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Identifying Waveband Roughness in Highway Pavements using Power Spectral Density Analysis

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The surface of a road pavement can become rough due to many factors:

1. Repetitive traffic loading – causing permanent deformations within the pavement structure.

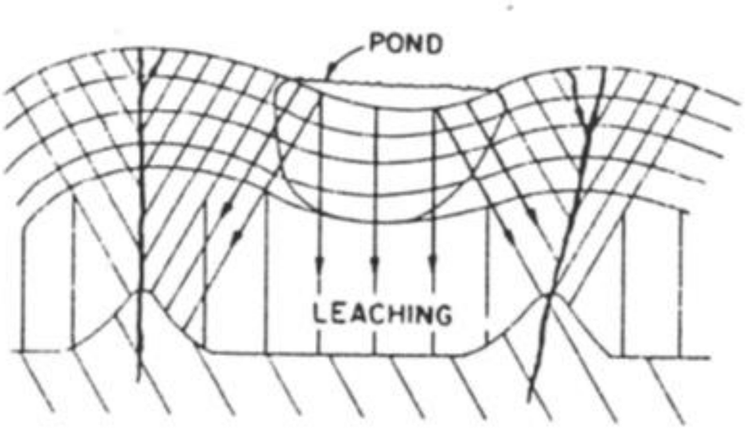
2. Aging or wear of the bituminous pavement seal, which leads to cracking and associated pot holes.

3. The occurrence of differential volume change within an expansive subgrade, which increases roughness and loss of shape. This increases in magnitude due to the presence of Gilgai relief.

Gilgai Phenomenon

Gilgai is best described as a soil that is in a state of slow continuous movement where the soil from the deeper layers is brought to the surface on the mounds, and the soil from the surface slips down to lower levels in the soil profile through the shrinkage cracks.

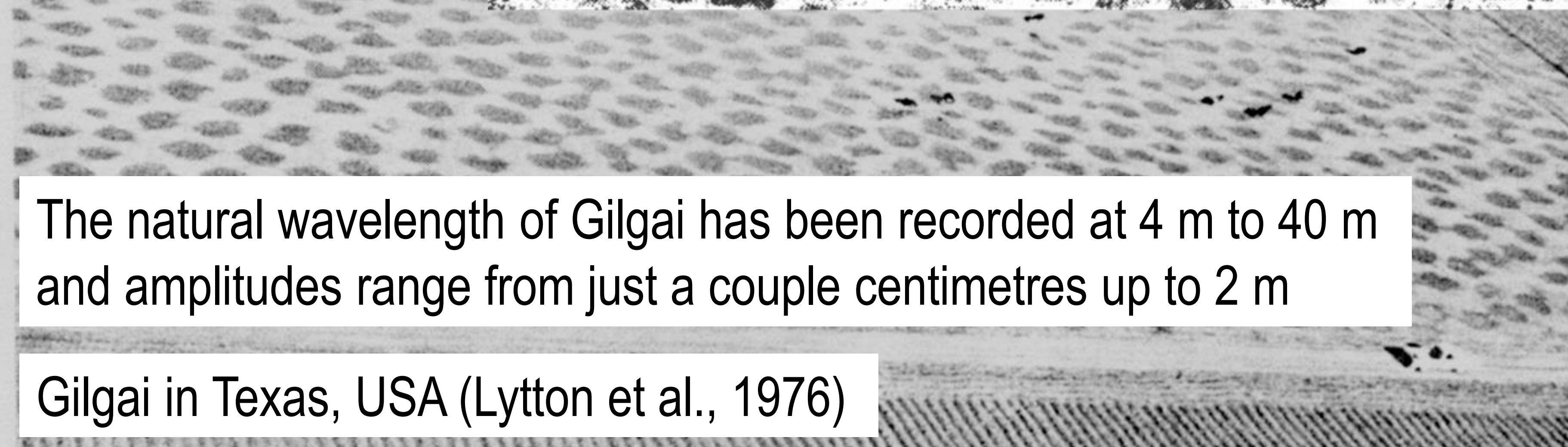
Model by Lytton et al. (1976)



Gilgai Phenomenon

Gilgai near Horsham, Victoria (2011)

Gilgai in Tara, Queensland (Beckmann et al., 1970)



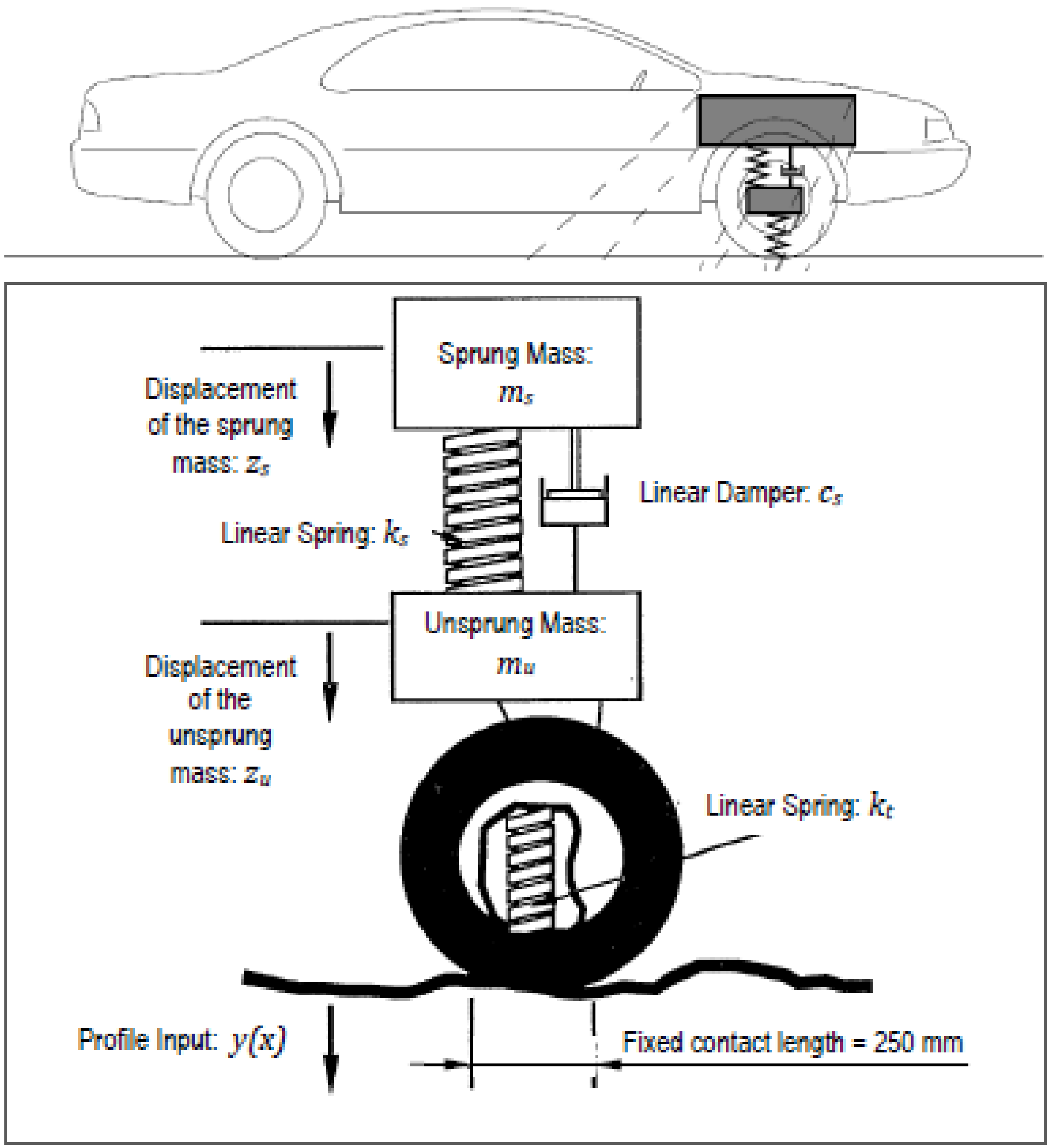
The natural wavelength of Gilgai has been recorded at 4 m to 40 m and amplitudes range from just a couple centimetres up to 2 m

Gilgai in Texas, USA (Lytton et al., 1976)

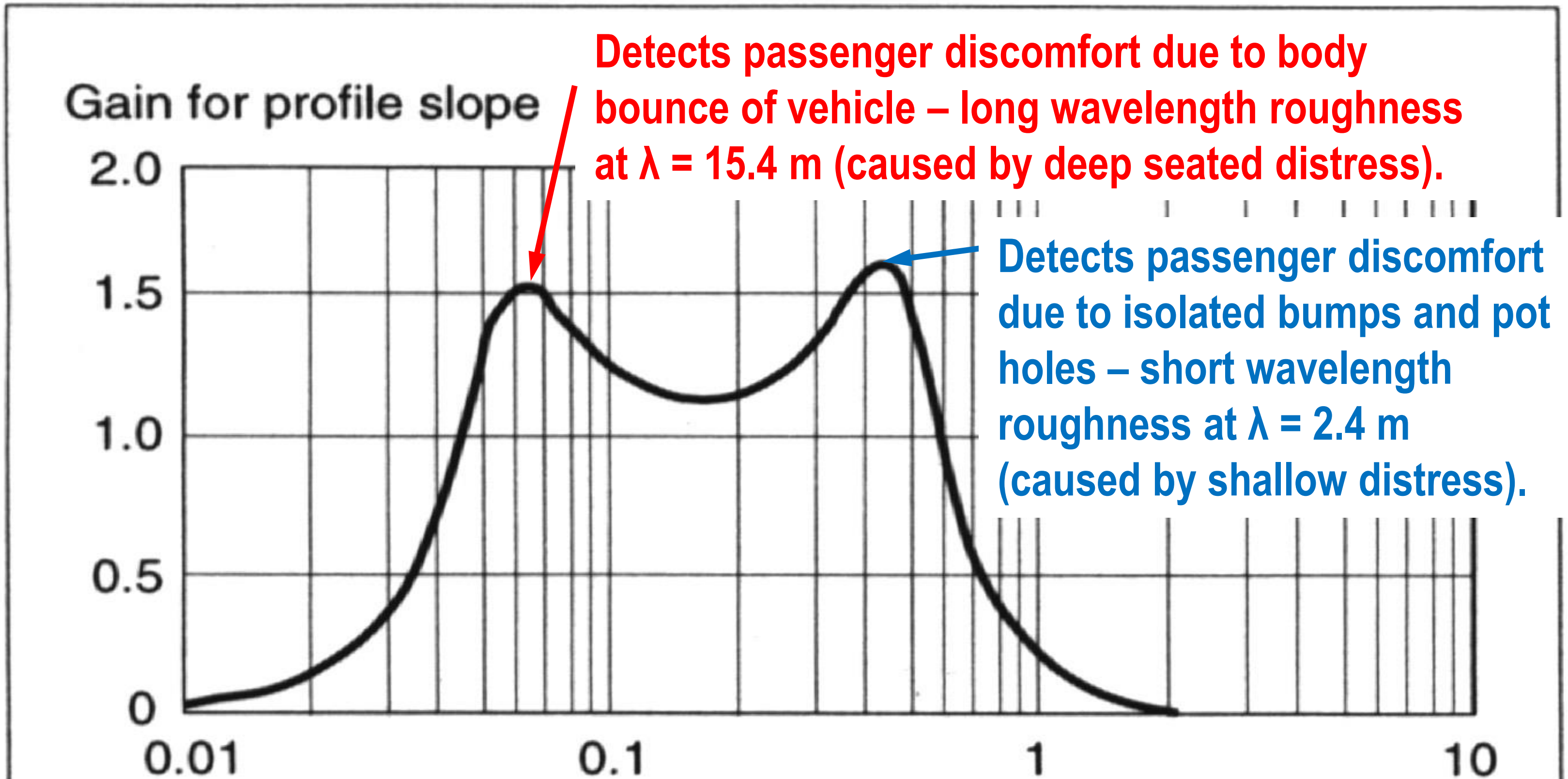
Short wavelength Roughness
vs.
Long wavelength Roughness

International Roughness Index (IRI)

- Developed in 1985 (World Bank Funds)
- Based on Quarter-Car Model that simulates behaviour of a passenger car at 80 km/hr.

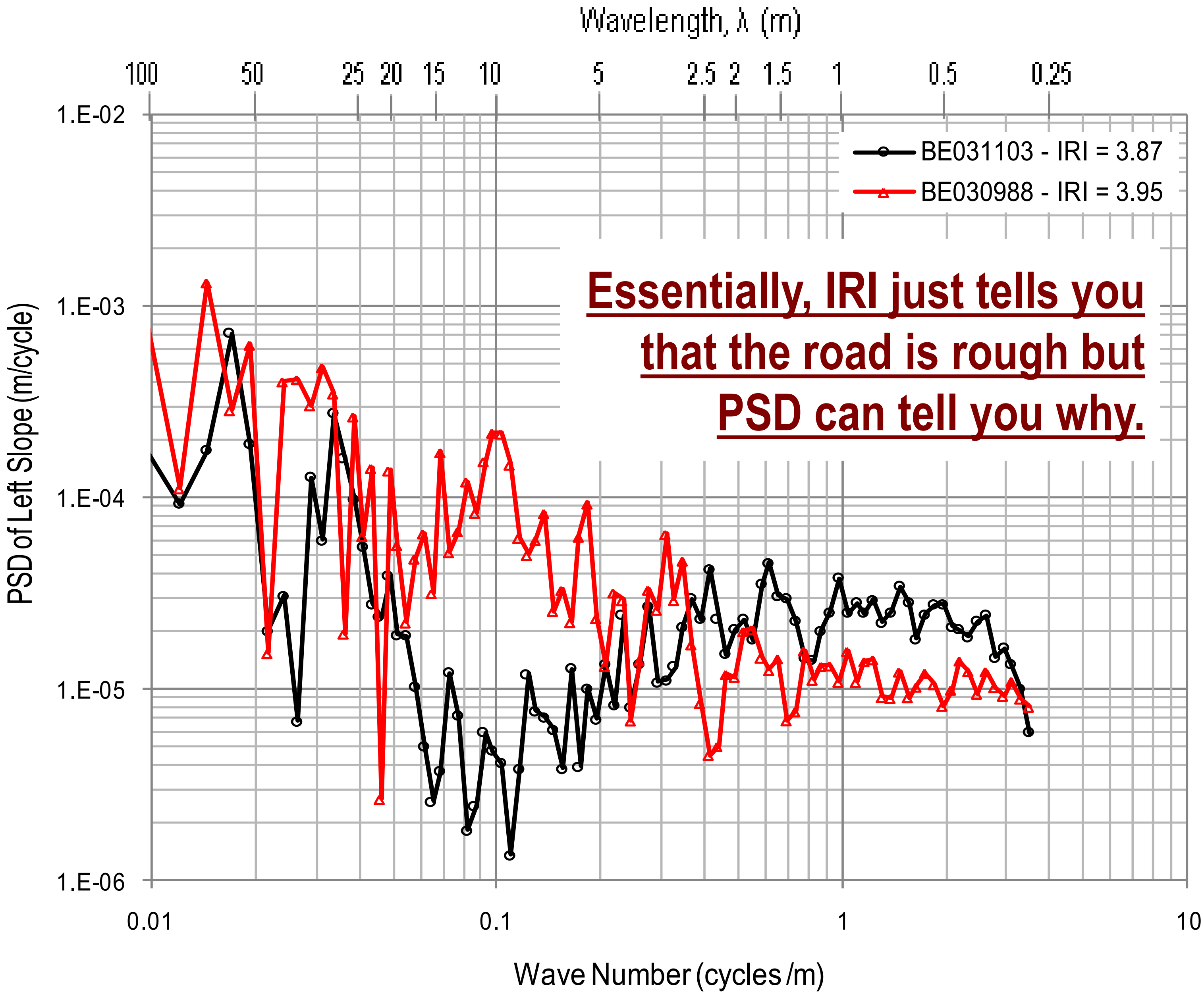


Response of the IRI Filter

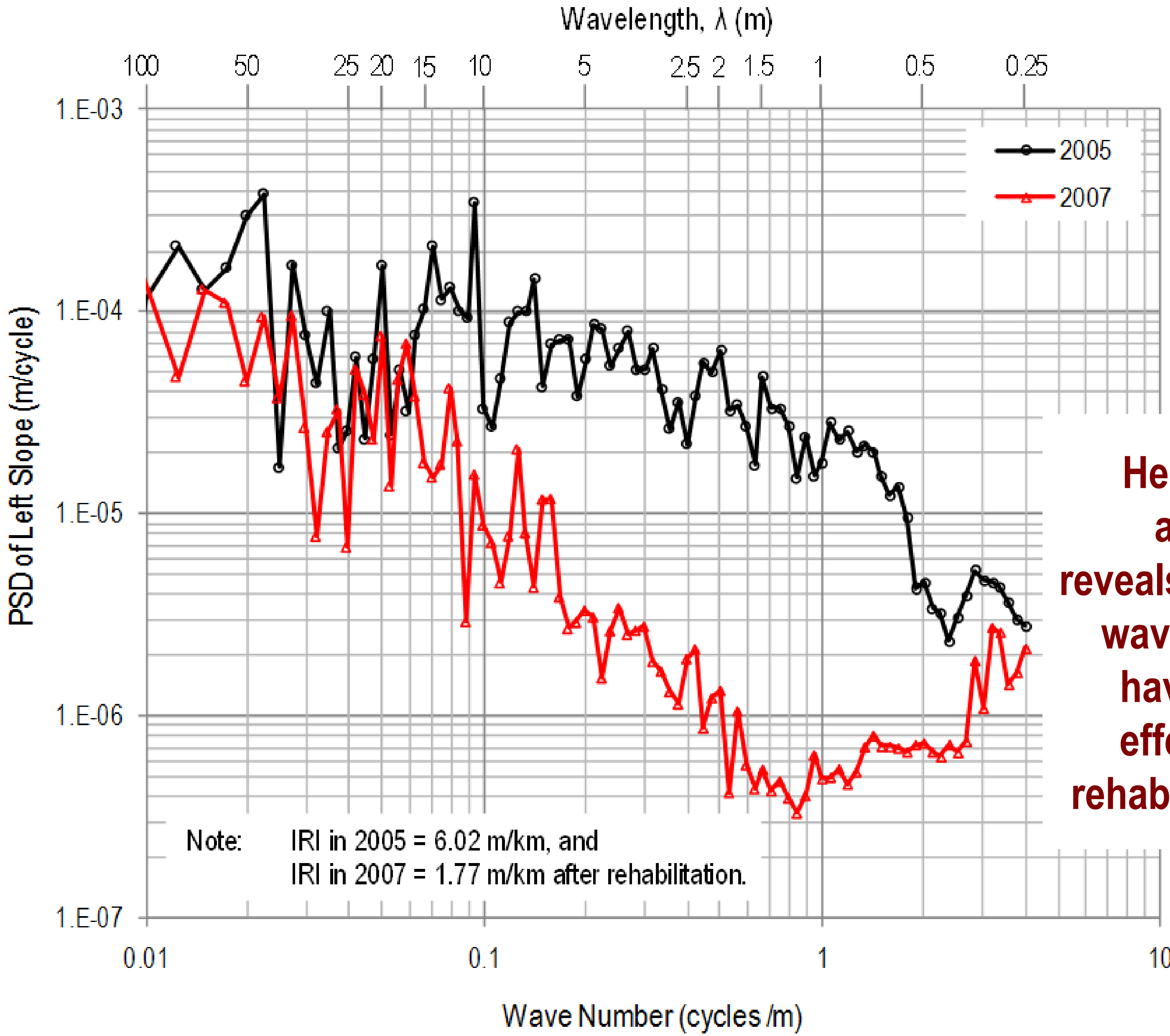


Problem: The IRI cannot discriminate between types of roughness due to averaging these two effects !!

Power Spectral Density Analysis



Power Spectral Density Analysis



Here, PSD analysis reveals which wavebands have been effectively rehabilitated.

Purpose of Research Project

1. To develop a series of new profile indices that clearly represent and quantify short and long wavelength roughness.

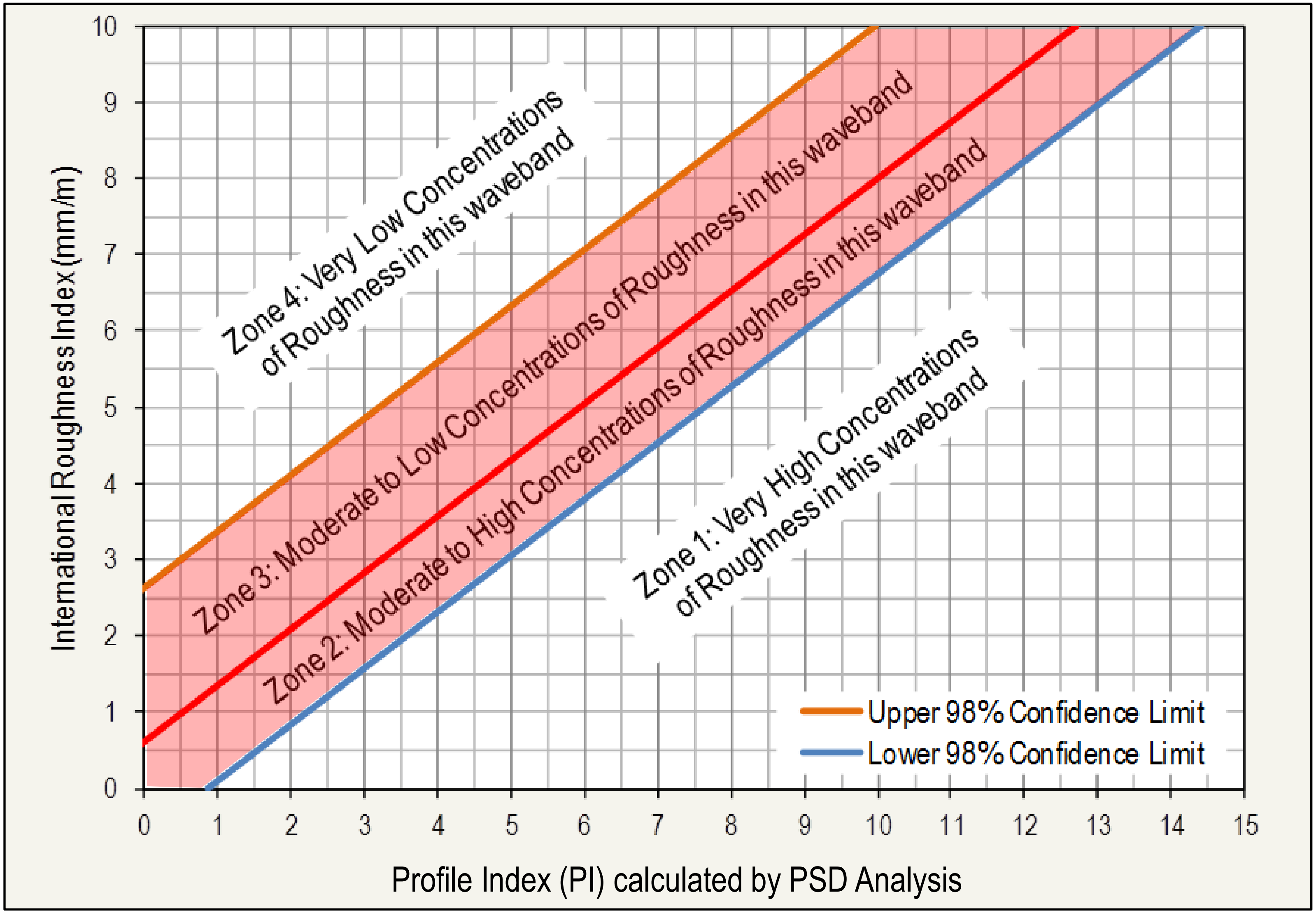
2. Create a series of new templates to identify pavements that contain unusually high concentrations of short or long wavelength roughness, and thus identify the critical roughness wavebands within individual pavements.

2. Evaluate waveband roughness progression rates.

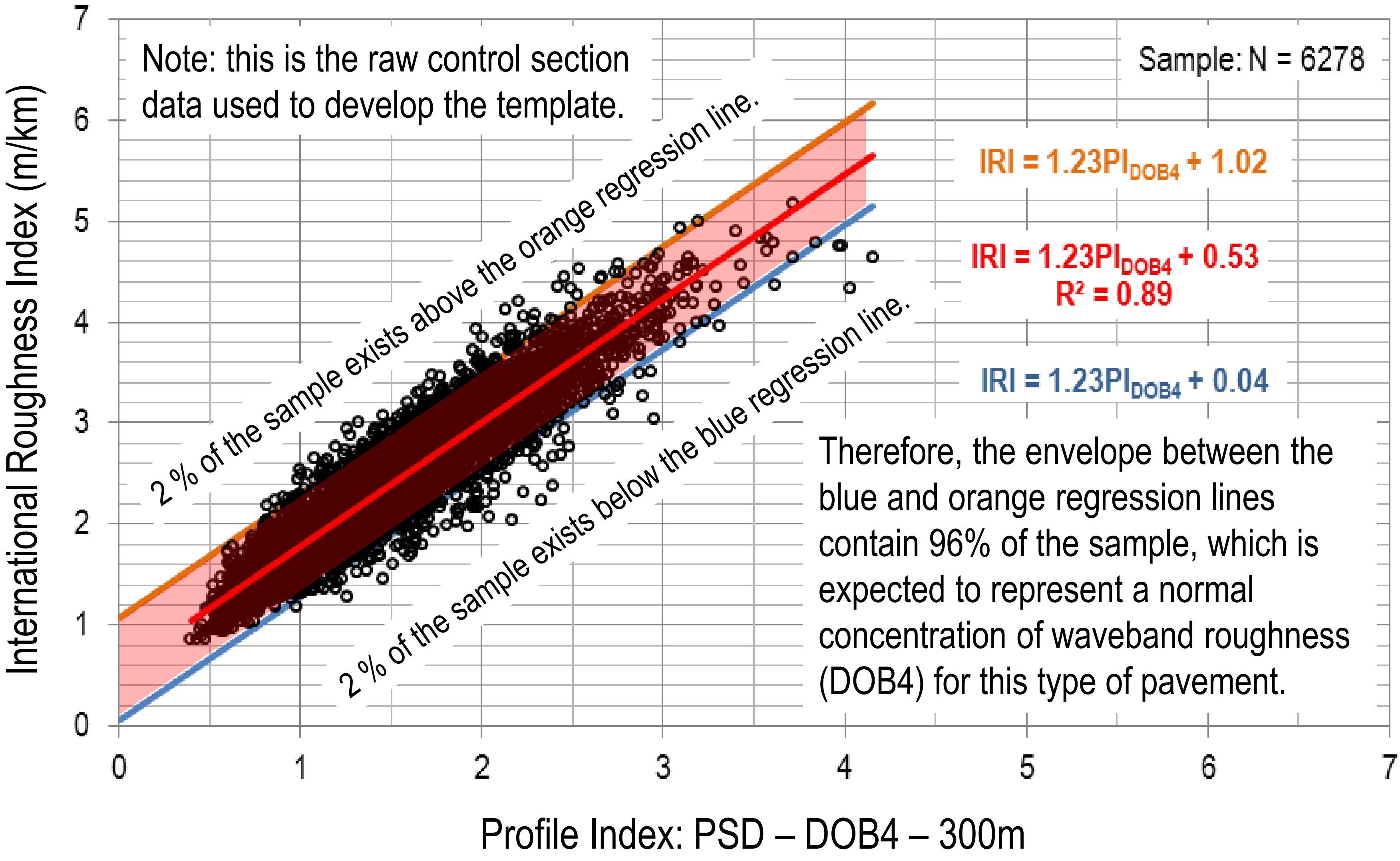
Waveband Intervals Selected

<table>
<tr><th rowspan="2">Wavelengths (m)</th><th colspan="4">Octave Bandwidths</th></tr>
<tr><th>Single</th><th colspan="2">Double</th><th>Triple</th></tr>
<tr><td>0.354 m – 0.707 m</td><td>SOB1
λ_{centre} = 0.5 m</td><td rowspan="2">DOB1
λ_{centre} = 0.707 m</td><td></td><td></td></tr>
<tr><td>0.707 m – 1.414 m</td><td>SOB2
λ_{centre} = 1 m</td><td rowspan="2">DOB2
λ_{centre} = 1.414 m</td><td rowspan="3">TOB1
λ_{centre} = 2 m</td></tr>
<tr><td>1.414 m – 2.828 m</td><td>SOB3
λ_{centre} = 2 m</td><td rowspan="2">DOB3
λ_{centre} = 2.828 m</td></tr>
<tr><td>2.828 m – 5.657 m</td><td>SOB4
λ_{centre} = 4 m</td><td rowspan="2">DOB4
λ_{centre} = 5.657 m</td></tr>
<tr><td>5.657 m – 11.31 m</td><td>SOB5
λ_{centre} = 8 m</td><td rowspan="2">DOB5
λ_{centre} = 11.31 m</td><td rowspan="3">TOB2
λ_{centre} = 16 m</td></tr>
<tr><td>11.31 m – 22.62 m</td><td>SOB6
λ_{centre} = 16 m</td><td rowspan="2">DOB6
λ_{centre} = 22.62 m</td></tr>
<tr><td>22.62 m – 45.25 m</td><td>SOB7
λ_{centre} = 32 m</td><td rowspan="2">DOB7
λ_{centre} = 45.25 m</td></tr>
<tr><td>45.25 m – 90.51 m</td><td>SOB8
λ_{centre} = 64 m</td><td></td><td></td></tr>
</table>

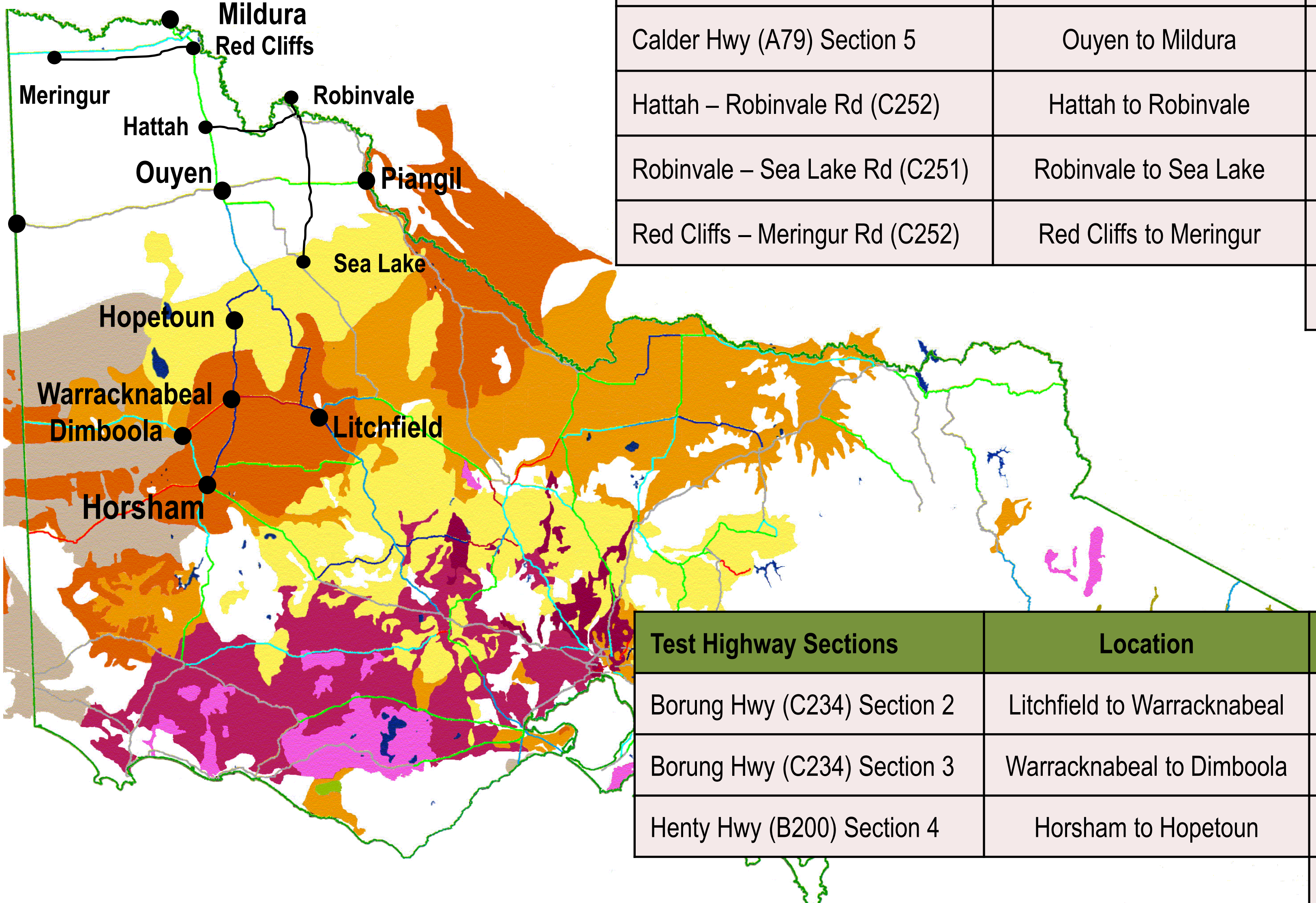
Philosophy of New Templates



Template for PI: PSD–DOB4–300m containing data



Pavement Sections



Control Highway Sections	Location	Length (km)
Mallee Hwy (B12) Sections 2 & 3	Piangil to SA Border	226.5 km
Calder Hwy (A79) Section 5	Ouyen to Mildura	169.9 km
Hattah – Robinvale Rd (C252)	Hattah to Robinvale	62.3 km
Robinvale – Sea Lake Rd (C251)	Robinvale to Sea Lake	108.7 km
Red Cliffs – Meringur Rd (C252)	Red Cliffs to Meringur	79.9 km
		647.3 km

Test Highway Sections	Location	Length (km)
Borung Hwy (C234) Section 2	Litchfield to Warracknabeal	41.8 km
Borung Hwy (C234) Section 3	Warracknabeal to Dimboola	39 km
Henty Hwy (B200) Section 4	Horsham to Hopetoun	117.6 km
		198.4 km

Equations to Build Templates

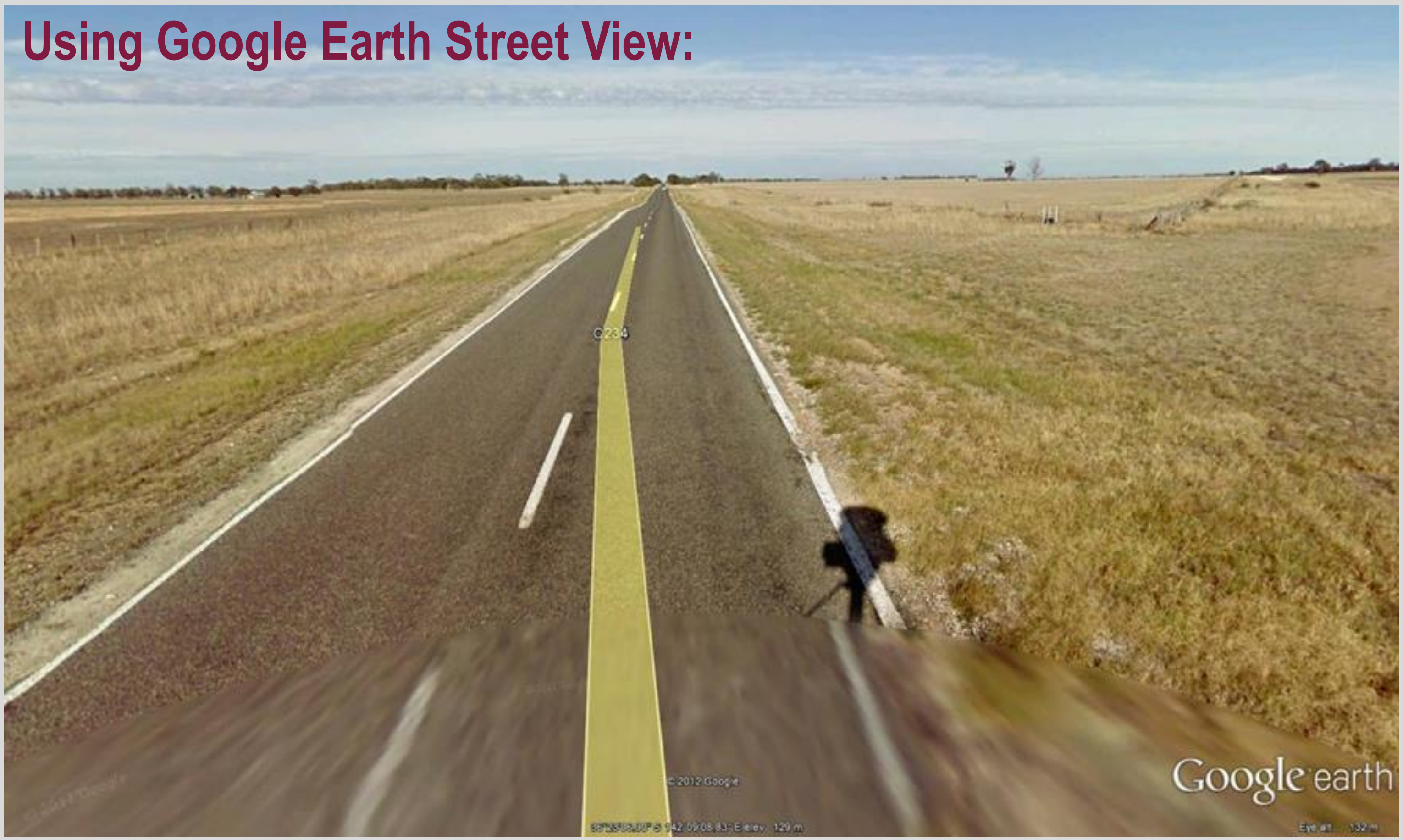
Waveband		Waveband Identification Template Equations		R^2
Single Octave Bandwidths	SOB3 1.41 m to 2.83 m	Upper	$IRI = 1.48\ PI_{PSD\text{-}SOB3\text{-}300m} + 0.86$	0.75
		Average	$IRI = 1.48\ PI_{PSD\text{-}SOB3\text{-}300m} - 0.01$	
		Lower	$IRI = 1.48\ PI_{PSD\text{-}SOB3\text{-}300m} - 0.61$	
	SOB4 2.83 m to 5.66 m	Upper	$IRI = 1.53\ PI_{PSD\text{-}SOB4\text{-}300m} + 1.11$	0.86
		Average	$IRI = 1.53\ PI_{PSD\text{-}SOB4\text{-}300m} + 0.53$	
		Lower	$IRI = 1.53\ PI_{PSD\text{-}SOB4\text{-}300m} - 0.03$	
	SOB5 5.66 m to 11.31 m	Upper	$IRI = 1.73\ PI_{PSD\text{-}SOB5\text{-}300m} + 1.64$	0.77
		Average	$IRI = 1.73\ PI_{PSD\text{-}SOB5\text{-}300m} + 0.88$	
		Lower	$IRI = 1.73\ PI_{PSD\text{-}SOB5\text{-}300m} + 0.24$	
	SOB6 11.31 m to 22.62 m	Upper	$IRI = 1.40\ PI_{PSD\text{-}SOB6\text{-}300m} + 2.07$	0.60
		Average	$IRI = 1.40\ PI_{PSD\text{-}SOB6\text{-}300m} + 1.07$	
		Lower	$IRI = 1.40\ PI_{PSD\text{-}SOB6\text{-}300m} + 0.28$	

Equations to Build Templates

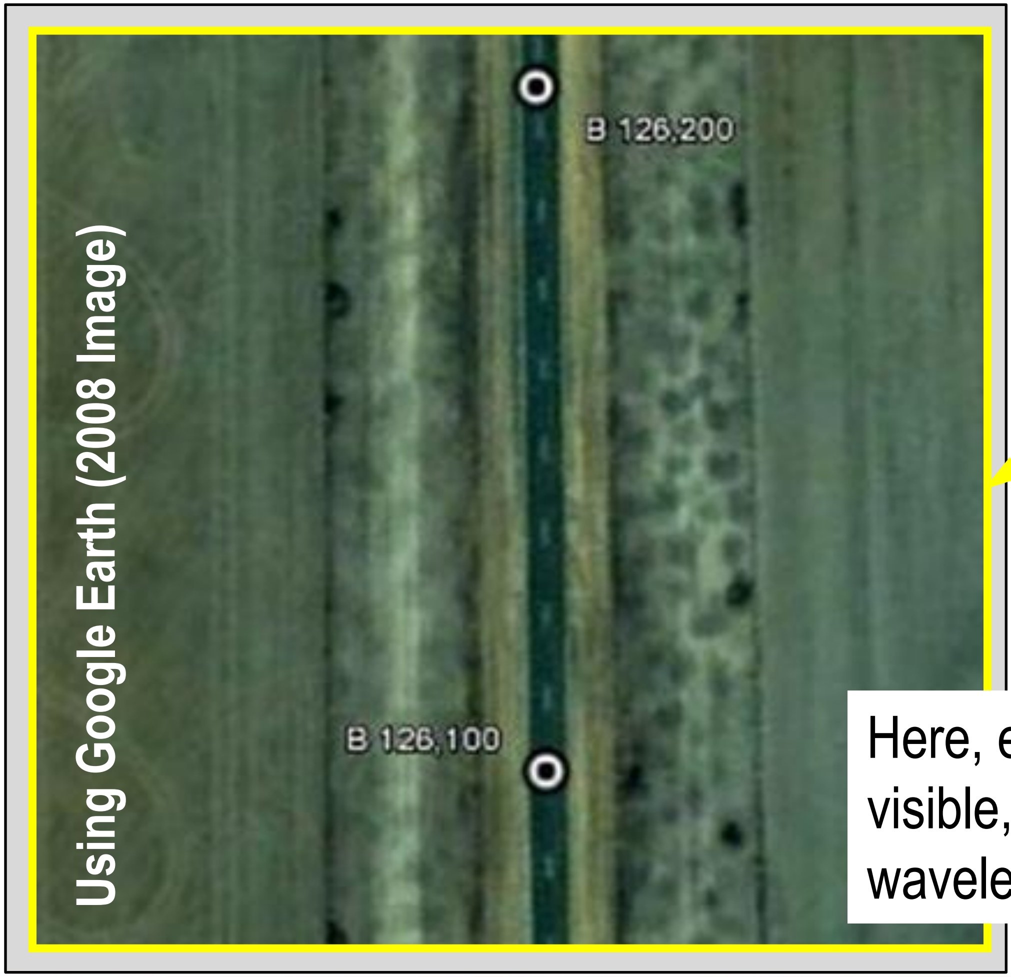
Waveband			Waveband Identification Template Equations	R^2
Double Octave Bandwidths	DOB3 1.41 m to 5.66 m	Upper	$IRI = 1.19\ PI_{PSD\text{-}DOB3\text{-}300m} + 0.59$	0.88
		Average	$IRI = 1.19\ PI_{PSD\text{-}DOB3\text{-}300m}$	
		Lower	$IRI = 1.19\ PI_{PSD\text{-}DOB3\text{-}300m} - 0.46$	
	DOB4 2.83 m to 11.31 m	Upper	$IRI = 1.23\ PI_{PSD\text{-}DOB4\text{-}300m} + 1.02$	0.89
		Average	$IRI = 1.23\ PI_{PSD\text{-}DOB4\text{-}300m} + 0.53$	
		Lower	$IRI = 1.23\ PI_{PSD\text{-}DOB4\text{-}300m} + 0.04$	
	DOB5 5.66 m to 22.62 m	Upper	$IRI = 1.18\ PI_{PSD\text{-}DOB5\text{-}300m} + 1.66$	0.74
		Average	$IRI = 1.18\ PI_{PSD\text{-}DOB5\text{-}300m} + 0.86$	
		Lower	$IRI = 1.18\ PI_{PSD\text{-}DOB5\text{-}300m} + 0.19$	
	DOB6 11.31 m to 45.25 m	Upper	$IRI = 1.07\ PI_{PSD\text{-}DOB6\text{-}300m} + 2.03$	0.52
		Average	$IRI = 1.07\ PI_{PSD\text{-}DOB6\text{-}300m} + 0.95$	
		Lower	$IRI = 1.07\ PI_{PSD\text{-}DOB6\text{-}300m} + 0.05$	

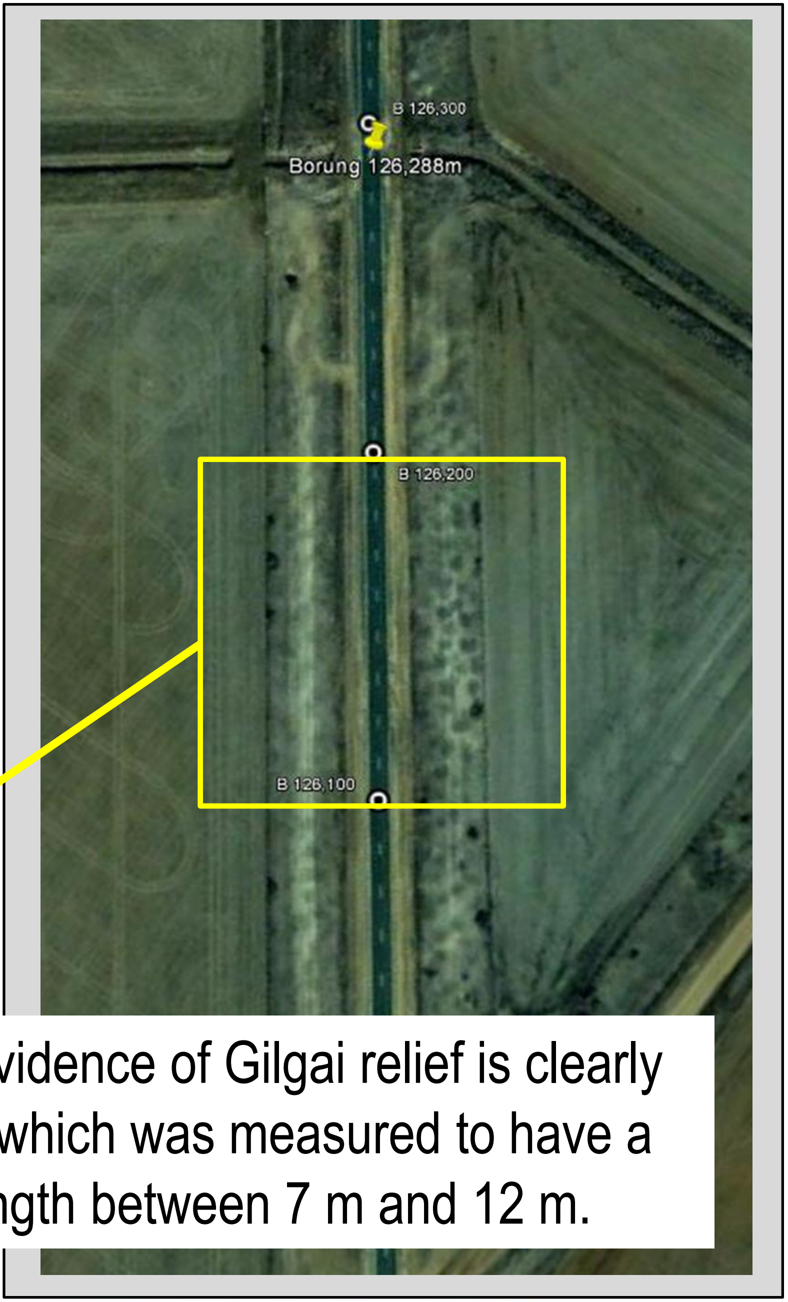
Section Identified as containing high concentration of waveband roughness

Borung Highway at Chainage 126,150 m



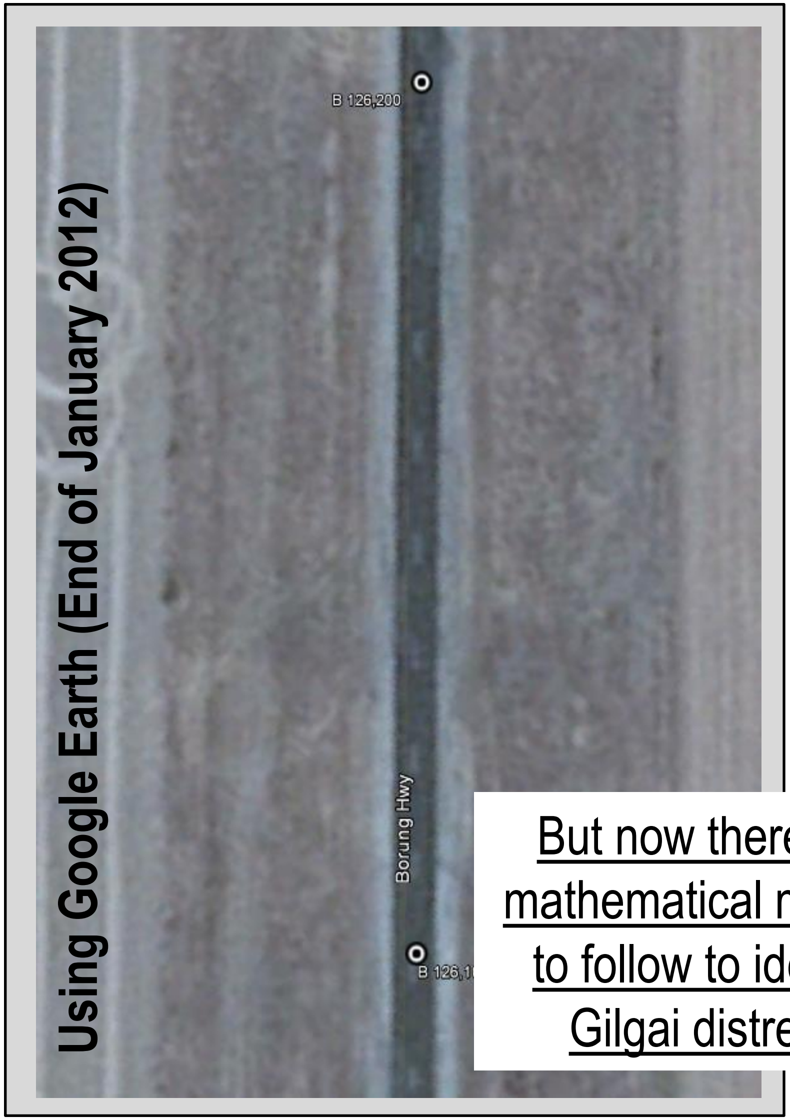
Analysis of site by Google Earth: Aerial View





Here, evidence of Gilgai relief is clearly visible, which was measured to have a wavelength between 7 m and 12 m.

Same Site at Different Times



But now there is a mathematical method to follow to identify Gilgai distress.

Frequency of Waveband Roughness Detection – Borung Hwy

		Waveband	SOB4	DOB4	SOB5	DOB5	SOB6	TOB2	DOB6
		Centre Wavelength	4 m	5.66 m	8 m	11.3 m	16 m	16 m	22.6 m
		Length of File	300 m	300 m	300 m	300 m	300 m	300 m	300 m
Detection of High Concentrations of Long Wavelength Roughness	1997	No.	6	6	45	28	12	11	9
		%	0.78	0.78	5.84	[illegible]	[illegible]	[illegible]	[illegible]
	1999	No.	5	13	58	[illegible]	[illegible]	[illegible]	[illegible]
		%	0.65	1.69	7.53	[illegible]	[illegible]	[illegible]	[illegible]
	2001	No.	8	18	64	[illegible]	[illegible]	[illegible]	[illegible]
		%	1.04	2.34	8.31	[illegible]	[illegible]	[illegible]	[illegible]
	2005	No.	15	29	64	[illegible]	[illegible]	[illegible]	[illegible]
		%	1.95	3.77	8.31	[illegible]	[illegible]	[illegible]	[illegible]
	2007	No.	9	24	62	[illegible]	[illegible]	[illegible]	[illegible]
		%	1.17	3.13	8.09	5.74	3.26	3.13	2.08
	2009	No.	13	34	77	55	33	27	14
		%	1.69	4.42	10.0	7.14	4.29	3.51	1.81

Here, SOB5 is shown to be dominant as there is up to five times more roughness in this waveband than normal:

λ = 5.66 m to 11.3 m

Frequency of Waveband Roughness Detection – Henty Hwy

		Waveband	SOB4	DOB4	SOB5	DOB5	SOB6	TOB2	DOB6
		Centre Wavelength	4 m	5.66 m	8 m	11.3 m	16 m	16 m	22.6 m
		Length of File	300 m	300 m	300 m	300 m	300 m	300 m	300 m
Detection of High Concentrations of Long Wavelength Roughness	1997	No.	20	38	70	55	37	20	11
		%	1.72	3.27	6.03				
	1999	No.	23	38	111				
		%	1.97	3.27	9.53				
	2001	No.	21	37	105				
		%	1.80	3.16	8.97				
	2005	No.	22	45	103				
		%	1.89	3.86	8.83				
	2007	No.	27	44	107				
		%	2.31	3.76	9.15	4.70	3.16	3.49	1.63
	2009	No.	23	48	123	72	53	38	30
		%	1.97	4.11	10.5	6.16	4.53	3.25	2.57

Again, SOB5 is shown to be dominant as there is more than five times more roughness in this waveband than normal:

λ = 5.66 m to 11.3 m

Conclusions

1. A new method (and series of templates) has been developed for identifying sections of pavement that contain high concentrations of roughness within a particular waveband.
2. These template proved very successful in identifying pavements that had been affected by the presence of Gilgai relief (i.e. affected by long wavelength roughness).

   They also remove the need for visual proof of Gilgai.
3. In areas of expansive soil geology, the frequency of pavement sections that revealed high concentrations of long wavelength roughness were up to 5 times greater.
4. Initial studies have revealed that pavement deterioration is quite different for the short and long waveband profiles indices.