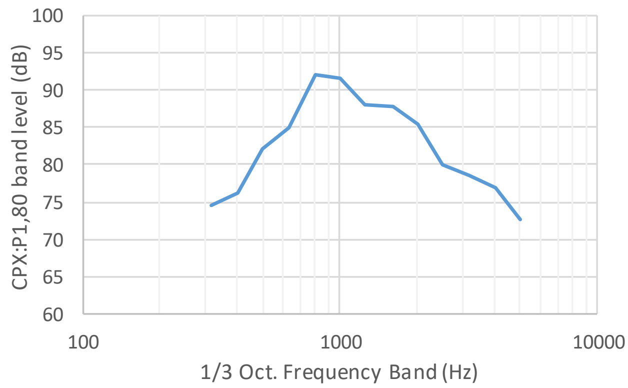

**Lcpx (surface age) ≈ 0.195 * years + 97.11 dB**




**Notes**

A very large sample, albeit with the vast majority of it (3800 samples) being both very young (1 year) and coming from a single stretch of Waikato Expressway.
The average level for 6 WEx sites is 97.3 dB.
The average of the non-WEx sites is 97.7 dB.
Calculation of aging effect is not weighted by sample size, and indicates a gradual increase ~ 1 dB / 5 years, which is statistically significant at $p<0.05$ [± 0.17 dB/y].
Within site variability is typically about SD ≈ 0.7 dB.

**Average spectrum of CPX:P1,80 for SMA 10**



# SMA 10 40 mm

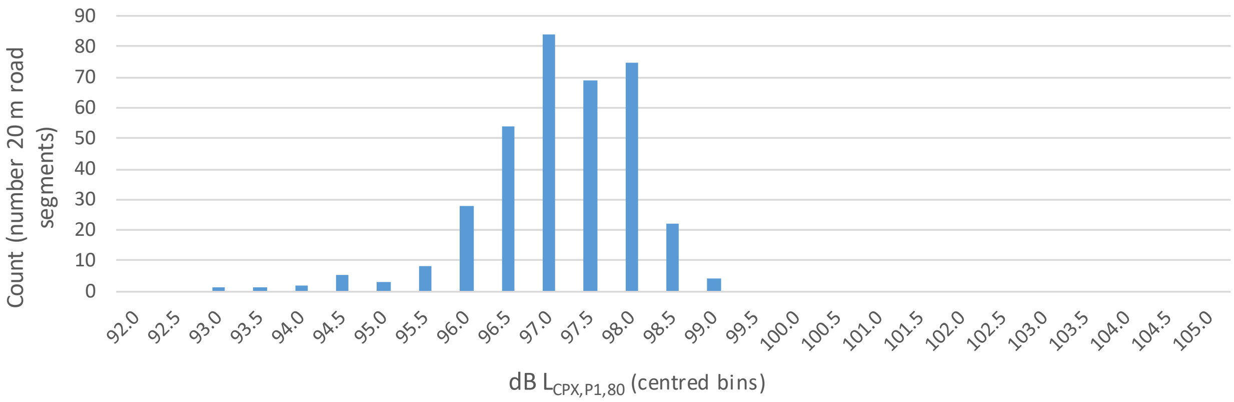
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 356 | | |
| dist = | 7.12 km | 25th | 96.64 |
| mean = | 97.15 dB | 50th | 97.18 |
| median = | 97.18 dB | 75th | 97.84 |
| mode = | 97.00 dB | 85th | 98.05 |
| SD = | 0.90 dB | 95th | 98.35 |

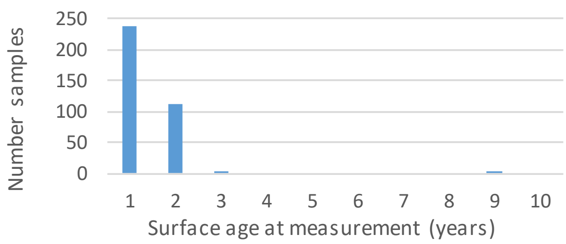
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 9 | n = | 356 |
| Distinct road region: | 2 | mean = | 573 days |
| Distinct road council: | 3 | mean = | 1.6 years |
| Distinct state highway: | 3 | SD = | 319 days |
| Distinct road_id & date: | 12 | SD = | 0.9 years |

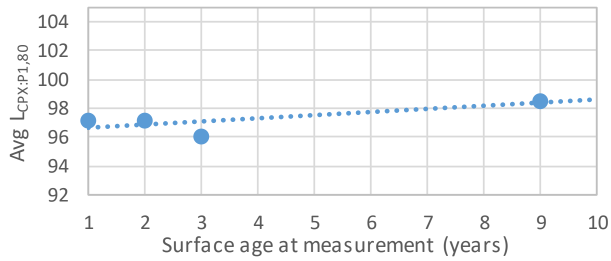
**Histogram of SMA 10 40mm levels (n=356)**




**Sample breakdown by age**



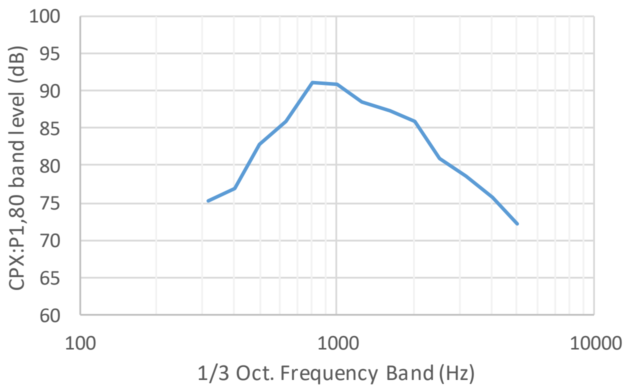

**Lcpx (surface age) ≈ 0.216 * years + 96.45 dB**




**Notes**

SMA 10 filtered for nominal 40 mm thickness.

**Average spectrum of CPX:P1,80 for SMA 10 40mm**



# SMA 10 50 mm

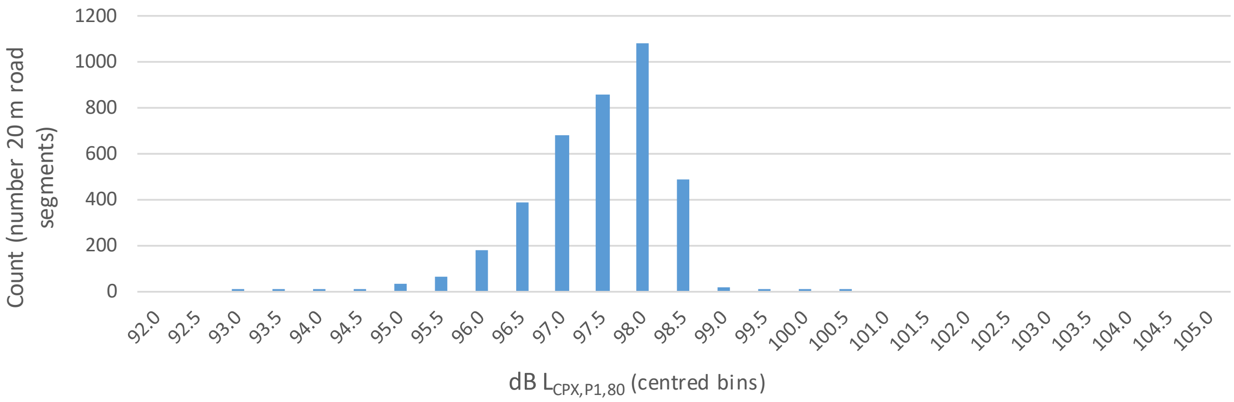
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 3798 | 25th | 96.97 |
| dist = | 75.96 km | 50th | 97.57 |
| mean = | 97.45 dB | 75th | 98.04 |
| median = | 97.57 dB | 85th | 98.22 |
| mode = | 98.00 dB | 95th | 98.45 |
| SD = | 0.77 dB | | |

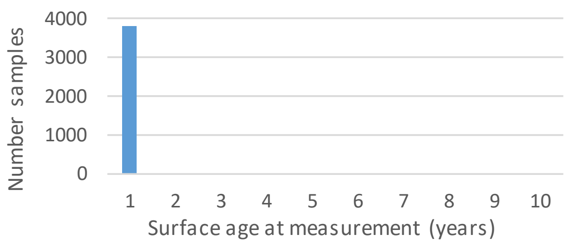
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 6 | n = | 3798 |
| Distinct road region: | 1 | mean = | 285 days |
| Distinct road council: | 1 | mean = | 0.8 years |
| Distinct state highway: | 1 | SD = | 6 days |
| Distinct road_id & date: | 6 | SD = | 0.0 years |

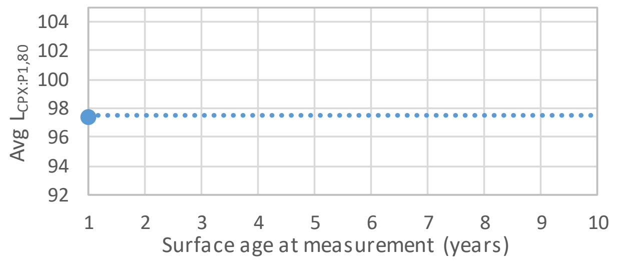
**Histogram of SMA 10 50mm levels (n=3798)**




**Sample breakdown by age**



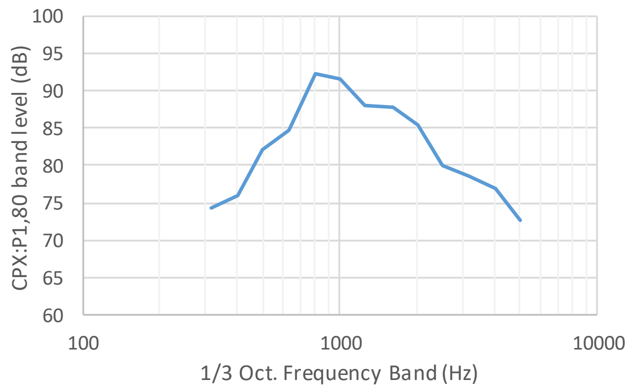

**Lcpx (surface age) ≈ 0 * years + 97.45 dB**




**Notes**

SMA 10 filtered for nominal 50 mm thickness.

**Average spectrum of CPX:P1,80 for SMA 10 50mm**



# SMA 11

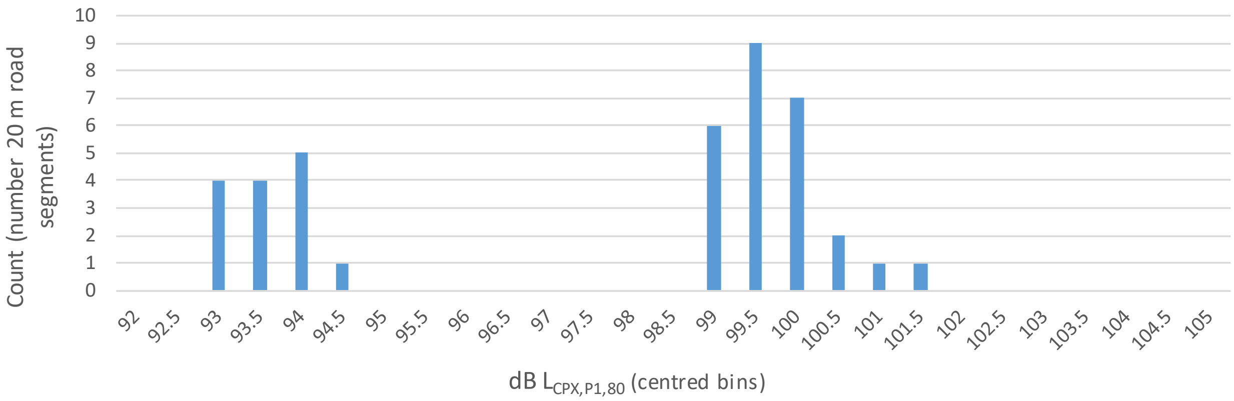
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 40 | 25th | 93.92 |
| dist = | 0.8 km | 50th | 99.22 |
| mean = | 97.57 dB | 75th | 99.77 |
| median = | 99.22 dB | 85th | 100.04 |
| mode = | 99.50 dB | 95th | 100.30 |
| SD = | 2.99 dB | | |

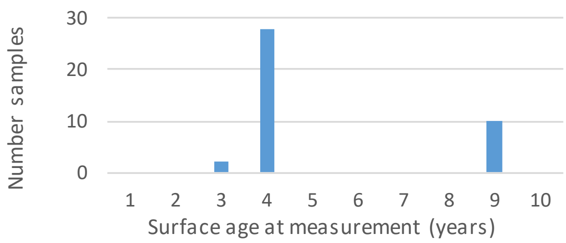
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 4 | n = | 40 |
| Distinct road region: | 2 | mean = | 1897 days |
| Distinct road council: | 3 | mean = | 5.2 years |
| Distinct state highway: | 2 | SD = | 858 days |
| Distinct road_id & date: | 4 | SD = | 2.4 years |

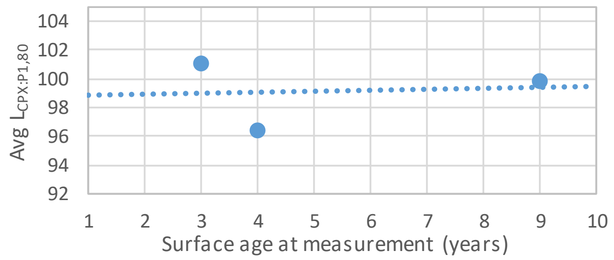
**Histogram of SMA 11 levels (n=40)**




**Sample breakdown by age**



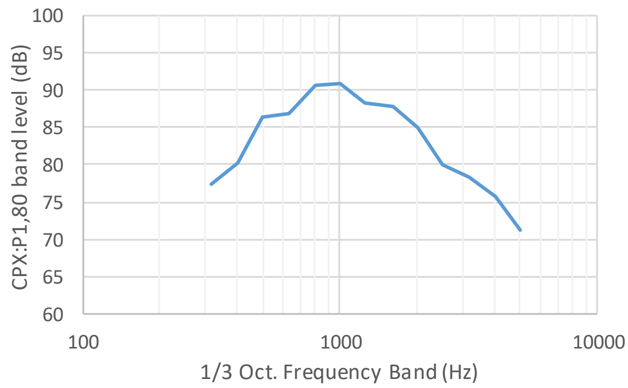

**Lcpx (surface age) ≈ 0.068 * years + 98.81 dB**




**Notes**

A small sample, but spread across 4 road sections and 3 council regions. The bimodal distribution is unusual, with one road section (01N-0504-I/0.6) averaging 93.6 dB, while another section of SMA 11 on the opposite carriageway with the same date averages 99.4 dB. Data may not be useful. No conclusion can be made on aging effects. Surprisingly, the within site variability is very low, typically about SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for SMA 11**



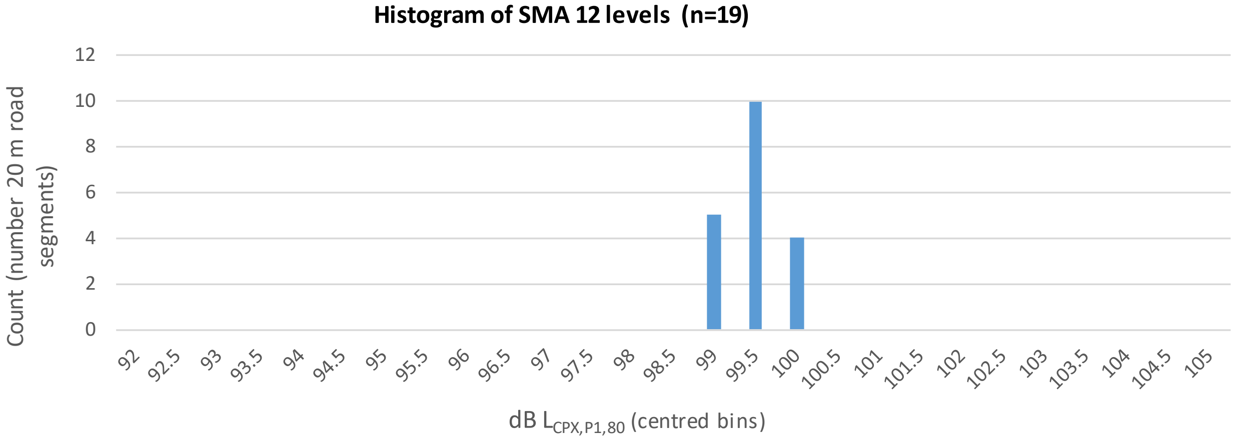
# SMA 12

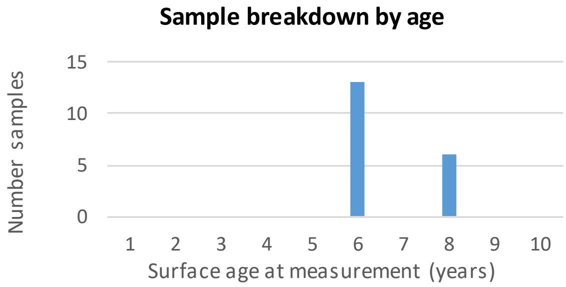
**CPX Levels**

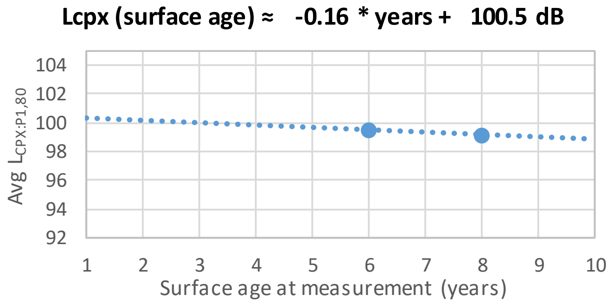
| | | Percentiles | |
|---|---|---|---|
| n = | 19 | | |
| dist = | 0.38 km | 25th | 99.24 |
| mean = | 99.43 dB | 50th | 99.44 |
| median = | 99.44 dB | 75th | 99.60 |
| mode = | 99.50 dB | 85th | 99.79 |
| SD = | 0.30 dB | 95th | 99.85 |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 19 |
| Distinct road region: | 1 | mean = | 2368 days |
| Distinct road council: | 1 | mean = | 6.5 years |
| Distinct state highway: | 1 | SD = | 278 days |
| Distinct road_id & date: | 2 | SD = | 0.8 years |



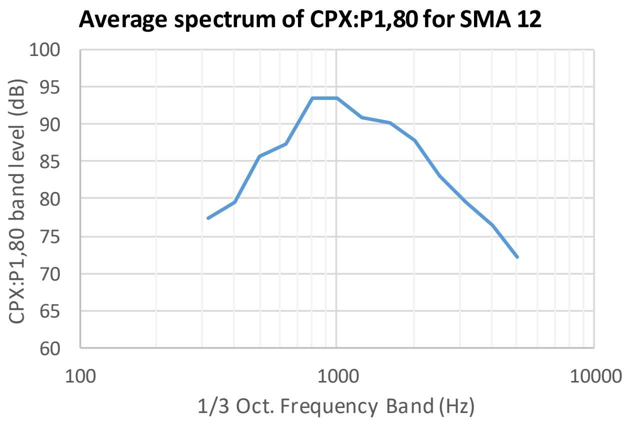




**Notes**

A very small sample from a single stretch of road. The very low variance probably reflects the lack of geographical diversity.

The average for SMA 12 should be treated with caution.



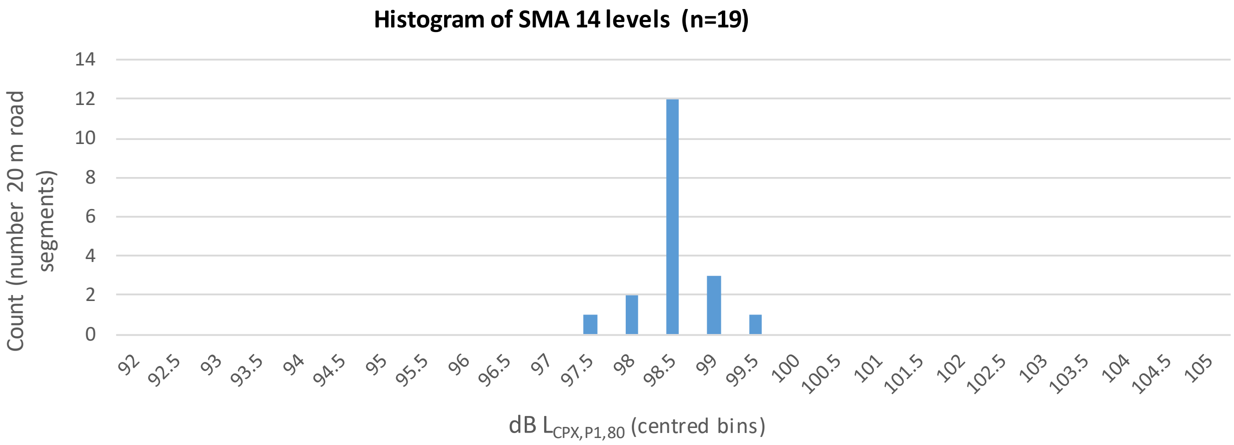
# SMA 14

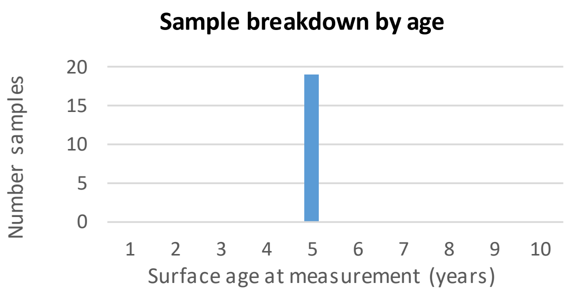
**CPX Levels**

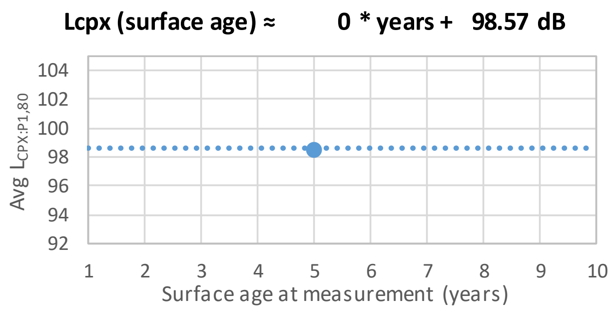
| | | Percentiles | |
|---|---|---|---|
| n = | 19 | | |
| dist = | 0.38 km | 25th | 98.51 |
| mean = | 98.57 dB | 50th | 98.64 |
| median = | 98.64 dB | 75th | 98.73 |
| mode = | 98.50 dB | 85th | 98.79 |
| SD = | 0.42 dB | 95th | 98.91 |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 2 | n = | 19 |
| Distinct road region: | 1 | mean = | 1809 days |
| Distinct road council: | 1 | mean = | 5.0 years |
| Distinct state highway: | 2 | SD = | 19 days |
| Distinct road_id & date: | 2 | SD = | 0.1 years |



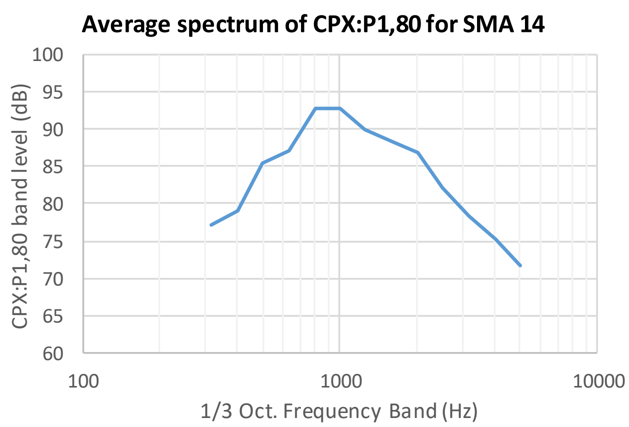




**Notes**

A very small sample from 2 different CHC roads. The very low variance probably reflects the lack of geographical diversity.

The average for SMA 14 should be treated with caution.



# SMA 15

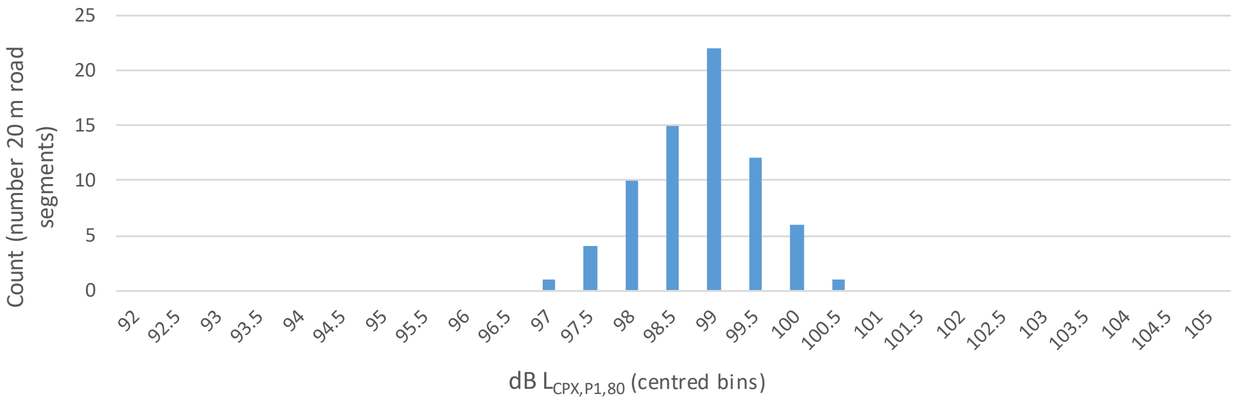
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 71 | 25th | 98.43 |
| dist = | 1.42 km | 50th | 98.91 |
| mean = | 98.85 dB | 75th | 99.32 |
| median = | 98.91 dB | 85th | 99.59 |
| mode = | 99.00 dB | 95th | 99.84 |
| SD = | 0.68 dB | | |

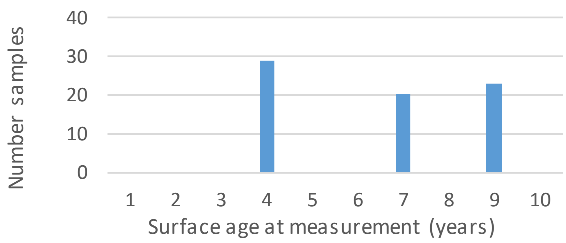
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 72 |
| Distinct road region: | 3 | mean = | 2357 days |
| Distinct road council: | 3 | mean = | 6.5 years |
| Distinct state highway: | 3 | SD = | 777 days |
| Distinct road_id & date: | 5 | SD = | 2.1 years |

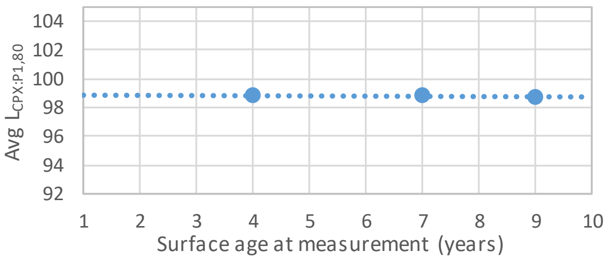
**Histogram of SMA 15 levels (n=71)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.01 * years + 98.91 dB**



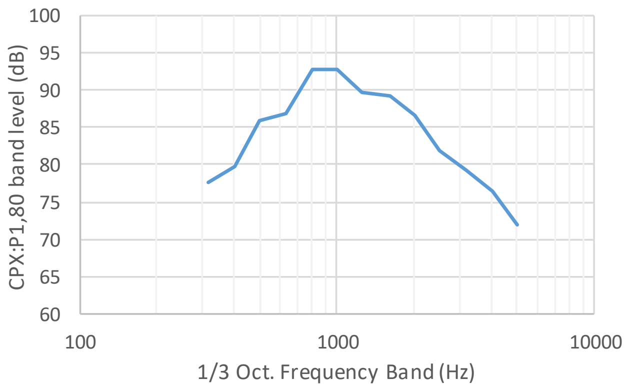

**Notes**

A reasonably small but diverse sample covering three regions, including 5 distinct road sections of similar length (200 -400 metres).

A reasonably mature sample, compared to other SMAs, and with no clear aging effect.

The within site variance was low, SD ≈ 0.6 dB.

**Average spectrum of CPX:P1,80 for SMA 15**



## B.5 Dense Graded Asphalt (DGA)

### AC 10

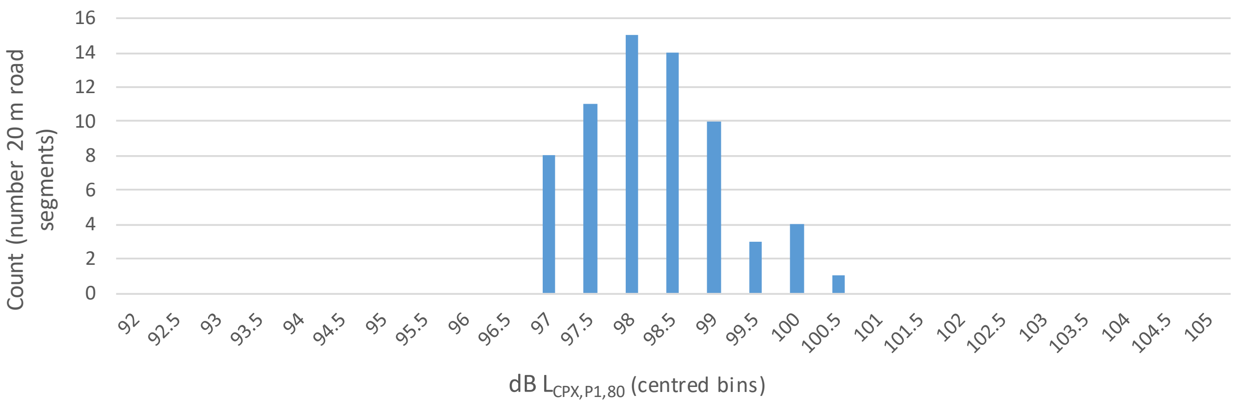
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 66 | | |
| dist = | 1.32 km | 25th | 97.55 |
| mean = | 98.26 dB | 50th | 98.22 |
| median = | 98.22 dB | 75th | 98.87 |
| mode = | 98.00 dB | 85th | 99.10 |
| SD = | 0.84 dB | 95th | 99.84 |

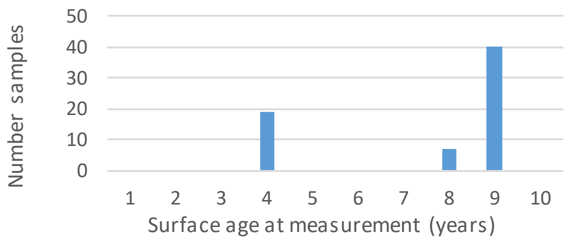
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 6 | n = | 66 |
| Distinct road region: | 2 | mean = | 1919 days |
| Distinct road council: | 3 | mean = | 5.3 years |
| Distinct state highway: | 3 | SD = | 599 days |
| Distinct road_id & date: | 6 | SD = | 1.6 years |

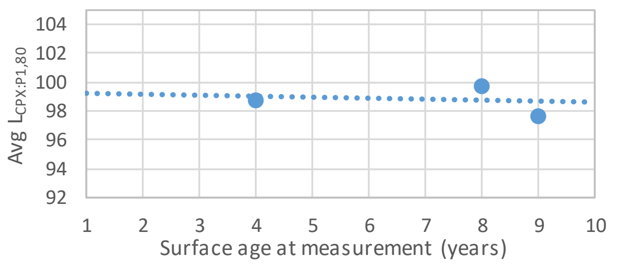
**Histogram of AC 10 levels (n=66)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.07 * years + 99.26 dB**



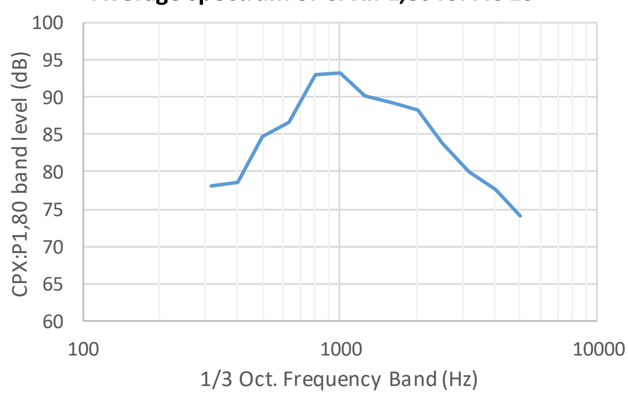

**Notes**

A small sample of four short (< 200 m) sections of state highway in Canterbury and two 400 m sections of local road in Wellington.

AC on the SH network is almost non-existent in high speed areas. AC is sometimes grooved (transverse) which greatly increases its CPX level but this can only be observed from the roadside.

The within site variance was low, SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for AC 10**



# UTA 10

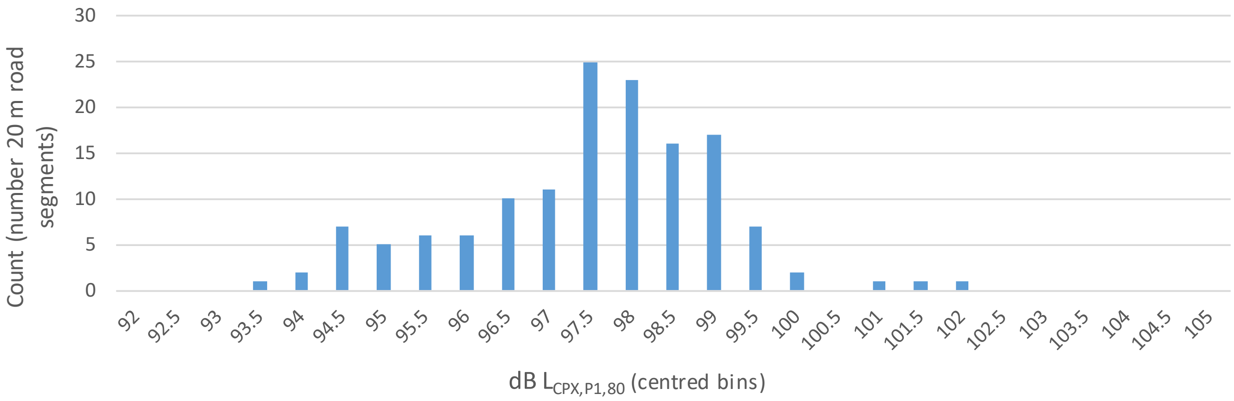
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 141 | | |
| dist = | 2.82 km | 25th | 96.72 |
| mean = | 97.53 dB | 50th | 97.69 |
| median = | 97.69 dB | 75th | 98.62 |
| mode = | 97.50 dB | 85th | 98.93 |
| SD = | 1.55 dB | 95th | 99.53 |

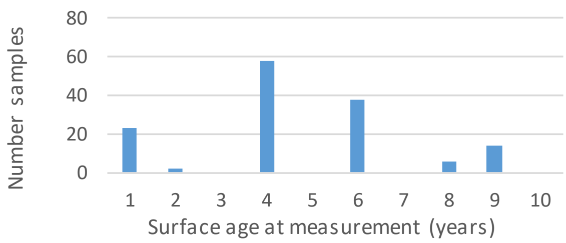
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 8 | n = | 141 |
| Distinct road region: | 3 | mean = | 1722 days |
| Distinct road council: | 5 | mean = | 4.7 years |
| Distinct state highway: | 3 | SD = | 832 days |
| Distinct road_id & date: | 12 | SD = | 2.3 years |

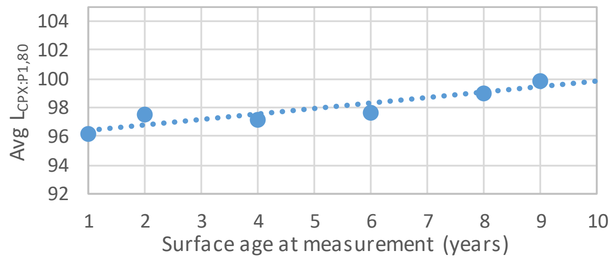
**Histogram of UTA 10 levels (n=141)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.378 * years + 96.04 dB**

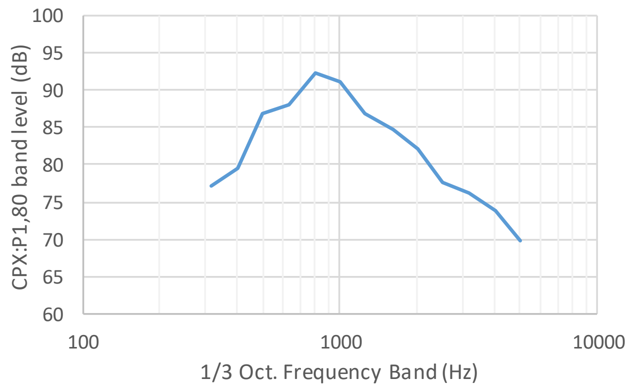



**Notes**

A small but geographically and chronologically diverse sample: three regions and 6 years.
The aging effect is significant $p<0.05$ [±0.22 dB/y].
The sample age is symmetrical about-, and biased towards-, the midpoint (5 years) anyway.

The 12 sites are typically short (200 m), and the within site variance is low, SD ≈ 0.6 dB compared with the variation between sites.

**Average spectrum of CPX:P1,80 for UTA 10**



## B.6 Single-Coat Chipseal (1CHIP)

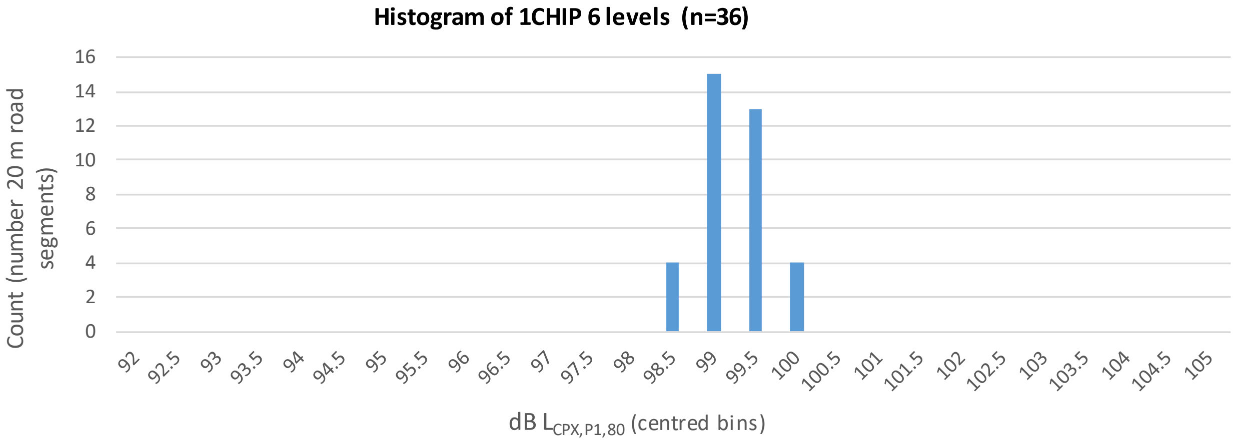
### 1CHIP 6

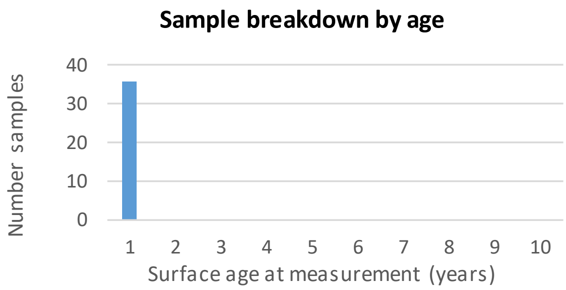
**CPX Levels**

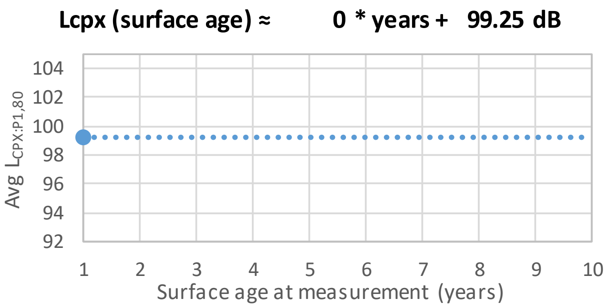
| | | Percentiles | |
|---|---|---|---|
| n = | 36 | 25th | 99.03 |
| dist = | 0.72 km | 50th | 99.23 |
| mean = | 99.25 dB | 75th | 99.45 |
| median = | 99.23 dB | 85th | 99.56 |
| mode = | 99.00 dB | 95th | 99.97 |
| SD = | 0.38 dB | | |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 36 |
| Distinct road region: | 1 | mean = | 423 days |
| Distinct road council: | 1 | mean = | 1.2 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

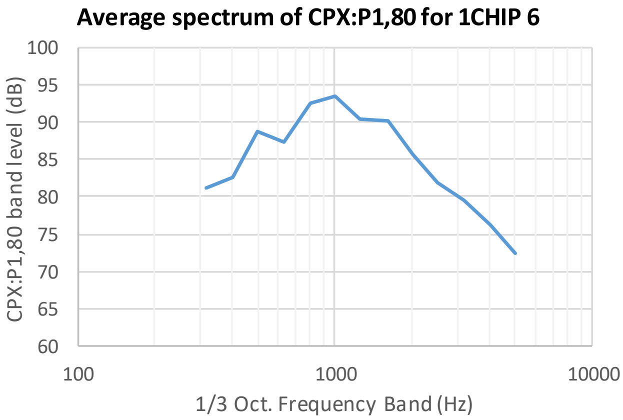



**Notes**

An extremely small sample from a single 1-year-old Wellington site. Useful only as a very rough estimate of where 1CHIP grade 6 lies, may not be representative of the surface specification.



# 1CHIP 5

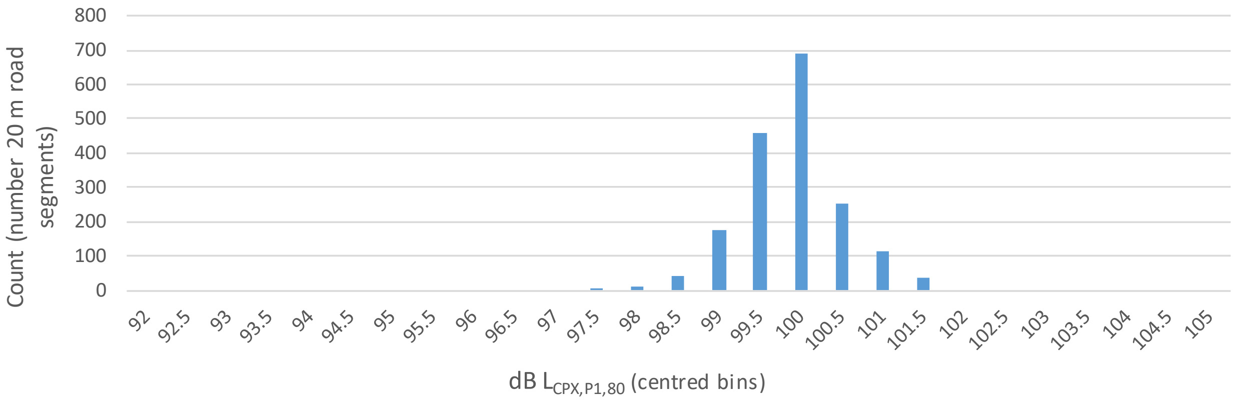
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1780 | | |
| dist = | 35.6 km | 25th | 99.53 |
| mean = | 99.89 dB | 50th | 99.90 |
| median = | 99.90 dB | 75th | 100.22 |
| mode = | 100.00 dB | 85th | 100.41 |
| SD = | 0.61 dB | 95th | 101.02 |

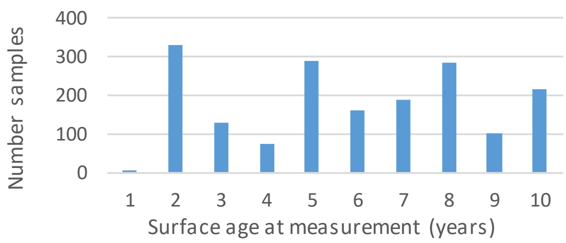
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 15 | n = | 1780 |
| Distinct road region: | 4 | mean = | 2192 days |
| Distinct road council: | 8 | mean = | 6.0 years |
| Distinct state highway: | 5 | SD = | 971 days |
| Distinct road_id & date: | 26 | SD = | 2.7 years |

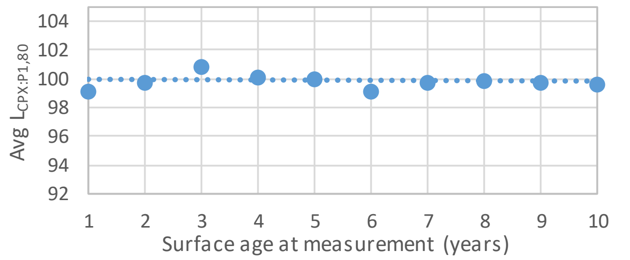
**Histogram of 1CHIP 5 levels (n=1780)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.01 * years + 99.93 dB**



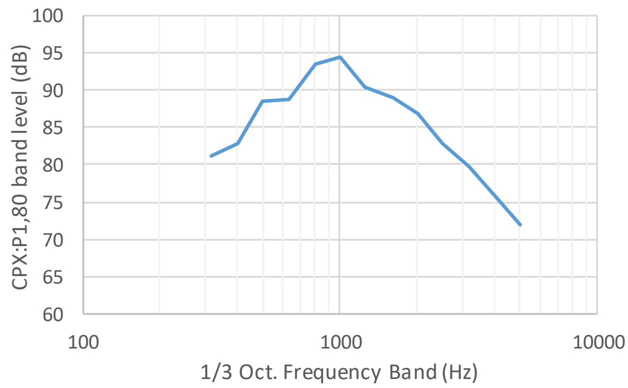

**Notes**

A large sample, collected from Waikato, Manawatu, Wellington and Canterbury.

The sample ages at the time of measurement are well distributed and there is no evidence of a significant aging effect on CPX level.

The within site variance is low, SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for 1CHIP 5**



# 1CHIP 4

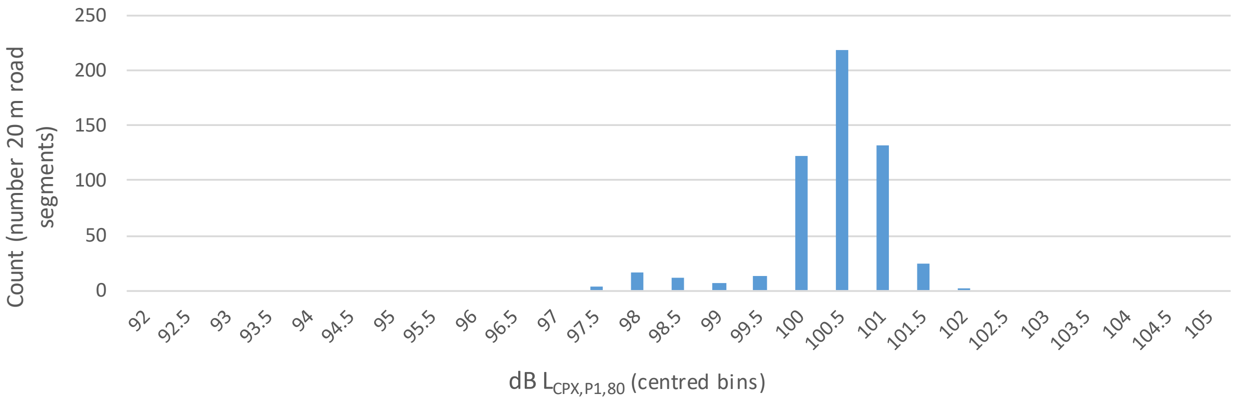
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 551 | | |
| dist = | 11.02 km | 25th | 100.14 |
| mean = | 100.38 dB | 50th | 100.50 |
| median = | 100.50 dB | 75th | 100.78 |
| mode = | 100.50 dB | 85th | 100.95 |
| SD = | 0.72 dB | 95th | 101.22 |

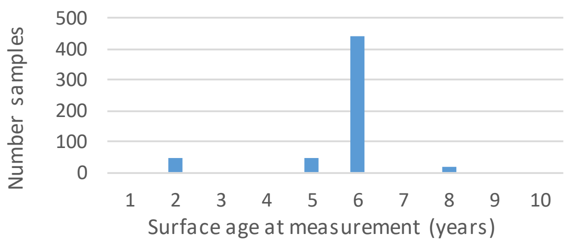
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 551 |
| Distinct road region: | 2 | mean = | 2047 days |
| Distinct road council: | 4 | mean = | 5.6 years |
| Distinct state highway: | 3 | SD = | 390 days |
| Distinct road_id & date: | 7 | SD = | 1.1 years |

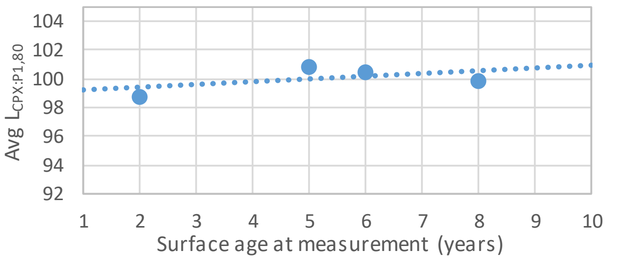
**Histogram of 1CHIP 4 levels (n=551)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.197 * years + 99.01 dB**

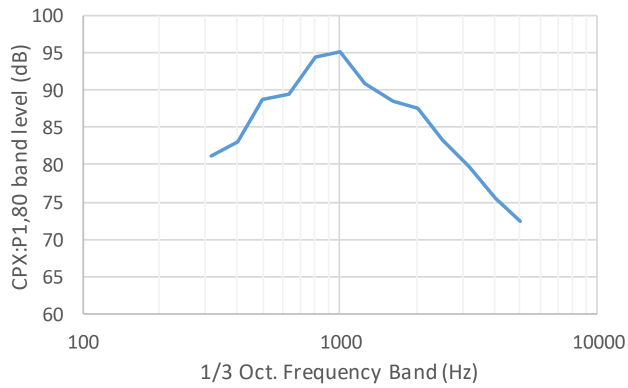



**Notes**

A moderate sized sample in terms of distance, from Wellington and Canterbury. Only 7 distinct sites of similar extent, typically about 1.5 lane-km. Despite this, the sample age is not well-distributed, with about 3/4ths being 6 years old. The aging effect shown is not statistically significant, p>0.05.

Distribution is skewed to the left, with a long tail.

**Average spectrum of CPX:P1,80 for 1CHIP 4**



# 1CHIP 3

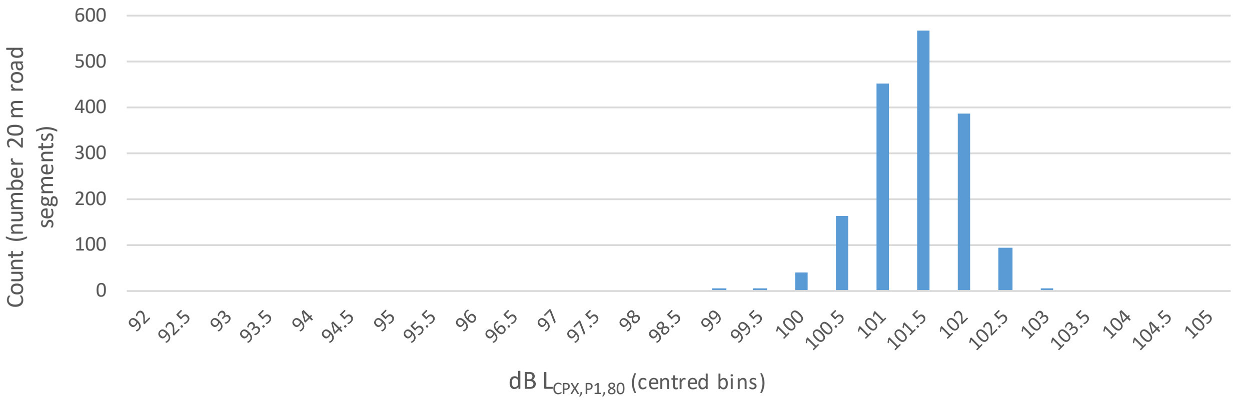
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1717 | 25th | 101.05 |
| dist = | 34.34 km | 50th | 101.40 |
| mean = | 101.40 dB | 75th | 101.81 |
| median = | 101.40 dB | 85th | 101.99 |
| mode = | 101.50 dB | 95th | 102.28 |
| SD = | 0.57 dB | | |

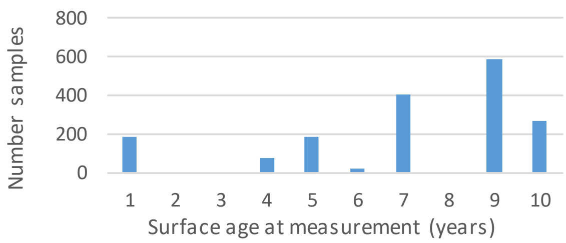
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 12 | n = | 1717 |
| Distinct road region: | 3 | mean = | 2614 days |
| Distinct road council: | 6 | mean = | 7.2 years |
| Distinct state highway: | 5 | SD = | 1015 days |
| Distinct road_id & date: | 24 | SD = | 2.8 years |

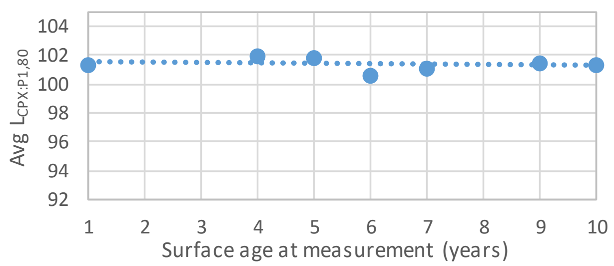
**Histogram of 1CHIP 3 levels (n=1717)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.03 * years + 101.6 dB**



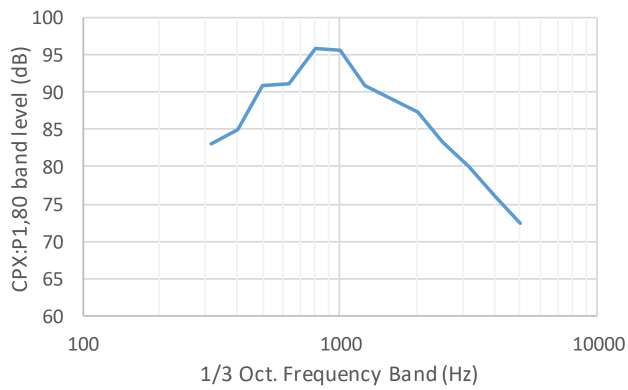

**Notes**

A large sample, drawn from Waikato, Manawatu, and Canterbury.

The sample is well-distributed in age and there is no statistically significant aging effect, p>0.05.

The within site variance is low, SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for 1CHIP 3**



# 1CHIP 2

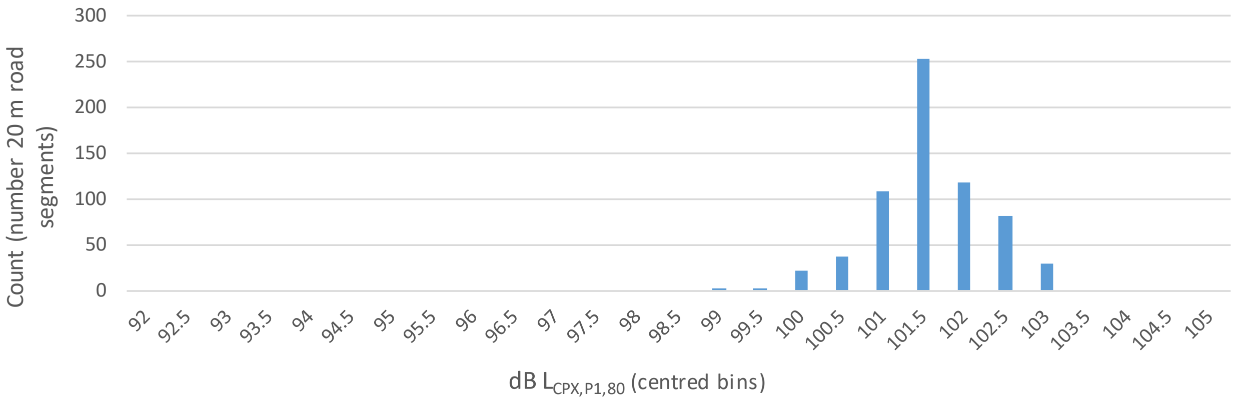
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 655 | 25th | 101.23 |
| dist = | 13.1 km | 50th | 101.57 |
| mean = | 101.58 dB | 75th | 101.98 |
| median = | 101.57 dB | 85th | 102.32 |
| mode = | 101.50 dB | 95th | 102.69 |
| SD = | 0.68 dB | | |

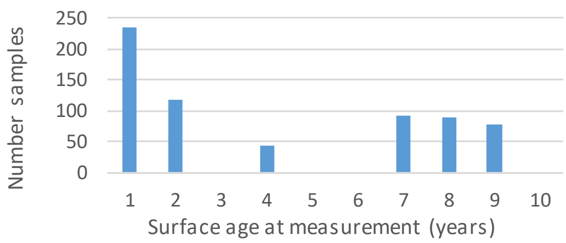
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 11 | n = | 655 |
| Distinct road region: | 2 | mean = | 1556 days |
| Distinct road council: | 4 | mean = | 4.3 years |
| Distinct state highway: | 4 | SD = | 1216 days |
| Distinct road_id & date: | 18 | SD = | 3.3 years |

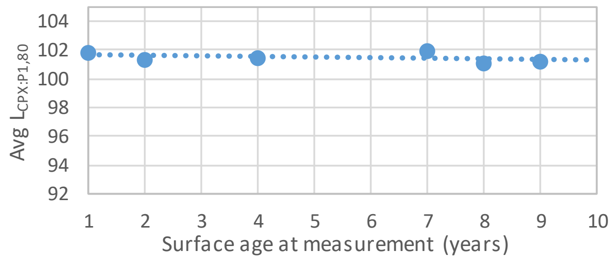
**Histogram of 1CHIP 2 levels (n=655)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.05 * years + 101.7 dB**



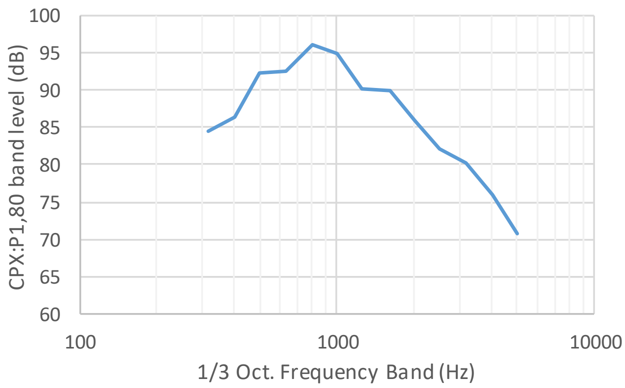

**Notes**

A reasonable sample size, limited to 4 local authority areas in the lower North Island. The average site is about 1 km in length.

The sample is well-distributed in age and there is no statistically significant aging effect, $p>0.05$.

The within site variance is low, SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for 1CHIP 2**



## B.7 Two-Coat Chipseal (2CHIP)

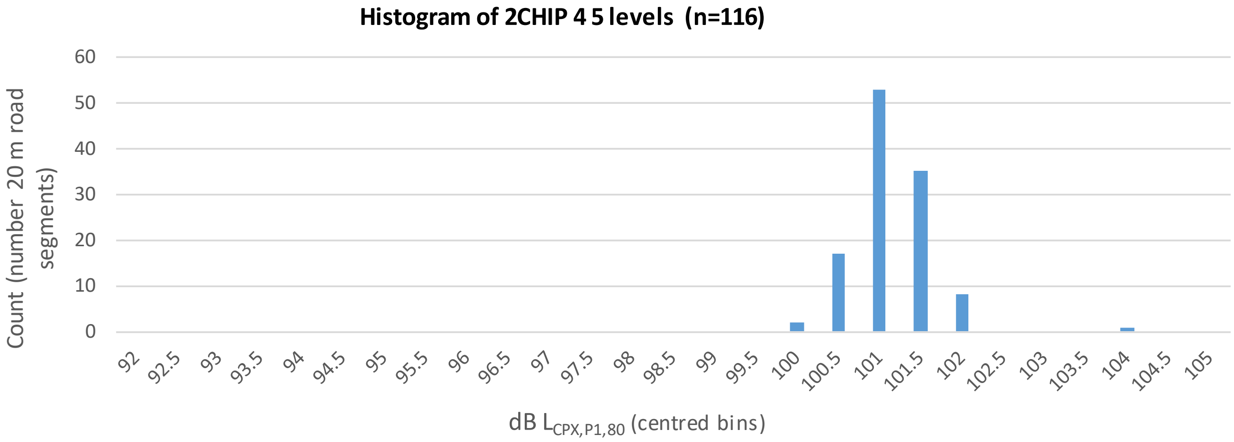
### 2CHIP 4/5

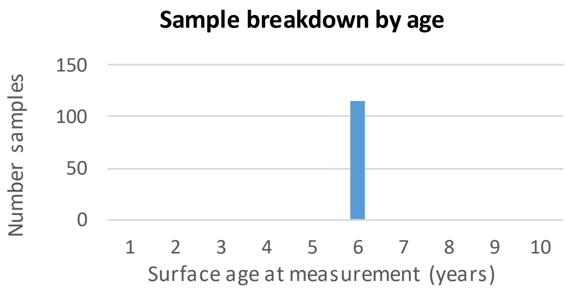
**CPX Levels**

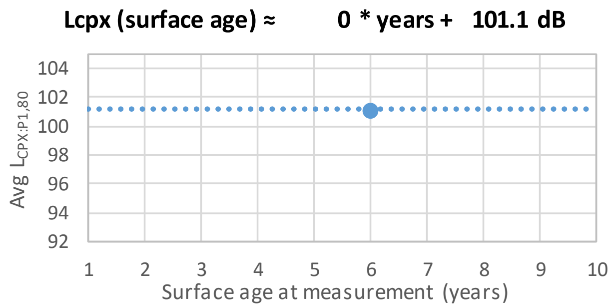
| | | Percentiles | |
|---|---|---|---|
| n = | 116 | | |
| dist = | 2.32 km | 25th | 100.81 |
| mean = | 101.13 dB | 50th | 101.10 |
| median = | 101.10 dB | 75th | 101.36 |
| mode = | 101.00 dB | 85th | 101.50 |
| SD = | 0.47 dB | 95th | 101.82 |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 116 |
| Distinct road region: | 1 | mean = | 2285 days |
| Distinct road council: | 1 | mean = | 6.3 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |



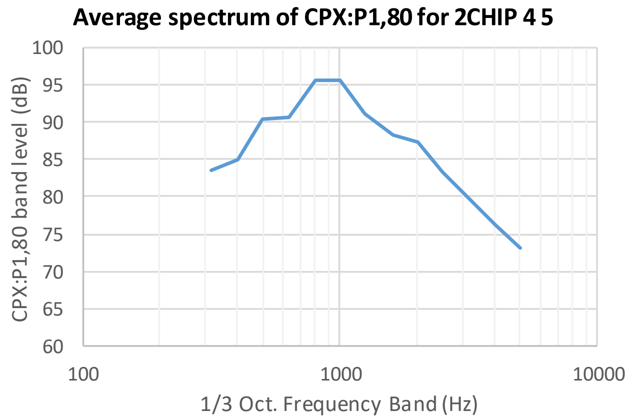




**Notes**

A sample from a single site (about 1.2 km long, and measured in both directions) in Canterbury.

Therefore may not be represenative of the 2CHIP 4 5 specification.



## 2CHIP 3/5

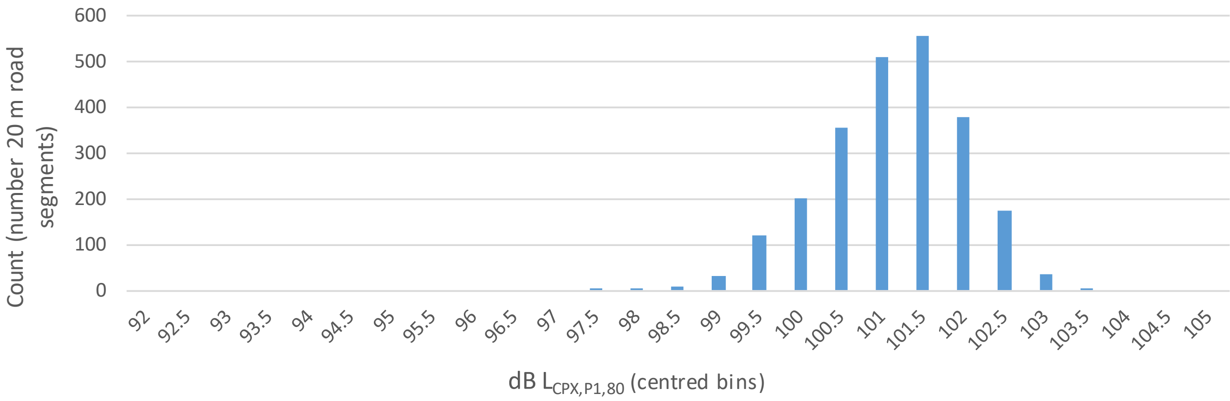
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 2374 | | |
| dist = | 47.48 km | 25th | 100.59 |
| mean = | 101.14 dB | 50th | 101.21 |
| median = | 101.21 dB | 75th | 101.75 |
| mode = | 101.50 dB | 85th | 102.02 |
| SD = | 0.85 dB | 95th | 102.41 |

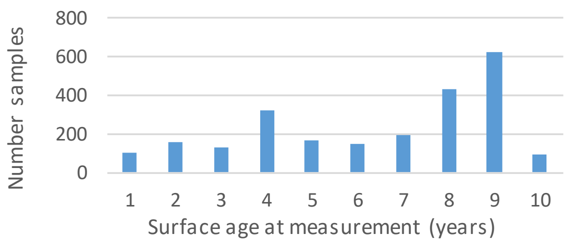
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 28 | n = | 2374 |
| Distinct road region: | 4 | mean = | 2376 days |
| Distinct road council: | 10 | mean = | 6.5 years |
| Distinct state highway: | 6 | SD = | 926 days |
| Distinct road_id & date: | 63 | SD = | 2.5 years |

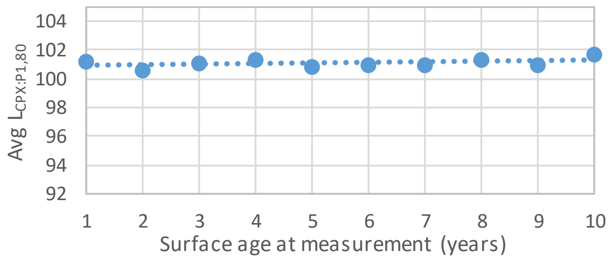
**Histogram of 2CHIP 3 5 levels (n=2374)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.047 * years + 100.9 dB**



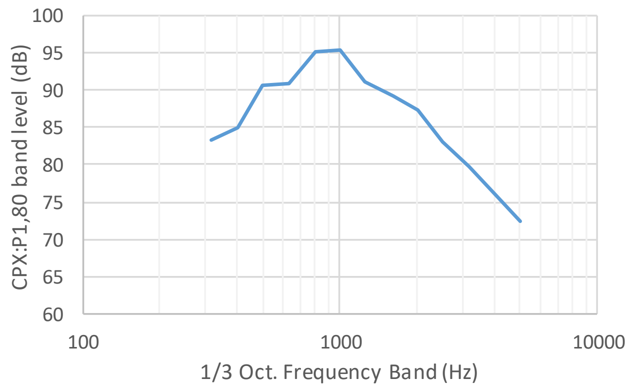

**Notes**

A very large sample, including sites across every region visited.

The sample ages are fairly well distributed. There is no statistically significant aging effect ($p>0.05$).

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for 2CHIP 3 5**



# 2CHIP 2/5

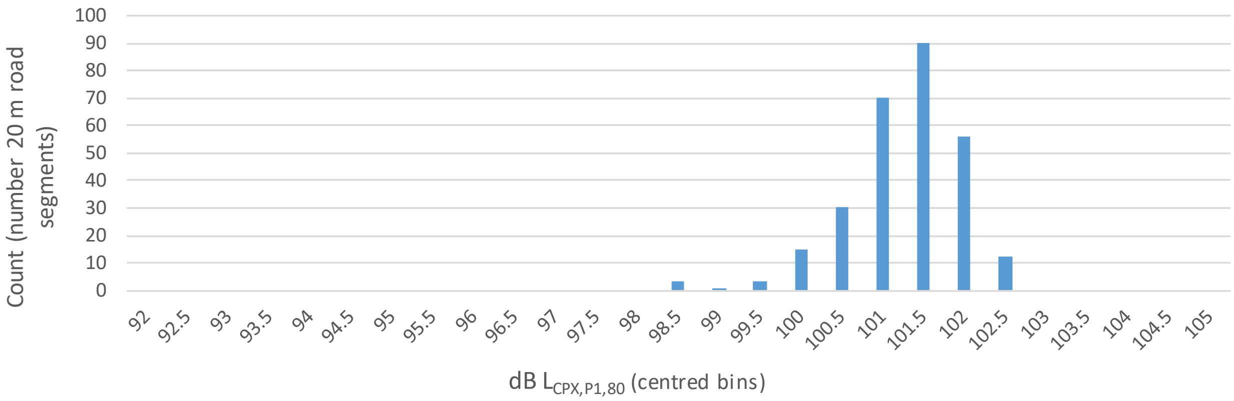
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 280 | | |
| dist = | 5.6 km | 25th | 100.88 |
| mean = | 101.26 dB | 50th | 101.33 |
| median = | 101.33 dB | 75th | 101.73 |
| mode = | 101.50 dB | 85th | 101.88 |
| SD = | 0.68 dB | 95th | 102.19 |

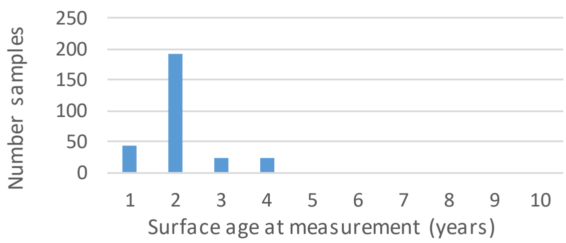
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 8 | n = | 280 |
| Distinct road region: | 2 | mean = | 791 days |
| Distinct road council: | 5 | mean = | 2.2 years |
| Distinct state highway: | 4 | SD = | 285 days |
| Distinct road_id & date: | 16 | SD = | 0.8 years |

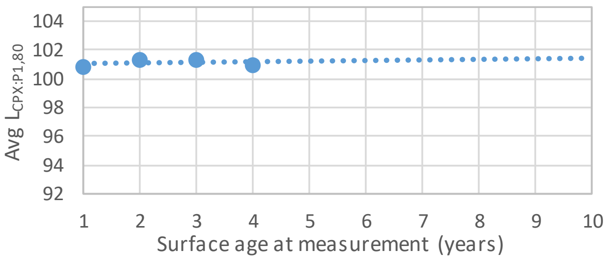
**Histogram of 2CHIP 2 5 levels (n=280)**




**Sample breakdown by age**



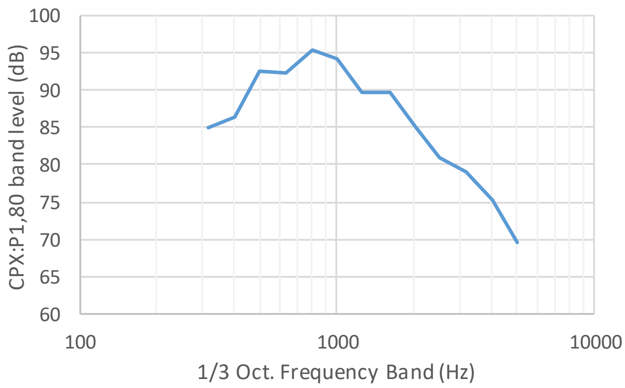

**Lcpx (surface age) ≈ 0.04 * years + 101 dB**




**Notes**

A fairly small but diverse sample that includes data from 16 sites of similar length within Waikato and Manawatu (typical length = 400 m).
No site was older than 4 years at the time of the CPX survey, but with no evidence of an aging effect here or in other 2CHIP surfaces, so the average level may still be represenative of lifetime average of the 2CHIP 2/5 specification.
The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for 2CHIP 2 5**



# 2CHIP 2/4

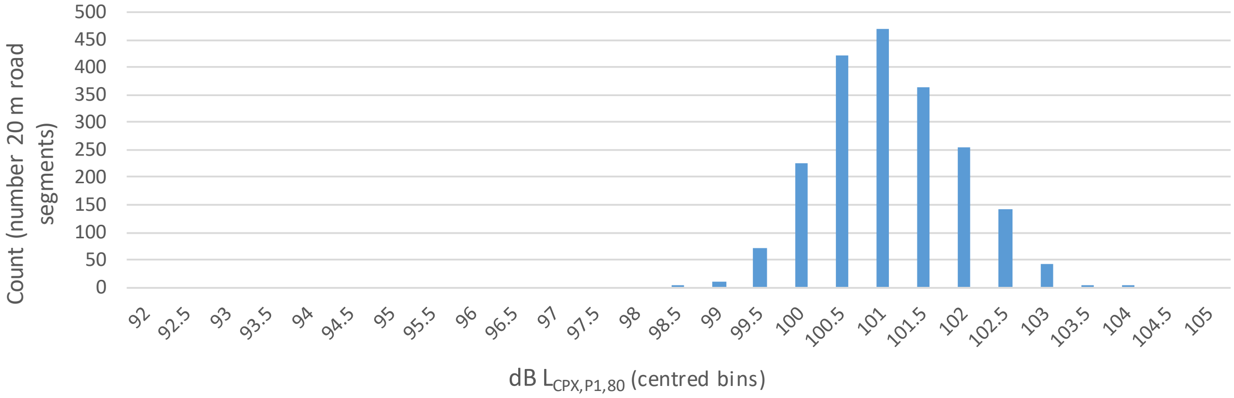
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 2004 | 25th | 100.50 |
| dist = | 40.08 km | 50th | 101.04 |
| mean = | 101.09 dB | 75th | 101.64 |
| median = | 101.04 dB | 85th | 102.00 |
| mode = | 101.00 dB | 95th | 102.48 |
| SD = | 0.81 dB | | |

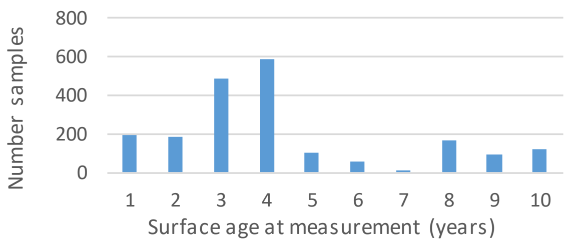
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 22 | n = | 2004 |
| Distinct road region: | 4 | mean = | 1554 days |
| Distinct road council: | 13 | mean = | 4.3 years |
| Distinct state highway: | 7 | SD = | 924 days |
| Distinct road_id & date: | 47 | SD = | 2.5 years |

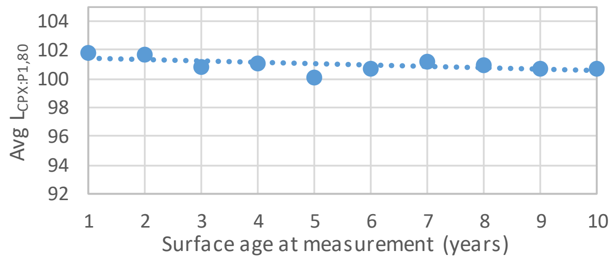
**Histogram of 2CHIP 2 4 levels (n=2004)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.09 * years + 101.5 dB**

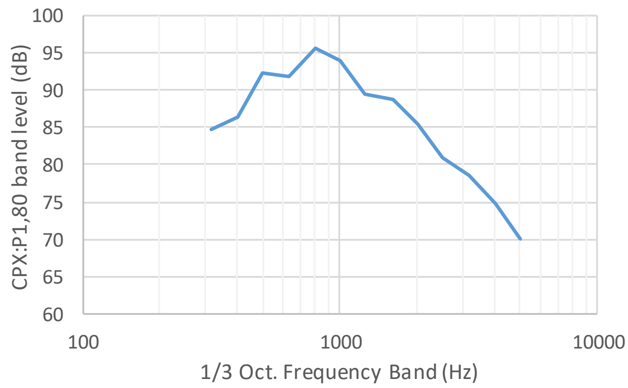



**Notes**

A very large sample, collected from Waikato, Manawatu, Wellington and Canterbury. Approximately normally distributed, but with slight right skew.

The sample ages are fairly well distributed. The apparent aging effect is **not** statistically significant, $p>0.05$.

**Average spectrum of CPX:P1,80 for 2CHIP 2 4**



## B.8 Racked-In Chipseal (RACK)

### RACK 4/6

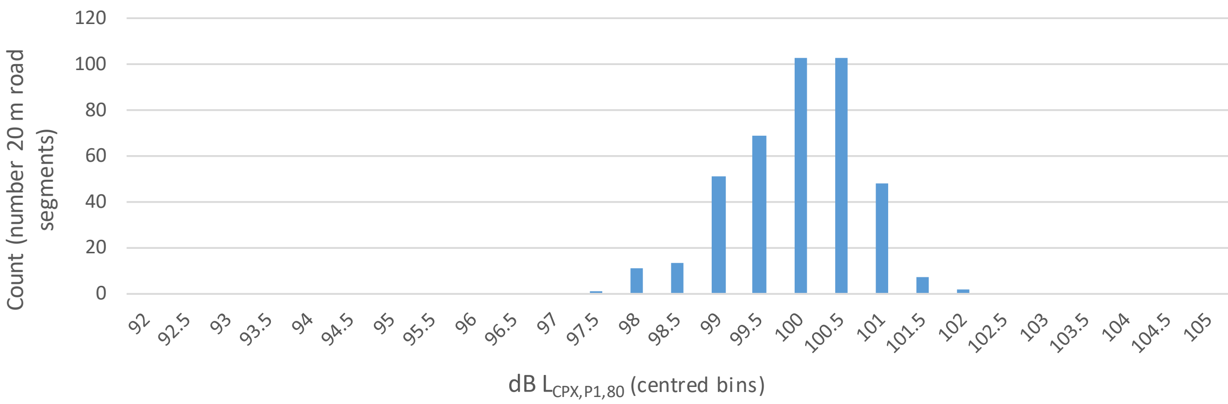
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 408 | | |
| dist = | 8.16 km | 25th | 99.41 |
| mean = | 99.97 dB | 50th | 100.05 |
| median = | 100.05 dB | 75th | 100.53 |
| mode = | 100.00 dB | 85th | 100.70 |
| SD = | 0.75 dB | 95th | 101.04 |

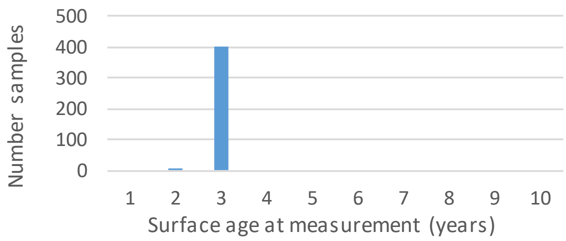
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 6 | n = | 408 |
| Distinct road region: | 2 | mean = | 1113 days |
| Distinct road council: | 3 | mean = | 3.0 years |
| Distinct state highway: | 2 | SD = | 34 days |
| Distinct road_id & date: | 6 | SD = | 0.1 years |

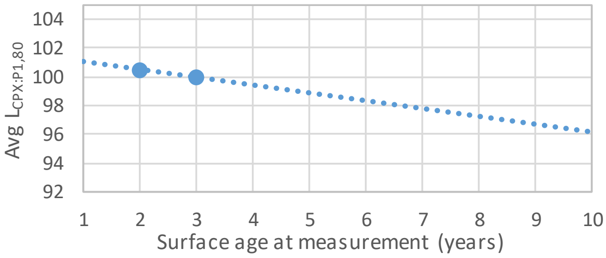
**Histogram of RACK 4/6 levels (n=408)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.54 * years + 101.6 dB**



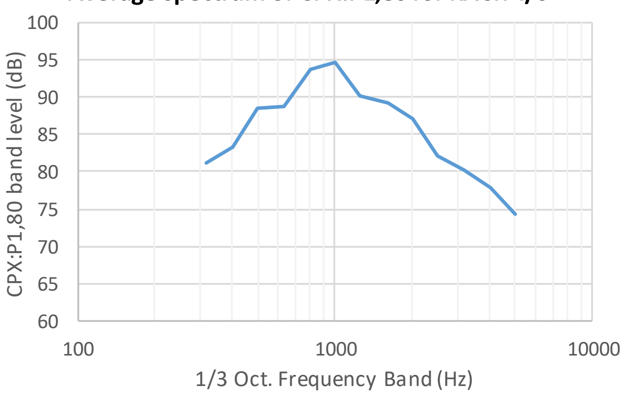

**Notes**

A decent sized sample, but almost entirely (99%) drawn from 4 sites in the Waikato: 2 dual carriageway sections: 01N-0486 and 01N-0504. All Waikato sites were laid on the same day according to RAMM data.

Much of the sample had moderate flushing, which is not remarkable.

The within site variance typically has SD ≈ 0.6 dB.

**Average spectrum of CPX:P1,80 for RACK 4/6**



# RACK 3/6

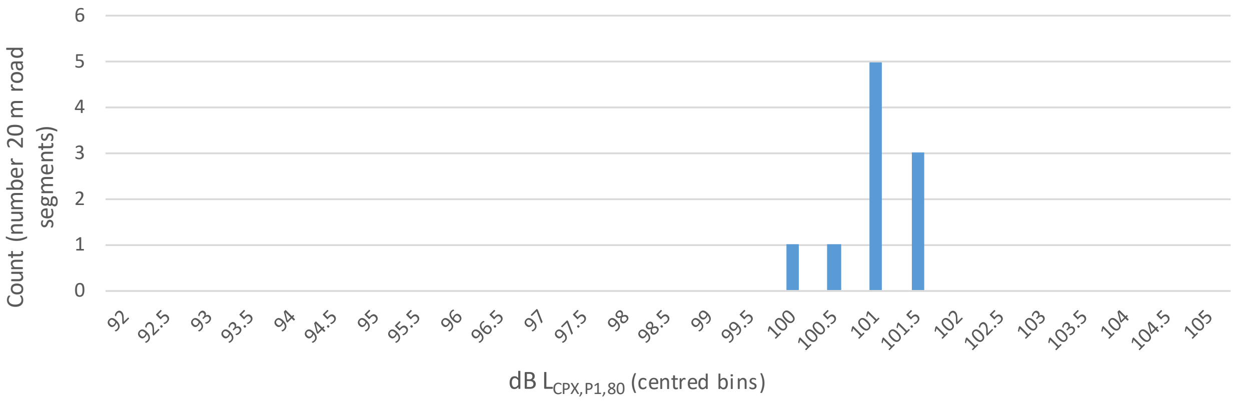
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 10 | 25th | 100.78 |
| dist = | 0.2 km | 50th | 100.99 |
| mean = | 101.01 dB | 75th | 101.24 |
| median = | 100.99 dB | 85th | 101.48 |
| mode = | 101.00 dB | 95th | 101.62 |
| SD = | 0.44 dB | | |

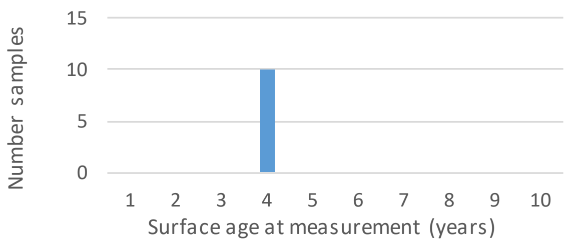
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 10 |
| Distinct road region: | 1 | mean = | 1489 days |
| Distinct road council: | 1 | mean = | 4.1 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

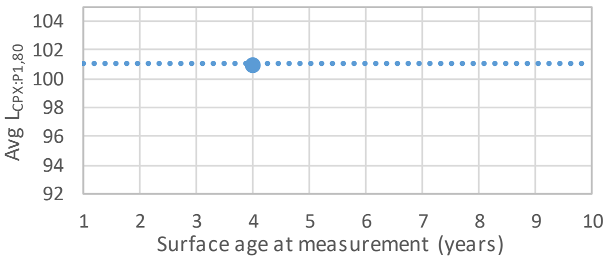
**Histogram of RACK 3/6 levels (n=10)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0 * years + 101 dB**

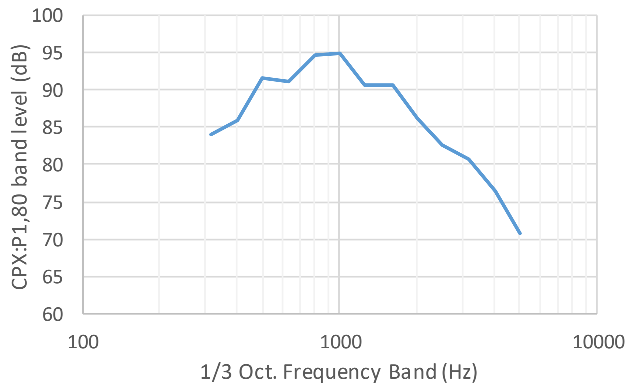



**Notes**

A tiny sample of 200 metres of road in the Manawatu, all laid on the same day.

No evidence to say whether or not this sample is representative of the RACK 3/6 specification.

**Average spectrum of CPX:P1,80 for RACK 3/6**



# RACK 3/5

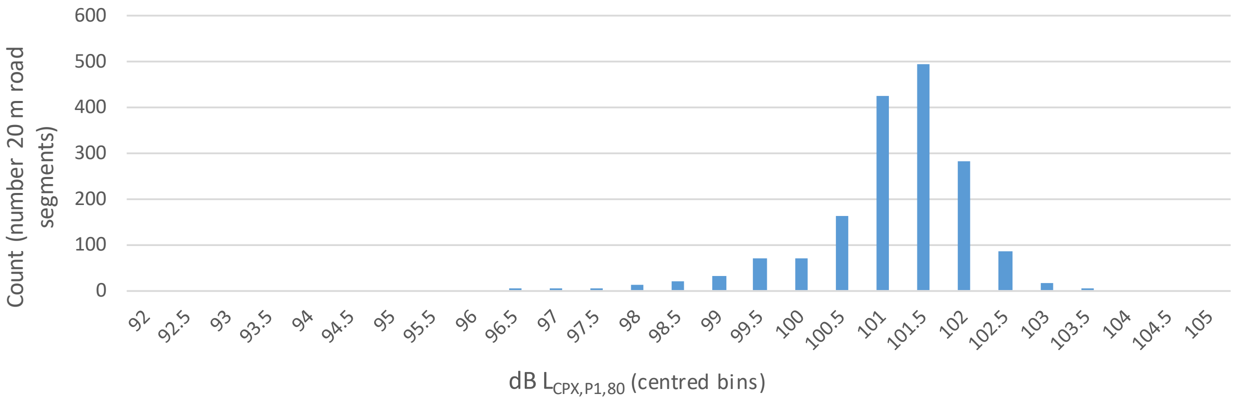
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1676 | 25th | 100.83 |
| dist = | 33.52 km | 50th | 101.28 |
| mean = | 101.15 dB | 75th | 101.71 |
| median = | 101.28 dB | 85th | 101.95 |
| mode = | 101.50 dB | 95th | 102.32 |
| SD = | 0.89 dB | | |

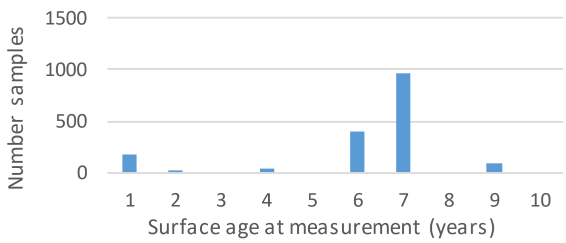
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 14 | n = | 1676 |
| Distinct road region: | 4 | mean = | 2237 days |
| Distinct road council: | 9 | mean = | 6.1 years |
| Distinct state highway: | 6 | SD = | 681 days |
| Distinct road_id & date: | 17 | SD = | 1.9 years |

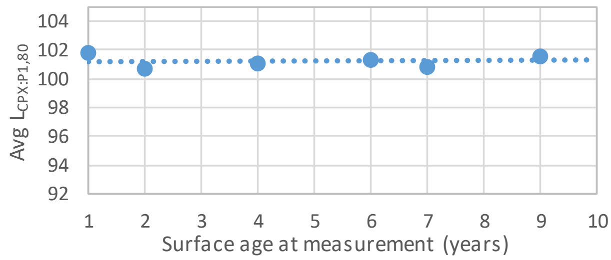
**Histogram of RACK 3/5 levels (n=1676)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 4E-05 * years + 101.3 dB**



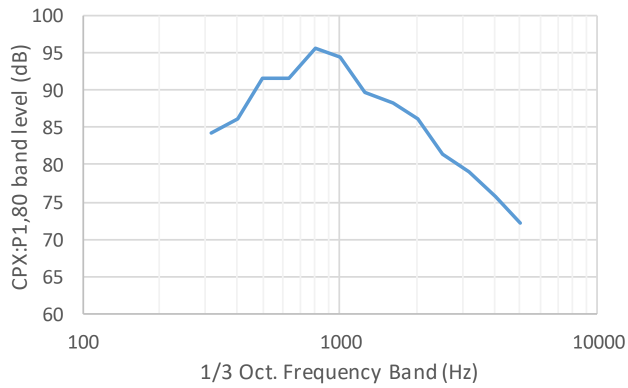

**Notes**

A very large and geographically diverse sample from Waikato, Manawatu, Wellington, and Canterbury (typical site length = 2 km).

There is no aging effect within the sample, which spans 9 years.

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for RACK 3/5**



# RACK 2/5

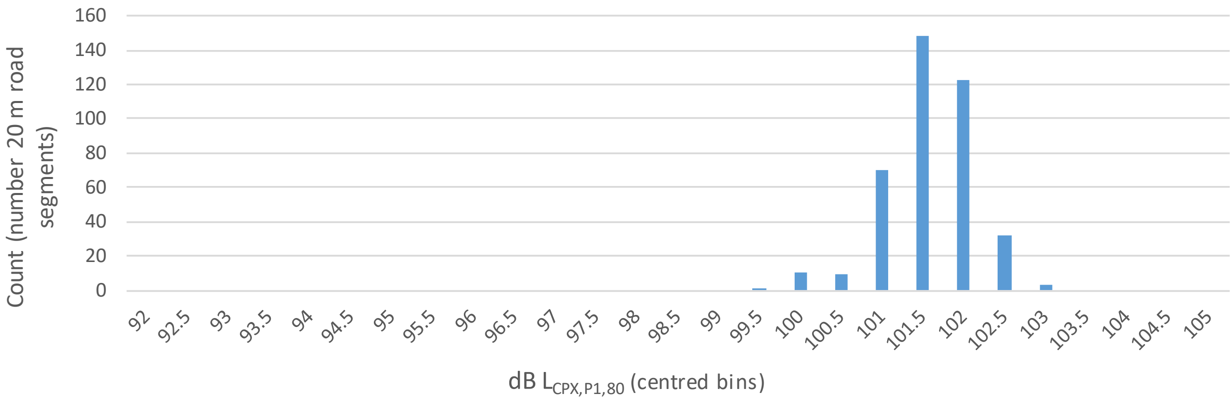
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 396 | 25th | 101.31 |
| dist = | 7.92 km | 50th | 101.64 |
| mean = | 101.60 dB | 75th | 101.93 |
| median = | 101.64 dB | 85th | 102.09 |
| mode = | 101.50 dB | 95th | 102.37 |
| SD = | 0.52 dB | | |

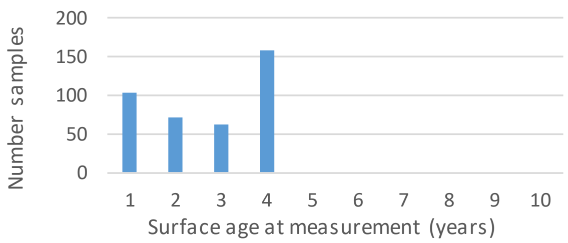
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 396 |
| Distinct road region: | 1 | mean = | 1051 days |
| Distinct road council: | 2 | mean = | 2.9 years |
| Distinct state highway: | 3 | SD = | 438 days |
| Distinct road_id & date: | 9 | SD = | 1.2 years |

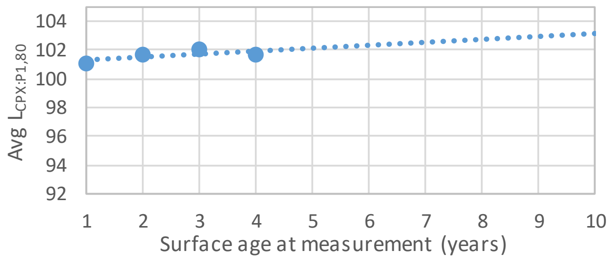
**Histogram of RACK 2/5 levels (n=396)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.2 * years + 101.1 dB**



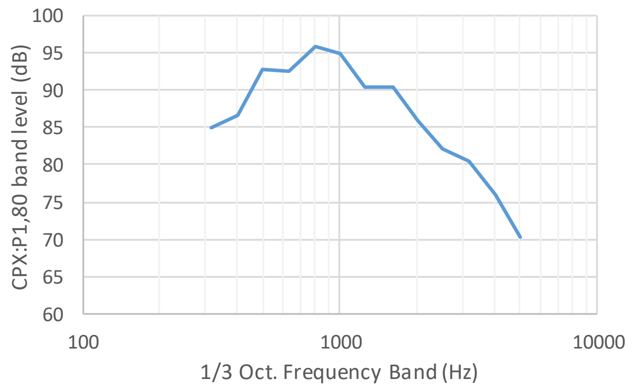

**Notes**

A small sample from Manawatu only.

The sample is fairly young, mean age 3 years, and there is not a sufficient range to examine any potential aging effect (shown slope is not statistically significant, p>0.5).

The within site variance typically has SD ≈ 0.4 dB.

**Average spectrum of CPX:P1,80 for RACK 2/5**



# RACK 2/4

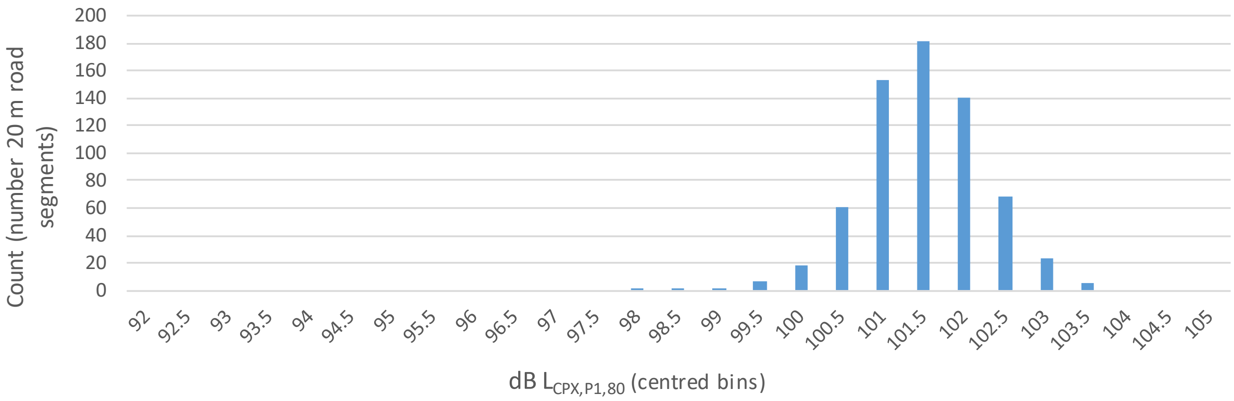
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 662 | | |
| dist = | 13.24 km | 25th | 101.02 |
| mean = | 101.47 dB | 50th | 101.47 |
| median = | 101.47 dB | 75th | 101.98 |
| mode = | 101.50 dB | 85th | 102.23 |
| SD = | 0.76 dB | 95th | 102.68 |

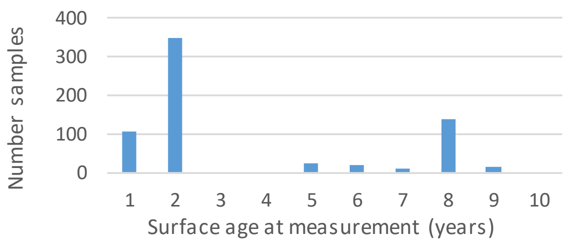
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 11 | n = | 662 |
| Distinct road region: | 3 | mean = | 1291 days |
| Distinct road council: | 7 | mean = | 3.5 years |
| Distinct state highway: | 4 | SD = | 1065 days |
| Distinct road_id & date: | 13 | SD = | 2.9 years |

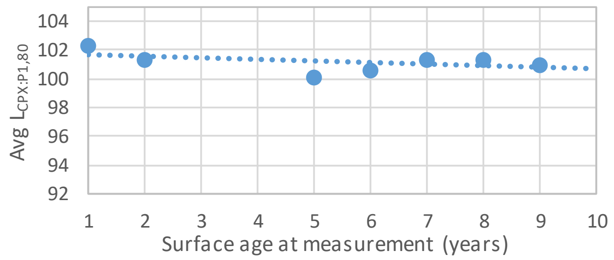
**Histogram of RACK 2/4 levels (n=662)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.11 * years + 101.8 dB**



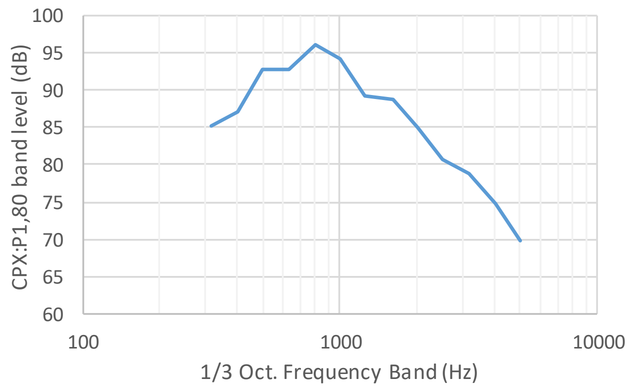

**Notes**

A large and geographically diverse sample within Waikato, Manawatu, and Wellington (typical site length = 1 km).

The apparent slight aging effect is not statistically significant, p>0.05. The sample is slightly biased towards younger age RACK 2/4.

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for RACK 2/4**



## B.9 Sandwich Seal Chipseal (BS or B/S)

### BS 3/5

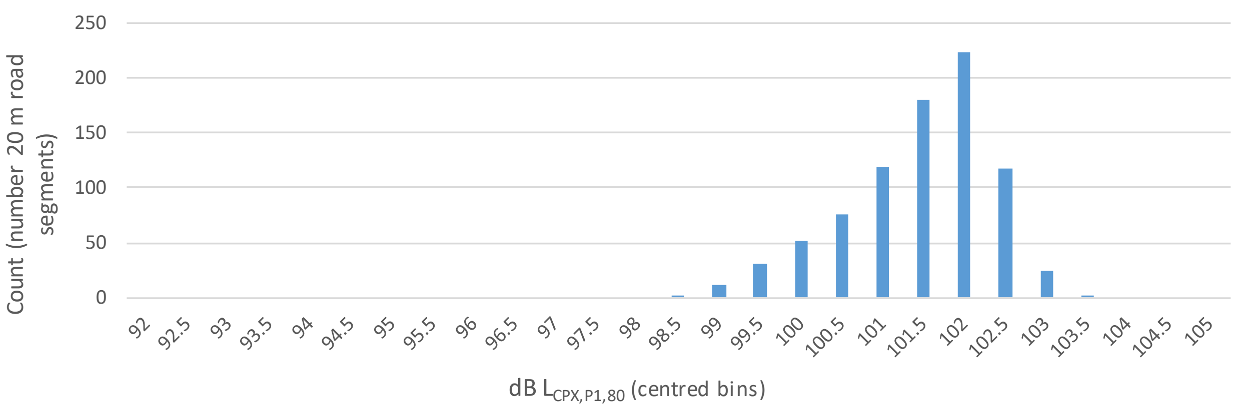
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 837 | 25th | 100.91 |
| dist = | 16.74 km | 50th | 101.63 |
| mean = | 101.46 dB | 75th | 102.09 |
| median = | 101.63 dB | 85th | 102.31 |
| mode = | 102.00 dB | 95th | 102.65 |
| SD = | 0.87 dB | | |

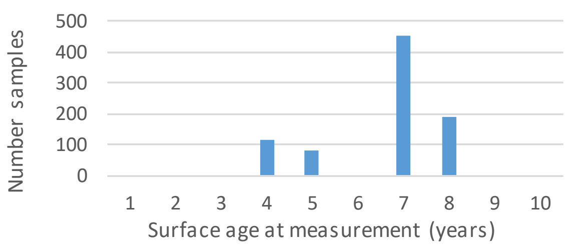
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 6 | n = | 837 |
| Distinct road region: | 2 | mean = | 2418 days |
| Distinct road council: | 5 | mean = | 6.6 years |
| Distinct state highway: | 3 | SD = | 480 days |
| Distinct road_id & date: | 8 | SD = | 1.3 years |

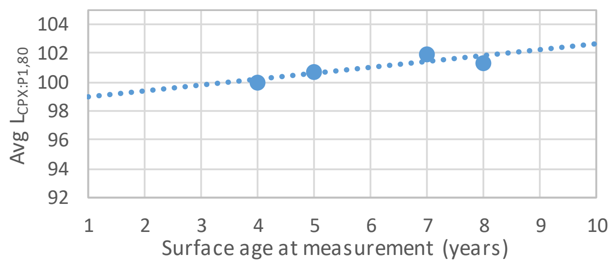
**Histogram of BS 3/5 levels (n=837)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0.402 * years + 98.63 dB**



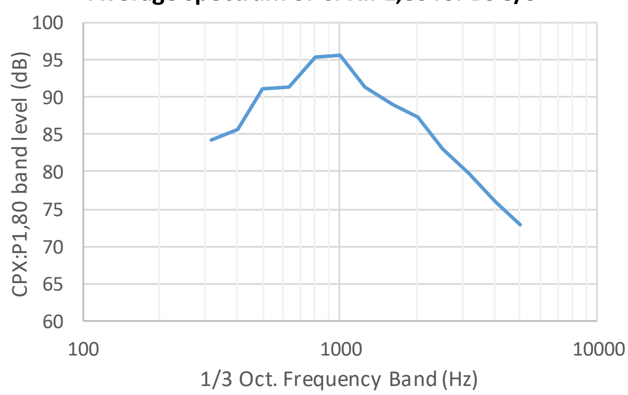

**Notes**

A good sample from 8 different sites in the Waikato (1) and Canterbury (7). Typical site length was 2 lane-kilometres.

The aging effect shown is **not** statistically significant (and is the opposite of the aging effect shown for B/S 2/4).

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for BS 3/5**



# BS 2/4

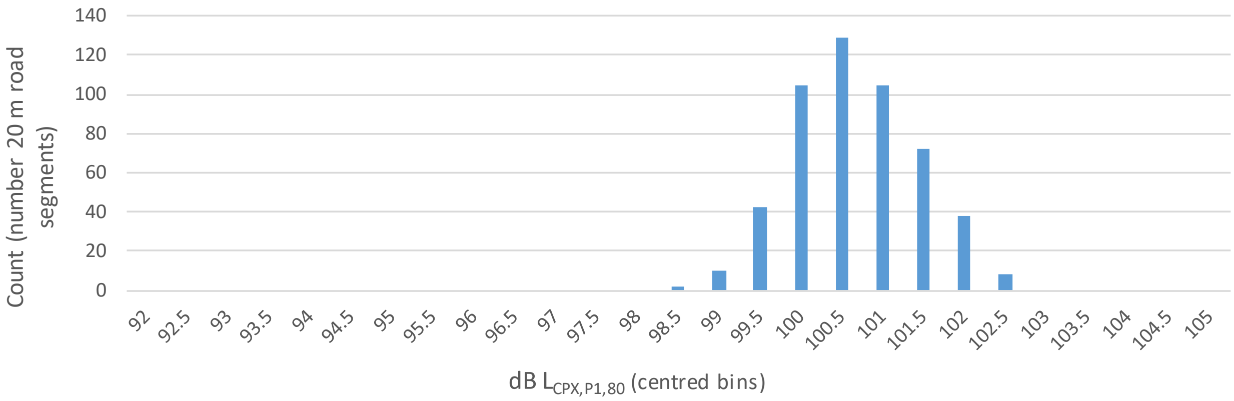
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 511 | | |
| dist = | 10.22 km | 25th | 100.12 |
| mean = | 100.67 dB | 50th | 100.64 |
| median = | 100.64 dB | 75th | 101.19 |
| mode = | 100.50 dB | 85th | 101.54 |
| SD = | 0.75 dB | 95th | 101.91 |

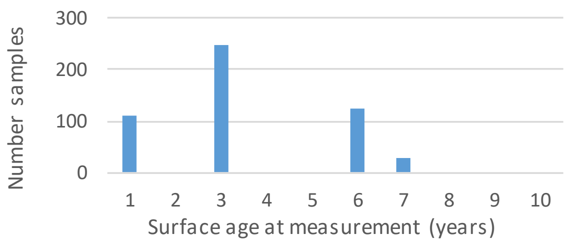
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 7 | n = | 511 |
| Distinct road region: | 2 | mean = | 1248 days |
| Distinct road council: | 4 | mean = | 3.4 years |
| Distinct state highway: | 3 | SD = | 702 days |
| Distinct road_id & date: | 10 | SD = | 1.9 years |

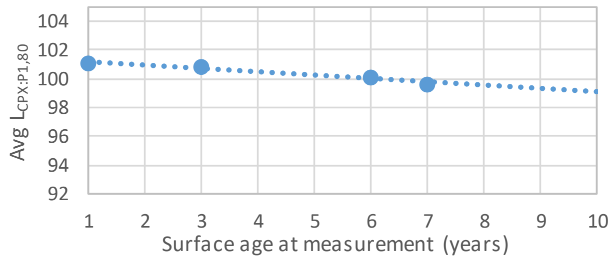
**Histogram of BS 2/4 levels (n=511)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.24 * years + 101.5 dB**



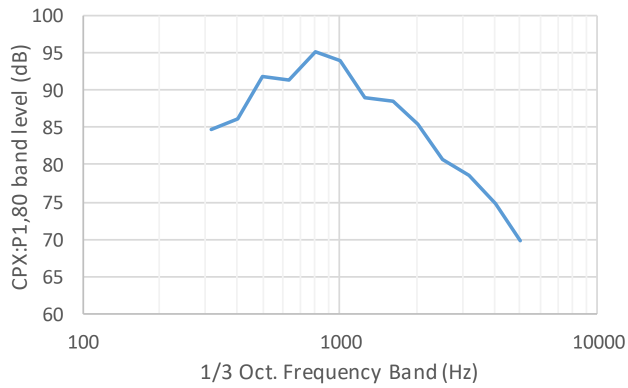

**Notes**

A good sample from 10 different sites in the Waikato and Canterbury regions.

Despite only 4 distinct ages, the aging effect of -1 dB / 4 years is statistically significant at p<0.05, but should still be treated with some caution given that other dual-chip chipseals appeared flatter.

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for BS 2/4**



## B.10 Combination Seal Chipseal (COMB)

### COMB 3/5

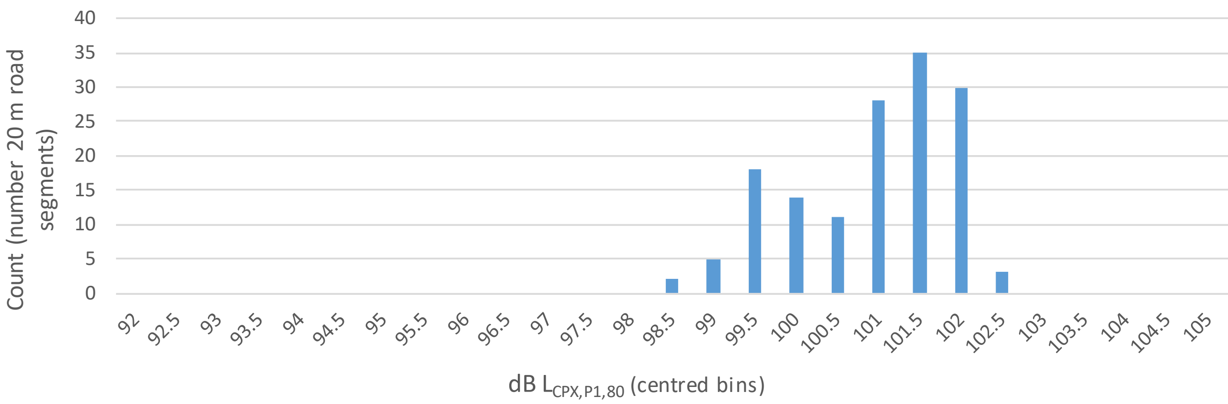
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 146 | | |
| dist = | 2.92 km | 25th | 100.21 |
| mean = | 100.95 dB | 50th | 101.21 |
| median = | 101.21 dB | 75th | 101.69 |
| mode = | 101.50 dB | 85th | 101.85 |
| SD = | 0.93 dB | 95th | 102.12 |

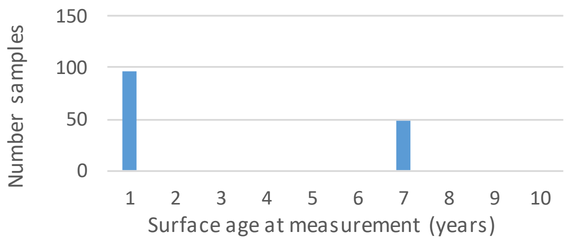
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 3 | n = | 146 |
| Distinct road region: | 2 | mean = | 1024 days |
| Distinct road council: | 3 | mean = | 2.8 years |
| Distinct state highway: | 2 | SD = | 1111 days |
| Distinct road_id & date: | 3 | SD = | 3.0 years |

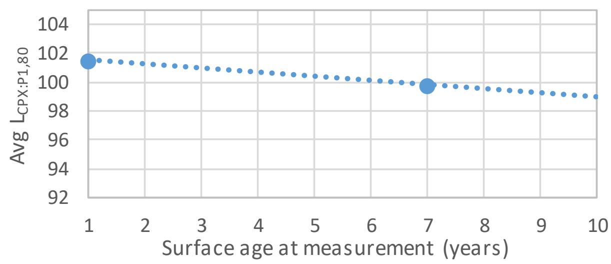
**Histogram of COMB 3/5 levels (n=146)**




**Sample breakdown by age**



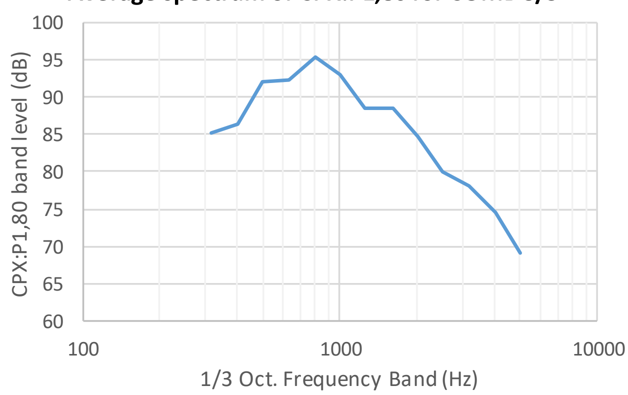

**Lcpx (surface age) ≈ -0.28 * years + 101.8 dB**




**Notes**

A fairly small sample from two sites in the Waikato and one in Canterbury.
The bimodal distribution arises because one of the Waikato sites is 2 dB quieter than the other two sites. That 7yo site is generally quite flushed, but the quietest segments of it are not flushed.
Judgement is required as to which central estimate to adopt for COMB 3/5.
The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for COMB 3/5**



# COMB 2/5

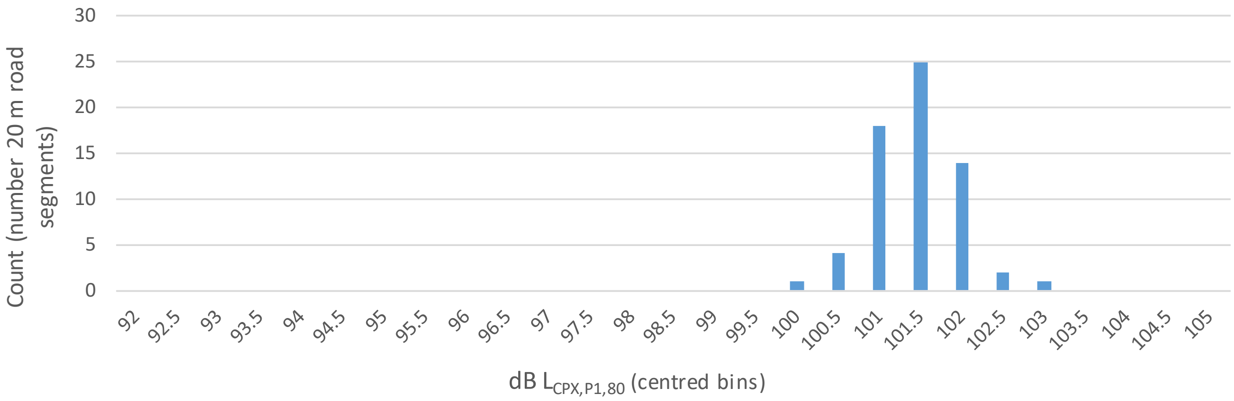
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 65 | 25th | 101.06 |
| dist = | 1.3 km | 50th | 101.44 |
| mean = | 101.42 dB | 75th | 101.75 |
| median = | 101.44 dB | 85th | 101.91 |
| mode = | 101.50 dB | 95th | 102.11 |
| SD = | 0.50 dB | | |

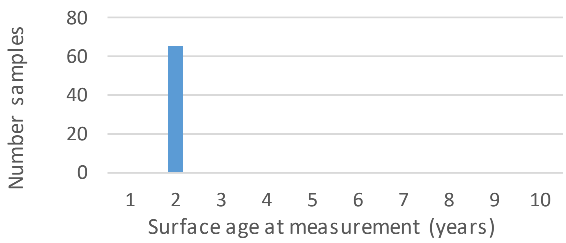
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 65 |
| Distinct road region: | 1 | mean = | 571 days |
| Distinct road council: | 1 | mean = | 1.6 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

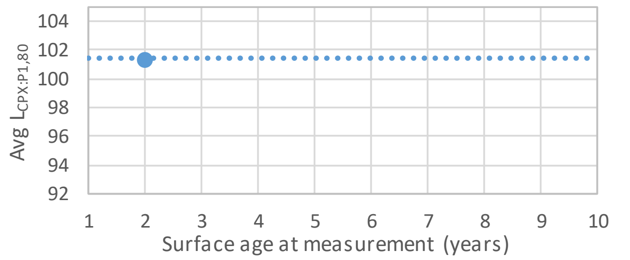
**Histogram of COMB 2/5 levels (n=65)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0 * years + 101.4 dB**



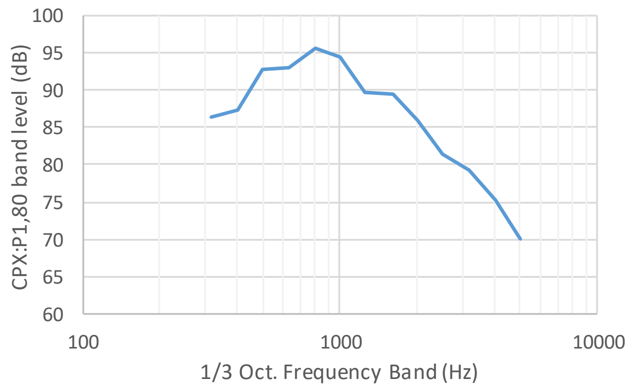

**Notes**

A small sample from a single site in Canterbury.

All segments were laid on the same day.

There is no evidence that this sample is representative of the COMB 2/5 specification.

**Average spectrum of CPX:P1,80 for COMB 2/5**



# COMB 2/4

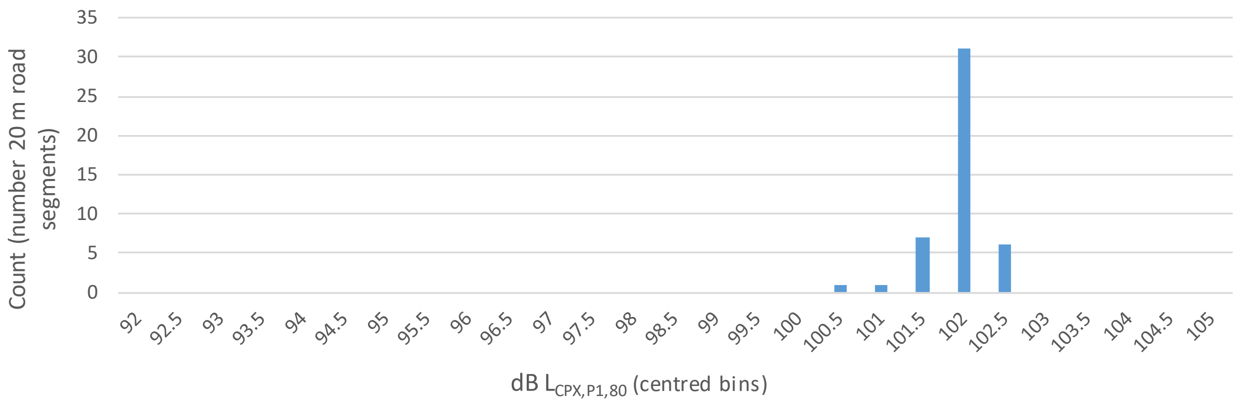
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 46 | | |
| dist = | 0.92 km | 25th | 101.81 |
| mean = | 101.92 dB | 50th | 101.99 |
| median = | 101.99 dB | 75th | 102.12 |
| mode = | 102.00 dB | 85th | 102.20 |
| SD = | 0.38 dB | 95th | 102.31 |

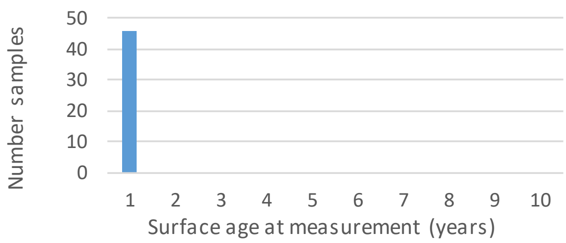
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 46 |
| Distinct road region: | 1 | mean = | 285 days |
| Distinct road council: | 1 | mean = | 0.8 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |

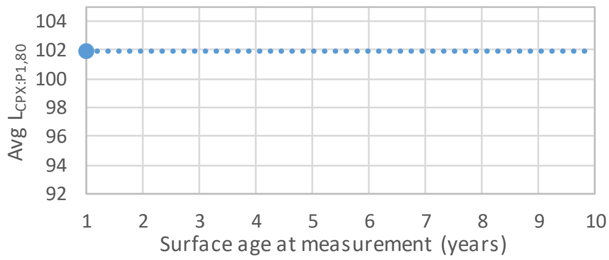
**Histogram of COMB 2/4 levels (n=46)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ 0 * years + 101.9 dB**



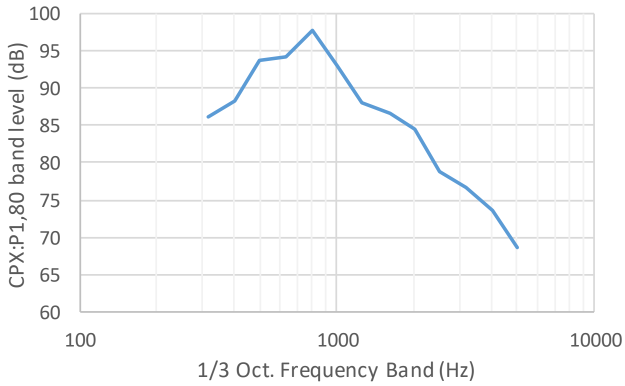

**Notes**

A small sample from a single site in the Waikato.

All road segments were surfaced on the same day, and were less than 1 year old at the time of the CPX survey.

There is no evidence that this data is representative of the COMB 2/4 specification.

**Average spectrum of CPX:P1,80 for COMB 2/4**



## B.11 Three-Coat Chipseal (3CHIP)

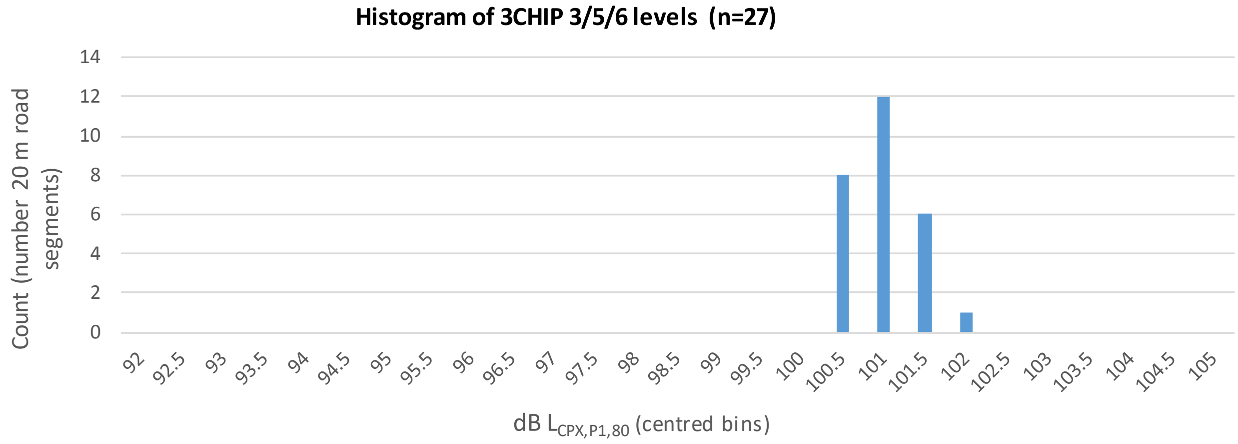
### 3CHIP 3/5/6

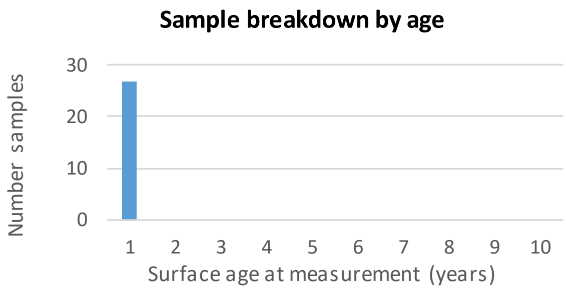
**CPX Levels**

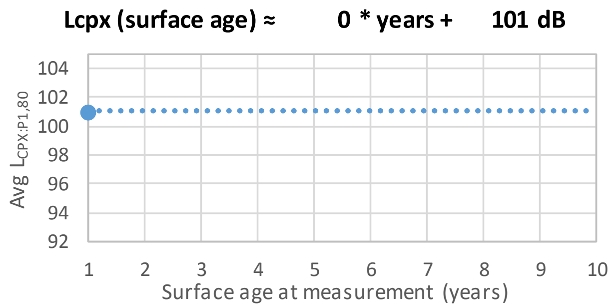
| | | Percentiles | |
|---|---|---|---|
| n = | 27 | | |
| dist = | 0.54 km | 25th | 100.70 |
| mean = | 101.02 dB | 50th | 101.00 |
| median = | 101.00 dB | 75th | 101.27 |
| mode = | 101.00 dB | 85th | 101.49 |
| SD = | 0.40 dB | 95th | 101.67 |

**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 1 | n = | 27 |
| Distinct road region: | 1 | mean = | 386 days |
| Distinct road council: | 1 | mean = | 1.1 years |
| Distinct state highway: | 1 | SD = | 0 days |
| Distinct road_id & date: | 1 | SD = | 0.0 years |



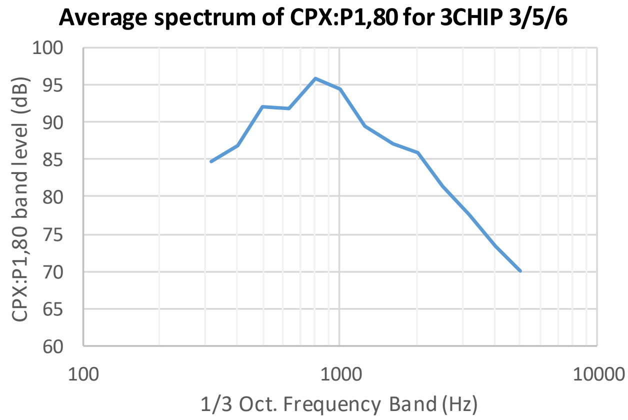




**Notes**

A single short site in Canterbury, measured in both directions one year after it was laid.

Site just outside of Darfield: 073-0041/0.1-0.4.

There is no evidence to show whether these noise data are representative of the 3CHIP 3/5/6 specification.



## B.12 Void Fill (VFILL)

### VFILL 6

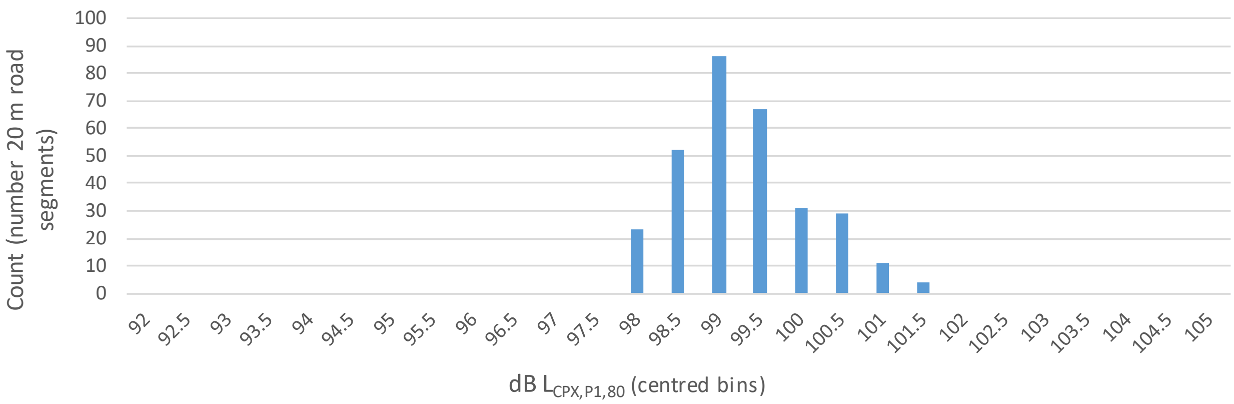
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 303 | 25th | 98.75 |
| dist = | 6.06 km | 50th | 99.19 |
| mean = | 99.30 dB | 75th | 99.74 |
| median = | 99.19 dB | 85th | 100.23 |
| mode = | 99.00 dB | 95th | 100.70 |
| SD = | 0.77 dB | | |

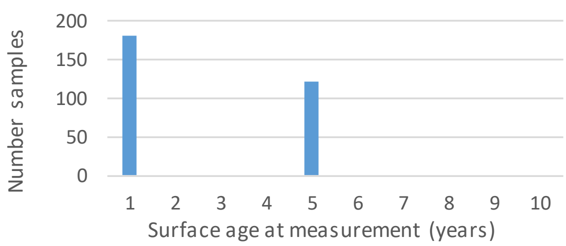
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 4 | n = | 303 |
| Distinct road region: | 2 | mean = | 893 days |
| Distinct road council: | 3 | mean = | 2.4 years |
| Distinct state highway: | 3 | SD = | 678 days |
| Distinct road_id & date: | 5 | SD = | 1.9 years |

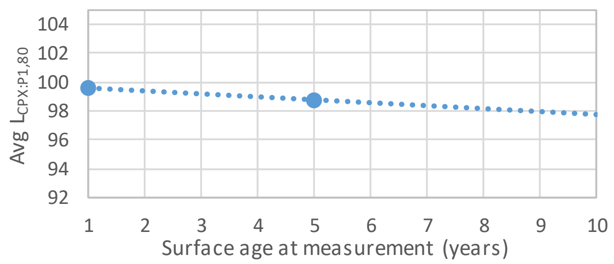
**Histogram of VFILL 6 levels (n=303)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.21 * years + 99.84 dB**



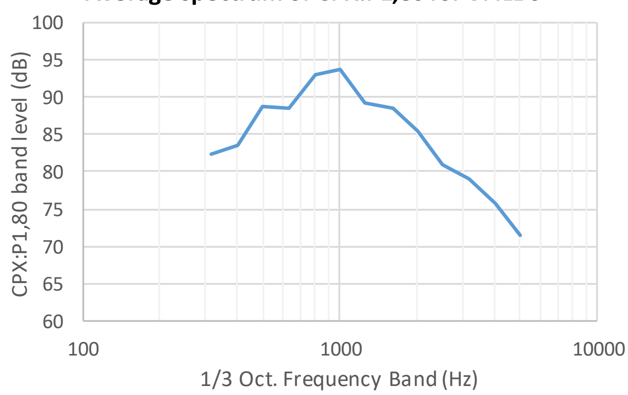

**Notes**

IMPORTANT: VFILL is a remedial chipseal surface treatment and its performance may be linked to the properties of the underlying chipseal.

A fairly small sample from 5 different sites in the Waikato and Wellington regions. Typical site length was 1 lane-kilometre.

The within site variance typically has SD ≈ 0.6 dB.

**Average spectrum of CPX:P1,80 for VFILL 6**



# VFILL 5

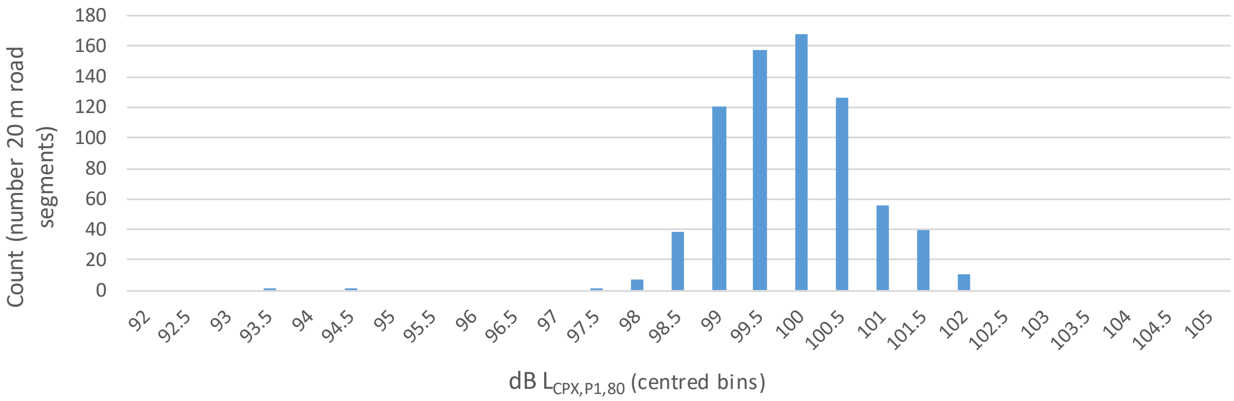
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 727 | | |
| dist = | 14.54 km | 25th | 99.29 |
| mean = | 99.88 dB | 50th | 99.89 |
| median = | 99.89 dB | 75th | 100.42 |
| mode = | 100.00 dB | 85th | 100.71 |
| SD = | 0.87 dB | 95th | 101.37 |

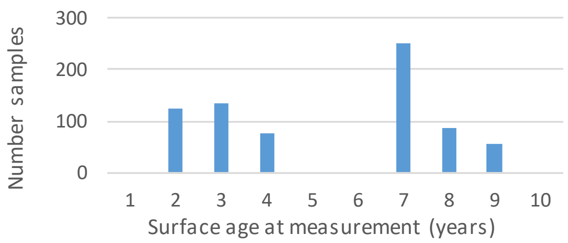
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 10 | n = | 727 |
| Distinct road region: | 3 | mean = | 1966 days |
| Distinct road council: | 6 | mean = | 5.4 years |
| Distinct state highway: | 4 | SD = | 927 days |
| Distinct road_id & date: | 13 | SD = | 2.5 years |

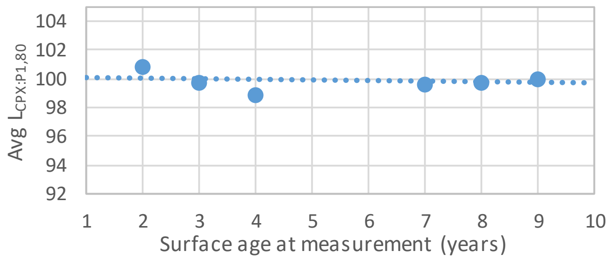
**Histogram of VFILL 5 levels (n=727)**




**Sample breakdown by age**




**Lcpx (surface age) ≈ -0.04 * years + 100.1 dB**



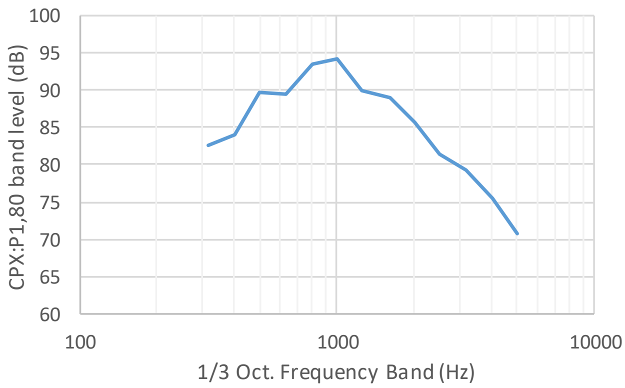

**Notes**

IMPORTANT: VFILL is a remedial surface treatment and its performance may be linked to the properties of the underlying chipseal.

A good sized sample from 13 different sites in the Waikato, Manawatu, and Wellington regions. Typical site length was 1 lane-kilometre.

The within site variance typically has SD ≈ 0.5 dB.

**Average spectrum of CPX:P1,80 for VFILL 5**



## B.13 Enrichment Seal over Asphalt (ENRAC)

### ENRAC

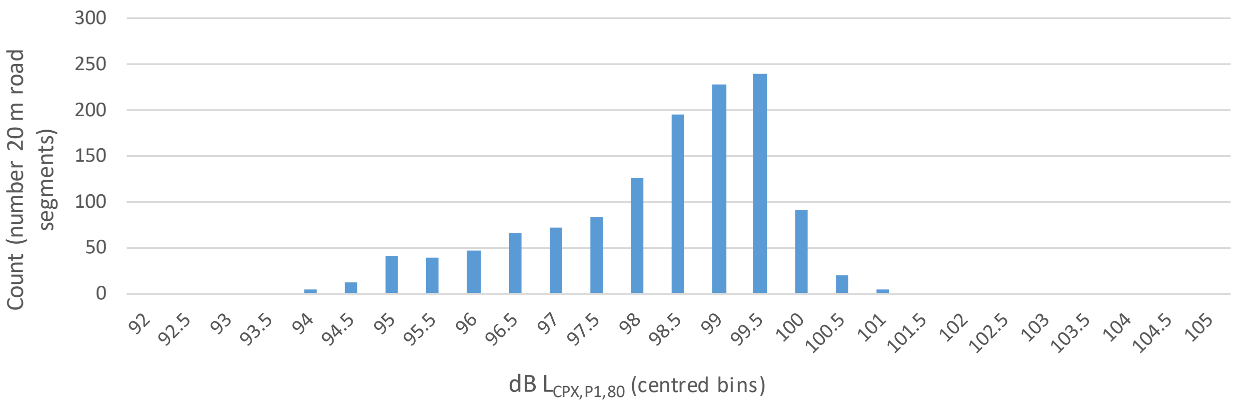
**CPX Levels**

| | | Percentiles | |
|---|---|---|---|
| n = | 1267 | | |
| dist = | 25.34 km | 25th | 97.46 |
| mean = | 98.27 dB | 50th | 98.65 |
| median = | 98.65 dB | 75th | 99.30 |
| mode = | 99.50 dB | 85th | 99.57 |
| SD = | 1.41 dB | 95th | 99.96 |

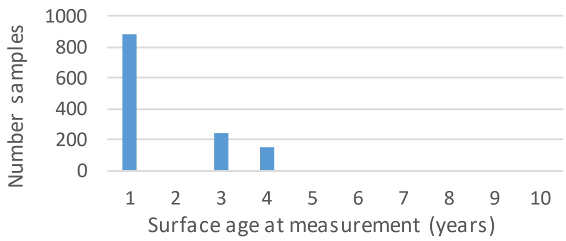
**Sample Information**

| Geographic Diversity | | Sample Age | |
|---|---|---|---|
| Distinct road_id: | 5 | n = | 1267 |
| Distinct road region: | 2 | mean = | 683 days |
| Distinct road council: | 4 | mean = | 1.9 years |
| Distinct state highway: | 2 | SD = | 406 days |
| Distinct road_id & date: | 9 | SD = | 1.1 years |

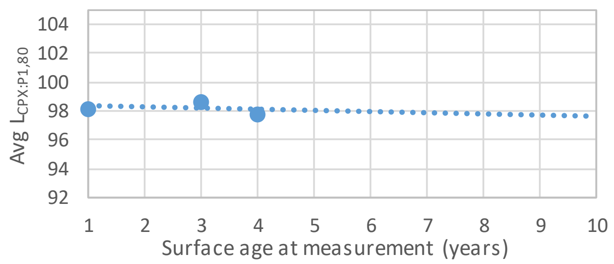
**Histogram of ENRAC levels (n=1267)**




**Sample breakdown by age**



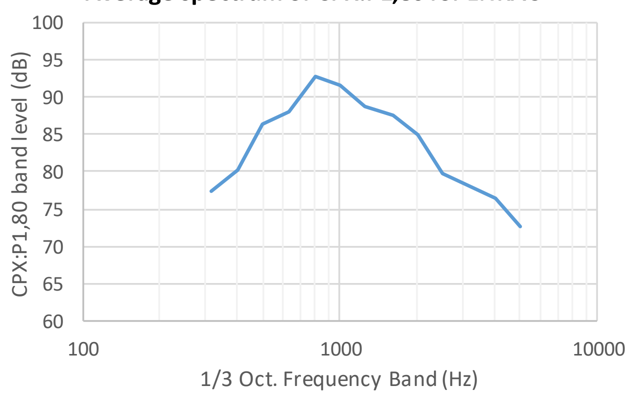

**Lcpx (surface age) ≈ -0.08 * years + 98.48 dB**




**Notes**

IMPORTANT: ENRAC is a remedial/maintenance surface treatment for OGPA. The noise level is very likely to mostly depend on the properties of the underlying surface. It isn't known what effect the ENRAC seal itself has on noise generation. This sample is from 9 different sites in Auckland and Wellington with long lengths (avg 3 lane-km) and very high within site variance (SD ≈ 1.3 dB) suggesting different underlying OGPA surfaces within some ENRAC treatment lengths.

**Average spectrum of CPX:P1,80 for ENRAC**



wsp.com/nz