Analysis and interpretation of New Zealand long-term pavement performance data

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An important note for the reader

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Executive summary

The purpose of this research project was not to recalibrate existing models with updated local data, but rather to examine the existing dataset to determine the following:

- Which maintenance strategies have evidence of achieving optimum lives?
- Do any maintenance strategies have a negative effect?
- Does surfacing condition affect pavement life, and if so, how?
- What is the effectiveness of different maintenance interventions, and their timing?
- Is there scope to improve the long-term pavement performance (LTPP) experimental design?

The key objectives of this research were to:

- Examine the LTPP database and use descriptive statistics to identify trends.
- Identify the key issues that cause pavements to fail, using correlations between pavement condition indices and pavement failure. In particular, does the LTPP data show that pavements displaying cracking are at a higher risk of failure?
- Recommend whether the dataset could be restructured to provide additional benefits.

Following a detailed analysis, it was found that the data available to undertake a statistical analysis to identify factors that need to be present for accelerated condition trending was not sufficiently robust. It was therefore not possible to find useful or significant statistical correlations with this dataset as it stands.

This in itself was a major outcome of the research.

Statistically, the numerical data was insufficiently accurate or complete to undertake a sufficiently robust analysis to identify or suggest what factors need to be present for accelerated condition trending to take place. This then required significant and time-consuming collation of data from different sources and formats, followed by data cleansing.

The data used to derive the dTIMS models would have needed similar collation and cleansing for the resulting models to be reasonable.

However, there is much scope available to improve the quality of the data in the LTPP and the road assessment and maintenance management (RAMM) databases, so these valuable resources can be more easily utilised.

Rather than pursuing further automated processing of data, a manual investigation was needed to investigate sites highlighted by the statistical analysis and to interpret site photographs, site notes and construction records. Thus the research moved from a purely statistical focus towards an engineering analysis of selected case studies. A table was then manually composed by a person with extensive experience in road maintenance, citing the engineering reasons for the anomalies highlighted by the statistical software. This proved to be time consuming and would be an expensive process to repeat regularly.

This review was unable to identify any reliable data to show that pavements displaying cracking are at a higher risk of failure.

The review does suggest, however, that the current selection of maintenance treatment type and the quality of maintenance and reconstruction practices may assist in making the level of service worse after maintenance, compared with sterilised sites where maintenance is restricted to emergency repair work only.

The maintenance practice of water cutting needs to be carefully reviewed. The detailed site notes revealed evidence that this maintenance activity can at times contribute to a more rapid condition deterioration of some pavements.

In addition to the numerical data, there is a significant wealth of information contained in the visual observations, records and photographs collected by the survey contractor and stored within the LTPP database. This contributes to a greater understanding of the distress and maintenance activities at each site; however, it is very time consuming to extract information from a variety of formats under the current data structure.

In the intermediate term, the LTPP data arrangement should be analysed and reorganised by smart computing specialists to enable data imputation through:

- data cleansing
- image analysis (eg crack mapping, site photographs)
- machine learning
- incorporation of 'big data' from other sources.

The aim is also to remove the reliance on resource-consuming human analysis.

Recommendations are provided on how the dataset could be restructured in the short term to provide additional benefit.

Abstract

A comprehensive statistical analysis and review of the dataset was undertaken on the March 2015 LTPP database, including application of transformations on the skewed raw data.

Following a detailed analysis, it was found that the numerical data available to undertake a statistical analysis to identify factors that need to be present for accelerated condition trending was not sufficiently robust. It is not possible to find useful or significant correlations with this data set as it stands.

A manual investigation by a person with extensive experience in road engineering and maintenance was undertaken. This investigated engineering explanations for the sites highlighted by the statistical analysis, which involved interpreting site photographs, notes and construction records.

This review was unable to identify any reliable data to show pavements displaying cracking are at a higher risk of failure. It does suggest, however, that the current selection of maintenance treatment type and the quality of maintenance and reconstruction practices may assist in making the level of service worse after maintenance, compared with sterilised sites where maintenance is restricted to emergency repair work only.

The maintenance practice of water cutting also needs to be carefully considered, as this may contribute to a more rapid condition deterioration.

Recommendations are provided on how the dataset could be restructured to provide additional benefit.

1 Introduction

With an annual expenditure of over $3.0 billion, land transport represents a large part of the Government's balance sheet. The Government Policy Statement on Land Transport 2015/16-2024/25 therefore maintains a focus on prioritising value for money, particularly with road maintenance. This focus on improving the returns from maintenance expenditure includes the ongoing implementation of the findings of the Road Maintenance Taskforce (for example, the One Network Road Classification system, which delivers optimal levels of service across New Zealand's diverse environment and road controlling authorities) and identification of further opportunities to improve productivity.

One opportunity to improve value for money is in the procurement of road maintenance and renewals. The NZ Transport Agency (the Transport Agency) needs to be confident road maintenance works are not implemented prematurely, while there is still remaining service life from the existing treatment. Intervention too early wastes money, and maintenance delayed too long becomes more expensive.

In accordance with world best practice, the Transport Agency uses specialist models such as highway development and management (HDM) software or the commercial software system Deighton Total Infrastructure Management System (dTIMS) to predict when maintenance is most economical. Long-term pavement performance (LTPP) sites were established in 2000 on state highways (SHs) and in 2003 on territorial local authority (TLA) networks to provide local data for calibrating these models.

However, data from the LTPP sites can also be used to return to first principles and thus provide guidance on the basic and actual relationships between various measures of pavement condition and economic performance.

The purpose of this research was not to recalibrate existing models with updated local data, but rather to examine the existing dataset to determine:

- What maintenance strategies have evidence of achieving optimum lives?
- Do any maintenance strategies have a negative effect?
- Does surfacing condition affect pavement life, and if so, how?
- What is the effectiveness of different maintenance interventions, and their timing?
- Is there scope to improve the LTPP experimental design?

The key objectives of this research were:

- Examine the LTPP database and use descriptive statistics to identify trends.
- Identify the key issues that cause pavements to fail, using correlations between pavement condition indices and pavement failure. In particular, does the LTPP data show that pavements displaying cracking are at a higher risk of failure?
- Recommend whether the dataset could be restructured to provide additional benefits.

2 Literature review

2.1 LTPP programme establishment

A number of LTPP studies have been established around the world, with a selection of the more relevant ones discussed below.

2.1.1 New Zealand

New Zealand first embarked on a national pavement management system in 1998, utilising dTIMS together with the World Bank HDM pavement condition deterioration models (initially HDM-III and later HDM-4). These deterioration models needed to be calibrated to local New Zealand conditions. To do this required the establishment of the New Zealand LTPPs (Henning 2008).

The LTPP programme was established in two parts (Henning et al 2004; Henning et al 2006).

- Transit NZ established 63 sections (48 as required by a well-considered selection matrix plus 15 backup sites) on the SH network in both the North Island and South Island during 2001.
- Approximately 21 road controlling authorities established 82 sections in both urban and rural areas.

The 145 sites that initially formed the LTPP programme (63 sites on SHs and 82 on TLA roads) are scattered throughout New Zealand, and are monitored in detail both in terms of more detailed knowledge of inventory than is usually collected in routine network inventory surveys, and more detailed annual condition surveys. Over time, the number of sites has dropped due to maintenance or financial reasons, leaving a total of 130 sites that are currently active (NZ Transport Agency 2009).

The sites are classified into two groups:

1 Sterilised: no maintenance is allowed other than pothole patching

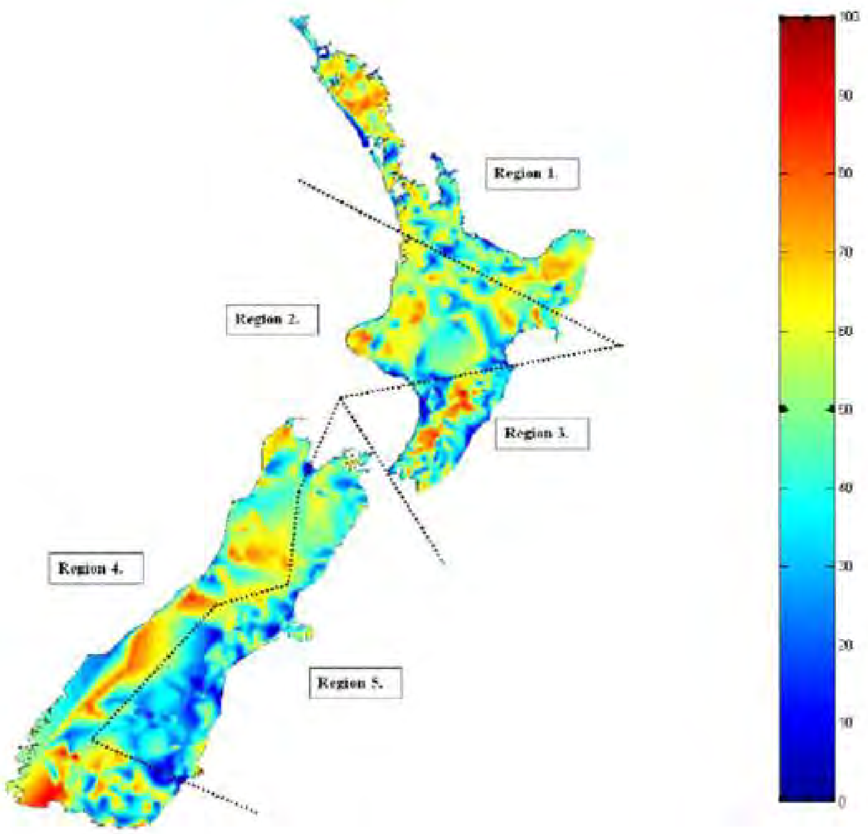
2 Normal: more extensive maintenance such as resealing and pavement strengthening is allowed

The factors considered important for inclusion in the original selection matrix are discussed below.

2.1.1.1 Climate

Cenek (2001) used a combined climate and soil stability factor to derive a ratio between the subgrade wet strength and the moisture index, to identify different geologically sensitive areas. These are shown in figure 2.1.

Figure 2.1 Climatic regions of New Zealand according to subgrade strength/moisture ratio (Cenek 2001)



NOTE: Blue shading represents high wet subgrade strength/low winter moisture whereas red shading represents low wet subgrade strength/high winter moisture. Green/yellow shading represents areas where compensatory factors are in play i.e. low wet subgrade strength/low winter moisture or high wet subgrade strength/high winter moisture.

These outputs were then examined more closely to establish regions of similar climatic and soil conditions, and thus the SH network was divided into four calibration areas as shown in table 2.1.

Table 2.1 Regional distribution based on climate and geology (Henning 2008)[1]

Moisture sensitivity	Calibration section within SH region
High	Northland, West Waikato, Gisborne, West Coast
Moderate	Coastal Otago, Auckland, Whanganui, Taranaki, Wellington
Low	Nelson, Marlborough, Napier, East Waikato
Limited	Canterbury

[1] The Central Waikato region did not appear on this list.

2.1.1.2 Traffic

Traffic categorisations for different regions based on equivalent standard axles (ESAs) were established as shown in table 2.2.

Table 2.2 Traffic classification (Henning 2008)

Volume classification	ESAs/day High- volume areas (eg Auckland and Wellington)	ESAs/day Low- volume areas (eg Canterbury)
Low	<400	<100
Moderate	400 – 1,000	100 – 400
High	>1,000	>400

2.1.1.3 Pavement strength

The pavement classification used is based on the structural number (SN) of the pavement modified for the effects of material depth – the adjusted structural number (SNP) (Rolt and Parkman 2000; Morosiuk et al 2001), as derived from falling weight deflectometer (FWD) measurements, as shown in table 2.3.

Table 2.3 Pavement strength classification (Henning 2008)

Pavement	Description
Weak	Unbound pavement with chipseals, total pavement depth < 300 mm; or estimated SNP < 3
Strong	Unbound pavement with chipseals, total pavement depth > 300 mm; or asphaltic concrete; or estimated SNP ≥ 3

2.1.1.4 Pavement condition

The factors used to express pavement condition/age are shown in table 2.4.

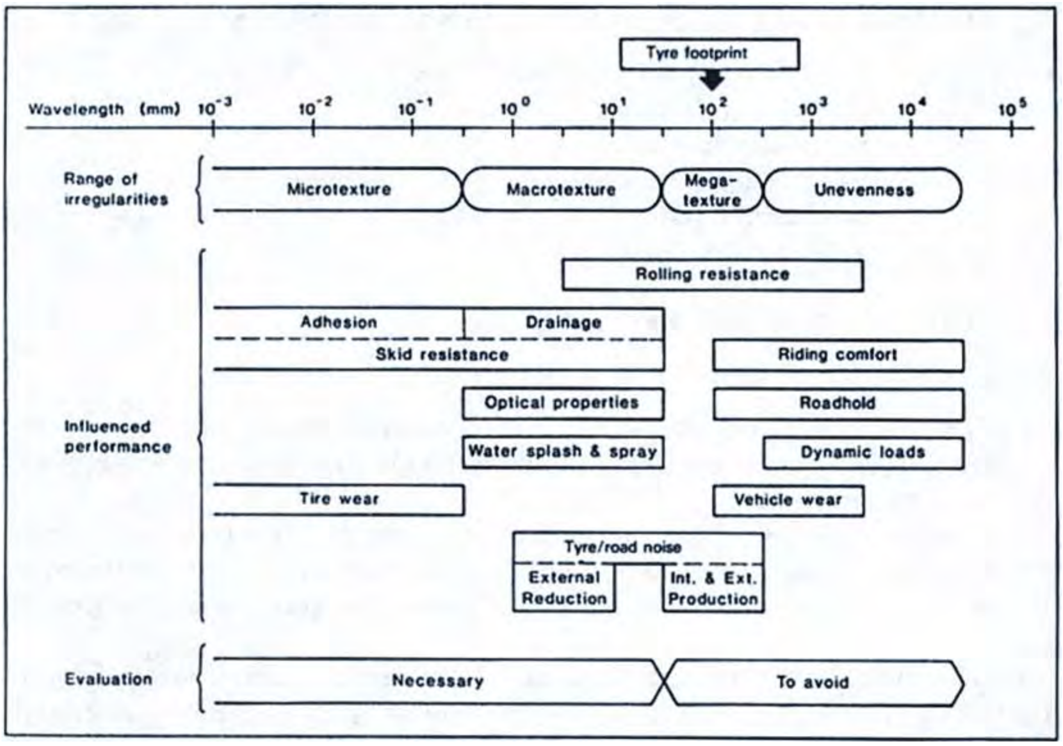
Table 2.4 Pavement condition (Henning 2008)

Parameter	Old	New
Cracking	>10%	<10%
Rut progression	>6 mm	<6 mm
Surfacing age	>5 years	<5 years
Pavement age	>15 years	<15 years

The walking profilometer was nominated as the collection method for pavement shape data.

Roughness is defined by Austroads (2007) as surface irregularities with wavelengths between 0.5 m ($5x10^2$ mm) and 50 m ($5x10^4$ mm) which equates with unevenness in figure 2.2.

Figure 2.2 The relationship between surface characteristics and defect wavelength (source: PIARC 1987)



Block cracking, pavement repairs and depressions should be expected to contribute to an overall increase in roughness.

2.1.1.5 Geometric criteria

The geometric criteria adopted for site selection are summarised in table 2.5.

Table 2.5 Geometric criteria (Henning et al 2004)

Parameter	Reason	Guideline
Horizontal curves	Safety and data accuracy	Should be able to drive through the curve safely at 80 km/h
Gradient	Consistency in deterioration	Gradient <7%
Sag vertical curves	Variability in drainage conditions	No sag vertical curves allowed
Crest vertical curves	Safety (for data collectors)	Sufficient sight distance for 80 km/h
Major drainage structures	Variability in drainage conditions and compaction	No major drainage structure allowed unless very deep and with no impact on surface roughness measurement
Total surface thickness	Very thick chipseal layers believed to 'corrupt' some models	Total surface thickness <70 mm

The New Zealand LTPP programme commenced on the SH network during 2000. The first calibration analysis was undertaken in 2005.

2.1.2 Australia

The establishment of the Australian LTPP programme appears to be ad hoc compared with the New Zealand development, and could be described as an amalgamation of many discrete components. A brief history has been extracted from the literature (Martin 1994; Roberts and Martin 1996; Hoque 2003; Austroads 2014; Choummanivong 2015).

2.1.2.1 ALF- LTPP study

Prior to 1995, a number of sites had been established to compare the predictions from the Australian Road Research Board's (ARRB) accelerated loading facility (ALF) with that of full-scale in-service pavement sections.

2.1.2.2 SHRP–LTPP study

In 1995 Austroads participated in the US Strategic Highway Research Program (SHRP) and established its own LTPP programme in Australia. Nineteen test sections including asphalt, granular and concrete pavements, and those set up for the ALF-LTPP study, were established in South Australia, Victoria, New South Wales and Queensland.

2.1.2.3 LTPPM study

In 1999 under funding from the Austroads Business Systems Program, another study was established to examine the influence of maintenance activities on long-term pavement performance (LTPPM). For this study an additional eight sites were established in four states (Victoria, New South Wales, Queensland and Tasmania), which accounted for different climates and levels of traffic.

2.1.2.4 AAPA- LTPP study

In 1999 the Australian Asphalt Pavement Association (AAPA) sponsored a pilot study of a selection of heavy duty asphalt pavements in four Australian states. These sites were up to 30 years old, and it was found more control was required to define the influence of the stiffness of the asphalt mix on performance.

2.1.2.5 State road authority sites

A large number of pavement performance sites are being monitored individually by various state road jurisdictions, largely on an ad hoc basis.

2.1.2.6 Stabilised pavements database

Following the Austroads project 'Characterisation and specification of stabilised quarry and recycled materials', a national database was established for the long-term performance modelling of stabilised pavements.

2.1.2.7 ALF- SHRP- LTPPM combined

In 2001/02 these studies were combined to be more cost effective, and their data was compiled into a single database, the LTPP/LTPPM database.

2.1.2.8 Development of a national database

By 2002/03 the number of LTPP sites reached 27 following the addition of new AAPA sites, and the older Australian Capital Territory (ACT) sites, to the existing ALF-SHRP-LTPPM combination.

2.1.2.9 Attrition

By 2014, of the 27 current LTPP sites 15 had reached a pavement age of 18 years, although some had been lightly maintained to extend their pavement life to maintain road user safety standards. Over the last few years the $2.25 billion western ring road upgrade in Melbourne has progressively moved through eight LTPP sites and transformed these sites ‘beyond recognition’ (Austroads 2014).

By September 2015, due to roadworks and the decommissioning of a number of sites, the only active sites remaining were: 13 LTPP and six LTPPM sites in Tasmania, South Australia, Victoria, New South Wales and Queensland (including an AAPA site); and six ACT LTPP sites. (Choummanivong 2015). Details of these sites can be found in Austroads (2014).

2.1.2.10 Renewal

To partially compensate for the loss of eight LTPP sites on the one road project, a steering group was formed in 2012 with a view to establishing replacement sites.

Site establishment guidelines were set (Clayton 2000), which can be briefly summarised as:

- consideration of pavement composition and availability of materials testing information
- availability of construction and maintenance activity records
- suitability of alignment, ie no sharp curves and longitudinal steep grade (less than 2%)
- minimum length of 200 m
- consistency of subgrade conditions
- availability of traffic volume information
- practicality and safety issues
- availability of historic pavement performance (preferably).

It appears that a specific programme design matrix similar to New Zealand practice was not established.

A number of potential sites were then offered in South Australia, of which two have since been established (Austroads 2014; Austroads 2015a).

Clayton (2000) specified collection of the following data for LTTP projects

- material tests
- traffic
- distress (visual assessment)
- profile (roughness)
- deflection
- environment
- maintenance
- rehabilitation.

The overall objective of the now combined Australian LTPP project was to enhance asset management strategies through the development of improved pavement performance models based on observed pavement behaviour. The two main aims of this were to (Hoque 2003):

- compare the results of accelerated pavement testing studies with observed in-service performance
- investigate the quantitative influence that maintenance has on observed pavement performance.

Data collected from the Australian LTPP and LTPPM (the maintenance effects study) has been compiled into a single database and posted on the LTPP website (www.arrb.com.au/ltpp/) for unrestricted access.

2.1.3 United States of America

The SHRP was originally proposed in TRB (1984), which quotes:

> *This study outlines a strategy for screening potential highway research areas to identify the most promising for a national program and thereby identifies six priority areas where a concerted research effort can produce major innovations that will increase the productivity and safety of the nation's highway system: asphalt, long-term pavement performance, maintenance, cost-effectiveness protection of concrete bridge components, cement and concrete in highway pavements and structures, and chemical control of snow and ice on highways.*

The programme's aim was to

> *Increase pavement life by the investigation of the long-term performance of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrades, soils, and maintenance practices.* (FHWA 2000)

The LTPP programme was initiated as a 20-year SHRP project in 1987 and designed a partnership between the individual US States and Canadian provincial highway agencies, the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board (TRB), the Canadian Strategic Highway Research Program and the Federal Highway Administration (FHWA 2008)

The strategic plan for LTPP data analysis is as follows (FHWA 1999):

- Improve traffic characterisation and prediction.
- Improve characterisation of materials.
- Improve consideration of environmental effects in pavement design and performance prediction.
- Improve evaluation and use of pavement condition data in pavement management.
- Evaluate existing and/or develop new pavement response and performance models applicable to pavement design and performance prediction.
- Provide guidance for maintenance and rehabilitation strategy selection and performance prediction.
- Quantify the performance impact of specific design features (presence or absence of positive drainage, differing levels of pre-rehab surface preparation etc).

The pavement test sections are organised as 17 specifically designed experiments, under two broad categories (Turner-Fairbank Highway Research Centre 2015):

- General pavement studies (GPS). These number 918 test sections and are restricted to materials and designs in current practice, and have a strategic importance
- Specific pavement studies (SPS). These number 1,591 test sections and have been specifically constructed to study certain engineering factors in pavement design.

These two broad categories and 17 specific experiments are summarised in tables 2.6 and 2.7.

Table 2.6 General pavement study (GPS) experiments (Turner- Fairbank 2015)

Experiment	Experiment title	Total sections	Active sections
GPS-1	Asphalt concrete (AC) pavement on granular base	109	11
GPS-2	Asphalt concrete (AC) pavement on bound base	65	8
GPS-3	Jointed plain concrete pavement	116	65
GPS-4	Jointed reinforced concrete pavement	49	16
GPS-5	Continuously reinforced concrete pavement	55	29
GPS-6	AC overlay on AC pavement	371	187
GPS-7	AC overlay on Portland cement concrete (PCC) pavement	129	62
GPS-9	Unbonded PCC overlay on PCC pavement	24	12
Total		918	390

Table 2.7 Specific pavement study (SPS) experiments (Turner- Fairbank 2015)

Experiment	Experiment title	Total sections	Active sections
SPS-1	Strategic study of structural factors for flexible pavements	175	35
SPS-2	Strategic study of structural factors for rigid pavements	207	166
SPS-3	Preventative maintenance effectiveness of flexible pavements	445	0
SPS-4	Preventative maintenance effectiveness of rigid pavements	220	0
SPS-5	Rehabilitation of AC pavements	182	39
SPS-6	Rehabilitation of jointed Portland cement concrete pavements	150	0
SPS-7	Bonded PCC overlays on concrete pavements	39	0
SPS-8	Study of the environmental effects in the absence of heavy loads	53	41
SPS-9P/ SPS-9A	Validation and refinement of SuperPave asphalt specifications and mix design process/SuperPave asphalt binder study	120	30
	Total	1,591	311

As in 2014, the LTPP programme monitors 2,509 in-service pavement test sections. Performance records, in some cases as old as 25 years have been collected and processed, and are publicly available from www.infopave.com/

2.2 Analysis approaches to LTPP data

A review of how the LTPP data is used, is useful when investigating the requirements of an LTPP database.

2.2.1 Models

Mathematical models are commonly used for problem solving. There are two different general approaches to building mathematical models:

- *Mechanistic modelling*. The model is based on established physical theories relevant to the problem, such as stress analysis, elasticity, or modulus. This model can be called a physics-based model, as these theories are the underlying mechanisms for the starting point for the model building.

- *Empirical modelling*. The observed data available forms the basis for the model building, and it does not require a theoretical understanding of the underlying mechanisms involved. This kind of model can also be called a data-dependent model (Murthy et al 2004).

For modelling road deterioration and maintenance effects there may be a third approach,

- *Mechanistic-empirical*, or structured empirical, identifying functional form and primary variables from external sources, and then using various statistical techniques to quantify their impact. The resulting models combine both the theoretical an experimental basis of mechanistic models with the behaviour observed in empirical studies (ND Lea International 1995).

In empirical modelling, if the analysis indicates a high degree of variability then models that can capture this variability are required. These are probabilistic or stochastic models (Murthy et al 2004).

- *Stochastic or probabilistic models* provide one or more reasonable solutions based on their probabilities.
- *Deterministic models* produce a single mathematically exact solution (Austroads 2015b).

The Markov chain theory is one probabilistic approach used to predict pavement deterioration. A distinguishing point of Markov theory is that the future state of a process or condition depends on its current state, but not its past states. Markov chain modelling involves developing a starting point or an initial vector, and then one or more transition probability matrices. By applying the Markov model over a series of years, a Markov chain is developed (Hassan et al 2015).

2.2.2 New Zealand

The first significant outcome from the New Zealand LTPP sites was published in 2006 (Henning et al 2006).

The HDM-adopted deterioration models for cracking, roughness, rutting and texture were calibrated using LTPP data processing by a traditional calibration coefficient of the HDM-4 model, and adjustment of all HDM-model coefficients based on maximum likelihood estimation, linear model regression and logistic model development.

The crack initiation was considered to be a significant point in the behaviour of a pavement, and was often the starting point of accelerated acceleration. It was also claimed that the crack initiation model contributed to the roughness and rutting models.

Three different definitions (groupings) for the climatic and geographical clusterings of regions were found, as shown in tables 2.8, 2.9 and 2.10. The groupings from table 2.10 were used in this report.

Table 2.2 Regional distribution of SH calibration sections (Henning et al 2004)

Sensitivity area (based on climate and geology)	Calibration sections within transit region
High	Northland, West Waikato, Gisborne, West Coast
Moderate	Southland
Low	Coastal Otago, Auckland, Whanganui, Taranaki, Wellington
Limited	Canterbury, Nelson, Marlborough, Napier, East Waikato

Table 2.3 Preliminary regional distribution of SH calibration sections (Henning 2008)

Sensitivity area	Calibration sections within SH regions
High	Northland, West Waikato, Gisborne, West Coast
Moderate	Coastal Otago, Auckland, Whanganui, Taranaki, Wellington
Low	Nelson, Marlborough, Napier, East Waikato
Limited	Canterbury

Table 2.4 Proposed regionalisation of New Zealand for pavement deterioration modelling (Cenek et al 2003)

Region No.	Transit New Zealand road network region
1	Northland, Auckland, Bay of Plenty, Waikato, Gisborne, Hawke's Bay, Taranaki, Whanganui and Southland
2	Manawatu, Wellington and Nelson/Marlborough
3	Canterbury and Otago
4	West Coast

2.2.3 Australia

The ARRB commenced pavement behaviour prediction research in 1990. It was decided to develop an Australian model rather than calibrate the existing HDM-III because of a perceived difference in Australian maintenance practices compared to other countries, and the cost of acquiring the specific input information. The ARRB models were deterministic, in line with HDM-III practices, and road roughness was used as a proxy for the surface condition data required by HDM-III (Martin 1994).

A decade later performance data from eight LTPPM sites and five LTPP sites, all on sealed granular pavements, was used to calibrate the default HDM-IV road deterioration model. Deterioration relationships were developed with various maintenance treatments, pavement strength, age and condition, environment and loading to enable calibration of the models for rutting, roughness and pavement strength (Martin 2004).

Austroads began investigations into probabilistic road deterioration modelling in 2011. Since then a range of modelling approaches including survivor curves, Markov chain, Monte Carlo simulations and stochastic information packets (SIPs) have been explored (Austroads 2016a).

The introduction of SIP provides a new data condensation technique by applying cumulative histograms (cumulative probability distributions) to the full data set. These are condensed into a SIP package stored in an HTML text string which occupies a single cell in Excel. This then allows the use of a full data set (ie a full population) rather than a mean or median value (Austroads 2015c). Austroads also has plans to improve SIP operation by bypassing Excel and performing the entire process in dTIMS (Austroads 2016b).

2.2.4 United States of America

The 1994 analysis of the LTPP database for SHRP purposes began with simple statistical calculations of mean, standard deviation, low value, median value high value, and range, as shown in table 2.11.

Correlation analyses for the significant variables were undertaken using SAS™ (Statistical Analysis System) which gave Pearson's correlation coefficient, R (not to be confused with the coefficient of determination R^2), and probability value p.

Scatter plots were drawn for selected distresses of interest, with distribution plots, box plots, probability density plots and normal quantile-quantile plots for the more significant independent variables (Killingsworth et al 1994).

For HDM 4 purposes, the analysis of the LTPP dataset was accomplished using the Weibull survivor function from SAS software. According to annex 4.2 of ND Lea International (1995), a detailed description of probabilistic failure time modelling and the process followed in this analysis in HDM-III is found in appendix B of Paterson's (1987) report. Consistent with Paterson's approach, this study assumed that the failure time model followed a Weibull (Weibull 1951) distribution.

More recently, in the analysis of flexible pavement sections the effectiveness of preventative maintenance treatments was statistically analysed using the Friedman test, described as 'a nonparametric test (distribution free) for comparison of paired observations' (FHWA 2011).

Paired observations were used to compare the performance of the control sections (without treatment) to the sections given preventative maintenance treatments. The Friedman test was applied to all design factors – moisture, temperature, subgrade type, traffic loading, and existing condition – for each distress type. The values then used were the weighted average for the distresses, normalised for the analysis period. The Friedman test determined whether statistically significant differences existed between the pairs.

Table 2.11 Example of statistical values for significant variables (Killingsworth et al 1994)

Variable	Unit	No. of values	Mean value	Standard deviation	Low value	Median value	High value	Range
Rut depth	Inches	188	0.29	0.15	0.05	0.25	0.99	0.94
Initial roughness index (IRI)	Inches/ mile	163	57	23	14	52	123	109
Measured roughness (IRI)	Inches/ mile	227	87	36	36	78	260	224
Measured friction number	%	184	46	12	10	47	90	80
Surface thickness	Inches	241	6.0	3.4	0.8	5.5	16.0	15.2
Granular base thickness	Inches	208	9.6	4.6	0.9	8.6	25.8	24.9
Granular subbase thickness	Inches	83	13.4	7.8	2.0	12.0	38.2	36.2
Treated subbase thickness	Inches	21	7.9	3.1	1.2	7.8	14.4	13.2
Age of pavement	Years	233	9.6	5.91	1.1	9.0	25.0	24.0
Cumulative equivalent standard axle loads x 1,000	No.	233	2,176	4,624	1	689	40,326	40,325
Hot-mix asphaltic concrete (HMAC) binder viscosity @140F	Poise	226	1,690	951	288	1,692	8,422	8,134
HMAC binder content	% (w/w)	233	5.2	0.8	2.4	5.1	7.4	5.0

Variable	Unit	No. of values	Mean value	Standard deviation	Low value	Median value	High value	Range
HMAC air voids	% (w/w)	228	4.7	2.1	0.9	4.5	13.6	12.7
HMAC aggregate passing #4 Sieve	% (w/w)	213	55.2	9.0	27.4	55.8	82.7	55.3
Comp. of base (mod. AASHTO)	%	163	95.0	5.7	76.4	95.2	128.3	51.9
Comp. of subbase (mod. AASHTO)	%	72	95.4	7.2	70	96.6	117.5	47.7
In situ moisture in subgrade	%	236	11.7	6.9	0	10.9	36.0	36.0
Subgrade soil passing #200 sieve	% (w/w)	232	36.1	27.4	0.4	29.2	97.5	97.1

The Arizona Department of Transportation Research Centre undertook a distress analysis of the flexible pavement LTPP site SPS-9A within their jurisdiction (Puccinelli et al 2015). They divided distress types into two general categories as shown in table 2.12.

Table 2.5 Arizona Department of Transportation flexible pavement distress types (Puccinelli et al 2015)

Distress type	Failure mechanism	
	Traffic/load related	Climate/materials related
Fatigue cracking	X	
Longitudinal wheel path cracking	X	
Longitudinal non-wheel path cracking		X
Transverse cracking		X
Block cracking		X
Ravelling		X
Bleeding		X
Rutting	X	X

To reduce variability and to consolidate the information for analysis, the researchers presented the quantities as one composite value, being either the structural damage index S for traffic/load related mechanisms, or the environment index E for distress resulting from climatic conditions.

The structural damage index is presented as a percentage of wheel path damage, and includes both fatigue cracking and longitudinal cracking. To normalise fatigue and longitudinal cracking, the structural damage index takes the form of equation 2.1.

$$S = \frac{F + 1ft \times C_{lwp}}{2W_{wp}L_s} \qquad \text{Equation 2.1}$$

where

S = Structural damage index

F = Area of fatigue (ft^2)

C_{lwp} = Length of longitudinal wheel path cracking

W_{wp}	=	Structural damage index
L_s	=	Structural damage index

The environmental damage index is a composite built generally from climatic effects. To normalise the environmental distress for the total area, the environmental damage index takes the form of equation 2.2.

$$E = \frac{B}{A_{tot}} + \frac{C_{nwp}}{L_s} + \frac{C_t}{L_s} \qquad \text{Equation 2.2}$$

where

E	=	Environmental damage index
B	=	Area of block cracking (ft^2)
C_{nwp}	=	Length of non-wheel path cracking (ft)
C_t	=	Length of transverse cracking (ft)
A_{tot}	=	Total area of test section (ft^2)
L_s		Length of test section (ft)

In addition to these structural and environmental factors, it was noted that rutting, patching, potholes, bleeding, ravelling etc also affected performance.

As replicate data was not collected for this project it was argued that standard statistical tests to determine significance (such as the t test) could not be conducted. Instead, graphical comparisons were made between test sections from data collected at the same points in time.

3 New Zealand LTPP site locations

All the New Zealand LTPP sites are listed in table 3.1 (for SHs) and table 3.2 (for TLAs). Note that the sites are classified into sterilised (CS or -S) or normal (CAL) sites. Each site is 300 m long. For the 'sterilised' sites, only pothole patching is allowed in order to maintain a safe surface and for 'normal' sites more extensive maintenance such as resurfacing and pavement strengthening according to local practice can be performed. Data from the 'sterilised' sites is to allow for the investigation of pavement deterioration beyond points of normal intervention (NZ Transport Agency 2009).

Table 3.1 SH LTPP sites (NZ Transport Agency 2009)

Section number	SH	RS	Start (km)	End (km)	Texture measurement	Sterilised
CS-1	1N	292	0.7	1.0	N	Y
CS-2	1N	319	13.3	13.6	N	Y
CS-3	1N	245	6.35	6.65	N	Y
CAL-4	12	17	14.39	14.69	N	N
CAL-5	12	185	10.45	10.75	N	N
CAL-6	1N	20	10.5	10.8	N	N
CS-7a	1N-inc.	431	1.0	1.3	N	Y
CS-7b	1N-inc.	431	1.95	2.25	N	Y
CS-8a	1N-inc.	461	3.1	3.4	N	Y
CS-8b	1N-inc.	461	3.7	4.0	N	Y
CS-11	1N	625	7.2	7.5	Y	Y
CAL-12	5	169	7.2	7.5	Y	N
CS-13a	1N	777	3.2	3.5	N	Y
CAL-13b	1N	777	3.88	4.18	N	N
CAL-53	5	29	1.4	1.7	Y	N
CAL-54	30	147	8.06	8.36	Y	N
CS-14	29	50	0.55	0.85	Y	Y
CS-16	1N-inc.	574	4.0	4.3	N	Y
CAL-17	2	0	5.0	5.3	N	N
CAL-18	3	36	1.6	1.9	N	N
CAL-19	3	16	13.5	13.8	N	N
CS-20	31	0	5.4	5.7	Y	Y
CS-21	35	250	10.15	10.45	Y	Y
CS-22	2	375	1.16	1.56	Y	Y
CAL-23	2	474	5.3	5.6	Y	N
CS-24	2	544	12.6	13.1	Y	YY
CAL-25a	2	729	8.8	9.1	Y	N
CAL-25b	2	729	9.1	9.4	Y	N
CS-26	5	204	14.2	14.5	Y	Y
CAL-27a	5	233	10.0	10.3	Y	N

Section number	SH	RS	Start (km)	End (km)	Texture measurement	Sterilised
CAL-27b	5	233	10.3	10.6	Y	N
CS-28	1N	815	11.8	12.1	Y	Y
CS-29	4	127	8.4	8.7	Y	Y
CAL-30	4	223	3.1	3.4	Y	N
CS-33	3	258	4.1	4.4	Y	Y
CAL-34	45	97	5.1	5.5	Y	N
CS-31	1N	985	0.6	0.9	Y	Y
CAL-32	2	751	4.52	4.82	Y	N
CAL-35	1N	995	14.4	14.7	Y	N
CS-36	2	858	9.0	9.3	Y	Y
CAL-37a	63	46	4.7	5.0	N	N
CS-37b	63	46	5.5	5.8	N	Y
CAL-38	1S	18	1.5	1.8	N	N
CS-39	6	131	16.15	16.45	N	Y
CS-40	6	225	10.0	10.3	N	Y
CAL-41	1S	284	7.8	8.1	N	N
CS-42	73	90	2.5	2.8	N	Y
CAL-43	1S	447	4.5	4.8	N	N
CS-44	8	99	4.0	4.3	N	Y
CAL-45a	6	445	12.7	13	N	N
CS-45b	6	445	13.1	13.4	N	Y
CS-46	7	239	3.3	3.3	N	Y
CAL-48	1S	618	9.1	9.4	N	N
CS-49	1S	729	12.0	12.3	N	Y
CS-50	1S	817	3.1	3.4	N	Y
CAL-51	8	417	2.5	2.8	N	N
CAL-52a	83	0	4.0	4.3	N	N
CS-52b	83	0	4.6	4.9	N	Y
CS-55	5	77	11.7	12.0	N	Y
CS-56	30	131	4.4	4.7	N	Y
CS-57	30	170	9.1	9.4	N	Y
CAL-58	38	0	16.83	17.13	N	N
CAL-59	5	47	1.22	1.52	N	N

Table 3.2 Local government LTPP sites (NZ Transport Agency 2009)

Network management authority	Section number	Road name	Start (m)	End (m)	Sterilised
Auckland CC	AKL1	Tamaki Drive	630	930	N
Auckland CC	AKL2-S	Pah Road	166	466	Y
Auckland CC	AKL3-S	Neilson Street	815	1115	Y
Western Bay of Plenty DC	BOP2-S	Lindemann Road	80	380	Y
Western Bay of Plenty DC	BOP3-S	Rangiura Road	10,700	11,000	Y
Dunedin	DUN1	David Street	50	350	N
Dunedin	DUN2-S	Marne Street	40	340	Y
Dunedin	DUN3-S	Queens Drive	100	400	Y
Dunedin	DUN4	Highcliff Road	1,500	1,800	N
Dunedin	DUN5	Riselaw Road	600	900	N
Dunedin	DUN6	Richardson Street	875	1175	N
Hastings DC	HAS1-S	Ada Street	535	835	Y
Hastings DC	HAS2	Thompson Road	1,370	1,670	N
Hutt CC	HUT1	Hutt Park Road	50	350	N
Hutt CC	HUT2A-S	Fenchurch Grove	50	250	Y
Hutt CC	HUT2B-S	Aldergate Grove	20	120	Y
Hutt CC	HUT3-S	Holyoake Crescent	30	330	Y
Marlborough DC	MAR1	Redwood Street	1,850	2,150	N
Marlborough DC	MAR2-S	Alabama Road	1,800	2,100	Y
Marlborough DC	MAR3-S	Northbank Road	650	950	Y
Marlborough DC	MAR4-S	Old Renwick Road	5,800	6,100	Y
Manukau CC	MCC1-S	Mahia Road	330	630	Y
Manukau CC	MCC2	Te Rakau Drive	1,600	1,900	N
Manukau CC	MCC3	Prince Regent Drive	550	850	N
Napier CC	NPE1-S	Tironui Drive	100	400	Y
Napier CC	NPE2-S	Shackleton Street	150	450	Y
Napier CC	NPE3-S	Guppy Road	1,200	1,500	Y
New Plymouth DC	NPY1	Waitara Road	8,025	8,325	N
New Plymouth DC	NPY2	Waitara Road	7,575	7,875	N
New Plymouth DC	NPY3	Waitara Road	4,475	4,775	N
New Plymouth DC	NPY4-S	Waitara Road	6,650	6,950	Y
New Plymouth DC	NPY5	Devon Street East	2,275	2,575	N
New Plymouth DC	NPY6	Connett Road East	100	400	N
Papakura CC	PAP1-S	Porchester Road	3,235	3,535	Y
Papakura CC	PAP2	Airfield Road	700	1,000	N
QL DC	QLD1	Centennial Avenue	37	337	N

Network management authority	Section number	Road name	Start (m)	End (m)	Sterilised
QL DC	QLD2-S	Glenorchy – Queenstown Road	133	433	Y
QL DC	QLD3-S	Crown Range Road	4,306	4,606	Y
QL DC	QLD4	Malaghans Road	2,185	2,485	N
QL DC	QLD6-S	Wanaka Mt Aspiring Road	13,009	13,309	Y
Southland DC	SDC1-S	Dusky Street	70	370	Y
Southland DC	SDC2-S	Queen Street 3	954	1,254	Y
Southland DC	SDC3-S	Balaklava Street	50	350	Y
Southland DC	SDC4	Winton Substation Road	1,140	1,440	N
Southland DC	SDC5	Bayswater Road	7,040	7,340	N
Tasman DC	TAS1	Moutere Highway	21,880	22,180	N
Tasman DC	TAS2-S	Eighty Eight Valley Road	3,962	4,262	Y
Tasman DC	TAS3-S	Haycock Road	600	900	Y
Tasman DC	TAS4-S	Telenius Road	100	400	Y
Thames – Coromandel DC	TCDC1	Hikuai Settlement Road	1,100	1,400	N
Thames – Coromandel DC	TCDC2	Morrison Road	150	450	N
Thames – Coromandel DC	TCDC3-S	Townsend Road	1,600	1,900	Y
Whanganui DC	WAN1-S	No. 3 line	3,800	4,100	Y
Whanganui DC	WAN2-S	No.3 line	4,370	4,670	Y
Whanganui DC	WAN3-S	Blueskin Road	3,260	3,460	Y
Waitakere CC	WCC1-S	Colwill Road	48	348	Y
Waitakere CC	WCC2	Forest Hill Road	1,550	1,850	N
Waitakere CC	WCC3-S	Wharf Road	400	700	Y
Wellington CC	WEL1	Adelaide Road	1,650	1,950	N
Wellington CC	WEL2	Duncan Street	60	360	N
Wellington CC	WEL3	Nalanda Crescent	250	550	N
Wellington CC	WEL4-S	Palm Avenue	15	315	Y
Wellington CC	WEL5-S	Churton Drive	700	1000	Y
Whangarei DC	WHG1-S	Kensington Avenue	400	700	Y
Whangarei DC	WHG2	Kamo Road	40	340	N
Whangarei DC	WHG3-S	Bream Bay Drive	800	1,100	Y
Whangarei DC	WHG4-S	Ngunguru Road	14,300	14,600	Y
Whangarei DC	WHG5-S	Whangarei Heads Road	1,100	1,400	Y
Waitaki	WTK1-S	Gibsons Road	450	750	Y
Waitaki	WTK3	McPhersons Road	900	1,200	N
Waitaki	WTK4	Ferry Road	1,000	1,300	N

4 Statistical analysis of the current New Zealand LTPP database

The database used in this analysis was obtained from the Transport Agency and contained information up until March 2015.

4.1 Descriptive statistics

The LTPP database was first processed as shown in table 4.1. Processed data was then used to prepare the descriptive figures, figures 4.1 to 4.13. It may be that a small portion of this data is of questionable accuracy. However, the plots below do not attempt to address these possible minor inaccuracies and plot the raw data as it is.

Table 4.1 Data sources for figures 4.1-4.13

Figure title	Figure	Table of the database	Fieldname in table	Processing of field
Financial year monitoring started – both current and non-current sites included	4.1	_300mRoughness	Financial year	None necessary
Number of sites removed/retired/ replaced from monitoring	4.2	Calibration sections	Current	If (Current = TRUE then site current), if Current = FALSE then site no longer current)
Number of current LTPP sites located on SH or local roads	4.3	Calibration sections	R	If (RS is blank then TLA), if (RS is not blank then SH)
Number of current LTPP sites that are sterilised/un-sterilised	4.4	Calibration sections	Sterilised?	If (Sterilised? = TRUE then site is sterilised), if (Sterilised? = FALSE then site is not sterilised)
Average December-February rainfall (mm) of 'current' LTPP sites	4.5	CAL_SEC_RAINFALL_DATA	SUMMER_DECPrevYr-FE	Average of applicable SUMMER_DECPrevYr-FEB rainfall for all applicable years
Average June-July rainfall (mm) of current LTPP sites	4.66	CAL_SEC_RAINFALL_DATA	WINTER_JUN-JUL	Average of applicable WINTER_JUN-JUL rainfall for applicable all years
Average annual rainfall (mm) of current LTPP sites	4.7	CAL_SEC_RAINFALL_DATA	ANNUAL	Average of applicable ANNUAL rainfall for all applicable years
Soil moisture sensitivity of current LTPP sites	4.8	Calibration sections	Sensitivity	None necessary
Maintenance of current LTPP sites	4.9	n/a - (The year of rehab, year of reseal, year of patching, year of other maintenance, speed environment and comments in tabulated form for all (SH and TLA) LTPP sites) were kindly provided by Doug Brown, pers comm 2016.		

Figure title	Figure	Table of the database	Fieldname in table	Processing of field
Surface type (chipseal or bituminous mix) of current LTPP sites	4.10	CAL_SEC_SURF_DATA	ChipSize_RAMM	If (ChipSize_RAMM <= 6 then assume chipseal), if (ChipSize_RAMM > 6 then assume bituminous mix)
Speed zones of current LTPP sites	4.11	n/a - (data kindly provided by Doug Brown, pers comm 2016) See discussion under figure 4.11)		
Average annual daily traffic (AADT) of current LTPP sites	4.12	CAL_SEC_TRAFFIC_DATA	MS_AADT	Average of applicable TMS_AADT for all applicable years
Surface ages of current LTPP sites	4.13	CAL_SEC_SURF_DATA	SurfDate_RAM'	(DATE(2015,7,1)-SurfDate_RAMM)/365.25

The definitions for some of the quantities plotted in figures 4.1 to 4.13 are in table 4.2:

Table 4.2 Definitions of variables

Item	Value	Definition	Database used	Table	Field	'Description (Optional)' recorded for field.
Current	TRUE	LTTP site recorded in 'NZTA_LTTP_working.mdb' as being current (ie site is a current member of the LTPP programme and has not been retired, replaced, removed, or otherwise withdrawn)	NZTA_LTTP_working.mdb	Calibration sections	Current	Is the site still active?
Current	FALSE	LTTP site recorded in NZTA_LTTP_working.mdb as not being current (ie site is no longer a current member of the LTPP programme and has been retired, replaced, removed, or otherwise withdrawn)	NZTA_LTTP_working.mdb	Calibration sections	Current	Is the site still active?
SH or TLA	SH	State highway	NZTA_LTTP_working.mdb	Calibration sections	RS (if blank then TLA, if populated then SH)	RS = Route station number of the section
SH or TLA	TLA	Territorial local authority	NZTA_LTTP_working.mdb	Calibration sections	RS (if blank then TLA, if populated then SH)	RS = Route station number of the section

Item	Value	Definition	Database used	Table	Field	'Description (Optional)' recorded for field.
Sterilised	TRUE	Repairs permitted only to address a significant hazard, and the repairs must be the *minimum* amount required to remove the hazard (refer: NZ Transport Agency 2016)	NZTA_LTTP_working.mdb	Calibration sections	Sterilised?	Is the site sterilised?
Sterilised	FALSE	Repairs permitted only if they are considered absolutely necessary', but there is no requirement that they must address a significant hazard (refer: NZ Transport Agency 2016)	NZTA_LTTP_working.mdb	Calibration sections	Sterilised?	Is the site sterilised?

Most of the SH LTPP sites were first established in the 2001/02 financial year, while most of the TLA sites were first established in the 2003/2004 financial year, as shown in figure 4.1. The definitions for 'current' are in table 4.2.

Figure 4.1 Financial year monitoring started - both current and non- current sites

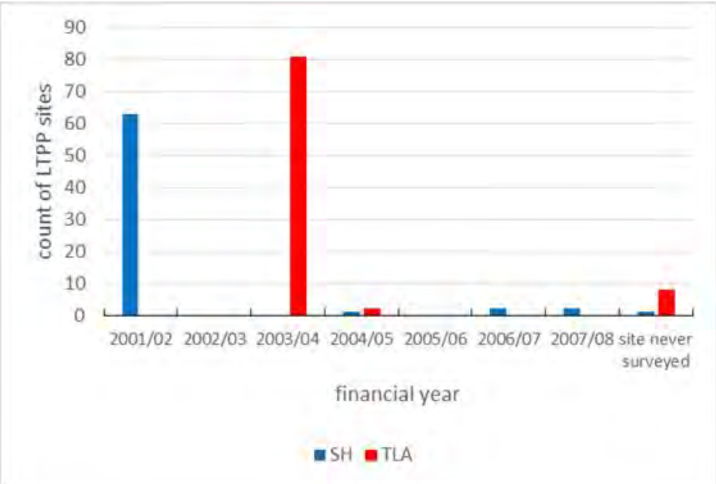
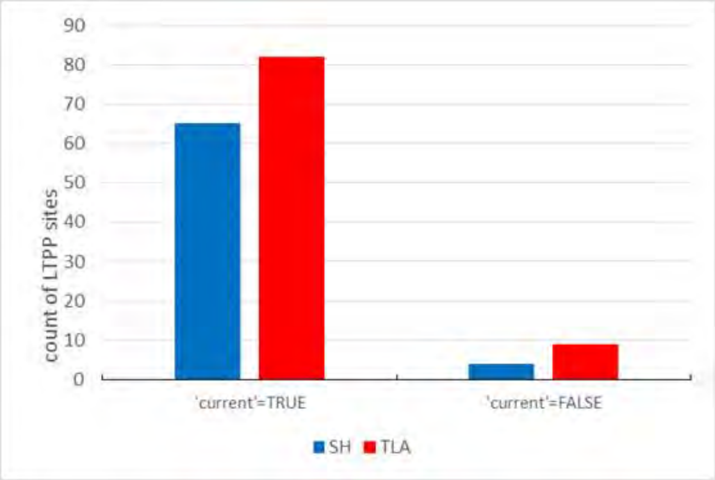


Figure 4.2 Number of sites removed/retired/replaced from monitoring



With reference to figure 4.2:

1 The number of 'current' TLA LTPP sites (82) exceeds the number of state highwat LTPP (65) sites slightly.

2 The ratio of LTPP sites that are no-longer-current to current is 6.2%-11.0%.

3 The percentage of TLA sites no longer current is greater than the proportion of SH sites that are no longer-current (6.2% for SHs and 11.0% for TLAs). This is due in part to the fact that four of the no longer-current TLA sites were abandoned when the Christchurch City Council (CCC) withdrew from the LTPP programme (refer table 4.3).

Table 4.3 Abandoned LTPP sites

CAL_SECTION_ID field entry	Comments	Financial year abandoned
CS-50	Not surveyed in 2003/04, replaced by CS-50a in 2004/05.	2003/04
CCC4	This site has never been surveyed. Abandoned site.	2003/04
BOP1	Lost in 2006 (period 4 - 2006/07) - Rehabilitation (refer to 2006/07 site notes).	2006/07
QLD5-S	Lost in 2007 (period 4 - 2006/07) - Rehabilitation (refer to 2006/07 site notes).	2006/07
CAL-32	Not surveyed in 2006/07, replaced by CAL-61 in 2006/07.	2006/07
CS-28	Not surveyed in 2006/07, replaced by CS-60 in 2006/07.	2006/07
CAL-59	Derek C Roux (8 May 2007): CAL-59 has been separated into 2 sites: CAL-59a for Increasing with ROAD_ID = 2500 and CAL-59b for Decreasing with ROAD_ID = 2501.	2007/08
CCC1-S	The council terminated participation at	2008/09

CAL_SECTION_ID field entry	Comments	Financial year abandoned
	end of 2008 (period 6 - 2008/09).	
CCC2	The council terminated participation at end of 2008 (period 6 - 2008/09).	2008/09
CCC3-S	The council terminated participation at end of 2008 (period 6 - 2008/09).	2008/09
CCC5-S	The council terminated participation at end of 2008 (period 6 - 2008/09).	2008/09

Figure 4.3 Number of current LTPP sites located on SHs or local roads

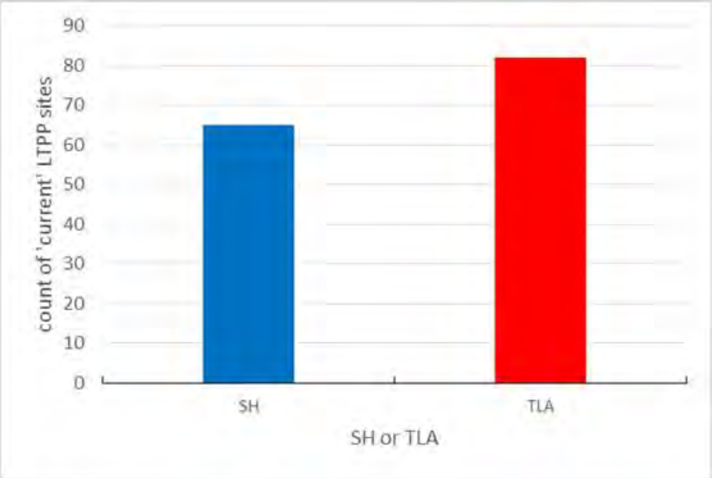


Figure 4.3 illustrates that the number of 'current' LTPP sites located on SHs is 65, slightly less than the number of current LTPP sites located on TLA road networks of 82.

Figure 4.4 Number of current sites LTPP that are sterilised/un- sterilised

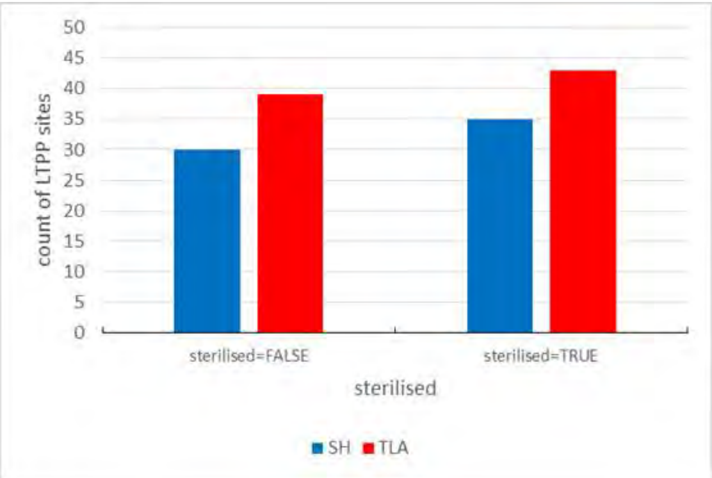


Figure 4.4 shows the percentage of un-sterilised/sterilised LTPP sites is similar for SHs at 86% and TLA roads at 91%. (Refer to table 4.2 for definitions of the terms 'sterilised' and 'un-sterilised'.)

Figure 4.5 Average December-February rainfall (mm) of current LTPP sites

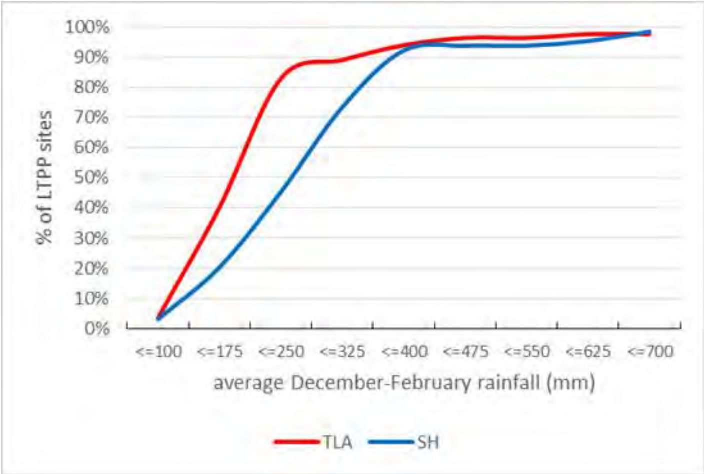


Figure 4.5 suggests that for cumulative percentage distributions of summer season rainfall (mm) below around 400 mm, there is a pattern of TLA LTPP sites experiencing less rainfall than SH LTPP sites. Reasons for this are not known, although it should be remembered the majority of SH LTPP sites were established two years prior to the majority of TLA LTPP sites (refer figure 4.1) and rainfall patterns in this initial two-year period could have been different from the rainfall patterns in subsequent years.

Figure 4.6 Average June-July rainfall (mm) of 'current' LTPP sites

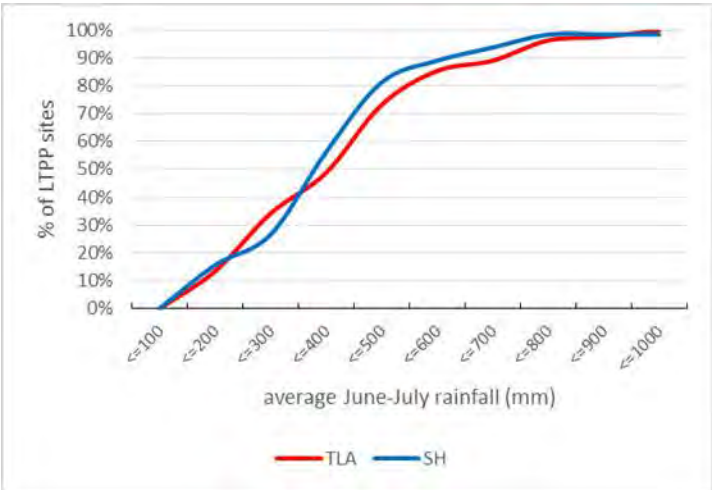


Figure 4.6 suggests that the cumulative percentage distributions of per annum average winter season rainfall (mm) for SH and TLA LTPP sites are similar. Also, comparing the above figure with figure 4.5 it seems the winter season average rainfall in mm/year is approximately twice that of the summer season.

Figure 4.7 Average annual rainfall (mm) of current LTPP sites

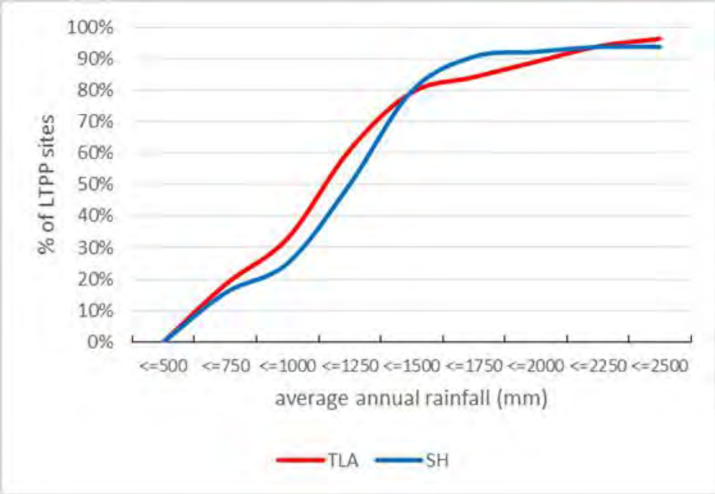


Figure 4.7 suggests that the cumulative percentage distributions of per-annum average rainfall (mm) for SH and TLA LTPP sites are similar.

Figure 4.8 Soil moisture sensitivity of current LTPP sites

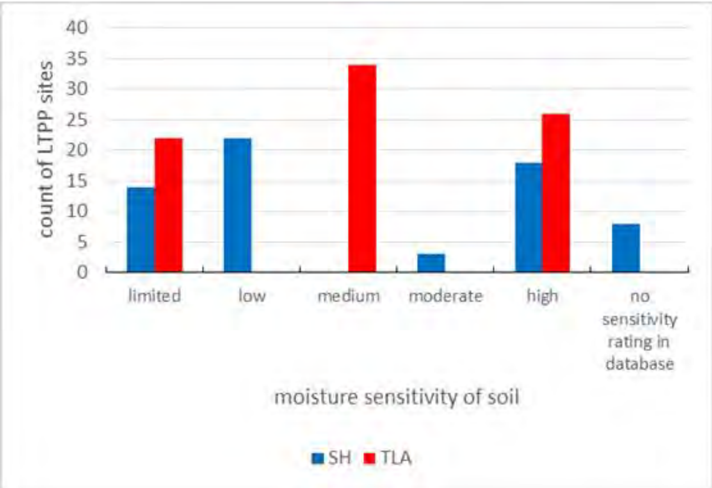


Figure 4.8 shows:

1 The number of SH and TLA sites categorised with soil moisture sensitivity as either ‘limited’ or ‘high’ is approximately equal.

2 It seems different terms are used for the ‘medium’/‘moderate’ categories of soil moisture sensitivity of SH and TLA LTPP sites and the ‘low’ category is only used for SHs.

If the second observation is accurate, the use of different terms is not helpful for analysis. Associated with this comment is the observation that the number of sites categorised as ‘moderate’ is very low and there may be a valid argument for merging the moderate category with another category.

Figure 4.9 Maintenance of current LTPP sites

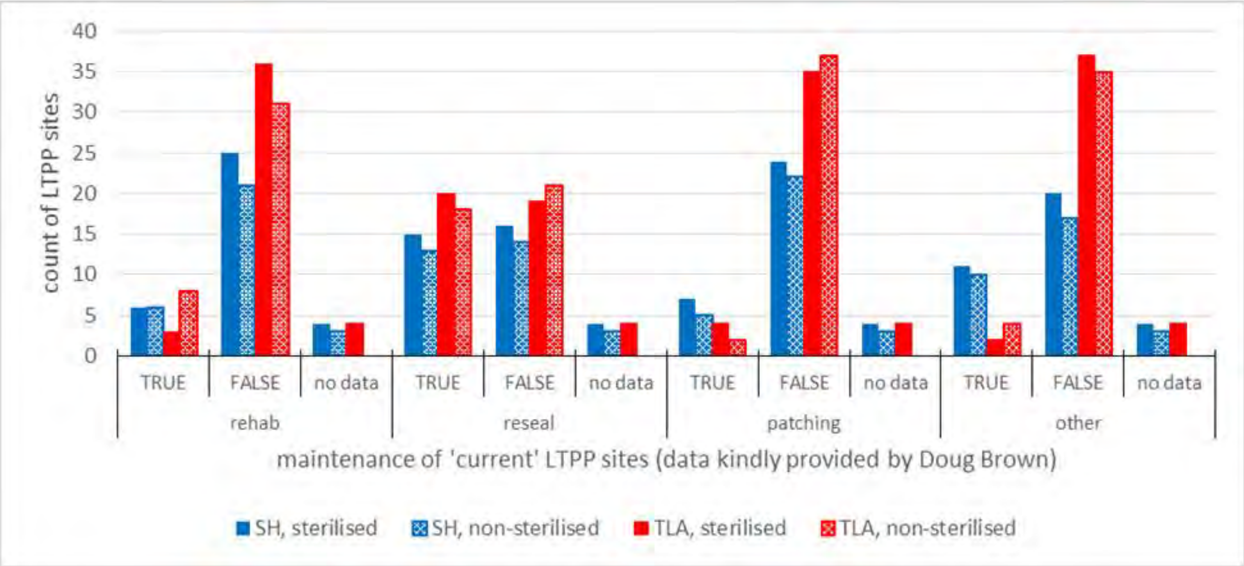


Figure 4.9 shows:

1 The most common repair applied to LTTP sites is 'reseal' (refer height of lines for the TRUE reseal category).

2 Just under half the LTPP sites have been resealed (compare TRUE and FALSE lines for the reseal category)

3 The proportion of sites in the three non-reseal maintenance categories (ie 'rehab', 'patching' and 'other') having maintenance is modest and varies from (very approximately) 15%-20%.

Figure 4.10 Surface type (chipseal or bituminous mix) of current LTPP sites

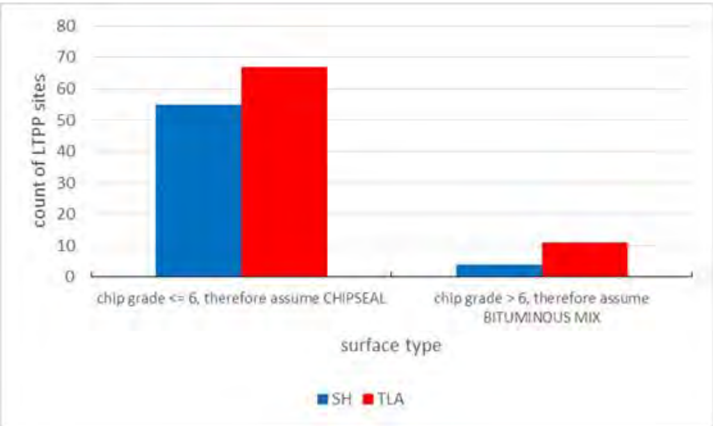


Figure 4.10 shows:

1 A clear majority of sites are chipseals rather than bituminous mixes.

2 The ratio of chipseal: bituminous mix sites is similar for TLAs and SHs. (It is interesting to note for some LTPP sites, the chip size recorded in RAMM differs from that recorded in the LTPP database.)

Figure 4.11 Speed zones of current LTPP sites

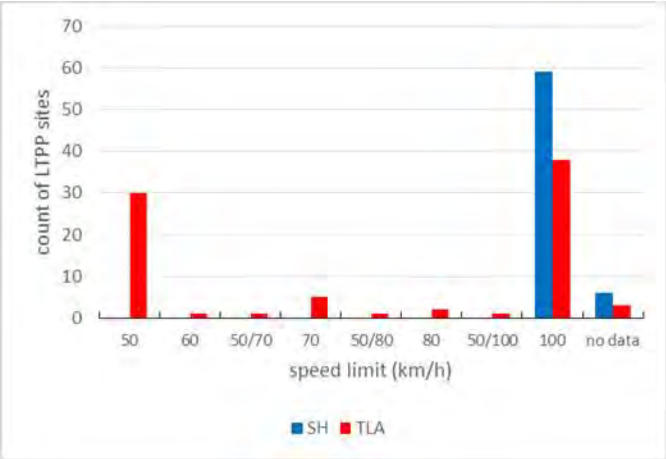


Figure 4.11 suggests:

1. A very clear majority of TLA sites are in 50 or 100 km/h speed limit zones (comparatively, there is an insignificant number of sites in the 60 to 90 km/h speed limit zones)
2. The number of TLA sites in a 100 km/h speed limit zone is 38 and this slightly exceeds the number of 30 in a 50 km/h speed limit zone. Also, 59 of 59 (ie 100%) of SH sites are in the 100 km/h speed limit zone. (This seems unlikely and suggests there may be source data accuracy issues.)

Figure 4.12 AADT of current LTPP sites

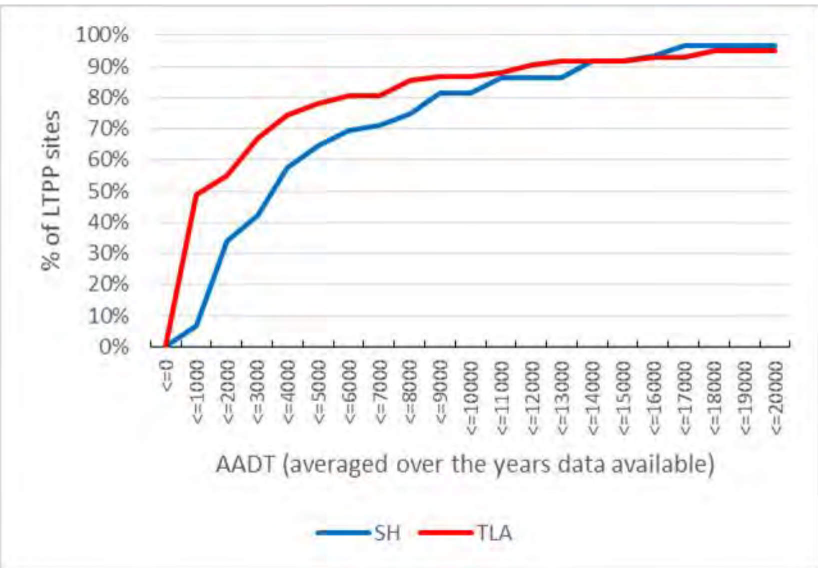


Figure 4.12 suggests the AADT of SH LTTP sites slightly exceeds that of TLA LTPP sites. Also, the source data used indicates the AADT for an LTTP site varies from 42 to 82,260. However, the calculation procedure used to prepare the above figure involved the questionable practice of averaging AADT data for a site for all years that data was available (refer table 4.1). It is therefore suggested the source database be supplemented so there is AADT data for each site for all years that each LTPP site was/is current so averaging is not necessary.

Figure 4.13 Surface ages of current LTPP sites

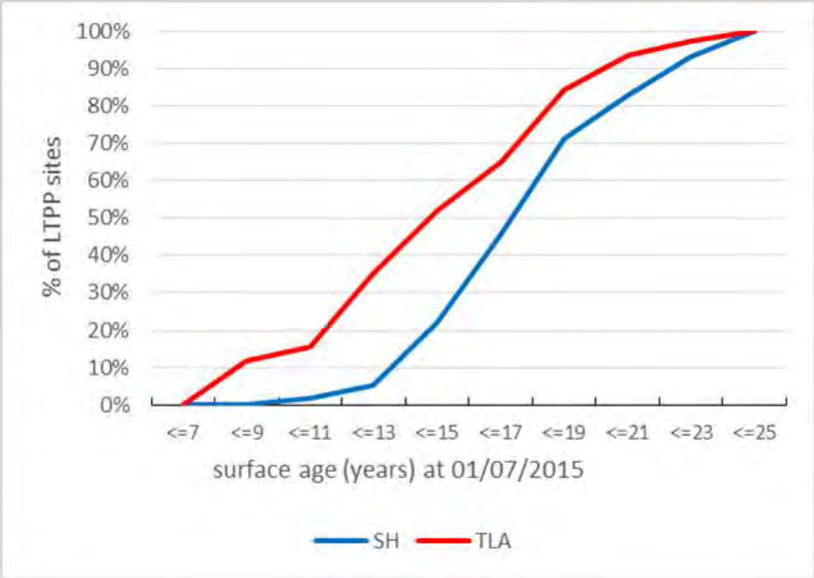


Figure 4.13 suggests:

1 For sites with surface ages from 11–19 years, the surface age of TLA LTPP sites is approximately 80% that of SH LTPP sites.

2 The range of surface ages of LTPP sites varies from 7–26 years.

4.2 Detailed review of selected case studies

Figure 4.14 Key to the cumulative distribution plots

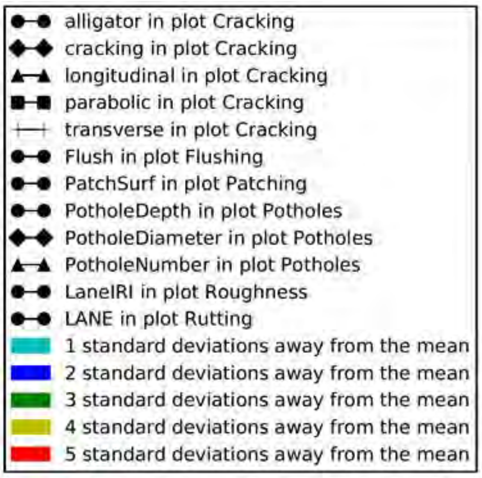


Table 4.4 Key to the vertical axis on the cumulative distribution plots

Plot	Vertical axis units
Cracking	Summation of 18 LTPP crack fields, each as a fraction 0–1
Flushing	Summation of three LTPP flushing fields: low, mid and high, each field as a fraction 0–1
Patching	Summation of surface patch area + structural patch, each as a fraction 0–1
Potholes	Diameter or depth (mm)
Roughness	Lane international roughness index (IRI)
Rutting	Lane rut depth (mm)

Three different definitions (groupings) for the climatic and geographical clustering of regions were found, and in the data analysis (attached in appendix B) the clustering shown in table 4.5 has been used.

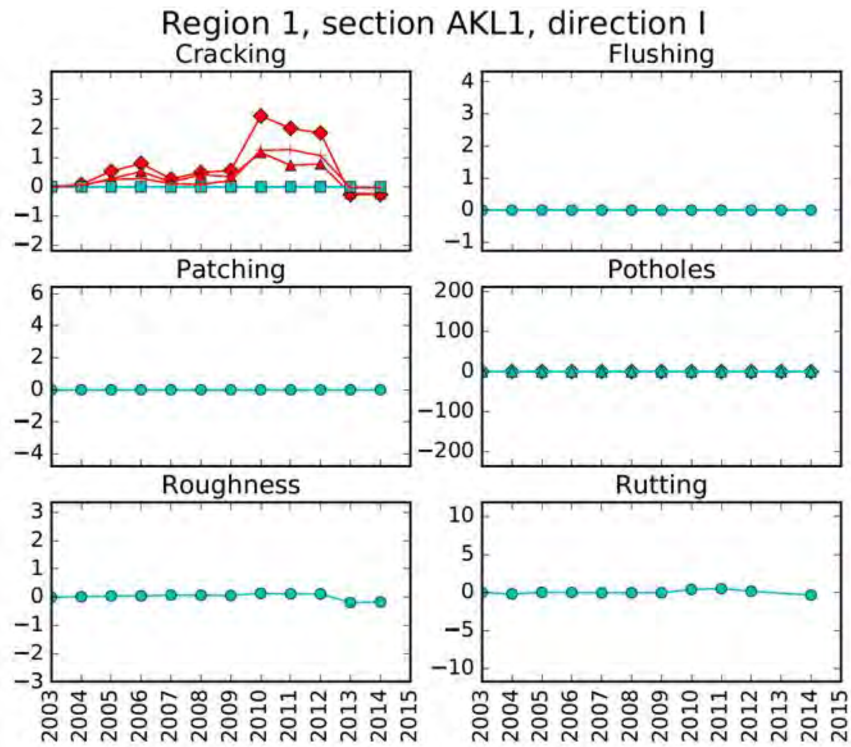
Table 4.5 Climatic and geographical clustering of regions

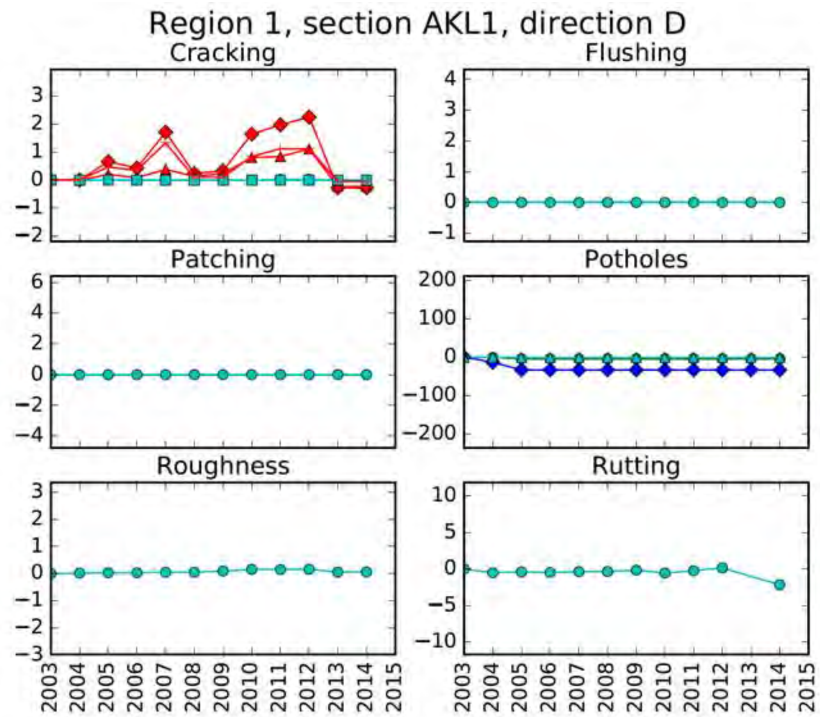
Region no.	Transit New Zealand road network region
1	Northland, Auckland, Pay of Plenty, Waikato, Gisborne, Hawke's Bay, Taranaki, Whanganui, and Southland
2	Manawatu, Wellington, and Nelson/Marlborough
3	Canterbury and Otago
4	West Coast

From perusal of the cumulative distribution plots there was no clear relationship between progression of cracking and initiation of further pavement distress. Some other interesting anomalies were detected, and these were subjected to a more in-depth engineering review rather than a statistical review. The results of this review are shown in sections 4.2.1 to 4.2.20.

4.2.1 Site AKL1, both directions (Tamaki Drive RP 630 to 930)

This site showed severe cracking, but no impact on pavement deterioration.


Region 1, section AKL1, direction I
Cracking
Flushing
Patching
Potholes
Roughness
Rutting
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015


Region 1, section AKL1, direction D
Cracking
Flushing
Patching
Potholes
Roughness
Rutting
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

RAMM data:

- Average daily traffic (ADT) 2015 is 32,681 with 3% heavy commercial vehicles (HCV).
- Only two surfaces are recorded in RAMM (G3 reseal 1983 and AC 2012) so some surfacing records are obviously missing.
- No pavement records recorded in RAMM for this site.
- No FWD recorded in RAMM for this site.
- No SNPs recorded in RAMM for this site.

Environmental information (taken from the site photographs):

- The site has two lanes in each direction, is flat and has a large radius curve at the south end.
- The drainage is kerb and channel and appears to be adequate.

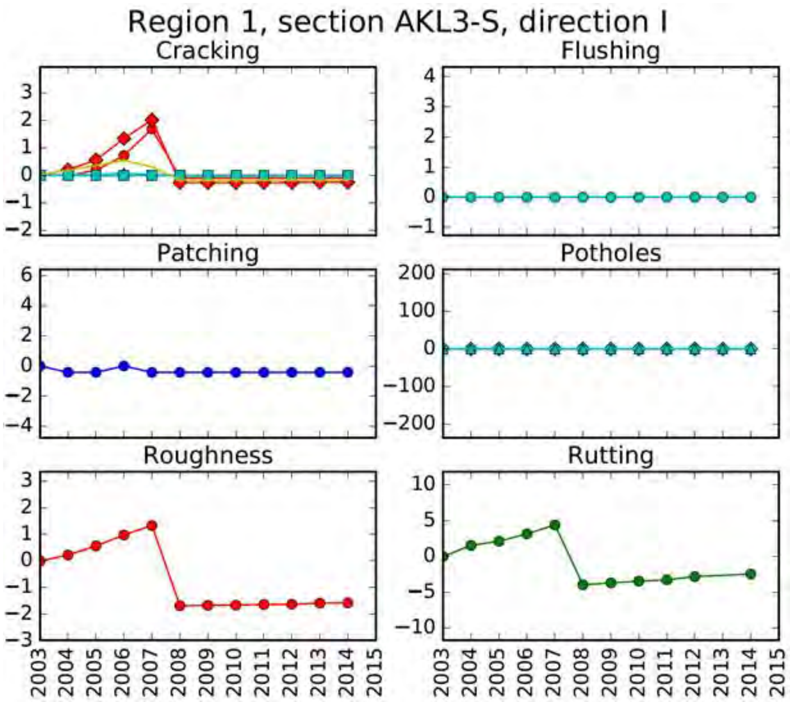
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in cracking until 2012 and the decrease in roughness and rutting post 2012.

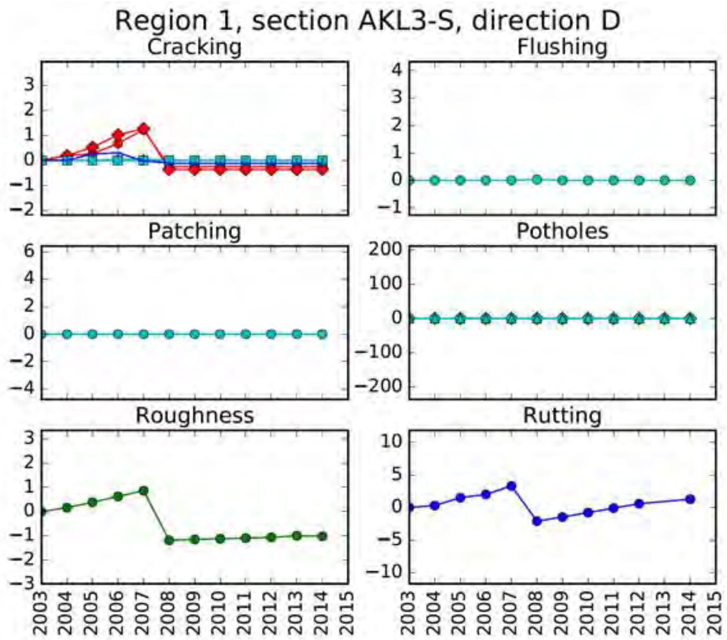
The road structure appears to be a structural asphalt pavement surfaced with an asphalt wearing course.

The wearing course developed extensive large block cracking which was evident by the extensive bandage crack sealing. Although extensive cracking developed, the pavement kept relatively good shape and did not appear to be pumping basecourse fines indicating a structural asphalt pavement. A new asphalt wearing course was constructed between the 2012 and 2013 inspections resetting the cracking at the site back to 0. It also corrected the minor roughness and rutting that existed prior to the resurfacing.

4.2.2 AKL3-S, both directions (Neilson St RP 815 to 1115)

Cracking plus deteriorating roughness and rutting





RAMM data:

- ADT 2012 is approximately 25,000 to 27,000 with 11 to 16% HCV.
- Three surfaces recorded in RAMM prior to the 2008 pavement renewal (G3 first coat 1971, G3/5 reseal 1989 and G3/5 reseal 2001 plus some sections of AC at various times in between). In 2008 a stone mastic asphalt (SMA) was applied as the wearing course for the pavement renewal.
- The original 1971 pavement is recorded in RAMM as approximately 200 mm of AP65. In 2008, 240 mm of pavement and surfacing were removed and replaced with 50 mm of mix20 asphalt followed by 190 mm of mix40 asphalt.
- No FWD recorded in RAMM for this site.
- No SNPs recorded in RAMM for this site.

Environmental information (taken from the site photographs):

- The site is two lanes in each direction with a divided carriageway.
- The drainage is kerb and channel and appears adequate.

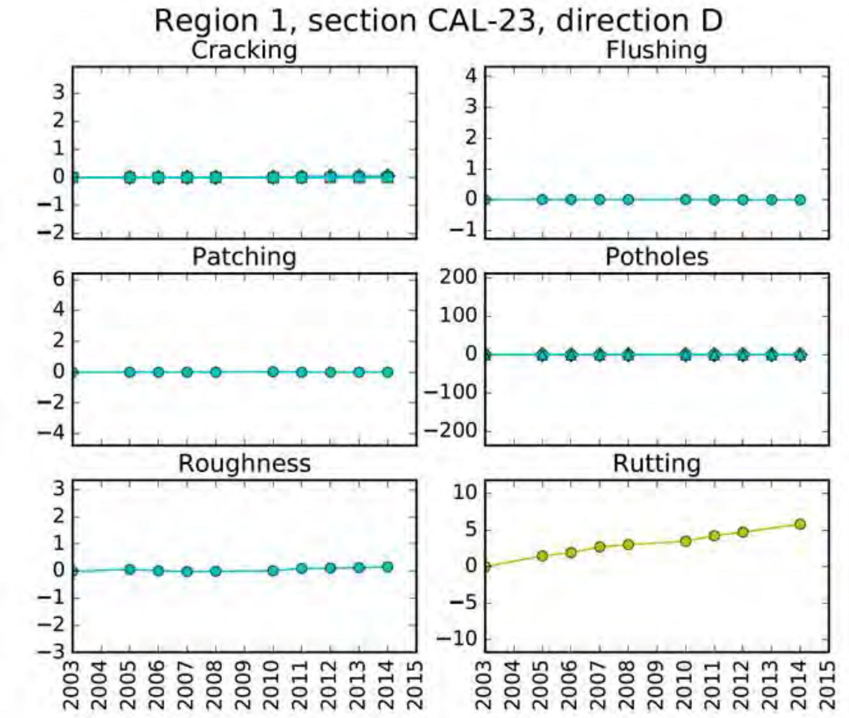
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in cracking, roughness and rutting until 2008 and then another increase in rutting.

Prior to 2008 the chipseal surface was extensively fatigued and small block cracked with some pumping fines particularly in the wheel paths, which was likely to be the cause for the increase in roughness and rutting at the site. An area wide structural asphalt pavement renewal was completed in 2008 followed by a 35mm SMA wearing course in 2008 resetting all distress back to 0.

There are two possible reasons for the increase in rutting since 2008. An isolated but large area of the SMA was flushed and required water cutting in 2009. The saturated SMA may have deformed in this location. Also a large repair was completed on the middle lane in the decreasing direction in 2011. This repair may also have contributed to the increase in rutting which has subsequently levelled off.

4.2.3 CAL-23, decreasing direction (SH2 RP 474/5.30 – 5.60)

Rutting deterioration only



RAMM data:

- ADT is 1,235 with 21% HCV.
- At least five chipseals (four recorded in RAMM: G2 second coat 1986, G5 1992, G2 1996 and G2/4 2006).
- Original pavement unknown but estimated at an approximate depth of 220 mm with the top 150 mm reconstructed in 1985.
- 2012 FWD reading shows a central deflection of 767 μm with a long bowl.
- Has a SNP of 3.6.

Environmental information (taken from the site photographs):

- The site has a narrow lane with a high percentage of HCVs, particularly logging traffic heading to Gisborne port, which travel in very defined wheel paths. The side slopes are quite narrow with average drainage opportunities. There are localised areas of cracking and shearing in the chipseal and basecourse that have not been repaired within an appropriate timeframe for an unsterilised site.
- Gisborne pavements are known for their moisture sensitive subgrades.

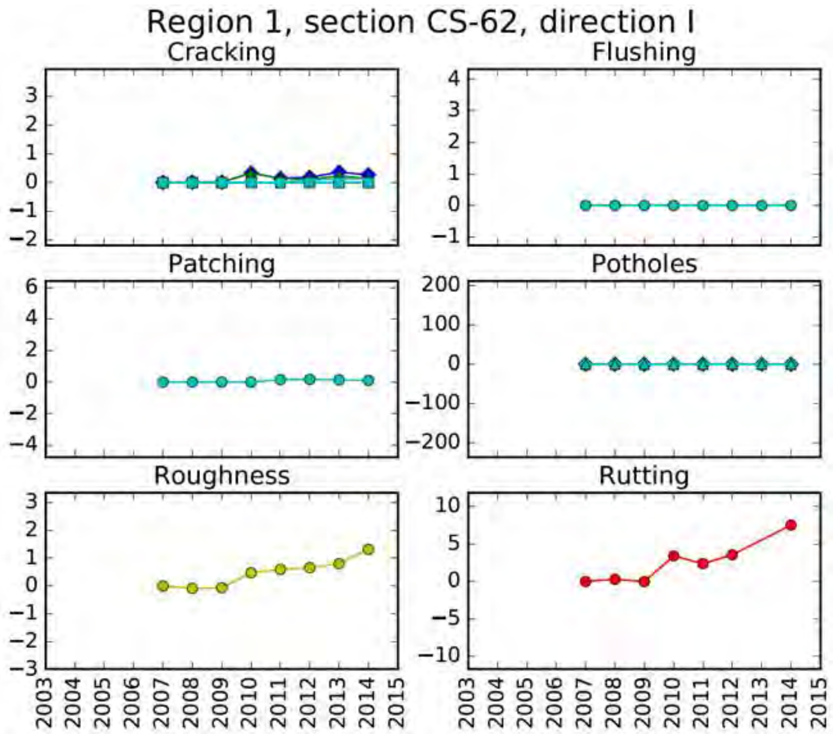
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in wheel path rutting.

The pavement has a relatively low deflection suggesting it is reasonably sound. The binder rise in the wheel paths would suggest some densification within the five chipseal layers due to the heavy trucks travelling in very defined wheel paths but this is likely to be minimal. The most significant cause of rutting is likely to be moisture in the subgrade allowing the basecourse to settle in the loaded wheel paths.

4.2.4 CS-62, increasing direction

(SH15A RP 0/0.69 – 0.99) now (SH15 RP 111/0.69 – 0.99).

Roughness and rutting deterioration in increasing direction only



RAMM data:

- ADT (2015 estimate) is 3,705 with 21% HCV.
- Three chipseals recorded (G3/5 first coat 2001?, G3/5 first coat 2005 and G3/6 2nd coat 2010).
- Original pavement unknown but estimated (1980?) AP40 at an approximate depth of 200 mm 6.0 m wide with the top 200 mm, 9.0 m wide, reconstructed in 2001.
- 2009 FWD reading shows a central deflection of 429 μm at an offset of 2.5 m with a long shallow bowl.
- Has a SNP of 4.49.

Environmental information (taken from the site photographs):

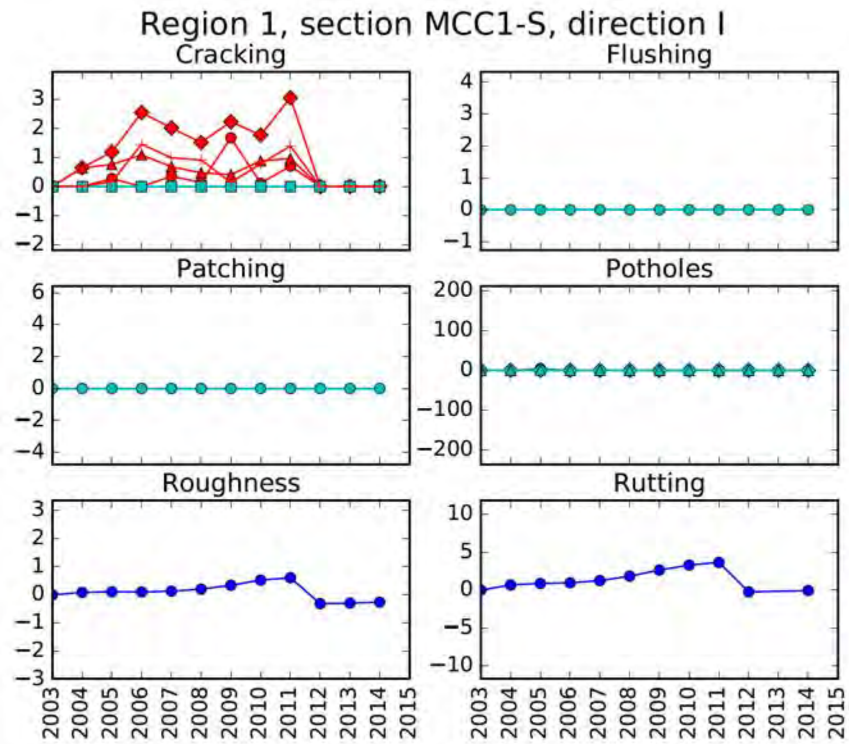
- The site is relatively flat and straight.
- The drainage systems appear adequate; however, there are photographs showing water sitting in the surface water channels and adjacent paddocks.

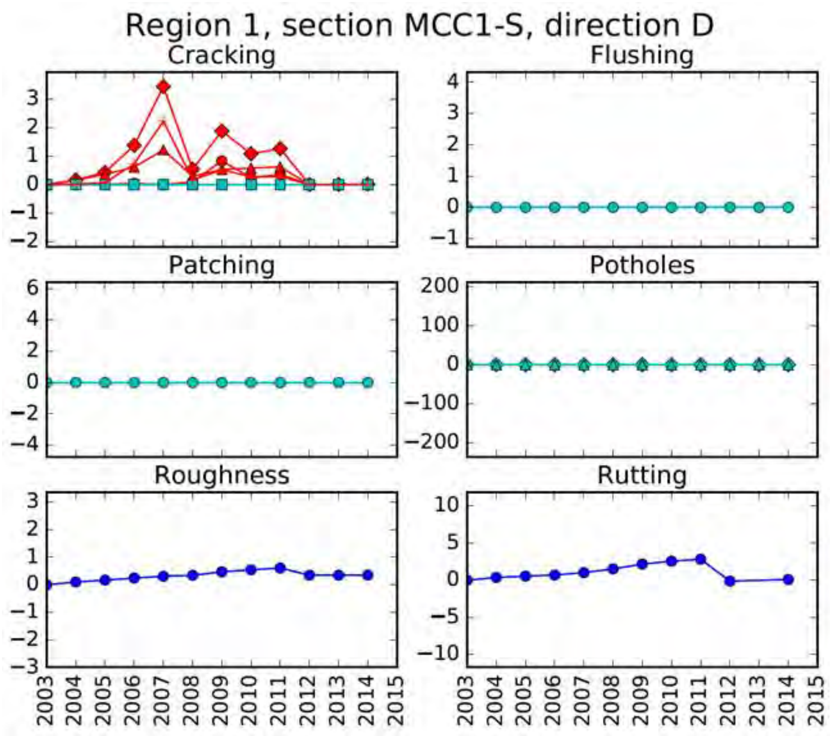
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in roughness and rutting.

RAMM pavement records show an approximately 200 mm deep 6.0 m wide pavement constructed in the 1980s, then overlaid with a 9.0 m wide 200mm deep pavement on 20 July 2001. The pavement deflection is low at 429 µm and will be measuring the total depth of pavement at an offset of 2.5 m. The bowl is long and shallow which would indicate a stiffer pavement over a weaker subgrade. However, the failures observed in the annual photographs suggest the FWD data is not representative of the additional seal widening along each side of the road which has failed and rutted along the two outer wheel paths. It could be that the seal widening has a relatively thin pavement but test pits would be required to confirm this. The photographs show a weak zone along the seal widening pavement joint causing cracking, scabbing and rutting to the extent that pavement repairs are required.

4.2.5 MCC1-S, both directions

Severe cracking but no impact on pavement deterioration





These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

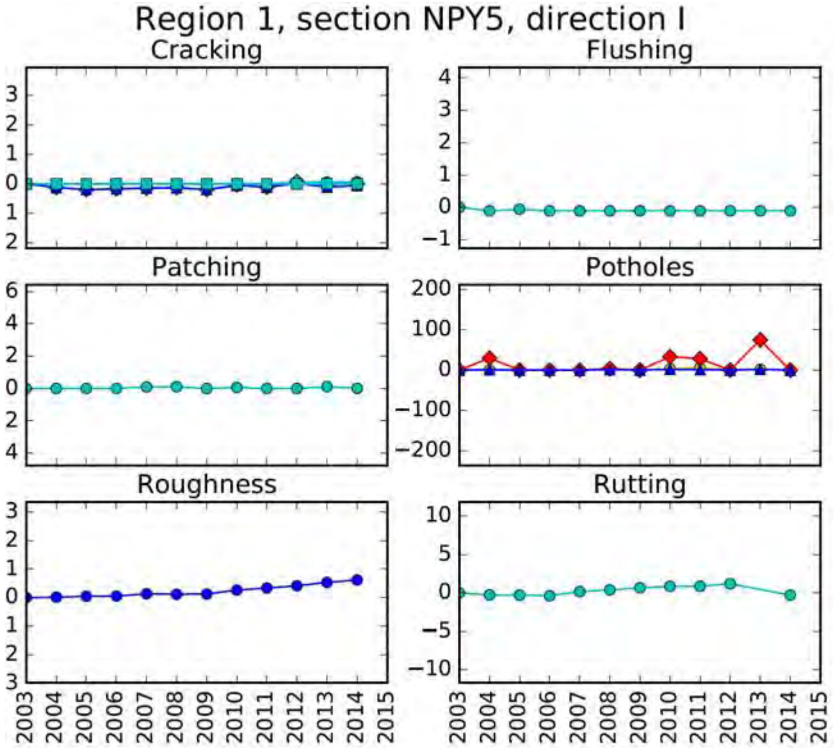
This is possibly a structural asphalt pavement with an asphalt wearing course.

This site had extensive alligator and small block cracking in the asphalt surface but very little pumping of fines. There was extensive bandage crack sealing. A structural asphalt pavement, while badly cracked, does not often show significant other distress.

A new asphalt wearing surface was applied between the 2011 and 2012 inspections, thus resetting the cracking, roughness and rutting distress at the site back to 0.

4.2.6 NPY-5, increasing direction

Very bad state. Is this because of poor reinstatement of trenching for underground services, rather than pavement failure?



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This site appears to include sections of both chipseal and asphalt surfaces.

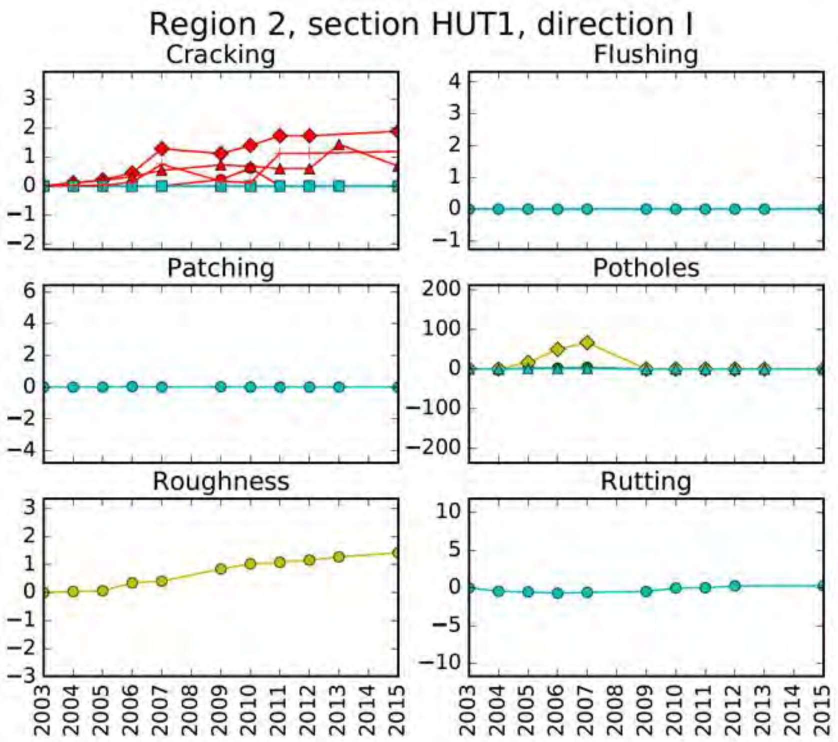
There is some settlement in a trench but there is also other general deterioration in the surfacing and pavement, which is particularly rough around service covers.

There is cracking and ravelling in the open-graded porous asphalt (OGPA), particularly the outer wheel path. Significant water cutting has been completed throughout the site. There is cracking and flushing within the chipseal surfaces at the site.

Apart from water cutting of flushing very few repairs have been completed at this site as would be expected.

4.2.7 HUT1, increasing direction

Cracking, potholing and roughness progression.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

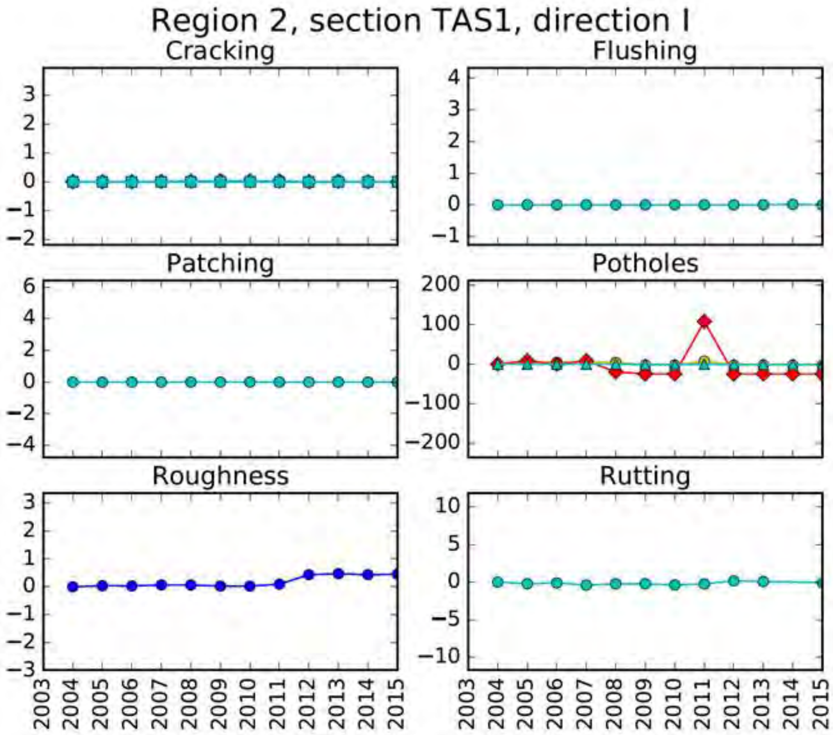
This is probably an asphalt surface over a granular pavement.

The pavement and underlying trenches and patches appear too weak for the asphalt surface. The asphalt surface has become extensively cracked due to high pavement deflections and reflective cracking from the underlying repairs. The asphalt has ravelled and cracked with small pieces of surfacing falling out and needing repair.

Only minor repairs have been completed (assume for safety reasons), so this is an excellent example of deterioration in a thin AC surface.

4.2.8 TAS1, increasing direction

Pothole formation in 2011, why?



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This is a granular pavement with a chipseal surface.

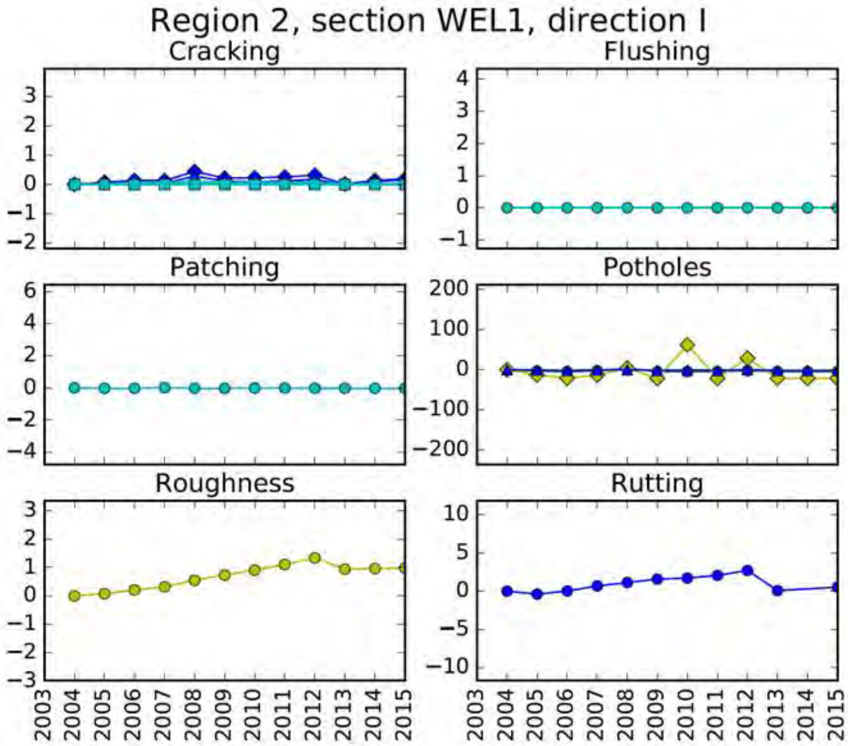
The section of road is very narrow and winding with minimal drainage opportunities either side.

The photographic record shows very few potholes within the site in any of the years recorded except for one associated with a survey mark and a large edge pothole at a driveway that may have been recorded and skews the data. The question arises over what constitutes a pothole and the number required to influence the data.

The new chipseal between 2011 and 2012 would remove the ongoing development of potholes for some years and reset potholes to 0.

4.2.9 WEL1, increasing direction

Roughness and potholing increasing, some cracking.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This is a granular pavement with an asphalt surface.

There is reflective cracking and depressions from underlying trenches.

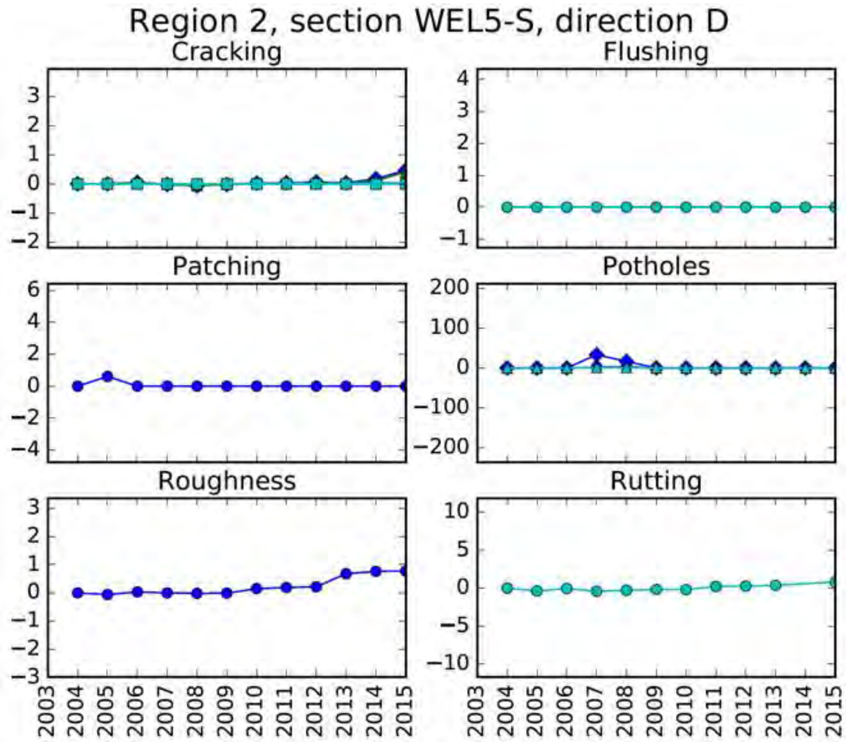
The pavement appears too weak for the asphalt surface particularly in the wheel paths where extensive alligator cracking pumping fines has developed. Potholes are very small and insignificant.

There is settlement adjacent to a new pavement at the site of some kerb and channel replacement, deterioration around surface covers.

Large asphalt repairs were completed between the 2012 and 2013 inspections.

4.2.10 WEL5-S, decreasing direction

Increasing roughness leading to cracking in one direction only.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This appears to be a polymer modified binder reseal over a variety of surfaces including chip seal and asphalt on a granular pavement.

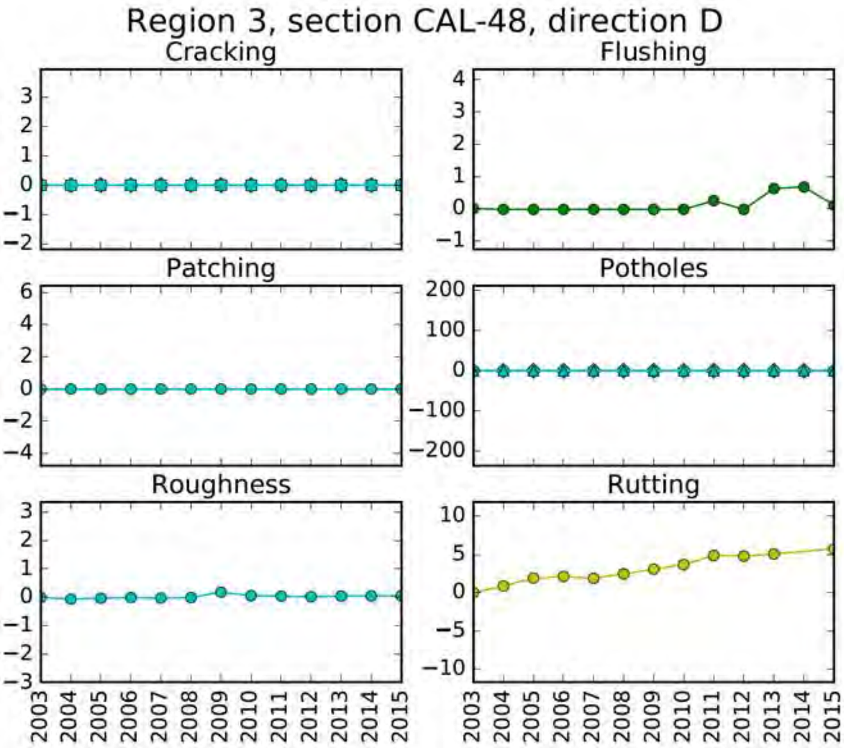
The polymer modified binder seal has scabbed quite badly and in some places is down to the underlying substrate, which would contribute to an increase in roughness.

There are areas of old cracked asphalt now exposed due to seal loss.

There are significant trenches within the site. Depending on how these are rated may greatly increase the cracking in one direction if the trench edge is rated as a crack. There is also some settlement cracking in the pavement just outside the trenches.

4.2.11 CAL-48, decreasing direction (SH1S RP 618/9.10 – 9.40)

Deterioration in rutting only.



RAMM data:

- ADT is 4,162 with 13% HCV.
- Unknown number of chipseals (four recorded in RAMM: G3 reseal 1982, G5 texturising seal 1991, G3 reseal 1997 (recorded in RAMM as G5 but clearly identifiable as a G3 in photographs) and a G4/6 reseal 2009 supposedly applied to treat cracking).
- Original pavement unknown (1980?). M4 AP40 estimated at an approximate depth of 140 mm.
- 2014 FWD reading shows a range of central deflection of 705 µm with a long bowl.
- Has a SNP of 3.27.

Environmental information (taken from the site photographs):

- The site is generally open, is straight with part of the site on an easy grade.
- The drainage appears adequate.

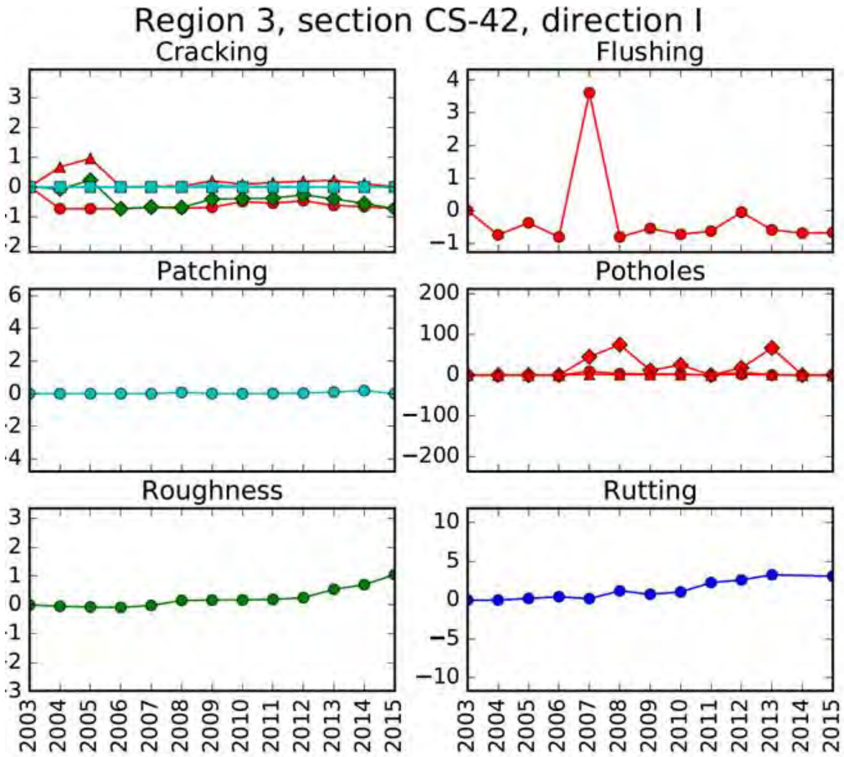
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in flushing and wheel path rutting.

There are four chipseals recorded, but possibly up to six or more chipseals as the first record in RAMM is recorded as a reseal. This is likely to contribute to the flushing at the site and may contribute a little toward the rutting at the site due to chip embedment from unstable seal layers. It is clear in the photographs where pavement repairs have removed the seal layers as reflective flushing is not present above these repairs.

It is clear from the photographic record that significant repairs were completed in the outer wheel path prior to the 1997 grade 3 reseal. It also appears that seal widening was completed on both sides of the road at some stage although not recorded in RAMM. Both the outer wheel path repairs and seal widening could contribute to the wheel path rutting and flushing at this site.

4.2.12 CS-42, increasing direction (SH73 RP 90/ 2.50 – 2.80)

Deterioration in everything except patching.



RAMM data:

- ADT is 1,549 with 15% HCV.
- Unknown number of chipseals (five recorded in RAMM: G6 texturising 1989, G3 single coat reseal 1993, G5 texturising 1997, G3/5 two coat 2001 and G3/5 two coat 2014).
- Original pavement unknown (~1964?). No pavement type or depth recorded.
- 2013 FWD reading range between 1309 μm and 1614 μm. Other years' deflections as high as 2469 μm.
- 2013 SNP range between 2.27 and 2.71. Other years' readings as low as 0.26.

Environmental information (taken from the site photographs):

- The site is partially shaded, is straight with an easy grade at one end.
- The drainage is quite poor with relatively flat shoulders and shallow surface water channels.

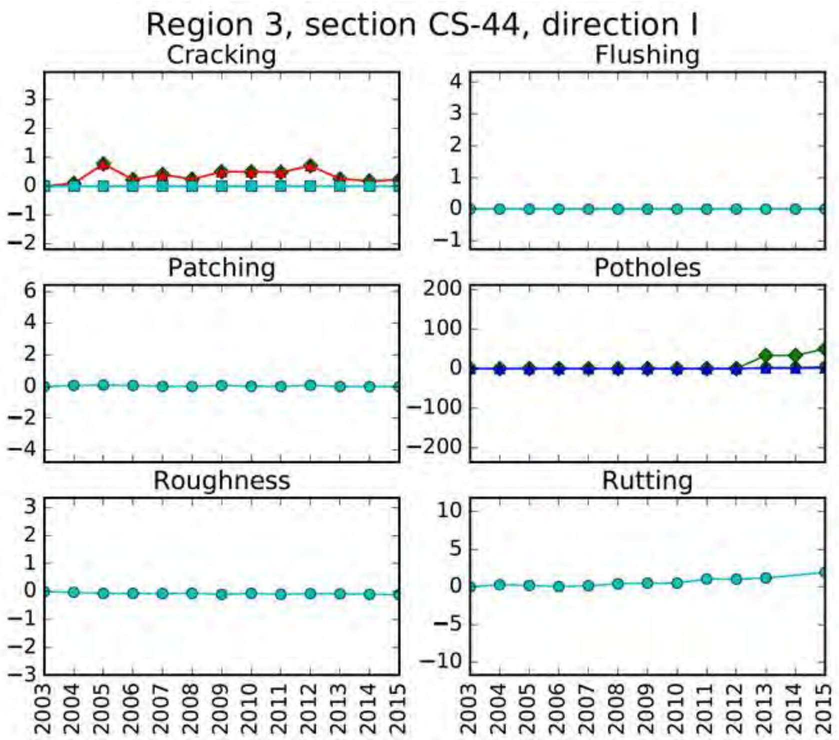
From the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured change in flushing, potholes and cracking and the increase in rutting and roughness.

The data shows the pavement is old and weak and has a relatively weak subgrade. There is likely to be at least six or seven chipseals in the surfacing layer. In 2001 the site was showing some flushing in the wheel paths but by 2006 there was significant flushing and cracking throughout the site. Crack seals, pothole repairs and isolated asphalt rut/shear fills have been used to keep this site safe. This site has suffered genuine pavement deterioration over time without significant pavement maintenance intervention. It appears this site has been allowed to deteriorate without major repair as was intended for a sterilised site. The flushing graph shows a huge increase in flushing followed by water cutting in 2007. Two asphalt patch repairs have been completed at the site which should have shown in the patching graph.

4.2.13 CS-44, increasing direction (SH8 RP 99/ 4.00 – 4.30)

Transverse cracking only

(Note: This statement ‘Transverse cracking only’ is a good illustration of the potential errors within the LTPP data and supports the recommendation in section 8.2.16 ‘Crack assessment’ (see chapter 8). The statistical analysis used cracking codes in the data to make this statement when a review of the site photographs clearly shows the predominant crack type on this site is longitudinal cracks and particular to the probable cause of the failure at this site.)



RAMM data:

- ADT is 3,726 with 10% HCV.
- Unknown number of chipseals although the distress evident in photographs would suggest a relatively thin layer of chipseals (two recorded in RAMM: G5 void fill 1985 (could be second coat), G3 single coat seal 1990).
- Original pavement unknown (RAMM has 50 mm of AP20 ~1961?).

- The latest 2012 FWD reading for the site is <350 µm with some older results a little higher but all <550 µm with longer bowls.
- The SNPs are general between 3.0 and 6.0.

Environmental information (taken from the site photographs):

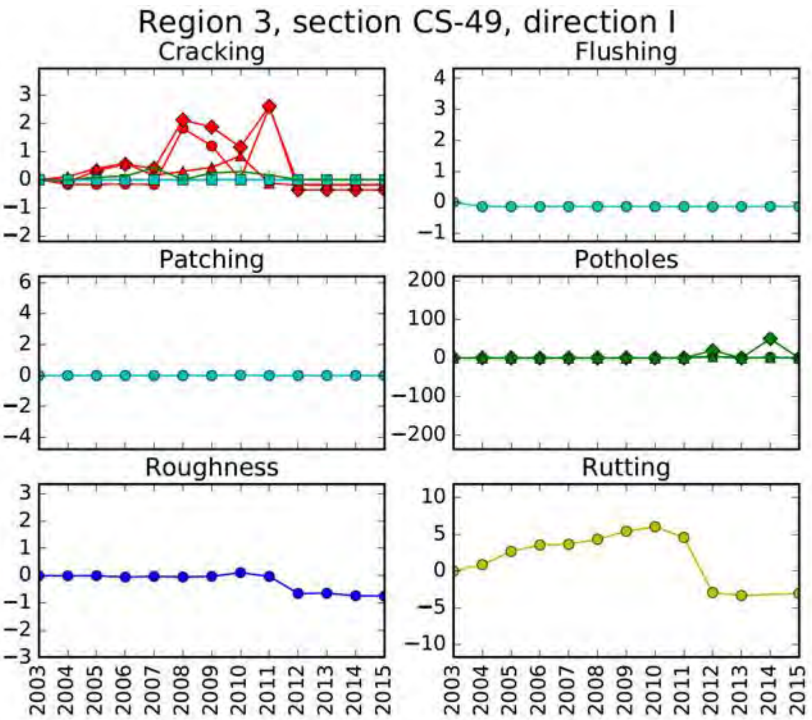
- The site is generally open, flat and has an easy curve.
- The drainage appears to be good.

Looking at the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the cracking and potholes recorded at the site.

There are no genuine pavement records for this site recorded in RAMM; however, looking at the photographs it appears an earlier narrow carriageway has had seal widening constructed possibly both sides of the road. The seal layers appear quite thin, especially on the edges. There is longitudinal cracking just outside the outer wheel paths which may be along the joint of seal widening. There is also longitudinal cracking along the white edge lines which may be due to thin seal layers which is developing into edge breaks. There are a number of very small pothole repairs. However there should be an increase in patches due to the number of crack and edge break repairs. These are an example of poorly chosen and completed maintenance repairs that are failing shortly after completion.

4.2.14 CS-49, increasing direction (SH1S RP 729/ 12.00 – 12.30)

Cracking and rutting getting worse over time.



RAMM data:

- ADT is 6,547 with 12% HCV.
- One chip seal (G3/5 two coat first coat 2011).

- Original pavement unknown (~ 300 mm in 1966?) Additional lane added right-hand side in 2007 – 350 mm of AP65 followed by 150 mm of M4 AP40. Additional lane added left-hand side in 2011 with overlay across full width of pavement 200 mm of M4 AP40.
- The deflections prior to the 2011 overlay were all below 1500 µm and subsequent to the overlay reduced to below 755 µm and were generally shallow long bowls.
- Has a SNP of 3.27.

Environmental information (taken from the site photographs):

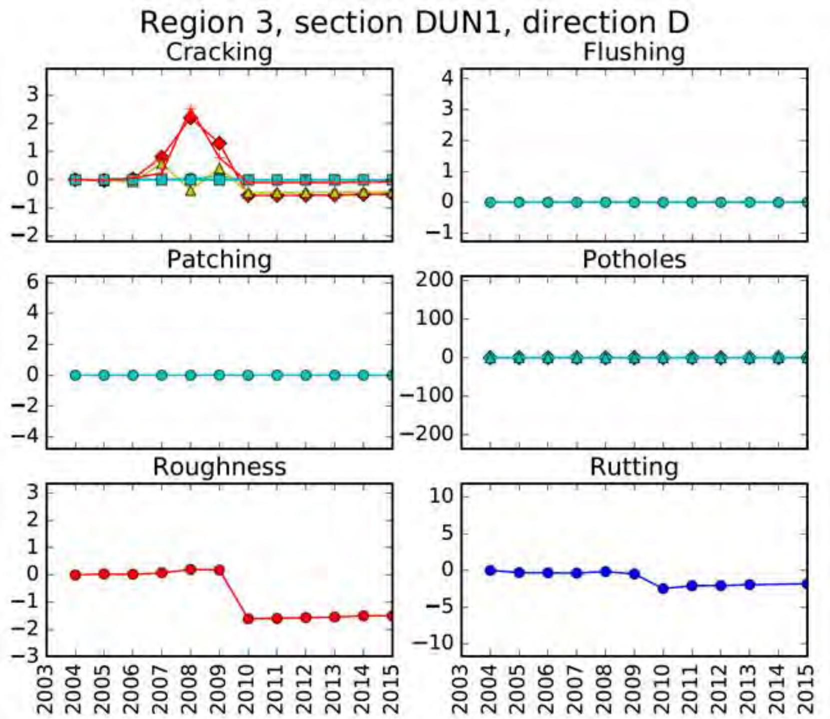
- The site is generally open, straight and flat.
- The drainage appears adequate.

Looking at the RAMM data and the gallery of annual photographs the following observations are made as to the likely causes for the measured increase in cracking, wheel path rutting and roughness. Following the corrections of the cracking, wheel path rutting and roughness there is an increase in potholes.

The deflection data suggests quite a stiff pavement with any weakness in the subgrade. The cracking is in and outside the wheel paths and appears as small block cracking suggesting the top pavement layer was bound or semi-bound. Movement of the small block cracking appears to have contributed to the increase in wheel path rutting and roughness. This was corrected with the pavement overlay in 2011 resetting the cracking, rutting and roughness. The site still has the 2011 first-coat seal which has developed small holes as seen in the increase in potholes.

4.2.15 DUN1, decreasing direction

Cracking, but no other deterioration.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

Appears to be a structural asphalt pavement with an asphalt wearing course.

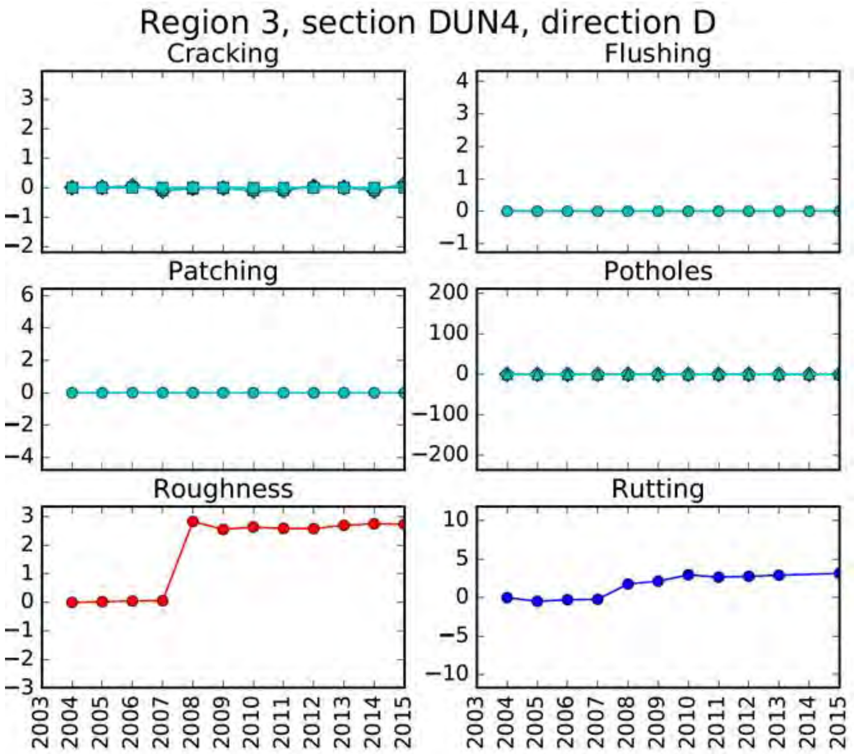
There were significantly wide block and reflective cracks but no pumping fines visible.

The asphalt wearing course was milled out and replaced between the 2009 and 2010 inspections.

Reflective cracking and gaps between mats have slowly increased since construction with no other distress as it is a structural asphalt pavement.

4.2.16 DUN4, decreasing direction

Big jump in roughness in 2008.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

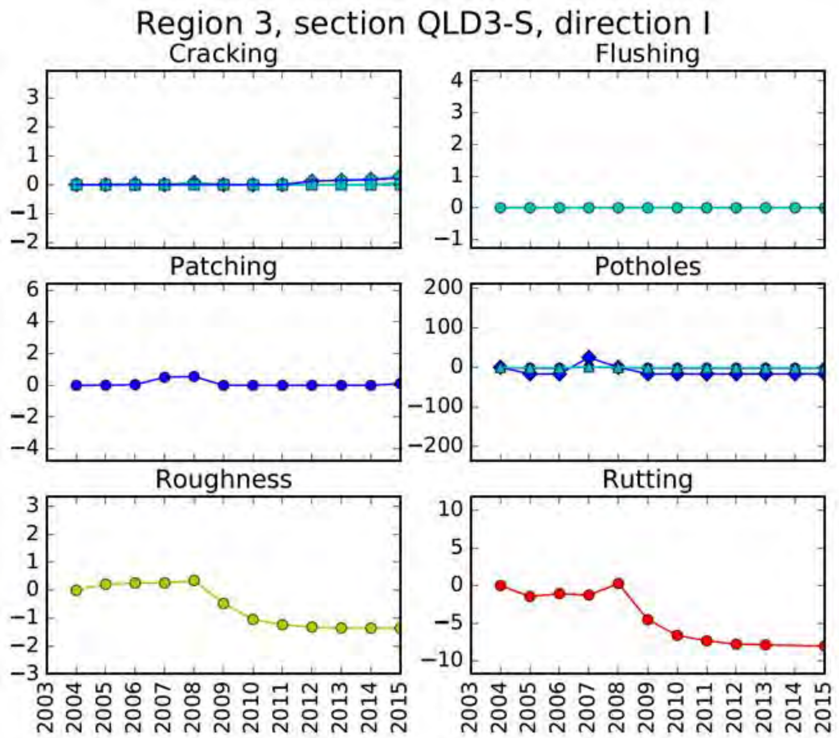
This is possibly a granular pavement with asphalt wearing course. It may be a structural asphalt pavement but there are significant areas of cracked thin AC pumping fines.

There are significant trenches along either side of the carriageway adjacent to the kerb and channel with a width to between the wheel paths creating three strips of pavement across the carriageway.

The decreasing side trench was partially reopened and resurfaced prior to the 2008 inspection. The new trench edge is in or near the inspection line for the outer wheel path. This has created a significant increase in roughness and some increase in rutting due to pavement settlement within the trench.

4.2.17 QLD3-S, increasing direction

Roughness and rutting improving on own accord.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This a granular pavement with a chipseal surface.

There is a short area of subsidence/settlement within the site which had asphalt smoothing completed prior to 2009. This contributed to a small improvement in the rutting data.

An area-wide pavement treatment (AWPT) (probably recycling) was completed between the 2008 and 2009 inspections and a second coat seal applied between the 2009 and 2010 inspections. The AWPT would have provided the greatest decrease in roughness and rutting.

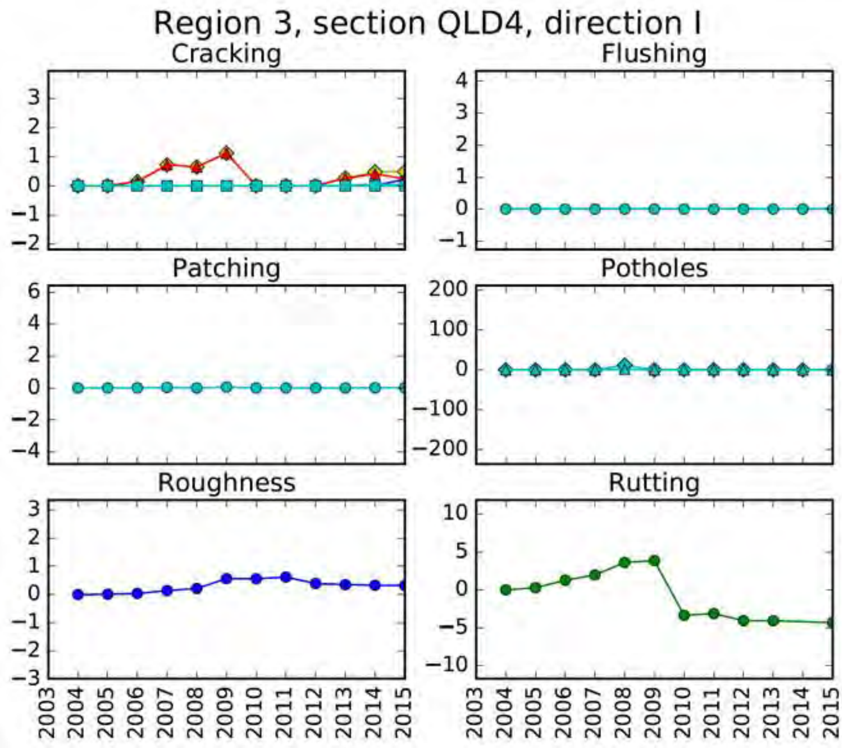
Significant trees shading part of the site were removed probably in conjunction with the AWPT.

The second coat seal also appears to have contributed to a smaller decrease in roughness and rutting.

After the second coat the improvement is very minor but hard to explain. Transverse cracks have become visible since the 2012 inspection suggesting basecourse and seal recycling with the inclusion of cement.

4.2.18 QLD4, increasing direction

Cracking and rutting appear related.



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This is a granular pavement with a chipseal surface

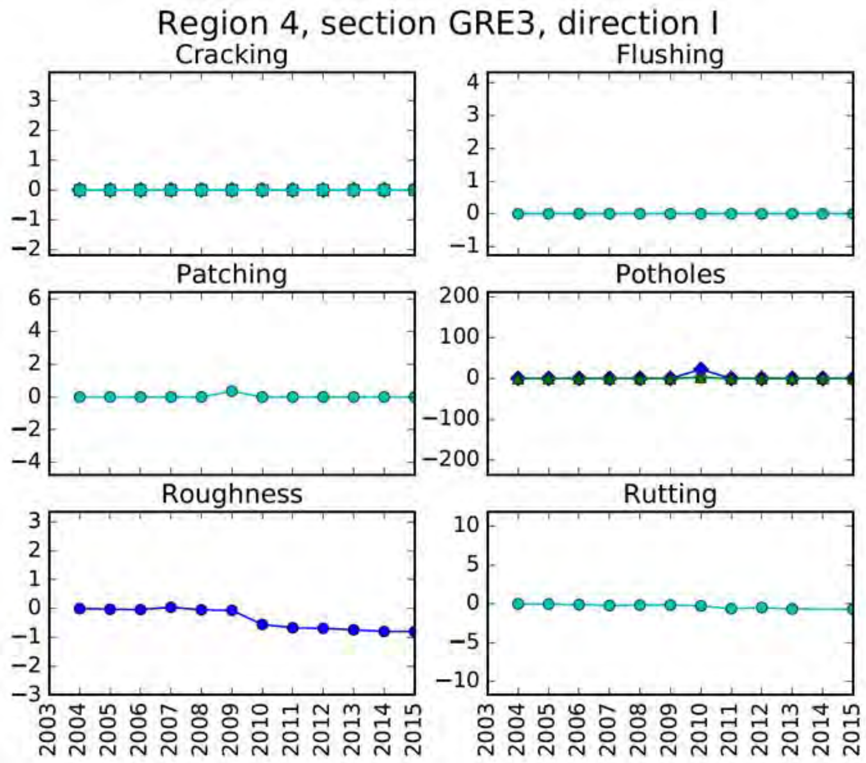
Up to 2009 the chipseal layer appears to be made up of a first and probably second coat seals but looks very lean on binder. This has resulted in scabbing of the second coat and later cracking has developed allowing water into the pavement causing rutting to increase.

The AWPT in 2009 reset the cracking, roughness, potholes and rutting back to 0.

In 2010 a slurry surfacing was placed on the sealed shoulders outside the white edge line and has now led to an increase in cracking (particularly from edge wear) as would be expected.

4.2.19 GRE3, increasing direction

Roughness improving (without intervention?).



These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

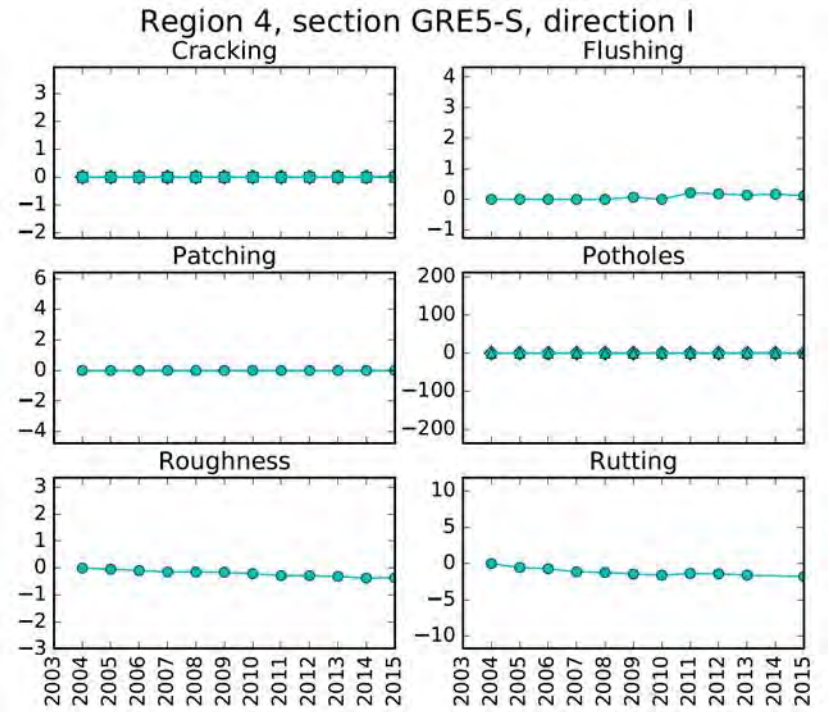
This is a granular pavement with a chipseal surface.

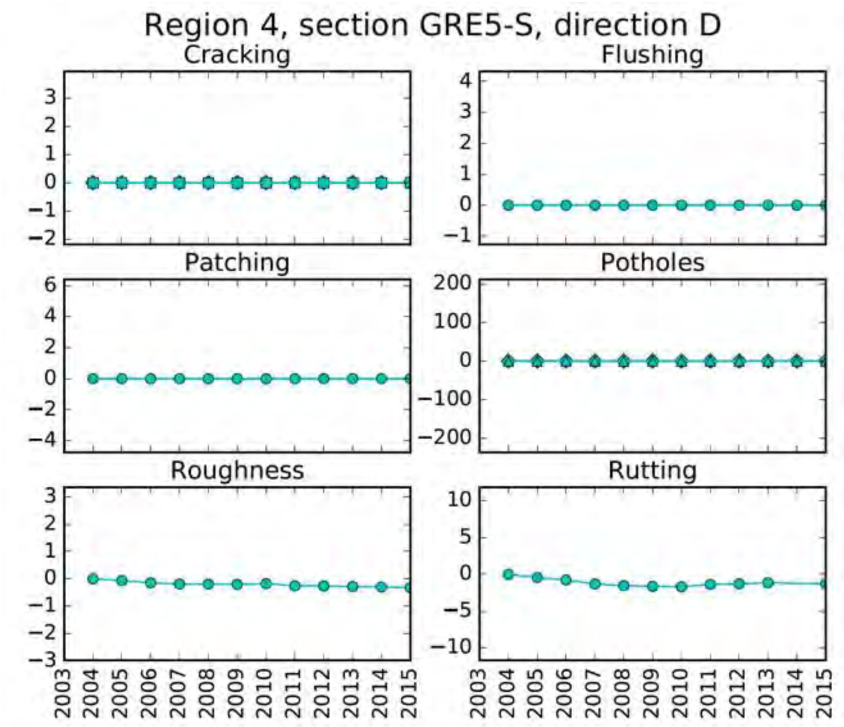
A full width AWPT was completed between the 2009 and 2010 inspections resetting roughness and rutting to 0.

The second coat seal did not have sufficient binder and is scabbing quite badly.

4.2.20 GRE5-S, both directions

Roughness & rutting improving on own accord.





These observations have been compiled using information from the LTPP database and annual photographs and do not include a review of any RAMM data.

This is a granular pavement with a chipseal surface

There does not appear to be any immediately obvious reason for the improvement in roughness and rutting from the photographic record at this site.

A possible explanation may be that the crown is being measured as the inner wheel path for each direction. However, it appears from the photographs that this line could be on the outer edge of the wheel path. So if there is slight chip embedment/depression in the centre of the wheel paths this may show an improvement in rutting on the measured crown.

4.3 LTPP database – detailed statistical analysis

An experienced statistician was engaged to undertake a more detailed statistical analysis which involved the following:

- Calculate average annual changes using regression analysis:
  - Identify any acceleration in the rate of change or any jump changes in the condition
  - Determine expected useful life (calculate years it would take to reach intervention thresholds)
  - Establish factors that have the most influence on the magnitude of the average annual change.
- Compare differences in average annual changes between SHs and TLA LTPP sites, and sterilised and normal sites.
- Carry out statistical analysis to identify or suggest factors that need to be present for accelerated condition trending to take place.

Reasonably linear regions in the 50 metre data were first identified where fitting linear regression made sense, and a linear regression with respect to time was carried out. Attempts were then made to find cases of acceleration in the rate of change and jump changes in the condition, but it was challenging to present this in a useable way.

The expected useful life estimation did not make sense because the slope on the regression varied significantly from site to site, and in the case of roughness it was not much different from zero.

A graphical investigation of what influences the slope of the graphs was carried out on the complete data set. This investigation could not be completed for each year as there was insufficient annual data.

There was no suitable data for the statistical analysis to identify or suggest what factors needed to be present for accelerated condition trending to take place, and in any case the data available was not considered sufficiently robust to identify accelerated condition trending.

The following sections are a summation of the key findings set out in appendix B.

4.3.1 Histograms and identification of relevant road works and outliers

4.3.1.1 Distribution skewness

Plots of the raw roughness and rut depth data were skewed (as shown in appendix B, section B2.1), and thus were subsequently transformed by a log or a square root transformation as shown in table 4.6 to bring them to a normal distribution.

Table 4.6 'Skewness' of pavement condition measure distributions

Measure	Transform	Distribution observations (see appendix B)
Lane (ie wheel path average) roughness of 50 m LTPP segments	None	'Positively skewed' = 'skewed to the right' (ie long tail is on the positive side of the peak, and the mean is on the right of the peak value) (MathsIsFun.com 2016).
Lane (ie wheel path average) roughness of 50'm LTPP segments	Log	'Normally distributed'.
Lane (ie wheel path average) rut depth of 50'm LTPP segments	None	'Positively skewed'.
Lane (ie wheel path average) rut depth of 50'm LTPP segments	Square root	Somewhat 'positively skewed'. One could apply a stronger transformation such as [a] cube root or logarithm. However stronger transformations have the effect of spreading out the smaller values of the rut depth and hence giving them too much emphasis in any analysis. So it is better to stay with the square root transform (see appendix B).
Lane (ie wheel path average) texture of 50 m LTPP segments	None	Normally (i.e. symmetrically) distributed with two peaks: 1 peak at around 1.8–2 mm mean profile depth (MPD), and a secondary peak between the values of 1 and 1.5. (Presumably, this secondary lower peak corresponds to low-texture (e.g. bituminous mix) surfaces, and the other higher peak to chipseal surfaces.)

4.3.1.2 Condition measures: comparison of unsterilised and sterilised LTPP sites

Table 4.7 records findings when condition measure histogram distributions are compared between the two groups of sterilised and unsterilised LTPP sites.

Table 4.7 Performance measure comparisons: sterilised sites versus unsterilised sites

Measure	Observation
Lane rut depth (transformed with sqrt)	The rut depth of the group of sterilised LTPP sites tends to be a little lower than the group of unsterilised LTPP sites.
Lane roughness (transformed with log)	The roughness of the group of sterilised LTPP sites may be slightly lower than the group of unsterilised LTPP sites.
Lane texture (not (transformed)	The texture of the group of sterilised sites is markedly lower than unsterilised sites. This is an expected outcome due to reduced renewals on sterilised sites. A check of AC-like surfaces found them to be spread quite evenly between sterilised and unsterilised LTPP sites but with TLA having twice the number of AC sites as SH AC sites.

It is recommended for future texture analysis that surface types are broken into chipseal and asphalt surfaces and analysed separately for both sterilised and unsterilised sites. See recommendation in section 8.2.17 'Surfacing and pavement codes' (chapter 8).

4.3.1.3 Condition measures: comparison of SH with TLA LTPP sites

Table 4.8 records the findings when condition measure histogram distributions are compared between the two groups of SH and TLA sites.

Table 4.8 Performance measure comparisons: SH sites versus TLA sites

Measure	Observation
Lane rut depth (transformed with sqrt)	The rut depth of the group of SH LTPP sites is greater than the group of TLA LTPP sites.
Lane roughness (transformed with log)	The roughness of the group of SH LTPP sites is less than the group of TLA LTPP sites.
Lane texture	[Texture is measured only on SH roads so it does not appear here.]

4.3.1.4 Condition measures: comparison of SH with TLA LTPP sites

The box-and-whisker plots in figures 4.15 to 4.17 show much the same information as in the two preceding tables. In these box-and-whisker plots:

- the upper and lower lines of the box represent the upper and lower quartiles (ie half the data lies within the box)
- the line through the box shows the median
- the whiskers show the range of the data.

Figure 4.15 Lane rut depth, transformed (mm)

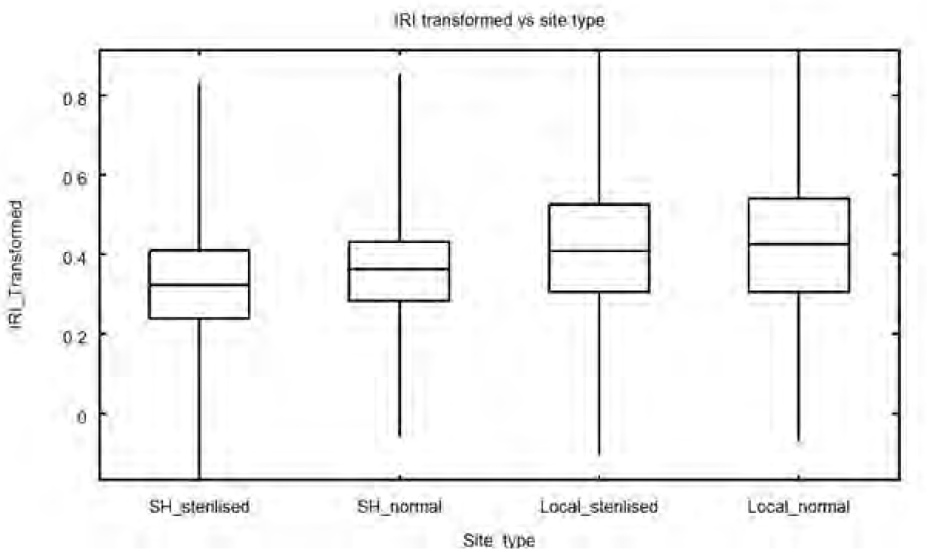


Figure 4.16 Lane roughness, transformed (IRI m/km)

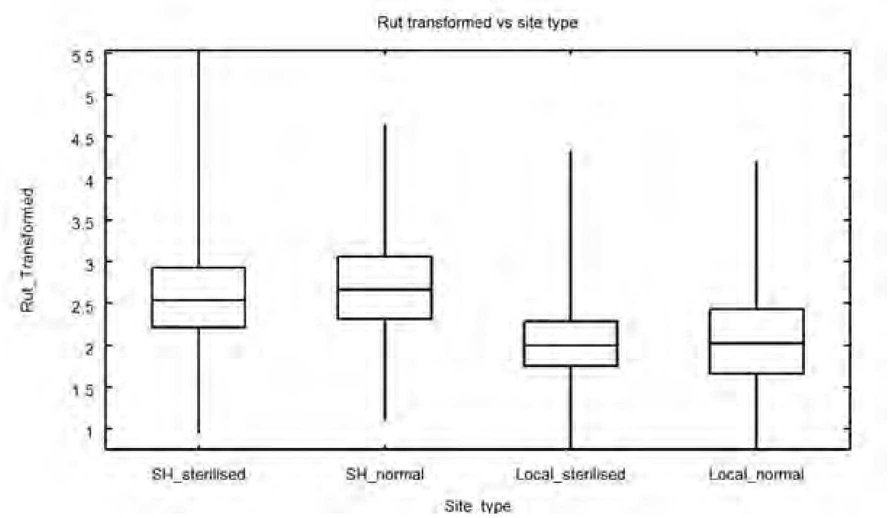
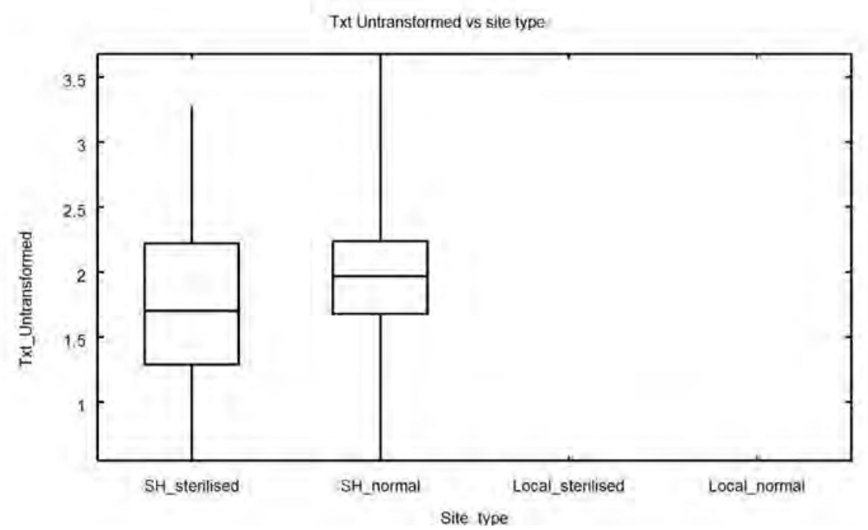


Figure 4.17 Lane texture, mean profile depth (mm)



4.3.1.5 Inter- year differences

Count of inter-year differences: all.

Figures 4.18 to 4.20 summarise the differences between a measurement of one year and the next (ie this year's measurement minus last year's). (Transformed data is used and is only included where there is data for adjacent years.)

Figure 4.18 Adjacent- year rut depth differences

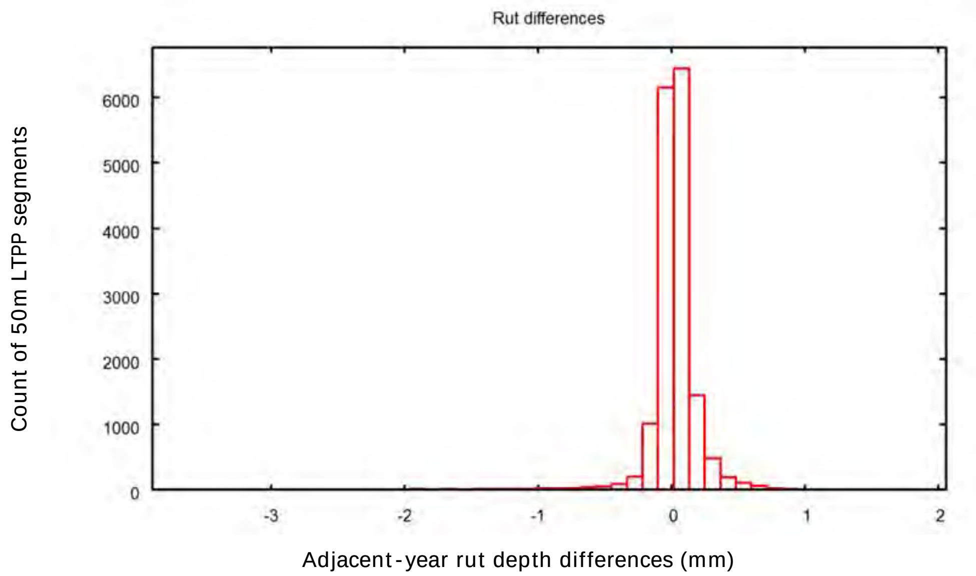


Figure 4.19 Adjacent year roughness differences

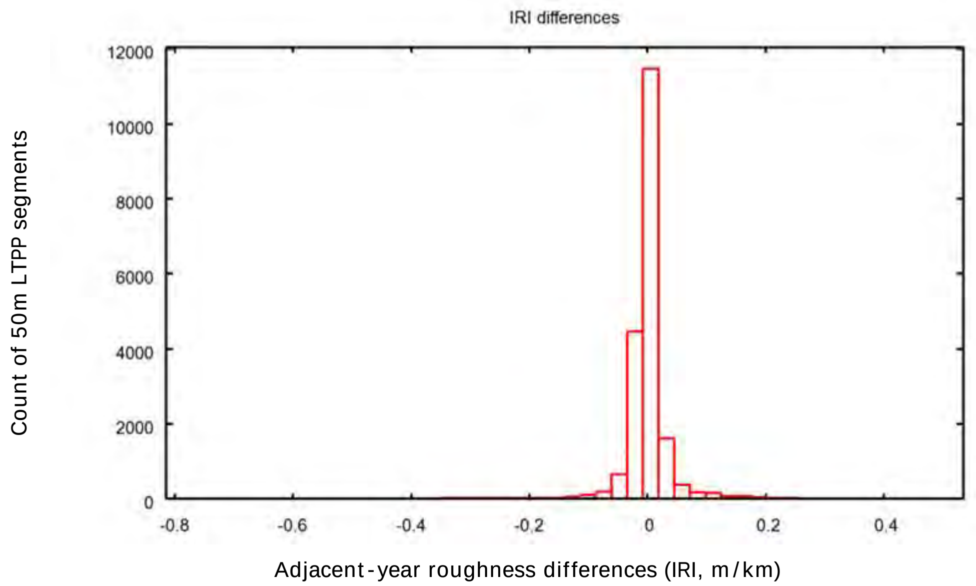
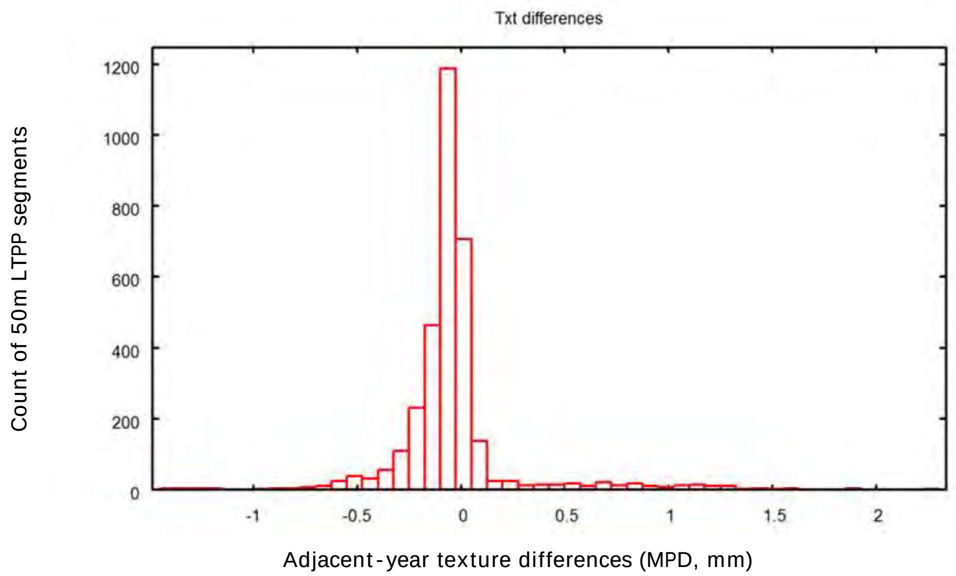


Figure 4.20 Adjacent year texture differences



The histogram program used to prepare the above three figures automatically sets the width of the graph to run from the lowest value to the highest value. Accordingly, there is a very wide spread of upper and lower-limits for the x-axes.

Interpretation of observations from figures 4.18 to 4.20 are:

- low values of rut and roughness differences may correspond to repair work
- high values for texture differences may correspond to repair work
- low values of texture may correspond to a chipseal surface being replaced by an AC surface.

High values of rut or roughness differences and low values of texture differences may correspond to accelerated ageing, so they may be what is being looked for in this project. (Alternatively, some of these differences may simply correspond to some types of road work or bad observations.)

Percentage of inter-year differences: sterilised and unsterilised

In appendix B2.1 there are a series of figures (one for each of rutting, IRI and MPD) showing in separate colours: percentage histograms for measurements on sterilised LTPP sites, and measurements on unsterilised/normal LTPP sites. As these histograms for sterilised LTPP sites and unsterilised/normal LTPP sites are very similar, they are not shown here in this summary.

Percentage of inter-year differences: SH and TLA

As above, but for SH and TLA LTPP sites, the percentage histograms for adjacent-year rut/IRI/MPD differences are not shown here as the SH and TLA plots are very similar. (Readers wishing to view these plots should consult appendix B.2.1.)

Percentage of inter-year differences: roadworks separated out

A set of percentage histograms has been prepared where sites that have had road works were identified and separated out. (Roadworks that were relevant for each of the measurements were identified from the raters' site notes.) As expected the difference data for sites with road works is a lot more spread out (see appendix B.2.1) than in the previous three graphs.

Count of inter-year differences: roadworks separated out

Identifying the point at which the rut/IRI/MPD data for sites with works tend to dominate is of key interest for this research report. The histograms discussed above were then modified to graph *counts* rather than *percentages,* and the vertical scale was expanded to enable very small values to be seen, as shown in figures 4.21 to 4.23.

Figure 4.21 Adjacent- year rut depth differences with and without roadworks

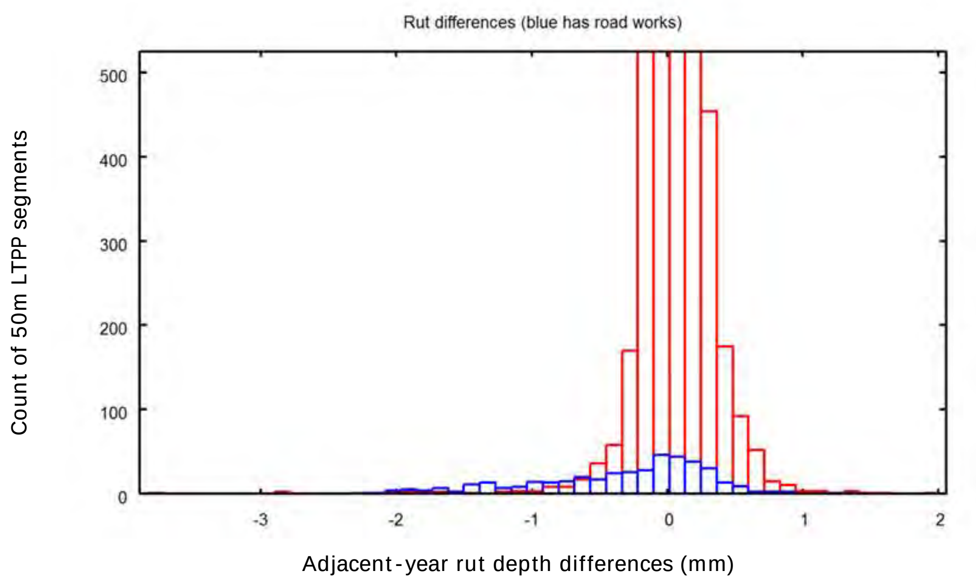


Figure 4.22 Adjacent- year roughness differences with and without roadworks

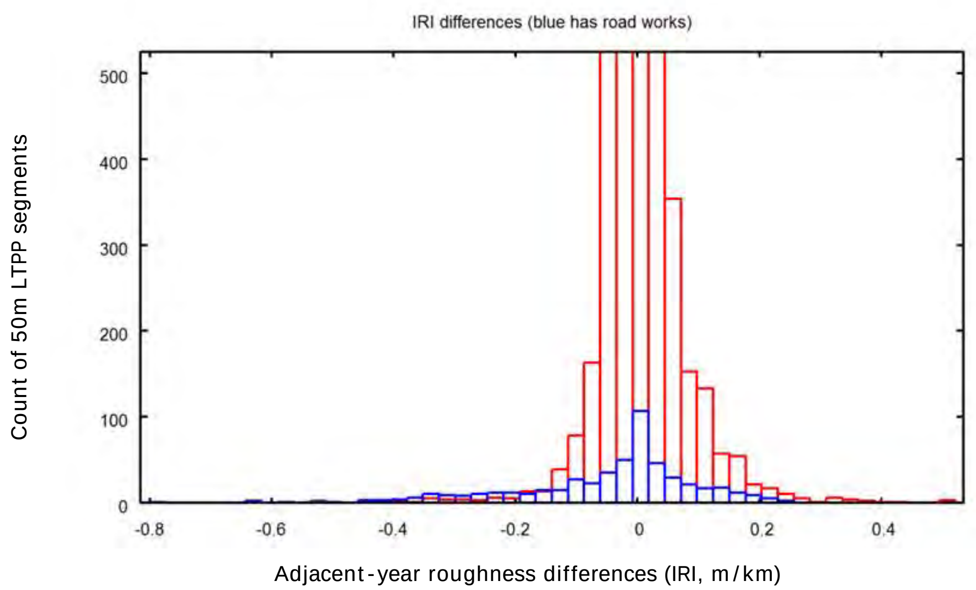
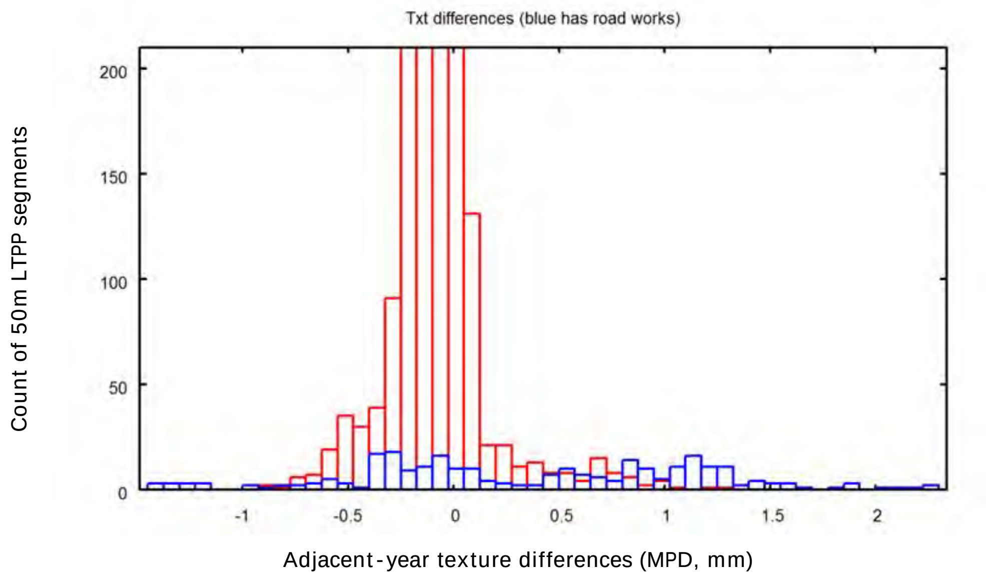


Figure 4.23 Adjacent- year texture differences with and without roadworks



Difference thresholds

Figures 4.21 to 4.23 were then used to judge the difference thresholds, which are given in table 4.9.

Table 4.9 Judged difference thresholds

Measure	Judged difference thresholds (taken from figures 4.21, 4.22 and 4.23)		
	The point at which roadworks become dominant	Accelerated ageing	Decay rates during a period of linear decay
Lane (ie wheelpath average) transformed rut depth of 50 m LTPP segments	Transformed rut depth difference becomes less than -0.5	Leave in outlying positive values	Want to delete outliers – choose 0.8
Lane (ie wheelpath average) transformed roughness of 50 m LTPP segments	Transformed roughness difference becomes less than -0.1	Leave in outlying positive values	Want to delete outliers – choose 0.1
Lane (ie wheelpath average) MPD texture of 50 m LTPP segments	Texture difference becomes greater than 0.4	Leave in outlying negative values	Want to delete outliers – choose -0.6

4.3.2 Selecting the data

For the linear ageing analyses, the data analyst looked for stretches of data with at least an eight-year range (ie eight points if data was collected every year) that had no road works relevant to the particular data type and with between year differences within the ranges identified in the last column of the above table. If there was a missing year the data analyst applied the same limit to the two-year difference bridging the missing year.

For focusing on accelerated ageing, the data analyst deleted from the dataset only those outliers that could be attributed to road works – that is specifically identified road works of low outliers for rut depth and roughness and high outliers for texture.

4.3.3 Linear ageing

4.3.3.1 Initial analysis

A simple linear regression model was fitted to each 12 road segment at each site where there was:

1. At least an eight-year range
2. No outliers in the differences
3. No relevant road works.

Detecting a change in slope in the linear regression was achieved with the 'change point test' developed by Davies (2002).

For each of the three transformed variables (ie rut depth, roughness and texture) the following graphs were prepared:

- histogram of the residual standard deviation
- histogram of the slope (trend)
- histogram of the results of a change point test
- plot of slope versus the residual standard deviation (residual SD).

The residual SD shows the degree to which the transformed data follows a linear trend. The graphs show there is substantial variability in the quality of fit.

The slope (trend) shows how much the variable changes, on average, each year.

4.3.3.2 Graphs

The set of three lots of four graphs produced can be found in appendix B.2.3 – they are not included in this summary. Some of the observations made in appendix B regarding the slope graphs are:

- For rut depth slope tends to be positive; rut depth increases over time; but there is a lot of variability in the values.
- For roughness the slope values seem to be symmetrically distributed around zero, with perhaps a few more very high values.
- With texture the slope values are almost all negative; texture is decreasing but with a very wide range of values.

4.3.3.3 Further analysis

The purpose of this further analysis is to detect a relationship between the slopes found in the previous section and various variables available in the site data. All the analyses are graphical.

As there are few strong results graphically it should not be expected there will be many more from a more formal statistical analysis.

The graphs in the following sub-section attempt to find relationships between the slope or, in some cases residual standard deviation, and:

- site type
- sensitivity (soil moisture sensitivity based on climate and geology (Henning 2008))
- AADT

- SNP
- average rainfall.

Notes on the predictor variables:

- Sensitivity is given as one of five categories: 'limited', 'low', 'medium', 'moderate' or 'high'.
- The AADT estimate was made on different years for different sites and it is not known if any attempt was made to adjust them to allow for this.
- SNP – the database generally gives a site value for one year.
- Average rainfall is an average over the period from a nearby weather station.

4.3.3.4 Graphs

Using the edited/selected subset of data, box-and-whisker plots of year-by-year difference versus site type (ie SH/TLA sterilised/unsterilised) were prepared. These box-and-whisker plots are shown below (see figure 4.30, figure 4.37 and figure 4.44) and can be compared with the slope graphs of figure 4.25, figure 4.32 and figure 4.39.

In general, the graphs are first introduced below, and then the collective discussion on them is given in section 4.3.3.5.

Figure 4.24 Rut depth: residual SD vs site type

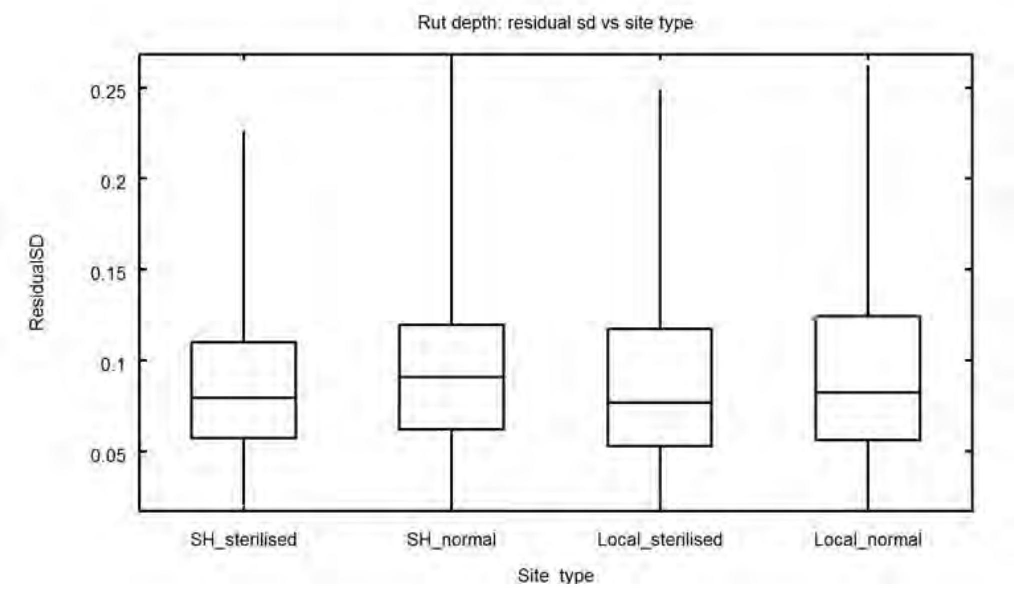


Figure 4.25 Rut depth: slope vs site type

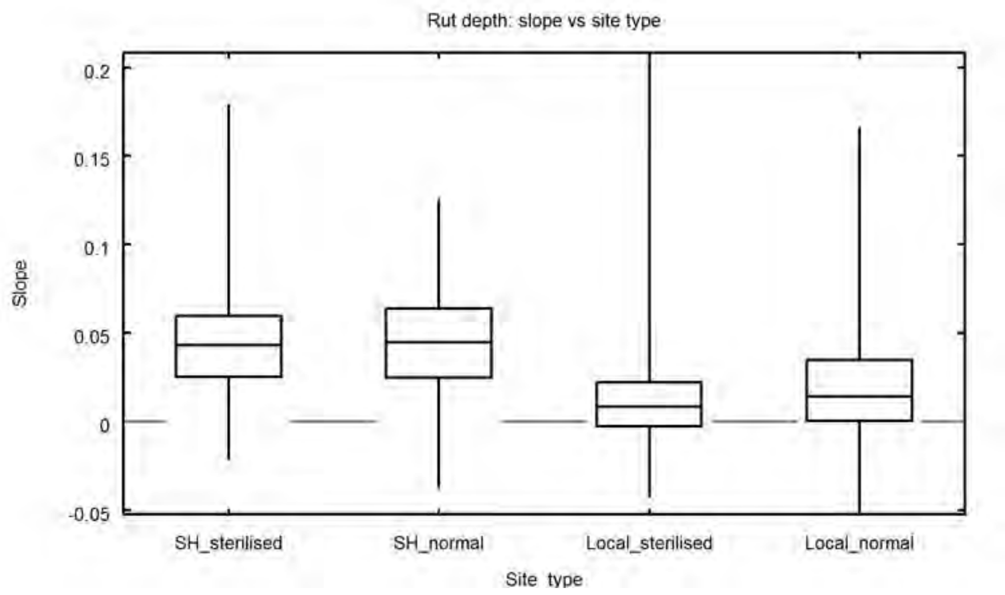


Figure 4.26 Rut depth: slope vs soil moisture sensitivity

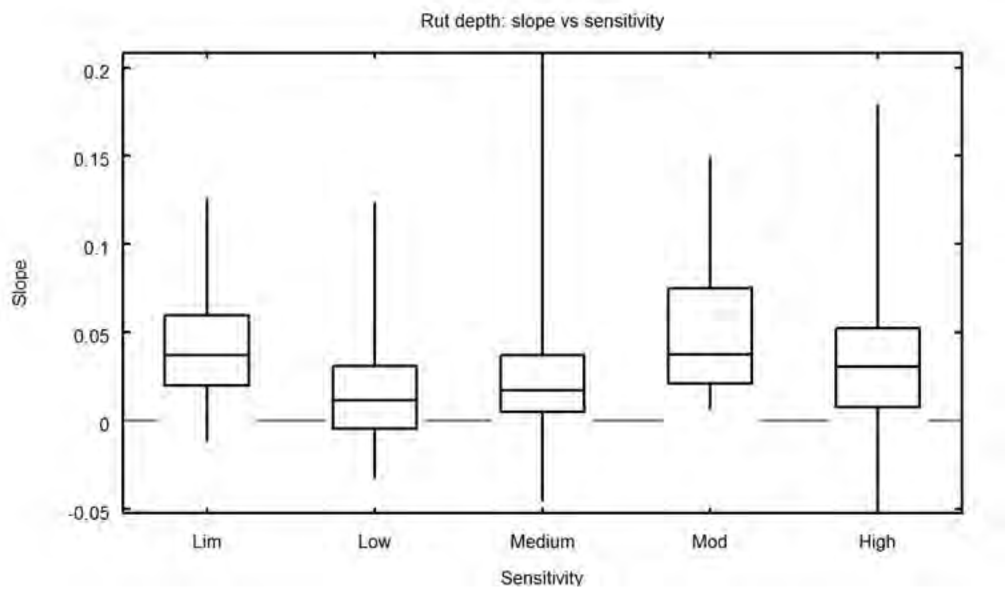


Figure 4.27 Rut depth: slope vs AADT (SH in blue, TLA in red)

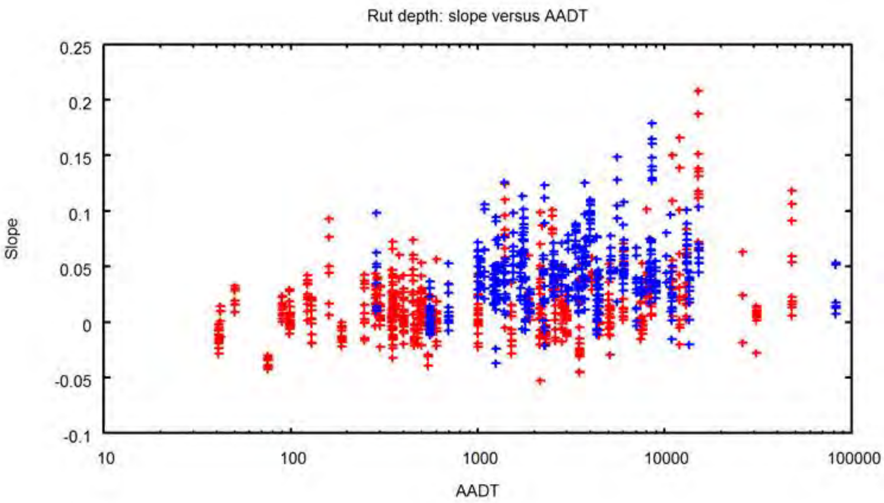


Figure 4.28 Rut depth: slope vs SNP (SH in blue, TLA in red)

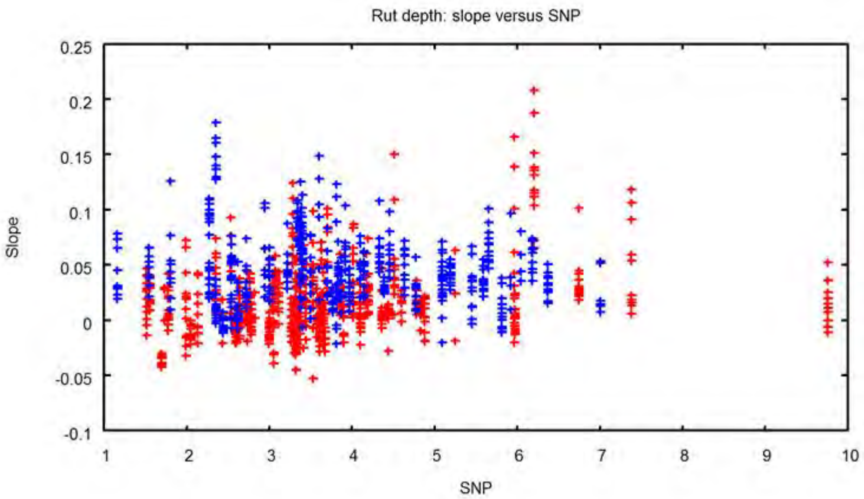


Figure 4.29 Rut depth: slope vs rainfall (SH in blue, TLA in red)

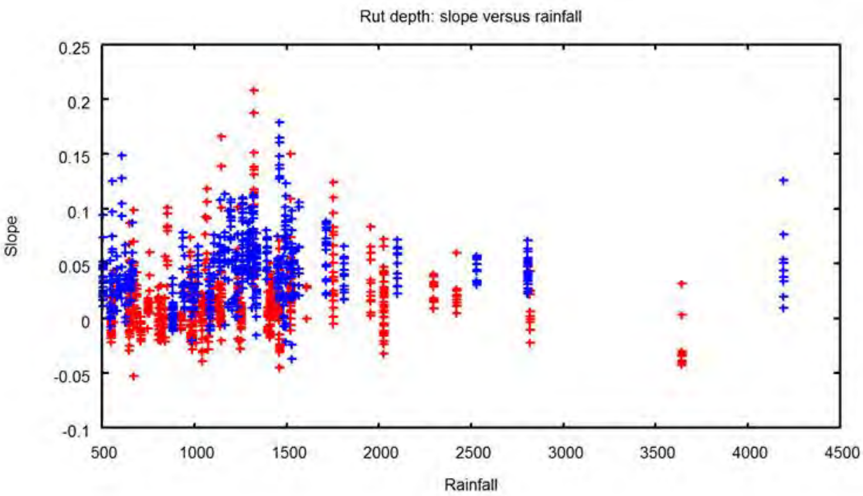


Figure 4.30 Rut depth: differences vs site type

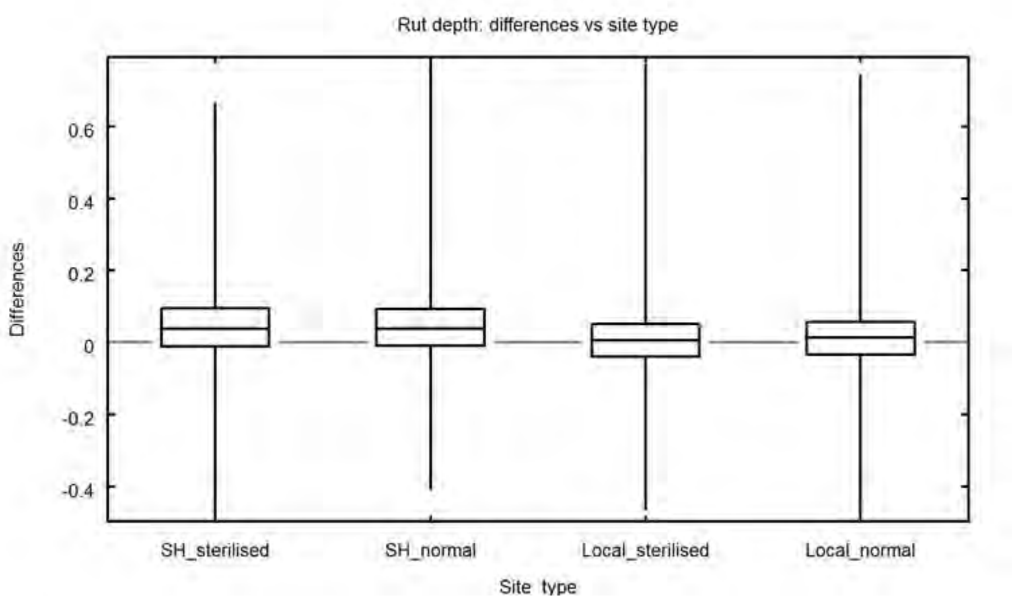


Figure 4.31 Roughness: residual SD vs site type

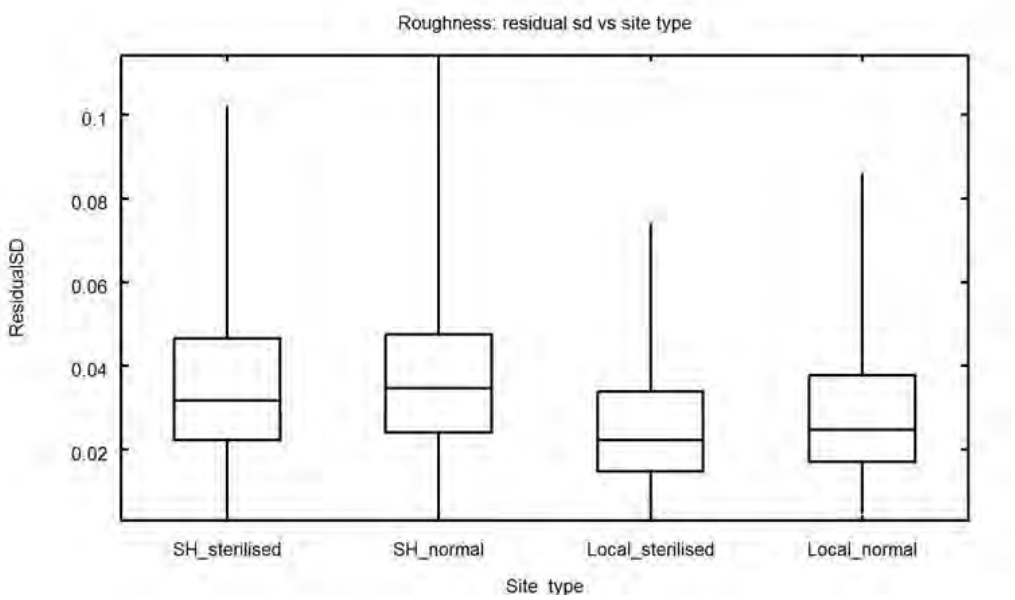


Figure 4.32 Roughness: slope vs site type

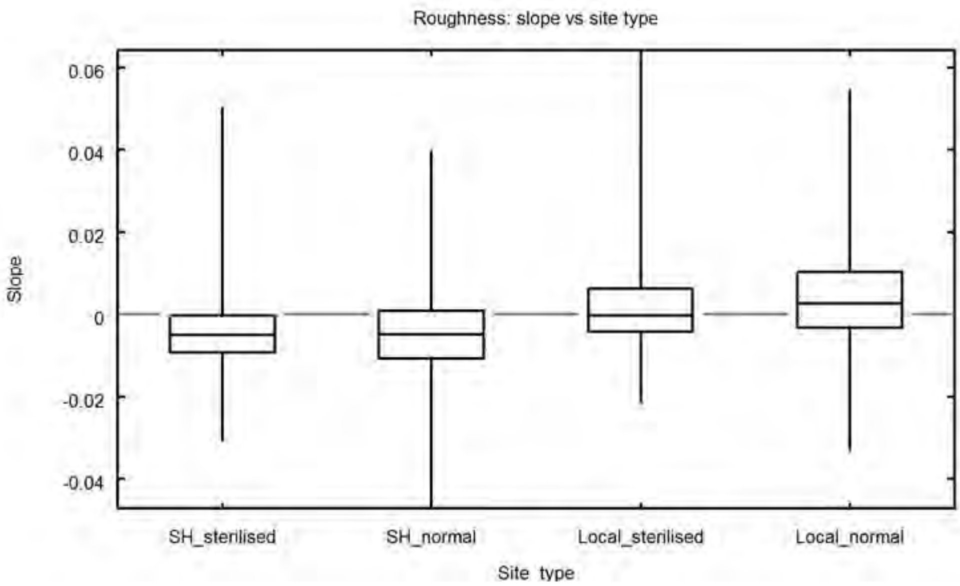


Figure 4.33 Roughness: slope vs soil moisture sensitivity

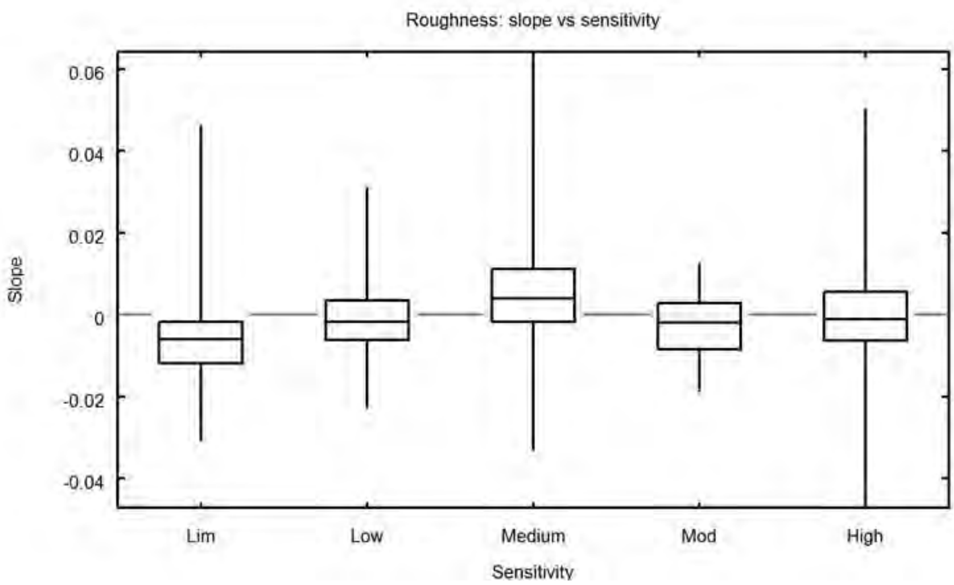


Figure 4.34 Roughness: slope vs AADT (SH in blue, TLA in red)

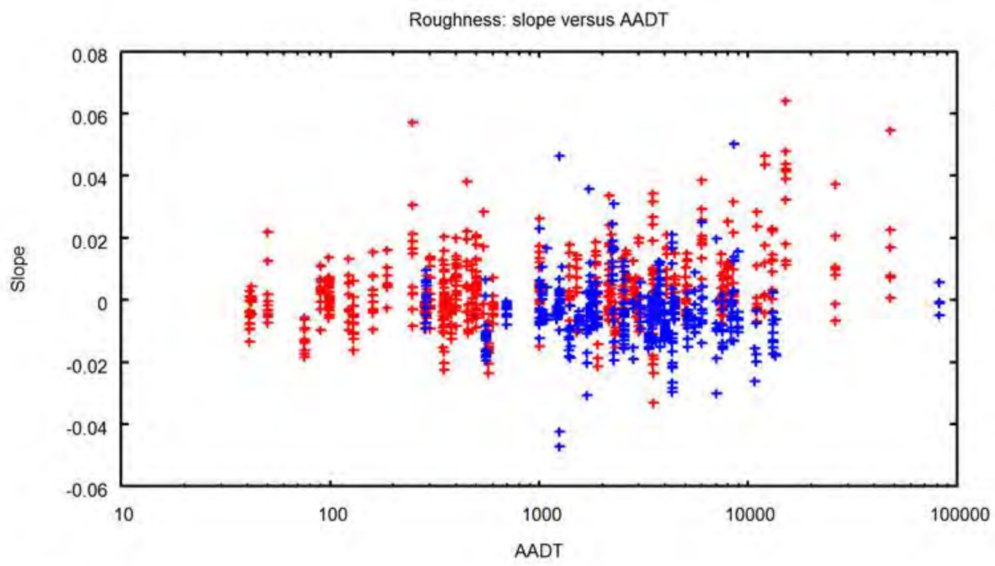


Figure 4.35 Roughness: slope vs SNP (SH in blue, TLA in red)

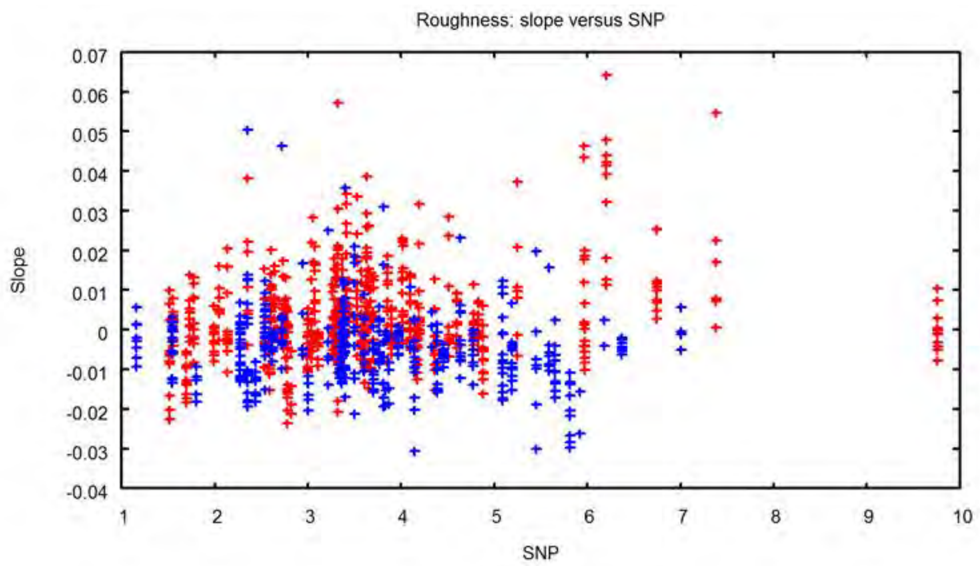


Figure 4.36 Roughness: slope vs rainfall (SH in blue, TLA in red)

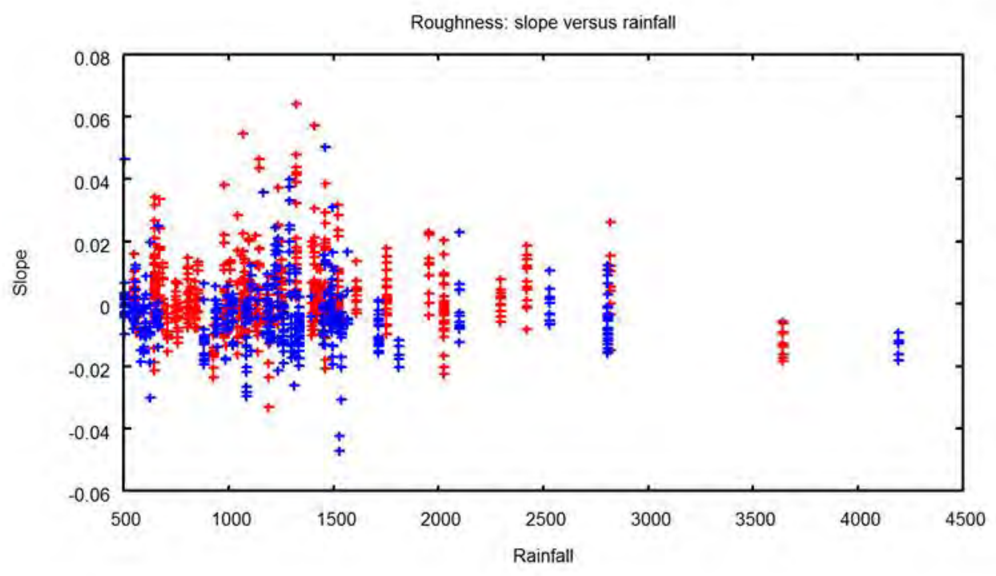


Figure 4.37 Roughness: differences vs site type

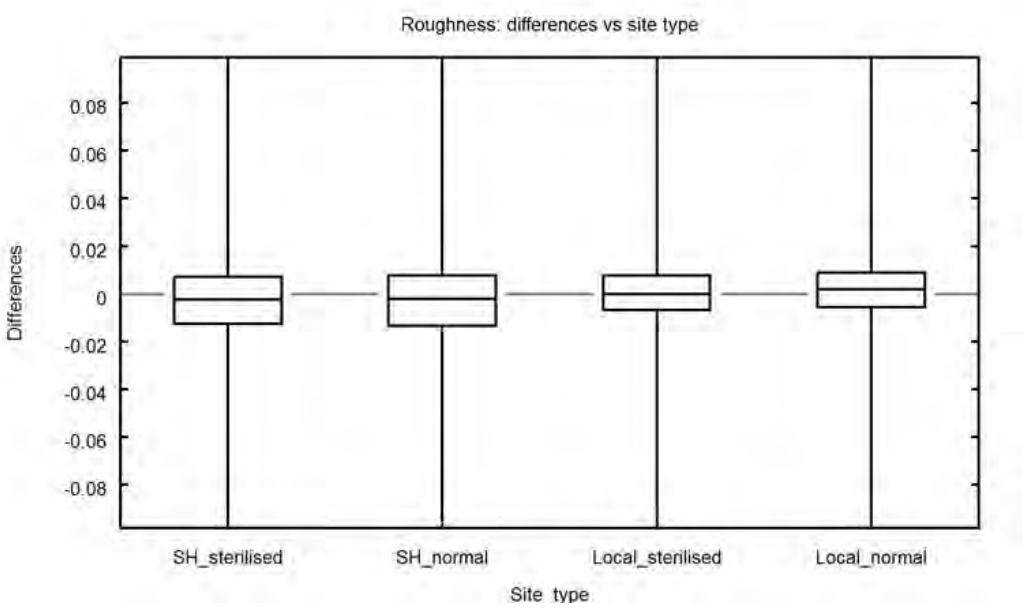


Figure 4.38 Texture: residual SD vs site type

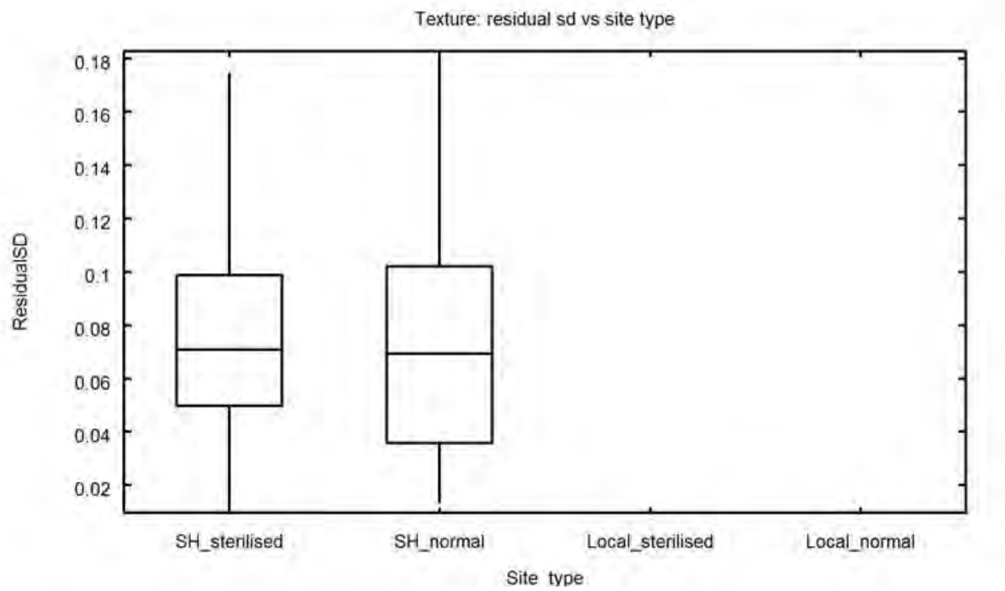


Figure 4.39 Texture: slope vs site type

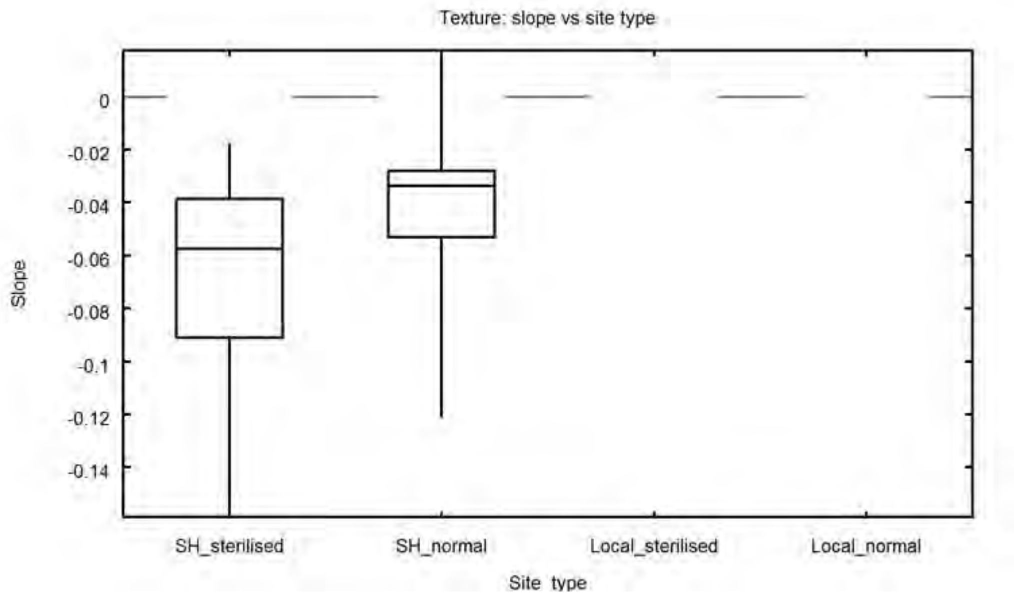


Figure 4.40 Texture: slope vs soil moisture sensitivity

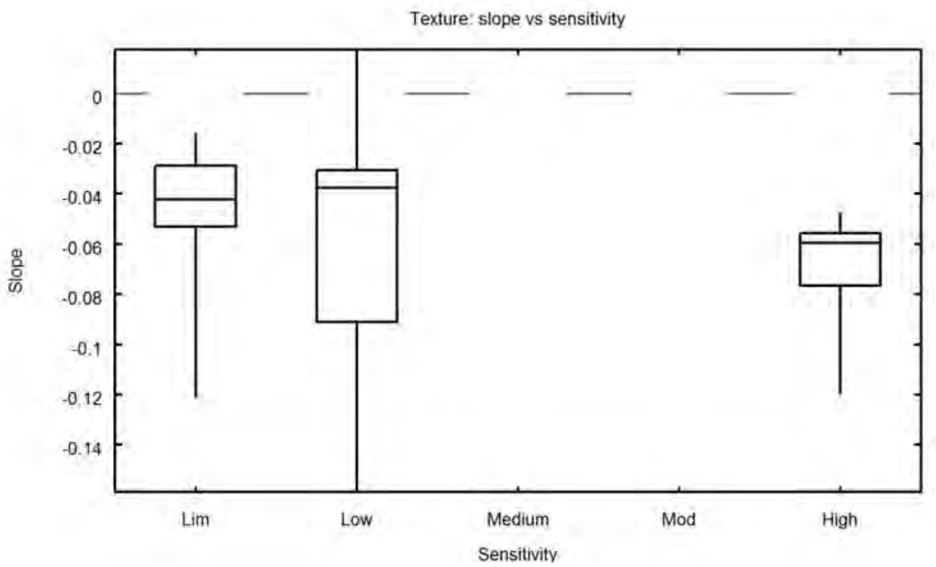


Figure 4.41 SH texture: slope vs AADT

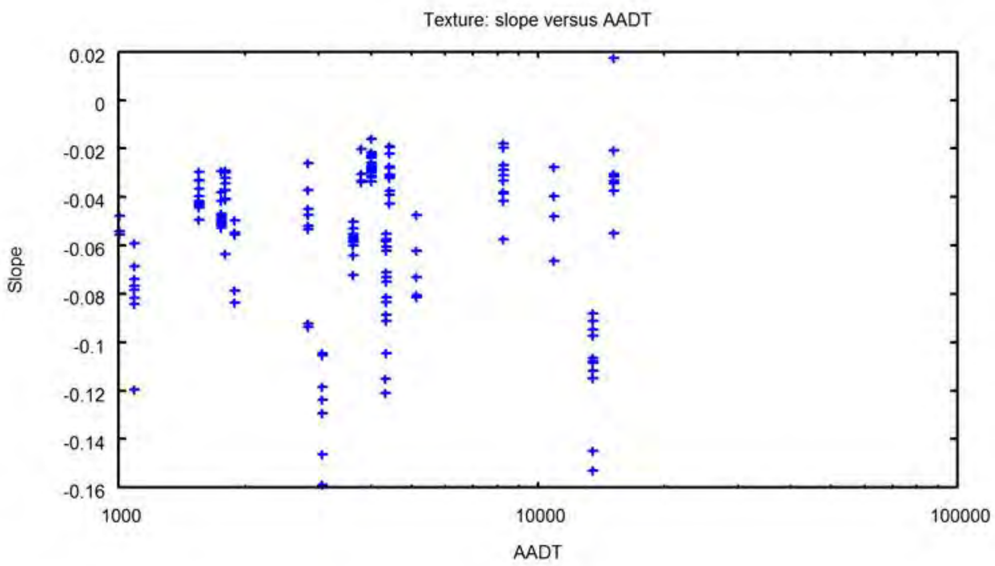


Figure 4.42 SH texture: slope vs SNP

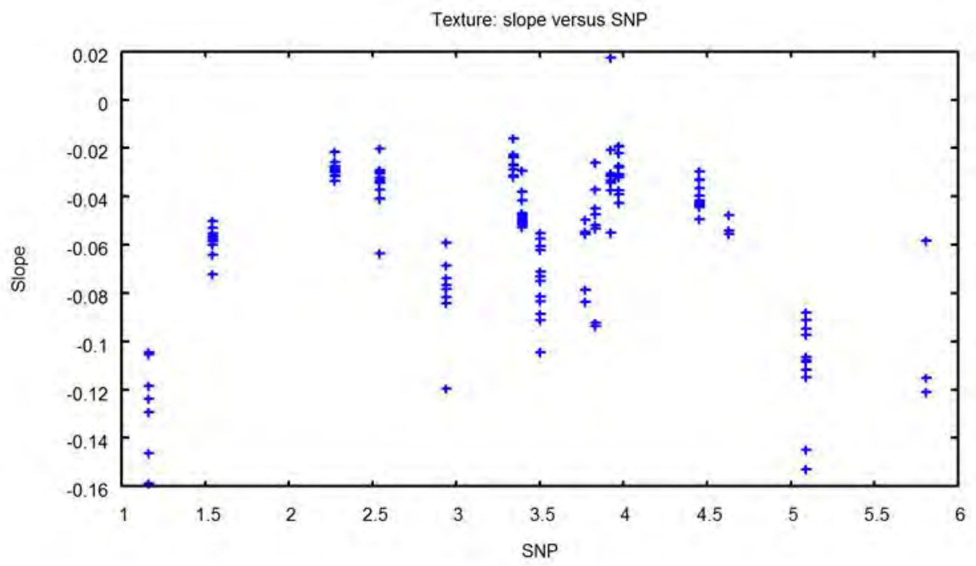


Figure 4.43 SH texture: slope vs rainfall

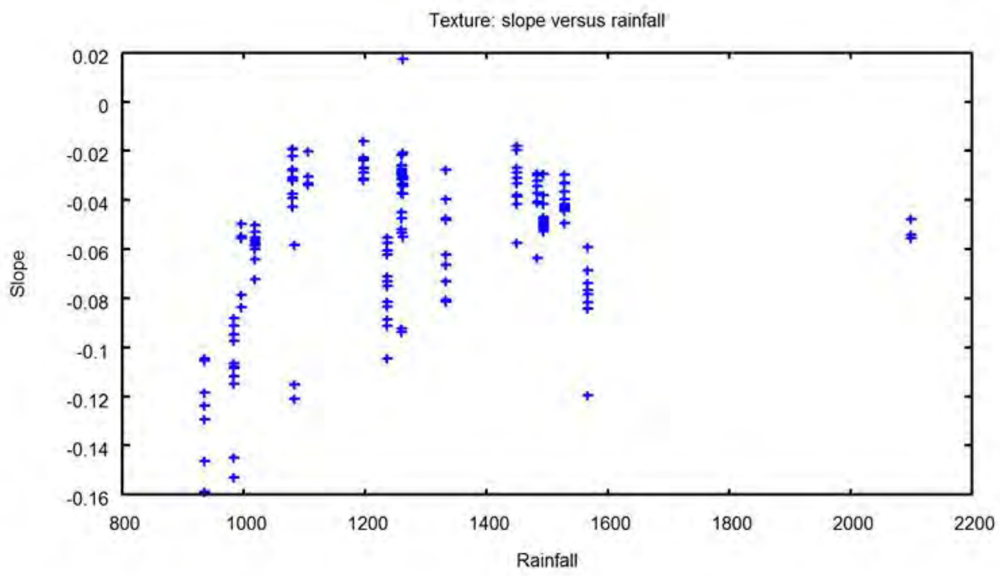
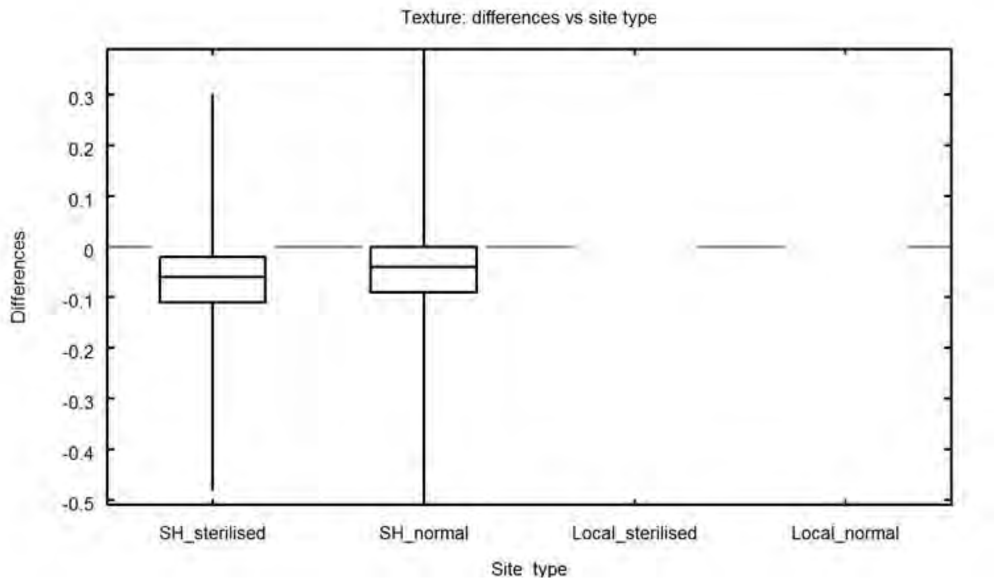


Figure 4.44 SH texture: differences vs site type



4.3.3.5 Observations on the graphs

Observations from figures 4.24 to 4.44 are:

1 Residual SDs are much the same for the different site types for rut depth (figure 4.24), but for roughness the TLA ones seem to be lower (figure 4.31). Given the smaller sample sizes it is difficult to gain significant meaning from the differences in the box plots for the texture data (figure 4.38).

2 With reference to figure 4.25, the trends for the rut depth data are much stronger for the SH data than for the TLA data. This may be related to the higher values of rut depth in the TLA data.

3 With reference to figure 4.32, roughness tends to be decreasing on the SH data and with little trend in the TLA data. With reference to figure 4.39, texture is decreasing and the difference between the sterilised and unsterilised/normal sites may be due to the different surface types.

4 With reference to figure 4.36, the trend in rut depth is stronger as the site sensitivity gets higher. The values for ‘limited’ are fairly meaningless because of the small sample size and otherwise the trend is fairly consistent. With reference to figure 4.33, the effect of sensitivity on roughness seems inconsistent and is probably small. With reference to figure 4.40, the trend in the texture data may be stronger for the high sensitivity sites.

5 With reference to figures 4.27 to 4.29, figures 4.34 to 4.36 and figures 4.41 to 4.43, there seems to be an increasing slope in the graph of rut depth versus AADT, but there is nothing obvious in the others.

6 The graphs of differences versus site type (ie figure 4.30, figure 4.37 and figure 4.44) are included for comparison with the graphs of slope versus site type (ie figure 4.25, figure 4.32 and figure 4.39). Given that we are looking at individual differences rather than slopes, which, in effect, represent an average of differences, the two sets of graphs are fairly consistent with each other.

5 Review of maintenance strategies

As has been discussed above, the numerical data available to undertake a statistical analysis to identify factors that need to be present for accelerated condition trending was not sufficiently robust. It was not possible to find significant and useful correlations with this dataset.

This chapter now describes a manual investigation undertaken to investigate in detail some of the sites highlighted by the statistical analysis, and to interpret site photographs, site notes and construction records. Manually populated tables then give engineering reasons for the anomalies highlighted by the statistical software. Improvement strategies are suggested for the future collection and management of LTPP data.

5.1 Normal and sterilised sites

A review of the maintenance strategies applied to the normal and sterilised sites reveals a possible lack of understanding by regional personnel on how to manage the differing maintenance requirements of the two benchmark site classifications. In some regions it appears that both normal and sterilised sites have been treated similarly. This includes not repairing maintenance defects in a timely manner on normal sites, addressing more than just safety defects on sterilised sites and often using low-cost inappropriate maintenance repairs on both the normal and sterilised sites. This means the deterioration and maintenance repair data collected on the sites has a degree of ‘contamination’ which makes pure statistical analysis of measured data and the interpretation of deterioration trends difficult. There is still the ability to use the data to compare pavement performance but this needs to be done carefully by identifying maintenance activities that may have distorted the data.

Improvement strategy one

To improve the quality of the data going forward there is a need for regional staff in the transport sector to be very clear about the difference between normal and sterilised sites and to apply the documented maintenance strategy that applies to each ensuring that an accurate record of maintenance activities is maintained. The maintenance approval system currently required for sterilised sites could be extended to cover normal sites also.

5.2 NZ Transport Agency LTPP database completeness

It appears the NZ Transport Agency LTPP database has not always been kept up to date so the available disk containing the years of data is not complete. This has made the review of the statistical analysis more difficult as useful information has not been readily available. There does not appear to have been the level of interest and attention to detail needed by the management, surveillance and quality assurance consultants and or NZ Transport Agency LTPP data managers at some stages in the past to ensure the accuracy and completeness of the LTPP database.

Improvement strategy two

Approach the survey contractor to provide a replacement copy of any data missing from the current database so that a complete record of all data recorded to date is available for statistical analysis and review.

Improvement strategy three

Clause 8.4 of the LTPP contract NO 09-543 (NZ Transport Agency 2009) requires a minimum of four photographs that show the site in relation to the surrounding landscape are taken to correctly identify the site. However the additional photographic record of the distress at the sites recorded each year by the survey contractor are extremely valuable for research and should be specified as a requirement under the contract. The specification should detail what photographs are to be taken and how they are to be catalogued. Again an approach should be made to the survey contractor to provide a copy of the annual photographs taken to date where these are missing from the current database. The use of the high-speed video for year-on-year comparisons is very valuable but the quality of the video has shown to be lacking when reviewing detail of specific distress.

5.3 Completeness of the RAMM database

Searching for pavement and surfacing history for the normal and sterilised sites has shown there are significant gaps in the pavement and surfacing records for these sites in the NZ Transport Agency RAMM database. This makes it more difficult to compare sites and to understand why some sites are performing the way they are. There appears to be real difficulty in getting correct yearly renewal data entered into RAMM and then have this information remain correct and accurate within the database going forward.

Improvement strategy four

It would be much easier to find and interrogate RAMM data if the normal and sterilised sites were separate treatment lengths within each network's forward work programme. It would also appear sensible that all pavement and surfacing renewals cover the total site rather than part of the site.

Improvement strategy five

There should be time committed for someone with the required technical skills to review the pavement and surfacing RAMM records for each site to ensure they are realistic, accurate and as complete as possible.

5.4 Timing, type and quality of maintenance repairs

The timing, type and quality of maintenance repairs has caused some 'contamination' of the pavement performance data.

5.4.1 Timing of maintenance repairs

Pavement and surfacing distress has been left for too long on some normal sites before maintenance repairs have been completed. This has two impacts:

- The data records pavement distress for a longer period than is necessary.
- There is the potential for the ingress of water to extend the area of failure beyond what it would have been if repairs were completed at the right time.

Conversely it appears some low-risk distress has been repaired on sterilised sites so the natural progression of distress over time has not been observable.

CAL-54 (SH30 RP 147/8.06 – 8.36) is a good example of cracking that was not programmed to be repaired in a timely manner for pavement preservation. In 2007 minor fatigue cracking and pumping of fines had developed. This progressed into a pothole in 2008 and then further into a pavement failure that was repaired in 2014. It also shows a significant increase in cracking following water cutting.

Table 5.1 records the survey contractor's visual comments about the distress evident at the site and has a reference to photographs taken annually by them. See appendix A for a copy of the photographs.

Table 5.1 Visual comments by the survey contractor of distress evident at the site

Visual comment	Date	Year	Photograph (appendix A)
Some cracking has developed in section 5 of the decreasing lane. The remainder of the site remained basically the same as last year.	19 January 2007	2006/07	Figure A.1
Rotorua airport site has not really changed. It is in pretty good condition but a bit flushed in places. Some cracking at the start (transverse) of the increasing lane and in section 5 of the decreasing lane.	22 November 2007	2007/08	Figure A.2
The site is quite badly flushed and has some chip loss. Two structural failures, one at loc2i and one at loc20d have formed. (Note: although the photograph shows the increasing direction the location of the photograph is actually in the decreasing direction.)	21 November 2008	2008/09	Figure A.3
A 5 m section of alligator cracking has developed in SS1 of the increasing lane, and there is some chip loss in the right wheelpath. Increased flushing and the structural failure identified previously are the only visible defects in the decreasing lane.	06 December 2009	2009/10	Figure A.4
The cracking and surface defects identified previously (Loc2I and Loc21d) look to have deteriorated further but the remainder of the site seems in reasonable condition and relatively unchanged. Note this site has a lot of heavy trucks and logging trucks.	02 November 2010		Figure A.5
A large surface or structural failure is developing in SS6, and the failure in SS5 looks to have increased. The chip loss does not look to have changed.	15 October 2011	2011/12	Figure A.6
The large surface or structural failures previously identified in SS5 & 6 have deteriorated and increased in size, and the cracking in SS1i has been partially sealed. The chip loss does not seem to have changed.	31 October 2012	2012/13	Figure A.7
This site has been scrubbed to remove all the excess binder and this has exposed extensive cracking in the left wheel path of the decreasing lane and some minor cracking in the left wheel path of the increasing lane. The site looks clean and fresh but has a lot of cracking. The decreasing lane in particular is extensively cracked in the left wheel path including the structural patch in SS1d. (Note: this activity is described as 'water blasting' in the RAMM 'Maintenance cost' table which does not have any record of water blasting being completed at this calibration site. Some water blasting to address SCRIM exceptions may have been completed at the site but should have been recorded in the RAMM maintenance cost table. The photographic record appears to confirm that no water blasting was completed in the decreasing lane in SS5.)	17 October 2013	2013/14	Figures A.8 and A.9

Visual comment	Date	Year	Photograph (appendix A)
This site has had some major structural repairs, some of which have significant cracking. Some have been spot patched and others have small potholes. The decreasing lane is lightly flushed in SS1-3 and moderately flushed in SS4. There is chip loss along the road edge but this is in a previous seal not the current wearing course.	05 November 2014	2014/15	Figure A.10
This site had some structural repairs, some of which have significant cracking, combined with multiple spot patches and some small potholes. The decreasing lane is lightly flushed in SS1-3 and moderately flushed in SS4. There is chip loss at various locations but this is predominantly confined to the road shoulder	29 October 2015	2015/16	Figure A.11

Improvement strategy six

Once improvement strategy one has been firmly embedded in local LTPP management, ensure the timing of maintenance repairs fits with the maintenance management strategy for each site.

5.4.2 Type of maintenance repairs

It appears that often an LTPP 'do minimum' mentality exists around the type of maintenance repairs that are appropriate to address pavement failures on both normal and sterilised sites. The repairs are often small, low cost and inappropriate for genuine pavement repair. These repairs often include:

- Thin in-situ cement stabilised repairs that fail again often within months of completion. Time of year, cement application rates, depth of the repair and moisture in the pavement can all contribute to early failure. This type of pavement repair failure is quite evident in the survey contractor's notes and site photographs.
- Thin asphalt surfaces. This repair method appears to be used without first knowing the strength of the pavement on which it is being constructed. The result is that an area of cracking larger than existed just prior to the completion of the repair often develops quite quickly and statistically shows an increase in cracking even though a maintenance repair has been completed. Again this type of pavement repair failure is quite evident in the survey contractor's notes and site photographs.

Figure 5.1 CS- 36 SH2 RP 858/9.00 – 9.30 increasing direction

Figure 5.1 shows an example of a pavement repair surfaced with a thin asphalt surface that has extensively cracked. The repair is not recorded in the RAMM maintenance cost table but appears to have been completed in 2005 and is showing significant cracking in the December 2007 photograph.

There are a number of possible reasons for the failure of this repair:

- The pavement deflections at 1,502 μm are too high for a thin asphalt surfacing.
- The pumping of basecourse fines suggests a water proofing seal between the basecourse and the asphalt may have been left out.

A review of the site notes and photographic record show there may be a link between water cutting (referred to as 'scrubbing' in the notes) and accelerated cracking of the surface on LTPP sites.

This is the note recorded for CAL-54 2013:

> *This site has been scrubbed to remove all the excess binder and this has exposed extensive cracking in the left wheel path of the decreasing lane and some minor cracking in the LWP of the increasing lane. The site looks clean and fresh but has a lot of cracking. The decreasing lane in particular is extensively cracked in the left wheel path including the structural patch in SS1d.*

This is the note recorded for CS-42 2009:

> *Structural A/C patches at 160 m and 280 m in the increasing lane appear to have sunk and are below the existing surface, edge cracking at the joins between the old and new seal have formed. The decreasing lane has been scrubbed and cracking in the inner wheelpath of the decreasing lane is evident particularly along the road edge from 120 m to 240 m.*

And in 2010:

The site has a lot of cracking especially along the edge of the left wheel path in the decreasing lane. The A/C patches in the increasing lane were sealed with a fine grade chip but most of this has been lost. Overall a slight deterioration in condition.

A quick review of 'scrubbing' in the annual LTPP site notes is given in table 5.2, which shows that six of the 10 water-cut sterilised sites and six out of seven water-cut unsterilised sites failed within the next two years.

Table 5.2 Performance of water cutting

LTPP sites	Number of sites water cut	Cracking next inspection	Cracking or failures <2 years following
Sterilised	10 (2 TLA)	5	1
Unsterilised	7 (1 TLA)	5	1

Improvement strategy seven:

Ensure the maintenance repairs approved at LTPP sites are appropriate for the pavement type and strength at the site. Consider alternative treatments to water cutting if there is a risk that water cutting will cause unnecessary failure in vulnerable weaker pavements.

5.4.3 Quality of maintenance repairs

The quality and ride of some maintenance repairs is influencing the data over a period of years at some sites as they continue to show an increase in roughness and cracking after the completion of maintenance repairs where they should be showing a reduction in distress.

There are two reasons for this:

- poor maintenance treatment selection
- poor construction practices.

Treatment selection has been partially covered in section 5.4.2 above under inappropriate repair types.

Figure 5.2 is an example of a poor-quality repair completed on a calibration site. This is in fact the third repair at this exact location. The RAMM maintenance cost table records a 105 m^2 digout completed at this site on 14 March 2013, a 112 m^2 digout completed on 12 September 2013 and a 131 m^2 in-situ stabilising repair completed on 5 April 2016. This photograph was taken on 5 December 2016. (RAMM data also shows the other larger repair at this site, currently in a similar state to this, has been dug out three times and subsequently in-situ stabilised.)

Figure 5.2 CAL- 58 SH38 RP 0/16.83 – 17.13 Decreasing direction

This site (figure 5.2) is a very good example of where poor maintenance repairs for whatever reason have dramatically affected the site data showing a dramatic reduction in pavement performance after spending a large amount of money on maintenance repairs. A total of $42,838.85 has been spent on pavement and surfacing repairs in the decreasing direction since 2011/12.

Poor designs have also contributed to the failure of chipseals on maintenance patches and also of some chipseal renewals. Incorrect seal selection to accommodate the existing texture or incorrect binder and chip application rates contribute to either flushing or chip loss. Poor repair reconstruction has led to failed rough repairs which are all too common in both calibration and sterilised sites.

Extracts from the LTPP survey contractor's site notes reveal documented issues with the quality of maintenance repairs, as shown in table 5.3. It should be noted that all these sites are 'un-sterilised', ie normal maintenance practice should have been applied.

Table 5.3 Extracts from the survey contractors site notes regarding maintenance quality

Site	Date	Site note
CAL-19	04/11/2003	'...decreasing lane, this lane has had a large patch repair in the decreasing lane at about 200 m, this repair has not been done very well and is deteriorating quite badly and will affect the roughness in the 50 m section. The patch at the start is also deteriorating quite badly...'
CAL-19	16/11/2012	'There is a large cement stabilised repair in the decreasing lane from 30–100 m which has started to fail....'
CAL-32	15/01/2003	'Several very large patches some new since last year which have already started to crack.....'
CAL-34	09/11/2011	'Cracking evident prior to the reseal some two or three years ago is again visible on the new seal...'
CAL-34	01/11/2013	'The site has moderate flushing throughout, the bulk of the cracking identified last year is unchanged; however, the structural failure at 150 m has deteriorated significantly and there is now a 100 mm rut and shove along with severe cracking. This has increased the rutting in 150 and 200 m subsections.'

Site	Date	Site note
CAL-34	16/11/2014	‘The site is moderately flushed throughout, the bulk of the cracking identified last year is unchanged. However, the structural repair at 140–160 m has failed or is failing (cracking). The repair reduced the rutting in the structural failure but increased the roughness in both SS3 and SS4.’
CAL-35	17/12/2014	‘There has been a considerable amount of work done on this site, the section from 70–190 m has had an OG A/C overlay to fix the subsidence problem and the section from 300–400 m has been resealed. (Note this affected the decreasing lane only). The A/C patches in the decreasing lane are badly cracked.’
CAL-38	21/01/2012	‘The structural repairs to the decreasing lane in subsections 4 and 5 last season are failing, cracking and potholes have been patched and the cracking at the beginning of the lwp increasing lane is much the same. The rest of the site remains unchanged.’

Improvement strategy eight

Apply improvement strategy one. Also ensure the quality of maintenance repairs is improved through appropriate design and reconstruction practices, for example not just defaulting to 150 mm stabilisation repairs or thin AC surfaces. Ensure there are inspection audits of designs and completed repairs on all LTPP sites.

Improvement strategy nine

Consider establishing a code to mark data where the data collection contractor believes the results have been adversely impacted by poor maintenance repairs. This would provide a flag and allow the data to be individually screened during analysis.

5.5 Walking profilometer

The analysis of the data has highlighted a new question on the use of the walking profilometer to measure roughness (reported in units of IRI) as it possibly leads to some confusion when completing the pure statistical analysis in Chapter 4. It is possible the walking profilometer measurements may also be influenced by macro texture change. If so, a new reseal with higher macrotexture may show an increase in ‘roughness’ compared with what existed before. This roughness progressively reduces over time as the chip re-orients and the texture in the new seal reduces.

Block cracking, pavement repairs and depressions should be expected to contribute to an overall increase in roughness. However the walking profilometer also showed an increase in roughness with on-going scabbing in a chipseal which is a useful indicator of surface deterioration.

The set out line for the walking profilometer does not always fall in the centre of the wheel paths and in some instances is near the edge of the wheel path. It is uncertain how much this roughness profile might differ from what might be measured in the centre of the wheel path.

Improvement strategy ten

Review the measurement location of the walking profilometer in terms of its location within the wheel path and what impact this has on the derived IRI.

5.6 Crack definition and identification

Following a close review of the LTPP database, there appears to be differing interpretation of some crack types that adds a level of confusion in the analysis of the crack data. Correct identification and recording of cracking will help with data analysis and reviewing crack development and progression. The LTPP contract NO 09-543 (NZ Transport Agency 2009) has quite clear definitions and causal factors for cracking. Table 5.4 is an extract from the contract document.

Table 5.4 Definition of distress modes (NZ Transport Agency 2009)

Distress mode	Definition	Mode of failure
Alligator cracks	These are numerous cracks closely spaced and mostly occurring in the wheel tracks. This is often associated with secondary distress mechanisms such as shoving.	Load associated, therefore caused by fatigue of pavement layers.
Transverse cracks	As the name indicates, these are oriented perpendicular to the centreline. Many attributes exist but have the common causing factor of relative movement in the pavement layers.	Three known causes including thermal, movement in the subgrade due to clay activity and vegetation next to road.
Longitudinal cracks	Cracks running parallel to the centreline.	In many cases a result of construction joints or resulting from multiple lifts during construction.

It would appear that early signs of fatigue cracking in some cases is being rated as longitudinal or transverse cracks where these appear as meandering cracks rather than numerous interconnected cracks. Brown et al (2015) have previously reported that single transverse or longitudinal cracks would over time develop and form an area of alligator cracking. The mode of failure in table 5.4 is clear that where the cracking is load associated and caused by fatigue of the pavement layers the crack definition should be alligator cracking. However the definition refers to *numerous cracks* which is somewhat misleading as the earliest signs of fatigue cracking may appear as single or meandering cracks. It would appear logical then to rate all fatigue cracking caused by pavement deflections in areas of weak pavement as alligator cracking as the reason for crack development is the same.

Transverse and longitudinal cracking are more commonly a result of shrinkage in bound or semi-bound pavements or are cracks that have reflected through the surface layer from underlying pavement joints. These include adjoining pavements of differing strengths such as seal widening, trenches and repairs or failure at pavement construction joints.

A document that provides some helpful direction on crack definitions is the *Austroads guide to pavement technology, part 5: pavement evaluation and treatment design* (Austroads 2011). It contains a photograph of each crack type, a good description of each crack type and the most likely causal reasons. This is very helpful in understanding the types of cracking that appear in various pavement types.

While manually examining the LTPP database to identify the crack types recorded it appears some cracks that have a photographic record are missing from the database or have been assigned an incorrect location. This may have been a coincidence on one of the sites looked at and have little impact on the accuracy of the data as a whole, but the actual extent is unknown. (An example of missing or misplaced data is seen in photographs ‘cs36_07_loc 3-4d cracks’ and ‘cs36_07_loc 4-5d cracks’ taken on the 7 December 2007 but where no cracking is recorded under any crack type in records 9124 and 9125 on the 50 m rating table in the Transport Agency LTPP data.)

Improvement strategy eleven

Review all crack types observed on roads in New Zealand, their description and most likely causal factors and review if changes are appropriate in the way cracking is visually assessed and recorded on LTPP sites.

Improvement strategy twelve

It may be appropriate to assign a code to each surfacing and pavement type as they perform and deteriorate differently. This could provide guidance to the likely distress types that may develop at each site, eg shrinkage and block cracking will most likely occur on semi bound pavements. Using a coding system could then make analysis of 'like' pavements easy as well as comparing the performance between different pavements and surfacing types. Coding could also be useful to group SH and TLA sites based on traffic volume and speed environment.

Improvement strategy thirteen

Complete annual audits of the LTPP database to ensure the accuracy of entered data.

5.7 Crack progression and treatment type and timing

One of the important questions concerning LTPP is trying to understand crack progression, how quickly cracks grow and how quickly the various crack types need to be repaired in order to maximise pavement life until rehabilitation.

Normal site CAL-54 (SH30 RP 147/8.06 – 8.36) was selected as a case study to examine the progression of fatigue cracking that was not programmed for repair in what most maintenance engineers would consider to be a timely manner for pavement preservation.

Table 5.1 from section 5.4.1 explains crack progression on this particular site.

The photographs referred to in table 5.1 can be seen in appendix A.

This site carries an AADT of 10,437 with 11% of that HCVs. The site has FWD readings between 860 and 2,075 and SNP between 1.02 and 3.06 in the decreasing lane. (The deflection and SNP at location 21 decreasing are 2,075 and 1.02.) This shows an area of weaker pavement and is the likely cause of the fatigue cracking evident at the site. There does not appear to be any test pit information available for this site and it would be interesting to know why this cracking has progressed at such a slow rate. It is likely that the pavement materials are quite free draining and have very low moisture sensitivity.

This does provide an interesting example of crack progression as this was first recorded as a small patch of fatigue cracking on 19 January 2007 and repaired using a digout repair on 19 November 2013. This would suggest that although this pavement was cracked and pumping some fines it was able to remain in a safe condition for at least 6 years 10 months. Interestingly, a photograph of cracking pumping fines in the first coat of the digout is recorded on 5 November 2014 and a pothole repair completed on 21 September 2015.

This case study then raises some questions regarding this specific failure:

- What type of repair should have been completed in this area of cracking?
- When should the repair have been completed?
- Did the years of water getting into the pavement cause the cracking and seal failure in the digout (clearly visible in the site photographs) or was it more related to poor reconstruction?

5.8 Performance of different pavement and surfacing types

As alluded to in *Improvement strategy eleven*, different pavement types perform differently, different surfacing types perform differently as do various combinations of the two. The long-term performance of these sites will also be influenced by the age and strength of both the pavement and the surfacing. To help with this review a simple spreadsheet was compiled, using the SH sites only, to look at the age of the pavement from RAMM, the age and type of the surfacing from RAMM, the daily traffic and percentage of heavy commercial vehicles, what and when surfacing renewals were applied and how many sites had deteriorated to the point of needing a full area-wide pavement renewal. It was felt this would provide insight into the availability and reliability of RAMM pavement and surfacing history (section 5.3) and provide an easy view of the general history of each site. It could also provide insight into the regional understanding of the two LTPP site classifications and the maintenance strategy adopted for each.

This spreadsheet is shown as table 5.5.

Table 5.5 LTPP surfacing and pavement renewals from the RAMM database

LTPP Surfacing and Pavement Renewals

Site	SH	RS	Start	End	AADT	% HCV	Pavement old	Pavement new	D Brown Flag	Earlier seal	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CS-1	1	292	0.70	1.00	10458	4	1981	2009	Rehab 0-90m 2002	OGPA - 1998			OGPA		3/5 two					3/5 two 1st							
CS-2	1	319	13.30	13.60	8651	8	1993			3 1chip 1998								3/5 two									
CS-3	1	245	6.35	6.65	9706	6	1938?			2 1chip 1999															2/4 two		
CAL-4	12	17	14.39	14.69	1348	4	1993	2004		3 1chip 1997					2 1chip 1st						5 VF 2nd						
CAL-5	12	185	10.45	10.75	1751	5	1998			2/5 two 1999 2nd				5 VF												2/4 two	
CAL-6	1	20	10.50	10.80	323	4	1995			3 1chip 1999																	
CS-7a	1 inc	431	1.00	1.30	81990	8	1966?		Rehab 2008	OGPA - 1997								OGPA									
CS-7b	1 inc	431	1.95	2.25	81990	8	1963?			OGPA - 1997								OGPA									
CS-8a	1 inc	461	3.10	3.40	17590	9	1975?		Rehab 2010	OGPA - 1997					OGPA						OGPA 50%	OGPA 50%					
CS-8b	1 inc	461	3.70	4.00	17590	9	1975?		Rehab 2010	OGPA - 1997					OGPA						OGPA 50%	OGPA 50%					
CS-11	1	625	7.20	7.50	8500	4	1990 66%	2009	Rehab 2009	5 1chip 1999										2/4 two 1st	5 VF 2nd		3/5 two				
CAL-12	5	169	7.20	7.50	3700	10	1993?			5 VF 1997		3 1chip															
CS-13a	1	777	3.20	3.50	3500	10	1991			3 1chip 1993	3 1chip																
CAL-13b	1	777	3.88	4.18	3500	10	1991			3 1chip 1993	3 1chip				3/5 racked												
CAL-53	5	29	1.40	1.70	5200	10	1984?			5 VF 1996		3/5 two														2/5 racked	
CAL-54	30	147	8.06	8.36	11085	4	1984?			3/5 two 1996			2/4 two														2/5 two
CS-14	29	50	0.55	0.85	4464	10	?	2005?	Rehab 2005	3/5 two 1997							? 1st	3/5 two 2nd									2/4 two
CS-16	1 inc	574	4.00	4.30	13800	11	?	2011?	O/L 2008, 11, 13	3 1chip 1998												2/4 two 1st		SMA 2nd			
CAL-17	2	0	5.00	5.30	13500	11	1985?			3 1chip 1999													5 VF				
CAL-18	3	36	1.60	1.90	6057	4	1998			3 1chip 1998 2nd														3/5 two			
CAL-19	3	16	13.50	13.80	10426	6	?	2013?	Part Rehab 2013	2/4 two 1998						2/4 two								3/5 two 1st	3/5 two 2nd	3/5 two 1st	5 text 2nd
CS-20	31	0	5.40	5.70	2150	15	?	2004?	Site changes 2004	?					2/4 two 1st	4 1chip 2nd		3 1chip									
CS-21	35	250	10.15	10.45	1105	10	?	2011?	Part 2003, Full 2011	?												2/4 racked 1st		5 VF 2nd			
CS-22	2	375	1.16	1.56	994	18	1990			2/4 BS 1999																	
CAL-23	2	474	5.30	5.60	1649	18	1985			2 1chip 1996							2/4 two										
CS-24	2	544	12.60	13.10	1448	18	1988			2 1chip 1997																	
CAL-25a	2	729	8.80	9.10	4314	13	1955?	2008?	Rehab 2008	2 1chip 1996									3/5 racked 1st		5 VF 2nd						2/4 racked
CAL-25b	2	729	9.10	9.40	4314	13	1955?	2011	Rehab 2011	5 text 1993?												3/5 racked 1st		2/4 racked 2nd			
CS-26	5	204	14.20	14.50	2825	17	1960?			3 1chip 1993													3/5 BS				
CAL-27a	5	233	10.00	10.30	3996	17	1996?			2/5 two 1996 2nd																	
CAL-27b	5	233	10.30	10.60	3996	17	1996?			2/5 two 1996 2nd																	
CS-28	1	815	11.80	12.10	4729	10	?	2006	Resealed?	?							2/4 racked 1st		5 VF 2nd						2/4 racked		
CS-29	4	127	8.40	8.70	1867	12	1955?			2 1chip 1992																	
CAL-30	4	223	3.10	3.40	1938	8	1979			5 text 1997				3 1chip													
CS-31	1	985	0.60	0.90	14831	8	1957?			3 1chip 1991	2 1chip										2/4 racked						
CAL-32	2	751	4.52	4.82	3955	15	?	2005	Rehab 2005							3/5 two 1st		5 VF				3/5 racked					
CS-33	3	258	4.10	4.40	8096	5	1994			2 1chip 1994 2nd																	
CAL-34	45	97	5.10	5.50	3807	10	1987			5 VF 1999										3/5 racked							
CAL-35	1	995	14.40	14.70	14394	4	1959?			2 1chip 1992															mix10 + OGPA		
CS-36	2	858	9.00	9.30	3183	5	?			5 1chip 1997	3 1chip													3/5 two 18%			
CAL-37a	63	46	4.70	5.00	541	5	1976			3 1chip 1999																	
CAL-37b	63	46	5.50	5.80	541	5	1976			3 1chip 1999																	
CAL-38	15	18	1.50	1.80	6195	12	1951			2 1chip 1998																	
CS-39	6	131	16.15	16.45	3275	12	1984?			5 VF 1998														3 1chip			
CS-40	6	225	10.00	10.30	1718	13	1950?			5 VF 1992												3/5 two					
CAL-41	15	284	7.80	8.10	6741	11	1978?		Rehab 0-50m 2003	4 1chip 1993			3/5 racked														
CS-42	73	90	2.50	2.80	1549	15	1964?		Rehab 2015?	5 text 1997		3/5 two													3/5 two		
CAL-43	15	447	4.50	4.80	5805	15	1938?	2010	Rehab 2011	5 VF 1998	5 VF				3 1chip						3/5 two 1st			3/5 racked 2nd			
CS-44	8	99	4.00	4.30	1194	13	1961?			3 1chip 1990																	
CAL-45a	6	445	12.70	13.00	2716	8																					
CS-45b	6	445	13.10	13.40	2716	8																					
CS-46	7	239	3.00	3.30	1077	18	?			3 1chip 1993																	
CAL-48	15	618	9.10	9.40	3794	6	1980?			5 text 1997										4/6 two							
CS-49	15	729	12.00	12.30	5508	6	1966?	2011	Rehab 2012	?												3/5 two 1st	2/4 B/S				
CS-50	15	817	3.10	3.40	1655	5	1984?			3 1chip 1994						5 1chip 2nd 50%						3/5 B/S					
CAL-51	8	417	2.50	2.80	1402	10	1950?	2002 50%	Rehab 2002	3 1chip 1996			3/5 two 1st 50%	3 1chip													
CAL-52a	83	0	4.00	4.30	1343	12	1941?			3 1chip 1993			4/6 two														
CS-52b	83	0	4.60	4.90	1343	12	1941?			3 1chip 1993			4/6 two														
CS-55	5	77	11.70	12.00	4662	10	1984			3 1chip 1990	5 VF				3/5 racked								2/4 two				
CS-56	30	131	4.40	4.70	2804	15	1984			3 1chip 1996						2/4 two								2/4 two			
CS-57	30	170	9.10	9.40	3960	11	1984			2/4 two 1999											2/4 two 50%		3/5 two 50%				
CAL-58	38	0	16.83	17.13	2286	18	1984			5 1chip 1998		2/4 two															
CAL-59a	5	45-I	2.00	1.52	10431	4	1984			Mix10 1995																	
CAL-59b	5	47-D	1.22	1.52	10423	4	1984			Mix10 1995																	

Some conclusions to be drawn from table 5.5 are:

1 A significant amount of the original pavement data is inaccurate (for dTIMS calibration modelling data would have had to be assumed) or does not exist in RAMM.

2 Some post-2000 pavement and surfacing data in RAMM is missing or incorrect.

3 The pavement age is not necessarily a good indicator of when a pavement renewal will be required. However this is difficult to evaluate given the amount of missing or incorrect data.

4 On sound pavements the surfacing type, available maintenance options and speed environment seem to influence the surface life more than traffic volume and loading, eg open-graded porous asphalts have only achieved short lives (six to seven years) in a 100 km/h speed environment, whereas dense mix10 asphalt in a 60 km/h speed environment may achieve 21 years. This is an example of the value of categorising sites as the onset of deterioration and type and timing of repairs can be very different for similar but different surfacing types.

5 The simple spreadsheet also shows:

   a Of the 33 sterilised sites, 10 or 30.3% have been rehabilitated.

   b Of the 31 calibration sites, 7 or 22.6% have been rehabilitated.

This simple view of the sites does not account for any sites that may have been removed or replaced since the 1 March 2009 schedule of sites was compiled except to split site CAL-59 into CAL-59a Increasing direction and CAL-59b decreasing direction. This would suggest the rehabilitation rate of sterilised sites is higher than for calibration sites and is an expected result. Intuitively you would expect the gap between the rehabilitation percentages to be wider but it is likely the maintenance mismanagement has brought them closer together.

6 Discussion

Following a detailed analysis, it was found that numerical data available to undertake a statistical analysis to identify factors that need to be present for accelerated condition trending was not sufficiently robust. It is not possible to find useful or significant correlations with this data set as it stands. This in itself is a major outcome of this research.

Expected useful life estimation was not reliable because the slope on the regression varies too much from site to site and in the case of roughness isn't much different from zero.

The data was insufficiently accurate or complete to undertake a sufficiently robust statistical analysis to identify or suggest what factors need to be present for accelerated condition trending to take place.

This also brings into question the data that was used to derive the dTIMS models

It was decided that rather than pursue further automated processing of data, a manual investigation by a person with extensive experience in road engineering and maintenance was undertaken. This investigated engineering explanations for the sites highlighted by the statistical analysis, which involved interpreting site photographs, site notes and construction records. A table was then compiled manually citing the engineering reasons for the anomalies highlighted by the statistical software. This proved to be a time consuming and would be an expensive process to repeat regularly

A significant amount of important data is scattered within the notes filed, photographs, which is time consuming to extract under the current data structure.

With regard to cracking, accurate tracking of individual crack development over time using existing methods is expensive and time consuming to both collect and then analyses. Visual analysis also has limits of precision, and the timing of crack mapping needs to be considered, for example dry or wet, summer or winter? There is also the likelihood that once a chipseal is flushed, some cracks will self-heal.

7 Conclusions

- This review was unable to identify any reliable data to show that pavements displaying cracking are at a higher risk of failure.
- The review does suggest, however, that the current selection of maintenance treatment type and the quality of maintenance and reconstruction practices may assist in making the level of service worse after maintenance, manifest as rutting and cracking after a very short time, compared with sterilised sites where maintenance is not undertaken.
- There is much scope available to improve the quality of the data in the LTPP and the RAMM databases. The data could be restructured to be more compatible with smart computing and machine learning (artificial intelligence) to make the extraction of meaningful results more affordable and hence more frequent.
- The maintenance practice of water cutting also needs to be carefully considered, as this may contribute to a more rapid deterioration in pavement condition. See section 5.4.2 'Type of maintenance repairs'.

8 Recommendations

The value of maintaining an LTPP project is fully supported. The following are recommendations on how the dataset could be restructured to provide additional benefit. Some of these recommendations can be achieved earlier than others while some may have greater impact than others. However, these recommendations as a composite are believed to useful in improving the value of the LTPP database for the benefit of future research.

8.1 Intermediate term

8.1.1 Smart computing

Analyse and reorganise the LTPP data arrangement by smart computing specialists to enable data imputation through:

- data cleansing
- image analysis (eg crack mapping, site photographs)
- machine learning
- incorporation of ‘big data’

to remove the reliance on resource-consuming human analysis.

8.2 Short term

8.2.1 Maintenance data

Populate the LTPP database ‘NZTA_LTPP_working.mdb’ with the maintenance data used to prepare figure 4.9. (This data was kindly provided by the survey contractor).

8.2.2 Speed zone data

Populate the LTPP database ‘NZTA_LTPP_working.mdb’ with the speed zone data used to prepare figure 4.11. (This data was kindly provided by the survey contractor).

8.2.3 Linear positions

Update the fields recording the positions of the LTPP sites in the RAMM LTTP table with linear positions calculated from the survey contractor’s GPS coordinates.

8.2.4 AADT data

Ensure the date for the AADT data in table ‘CAL_SEC_TRAFFIC_DATA’ of ‘NZTA_LTPP_working.mdb’ is the same for all LTPP sites. (The current situation of having a different ‘RecordedDate’ for many LTPP sites makes robust analysis an issue.)

8.2.5 Soil moisture sensitivity

With reference to the five ‘soil moisture sensitivity’ categories, as the number of sites classified as ‘moderate’ is very small, this category should probably be amalgamated with another category.

8.2.6 Enforce the maintenance differences between normal and sterilised sites

To improve the quality of the data going forward there is a need for regional staff (Transport Agency contract managers and maintenance contractors, including their consultants) to be very clear about the difference between normal and sterilised sites and to apply the appropriate maintenance strategy that applies to each. There will need to be a re-designation of some sterilised sites to non-sterilised where significant maintenance has changed the normal deterioration of the pavement at the site. Additional sterilised sites may be required to meet the shortfall in sterilised sites.

8.2.7 Missing data

Request the survey contractor to provide a replacement copy of any data missing from the current database so a complete record of all data recorded to date is available for statistical analysis and review. A view only copy of all LTPP data should also be available on RAMM.

8.2.8 Photographs

Clause 8.4 of the LTPP contract NO 09-543 (NZ Transport Agency 2009) requires that a minimum of four photographs showing the site in relation to the surrounding landscape are taken to correctly identify the site. However the additional photographic record of the distress at the sites recorded each year by the survey contractor are extremely valuable for research and should be specified as a requirement under the contract. The specification should detail what photographs are to be taken and how they are to be catalogued. Again an approach should be made to the survey contractor to provide a copy of the annual photographs taken to date where these are missing from the current database.

8.2.9 Separate treatment lengths

It would be much easier to find and interrogate RAMM data if the normal and sterilised sites were separate treatment lengths within each network's forward work programme. It would also appear sensible that all pavement and surfacing renewals cover the total site rather than part of the site.

8.2.10 Technical review of RAMM records for each LTPP site

There should be time committed for someone with the required technical skills to review the pavement and surfacing RAMM records for each site to ensure they are realistic, accurate and as complete as possible.

8.2.11 Timing of maintenance repairs

Ensure the timing of maintenance repairs fits with the maintenance management strategy for each site.

8.2.12 Water cutting

Ensure the maintenance repairs approved are appropriate for the pavement type and strength at the site. Consider the use of alternative treatments to water cutting on vulnerable weaker pavements where accelerated pavement deterioration is likely to occur if the surplus binder is removed allowing greater access for water to enter the pavement.

8.2.13 Appropriate maintenance treatments

Ensure the quality of maintenance repairs is improved through appropriate design and reconstruction practices, for example not just defaulting to 150mm stabilisation repairs or thin AC surfaces. Ensure there are inspection audits of designs and completed repairs on all LTPP sites.

8.2.14 Known poor maintenance repairs

Consider establishing a code to mark data where the data collection contractor believes the results have been adversely impacted by poor maintenance repairs. This would allow easy identification of this data during analysis.

8.2.15 Walking profilometer

Review the measurement location of the walking profilometer in terms of its location within the wheel path and what impact this has on the derived IRI.

8.2.16 Crack assessment

Review all crack types observed on roads in New Zealand, their description and most likely causal factors and review if changes are appropriate in the way cracking is visually assessed and recorded on LTPP sites.

8.2.17 Surfacing and pavement codes

It may be appropriate to assign a code to each surfacing and pavement type as they perform and deteriorate differently. This could provide guidance to the likely distress types that may develop at each site, eg shrinkage and block cracking will most likely occur on semi bound pavements. Using a coding system could then make analysis of ‘like’ pavements easy as well as comparing the performance between different pavements and surfacing types. Coding could also be useful to group SH and TLA sites based on traffic volume and speed environment.

8.2.18 Accuracy audit

Complete annual audits of the LTPP database to ensure the accuracy of entered data.

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Appendix A: LTPP site maintenance

Figure A.1 Photograph 1, CAL- 54, 19 January 2007, loc 20- 21d flushing and cracking

Figure A.2 Photograph 2, CAL-54, 22 November 2007 loc 20-21d flushing and cracking

Figure A.3 Photograph 3, CAL- 54, 21 November 2008 loc 20- 21d flushing and cracking

Figure A.4 Photograph 4, CAL-54, 6 December 2009 loc 20-21d flushing and cracking

Figure A.5 Photograph 5, CAL-54, 2 November 2010 loc 20-21d flushing and cracking

Figure A.6 Photograph 6, CAL- 54, 15 October 2011 loc 20- 21d flushing and cracking

Figure A.7 Photograph 7, CAL- 54, 31 October 2012 surface patch loc 20d

Figure A.8 Photograph 8, CAL-54, 7 October 2013 loc 20-21d flushing and cracking

Figure A.9 Photograph 9, CAL-54, 17 October 2013 loc 20-21d flushing and cracking

Figure A.10 Photograph 10, CAL- 54, 5 November 2014 loc 20- 21d cracking in the 2014 maintenance repair

Figure A.11 Photograph 11, CAL- 54, 29 October 2015 loc 20- 21d cracking and patching in the 2014 maintenance repair

Appendix B: Preliminary report on LTPP data analysis

B1 The data

The data has been taken from NZTA_LTPP_work.mdb. There is some documentation in 11-09-17 Data CD Users Manual.pdf.

All the data has been analysed as there is a probability all of it may be unreliable. Consistency checks have been relied on to identify incorrect data.

The main datasets are for roughness, rutting, texture and rating. These are available in 10 m, 50 m and 300 m sections – rating is on 50 m sections only. The texture data is available only on SH roads.

Other relevant data is

- Calibration sections: locations, where to find in RAMM, whether sterilised, sensitivity, comments on site
- SiteNotes: Log-on state of sites, any changes in location, observations on any work on site
- CAL_SEC_PAVE_DATA: structure of pavement
- CAL_SEC_PAVE_WIDTH: pavement width, number of lanes
- CAL_SEC_RAINFALL_DATA: rainfall data
- CAL_SEC_SNP_DATA: SNP data – just one year but varies from site to site
- CAL_SEC_SURF_DATA: surface data
- CAL_SEC_TRAFFIC_DATA: AADT etc – year varies from site to site
- GPS: GPS locations
- tMaintenanceDetail: maintenance dates; important columns are Det_CompletionDate and Det_ActivityCode. Activity codes are explained in table lActivity. As this does not include major work such as resurfacing, the data has not been used.

Because the rating is on 50 m sections, the 50 m data has been used. This helps to reduce correlation between adjacent sections. Rating does not distinguish between wheel paths so the lane values have been used for roughness, rut depth and texture (average of left and right wheel paths).

There are a small number of duplicate entries in the other files. In most cases they are straight duplicates or the differences are negligible so only averaging is required (as was probably done in the first place). In 2011/12 on two sites the 10 m texture data appears to be repeat measurements with noticeable differences.

In 2014/5, CAL35 there were some entries in SUBSECTION_IDs 7 and 8 rather than 1 and 2 in the 50 m data. It seemed best to ignore these and delete them from the combined record. (They changed the section in 2004/5 and this might reflect the change. What happened to the numbering in preceding years?)

SUBSECTION_END is given for rating and roughness. For rating it is always 50 above SUBSECTION_START but for roughness there is one section where it is zero. This is probably an error and it seems best to ignore SUBSECTION_END. There are some values of SUBSECTION_START that differ from the usual values

(0, 50, 100, ...). These may be an error or measurements may have started at a different point in these sections. The differences have been ignored in this analysis.

Calibration sections table: assume SECTION_ID labelled as 'h' should really be 'CAL-59b'.

In the 50 m roughness data the value for 2002/03, CS-8b, I, 6, left wheel path, run 1 is obviously an error and has been deleted. The average value and lane values are also wrong and have been recalculated. Looking at the 10 m data one can see the preceding records are also affected so record 2002/03, CS-8b, I, 5 has been deleted. The 300 m dataset has presumably also been affected.

In the 50 m texture data records 2014/15, CAL-34, D, 6, RWP and 2014/15, CAL-34, I, 2, LWP are obviously wrong due to 99s being entered in the 10 m data. These and the LANE values have been deleted. The 300 m data has presumably also been affected.

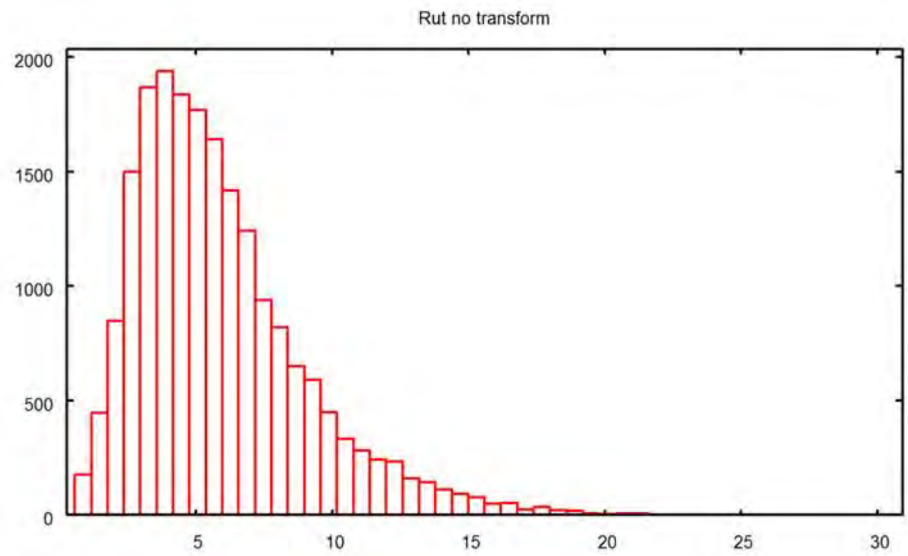
The 10 m data has not been included.

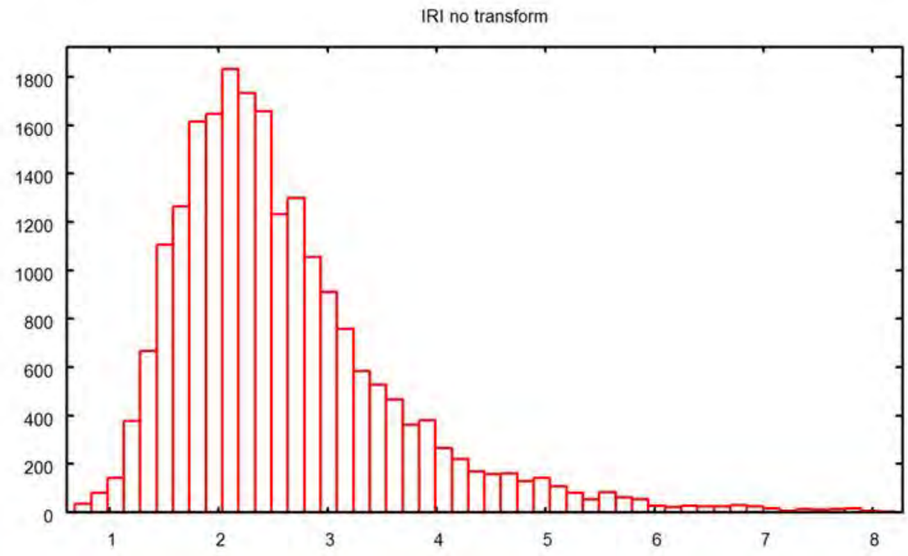
B2 Analysis

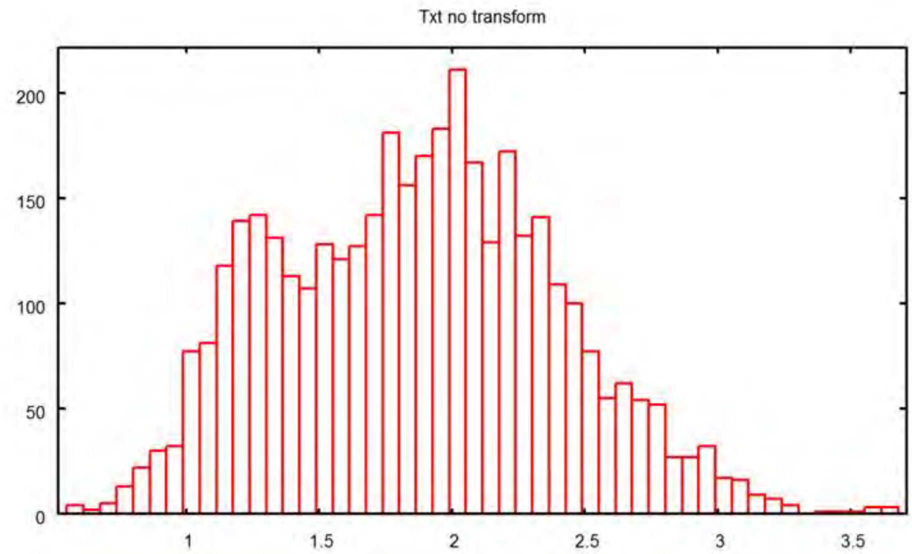
B2.1 Histograms and identification of relevant road works and outliers

This section studies the 50 m data and the lane values (average of left and right wheel paths) of rut depth, IRI roughness and texture. There are 160 sites, each with up to six 50 m sections in each of two directions.

The following three graphs are of the untransformed values of the data.

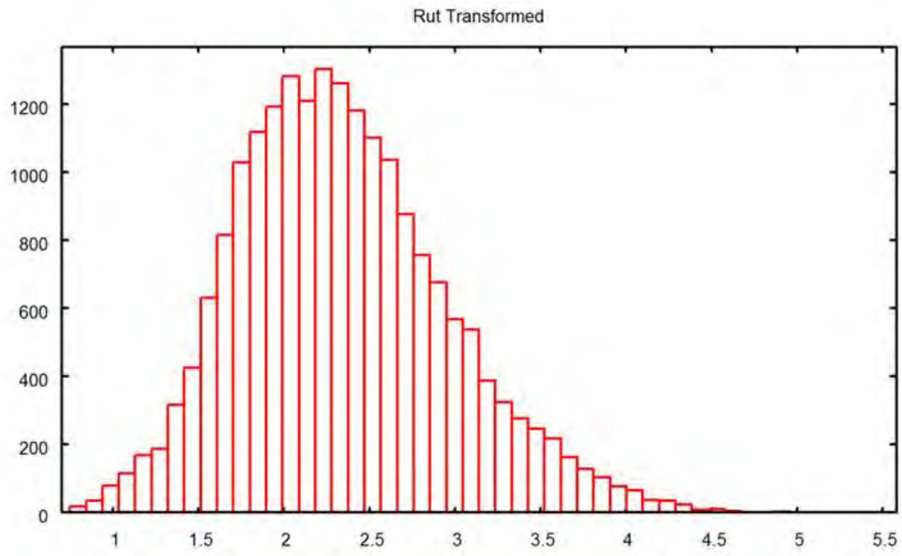


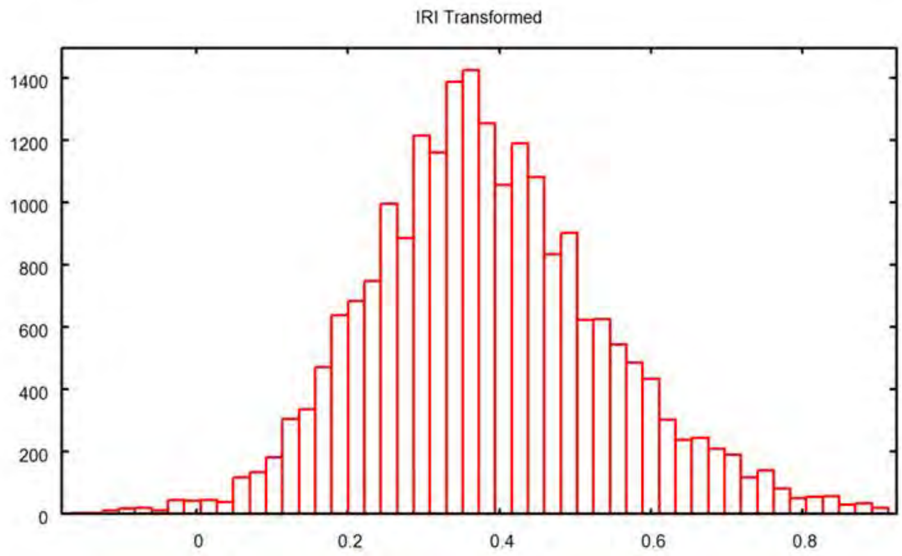




Rutting and roughness show a skewness with a longer tail to the right. Texture is approximately symmetrical with an extra peak between the values of 1 and 1.5. This corresponds to VFILL (voidfill) and B/S (chipseals) and possibly similar surfaces. Only the SH sites have the texture measurements and none of them are densemix asphalt concrete (AC) or opengrade porus asphalt (OGPA).

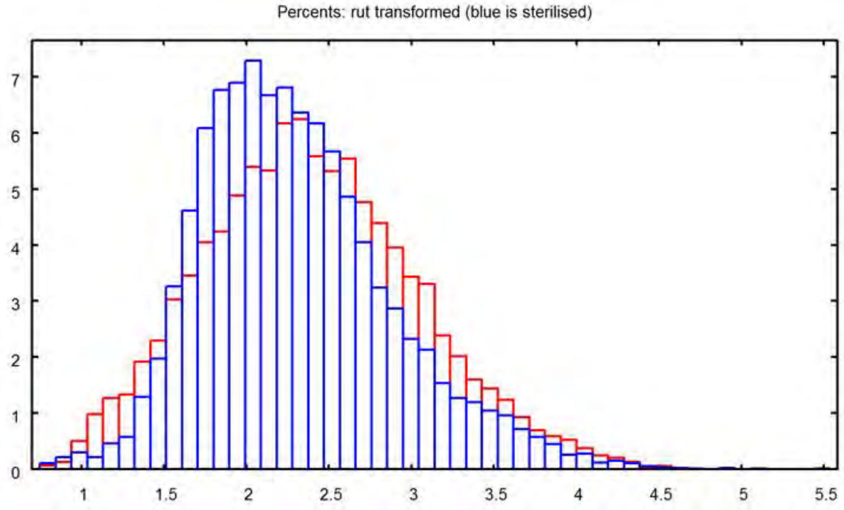
In the past, the square root transform for the rut depth and log transform for the roughness have proved useful for making the data closer to normally distributed. The following two histograms are of the transformed variables.

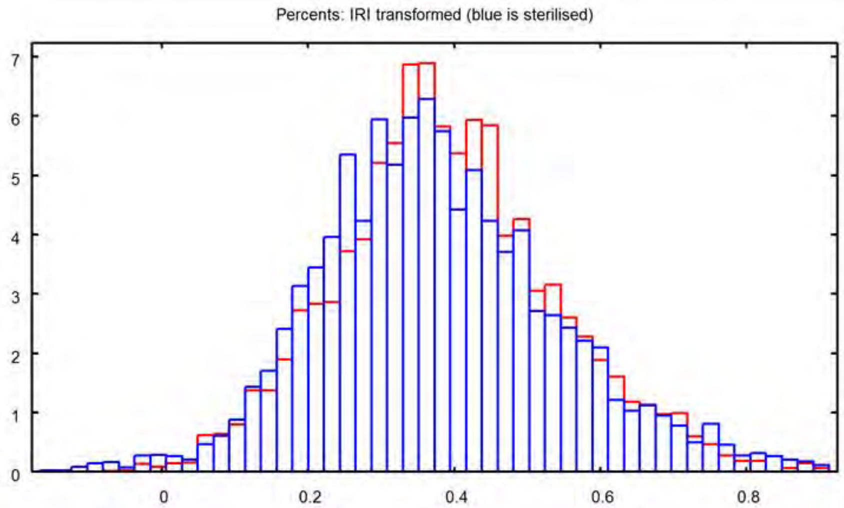


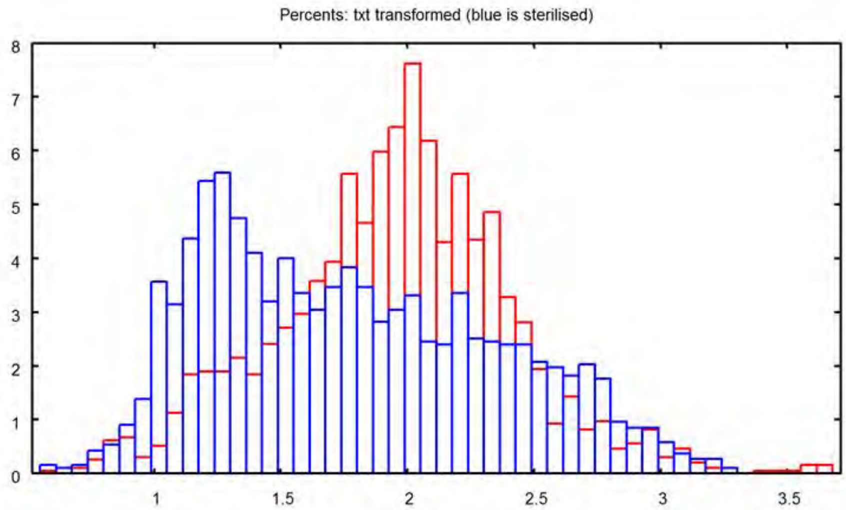


The roughness is reasonably normal but the rut depth is still somewhat skewed. One could apply a stronger transformation such as cube root or logarithm. However stronger transformations have the effect of spreading out the smaller values of the rut depth and hence giving them too much emphasis in an analysis. It is therefore better to stay with the square root transformation.

The next three graphs show the histograms giving the percentages of the points but with the histograms of the sterilised (blue) and normal (red) shown separately.

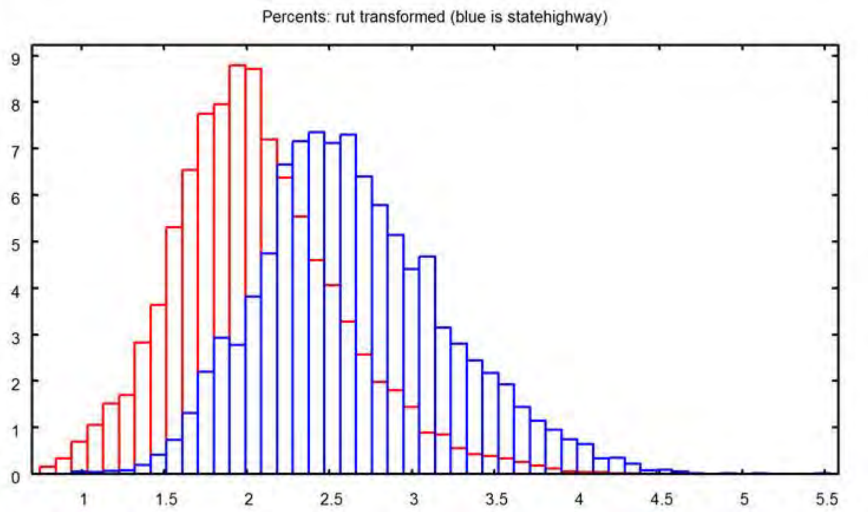


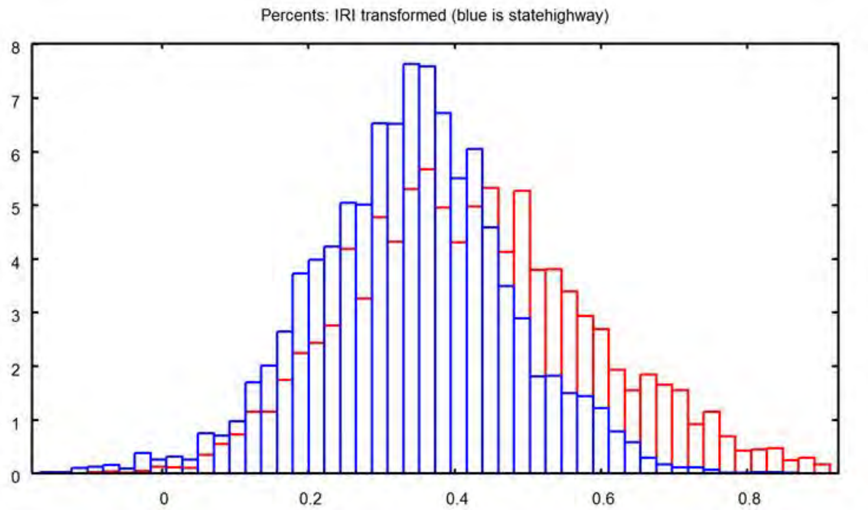




Rut depth in the sterilised sites tends to be a little lower and roughness may be slightly lower. The texture data looks quite different and this, presumably, is because there are a lot more VFILL and B/S surfaces in the sterilised group. Any analysis comparing surfaces in the two groups needs to take account of this.

The next two histograms compare SH (blue) with TLA (red) roads. Since texture is measured only on SH roads it does not appear here.

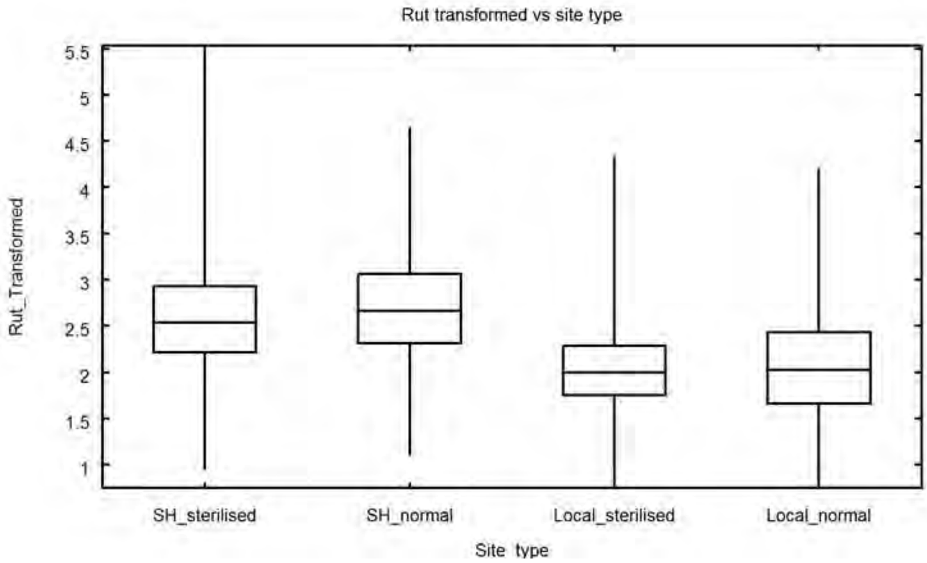


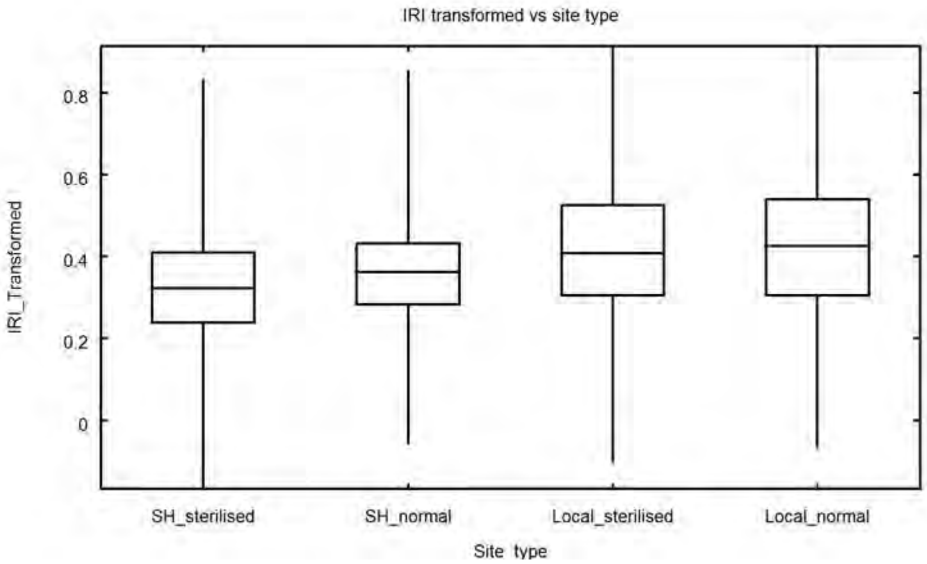


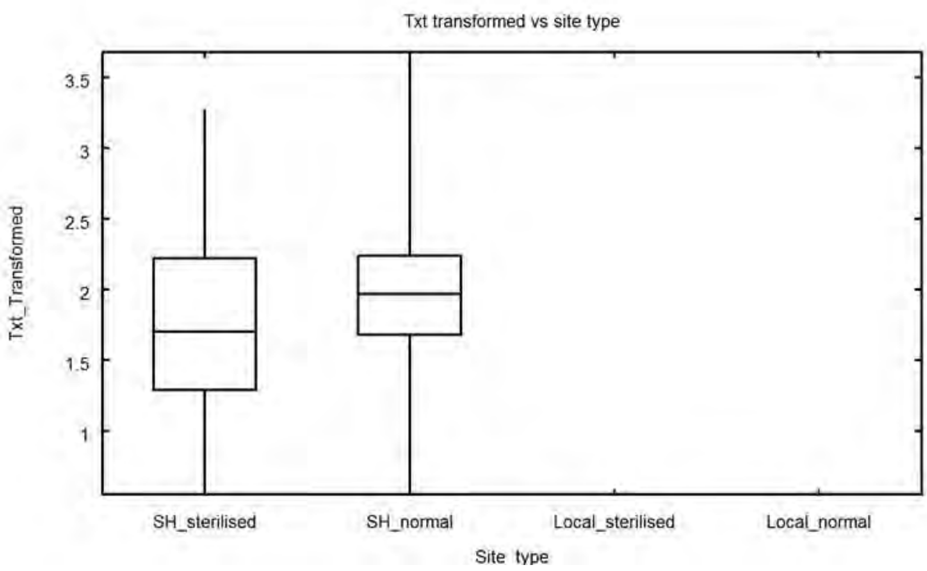
TLA roads tend to have lower rut depth and higher roughness.

The following three graphs show box plots of the data divided into four groups: SH; sterilised; SH normal; TLA sterilised; and TLA normal.

The box shows the upper and lower quartiles, the line through the box shows the medians and the whiskers show the range of the data. Half the data lies within the box.

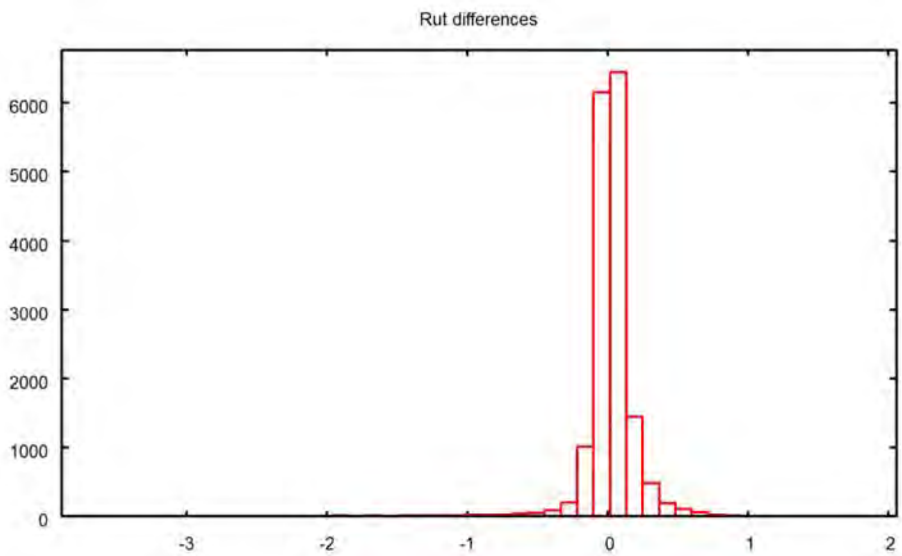


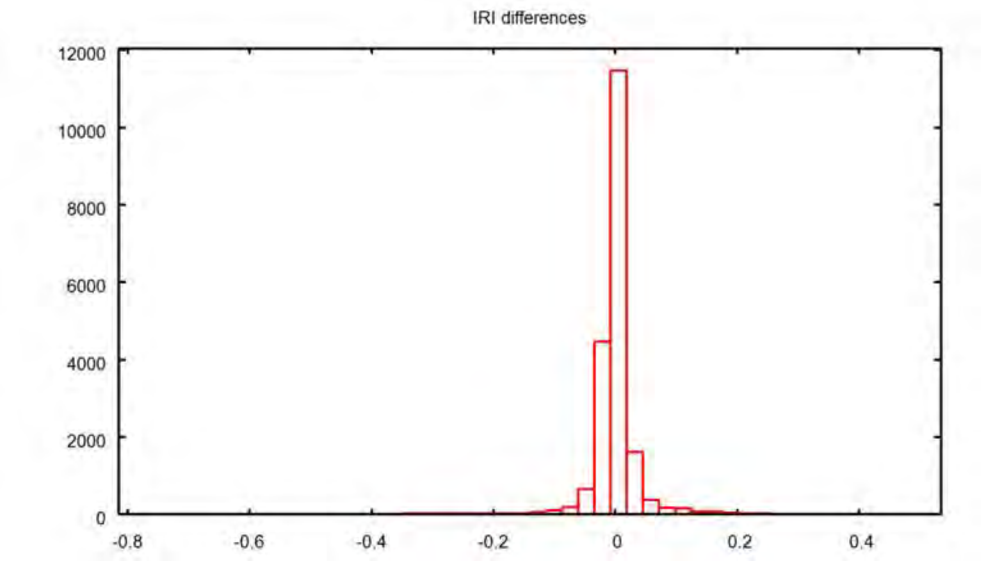


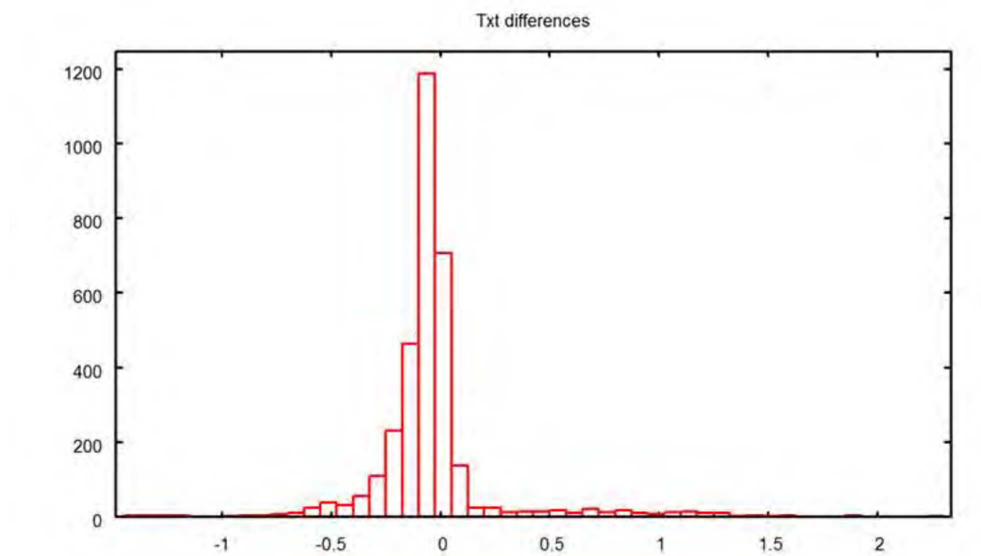


These show roughly the same information as the histograms. You can see higher rut depths in the SH data, and slightly higher and more spread out roughness in the TLA data. The sterilised and normal data is much the same for rut depth and roughness. The texture data is available only available for the SH sites and wider spread for the sterilised sited is due to the extra VFILL and B/S surfaces.

The following three graphs are for the differences between a measurement of one year and the next (ie this year's measurement minus last year's). Only the transformed data and data for adjacent years is included here.



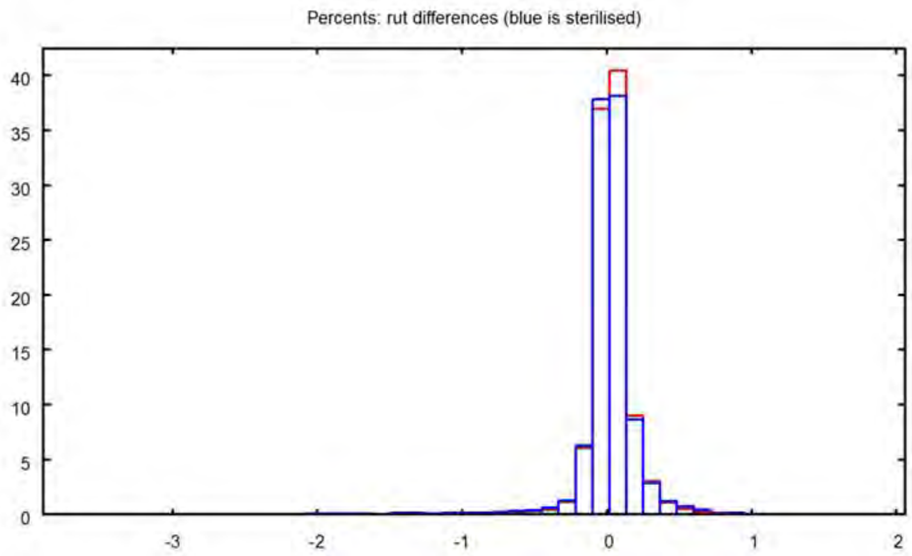


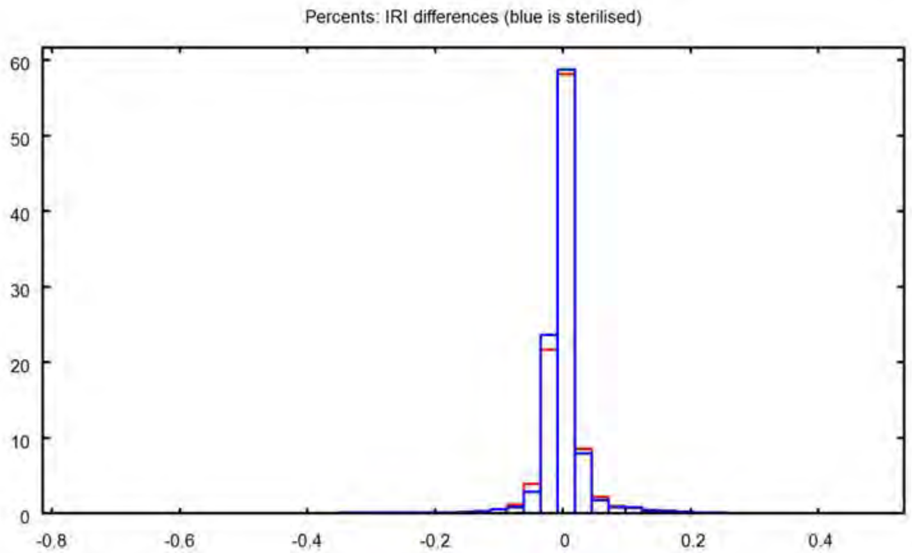


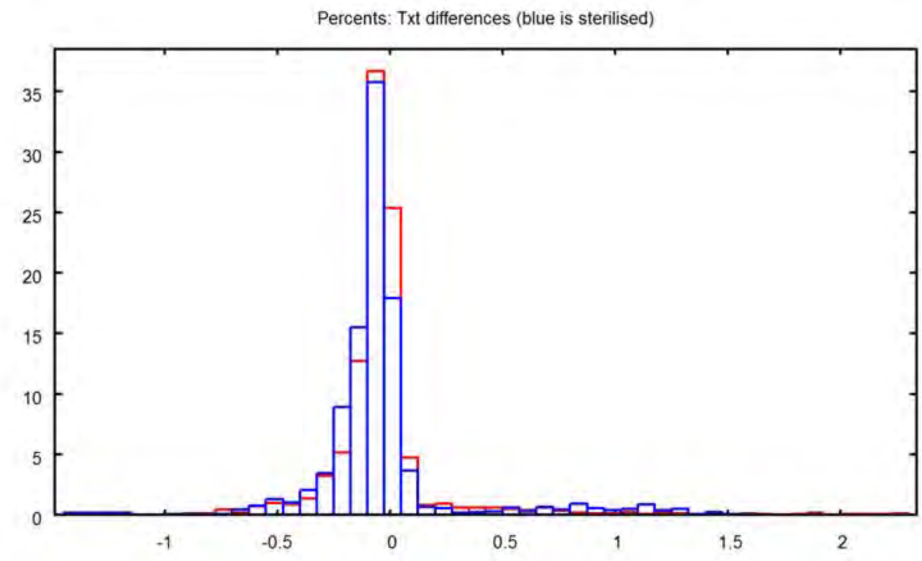
The histogram program sets the width of the graph to run from the lowest value to the highest value, giving a very wide spread. Low values of rut and roughness differences or high values for texture differences may correspond to repair work. Low values of texture may correspond to a chipseal surface being replaced by a low texture surface as well as loss of texture due to wear.

High values of rut or roughness differences and low values of texture differences may correspond to accelerated ageing, so they may be what we are looking for. But they may also correspond to specific types of road work or bad observations.

The following graphs show the percentage histograms with sterilised (blue) and normal (red) shown separately.

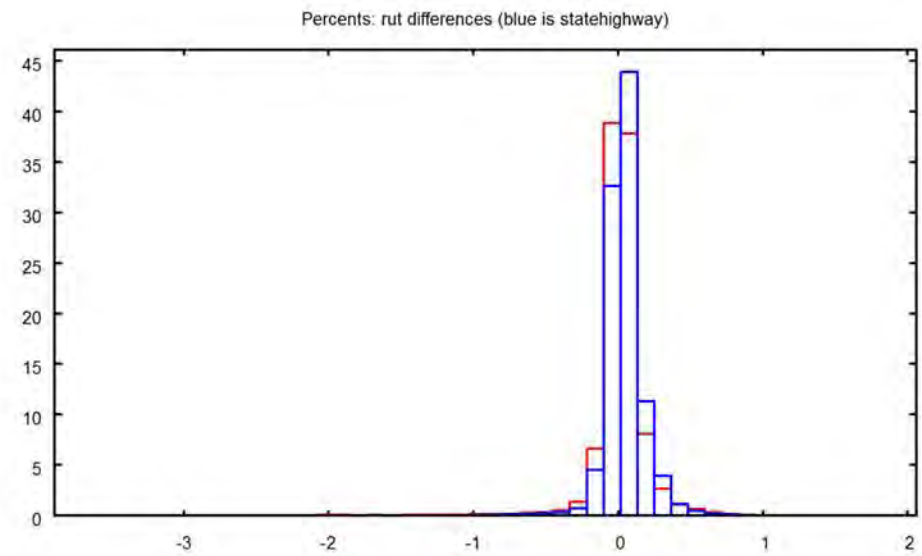

Percents: rut differences (blue is sterilised)
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2

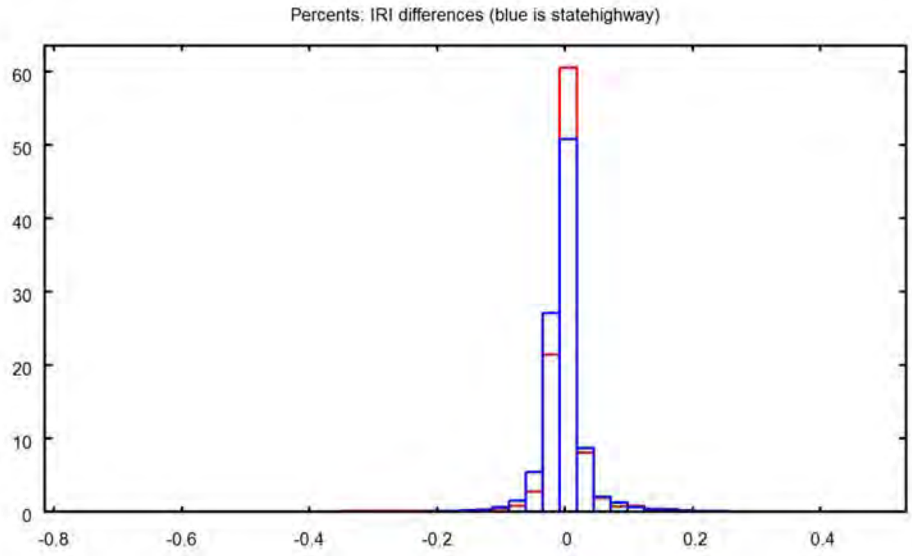

Percents: IRI differences (blue is sterilised)
60
50
40
30
20
10
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4



The histograms for sterilised and normal sites are very similar but without much detail.

The next two graphs are for SHs (blue) and TLA (red).

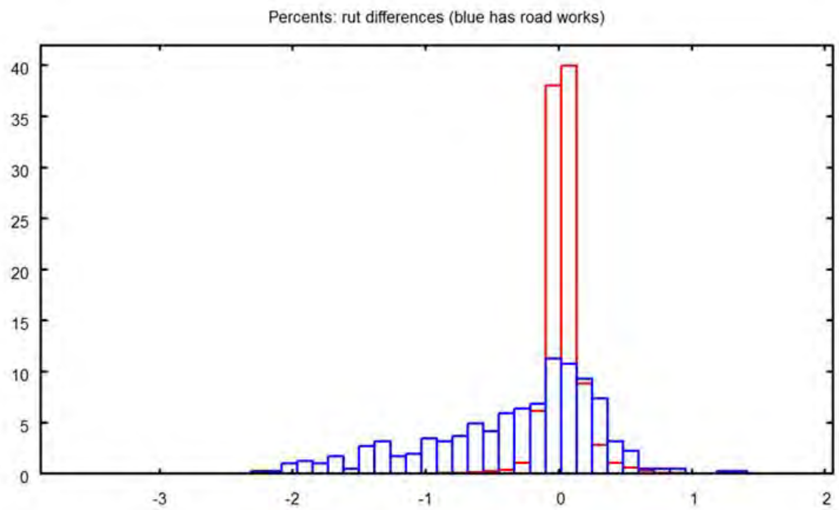


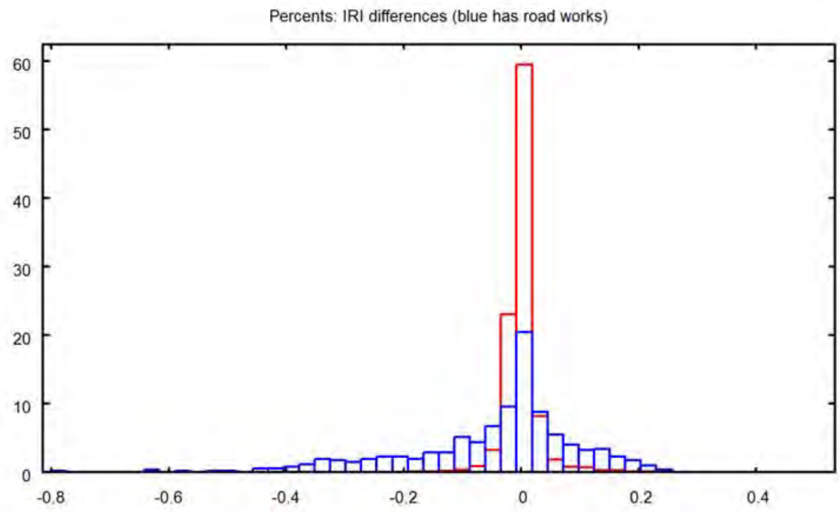


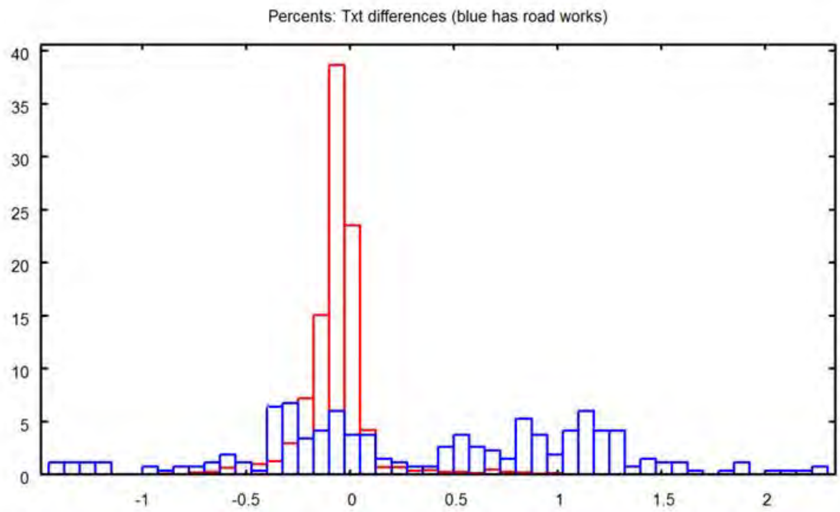
They are quite similar.

Box plots for this data do not work well because the bulk of the data occupies only a very small part of the overall range, and therefore are not shown.

In the next three percentage histograms, sites (blue) that have had road works are separated out. Roadworks that are relevant for each of the measurements were identified from the raters' site notes.

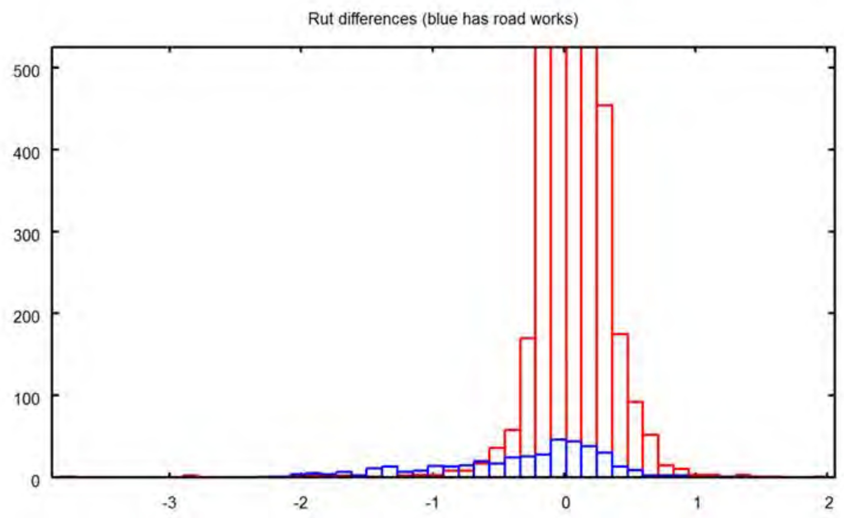


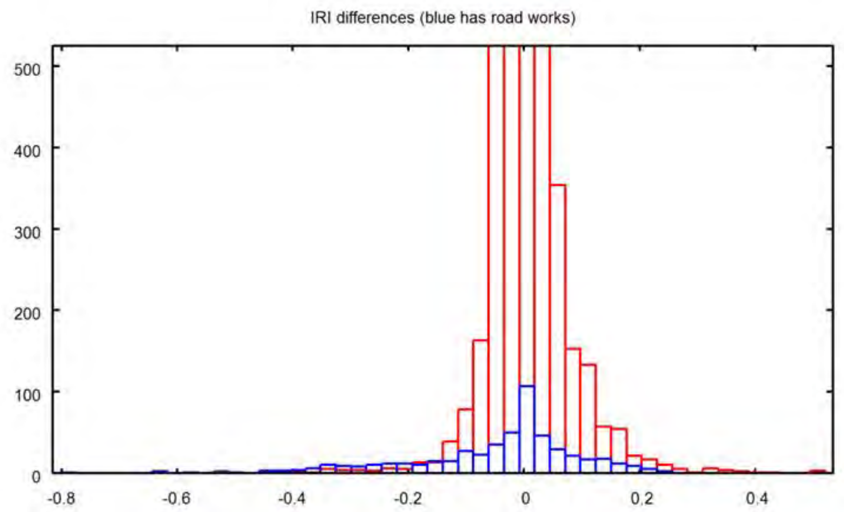


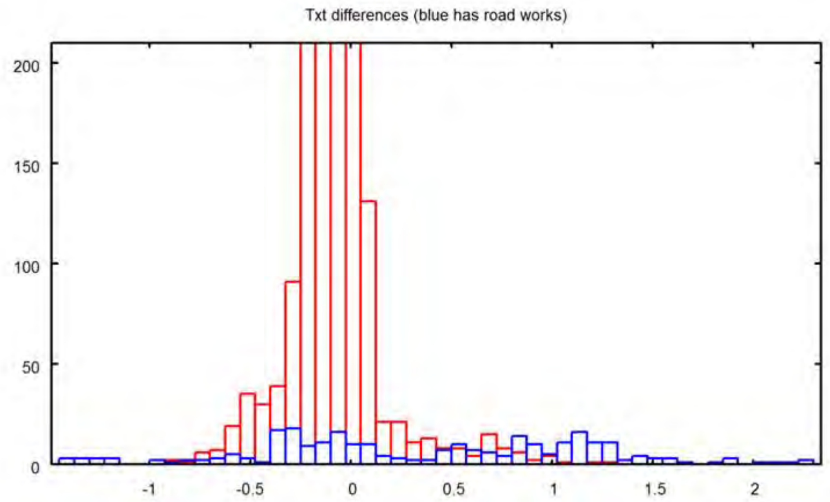


As one might expect the data for sites with road works is a lot more spread out.

To identify the point at which the data for sites with works tends to dominate, the next three histograms show the count data rather than the percentage data, and the vertical scale is expanded so we see the very small values.


Rut differences (blue has road works)
500
400
300
200
100
0
-3
-2
-1
0
1
2

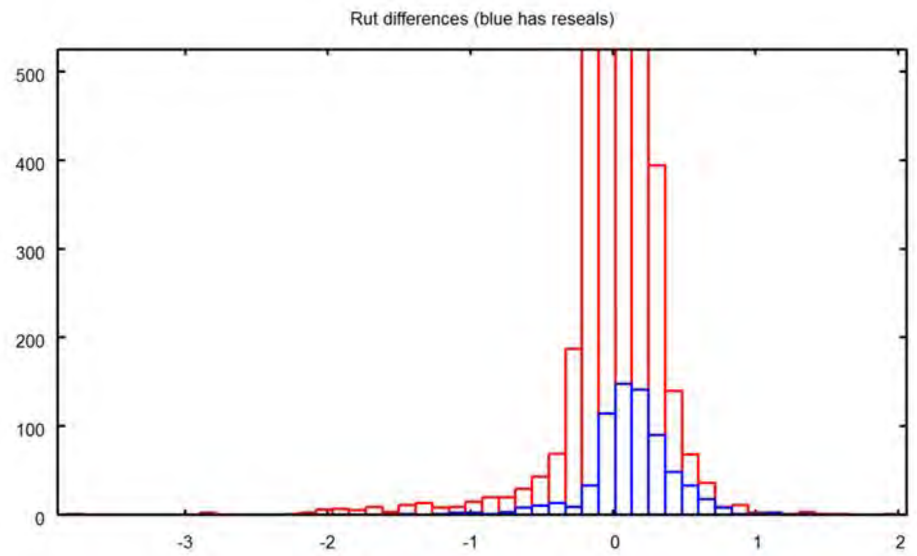

IRI differences (blue has road works)
500
400
300
200
100
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4

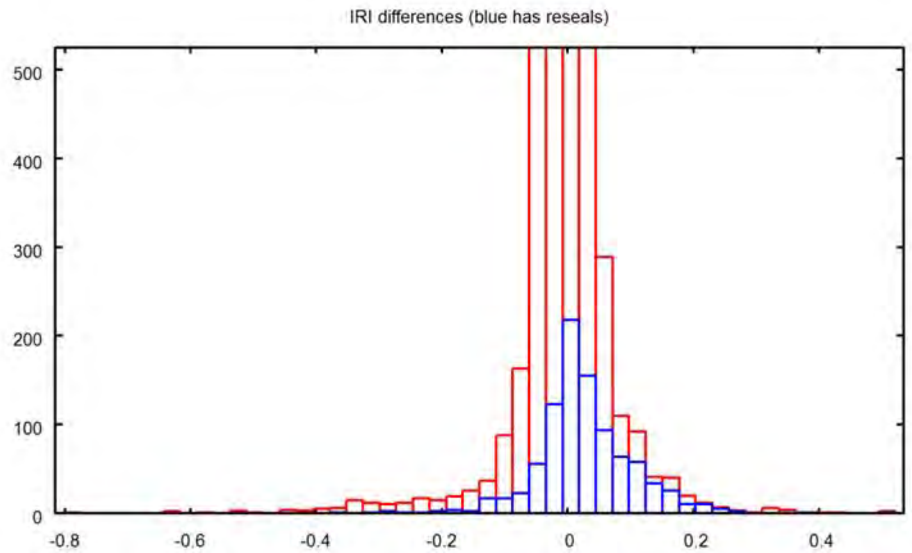

Txt differences (blue has road works)
200
150
100
50
0
-1
-0.5
0
0.5
1
1.5
2

The data for sites with road works becomes dominant for rut depth when the transformed rut depth difference is less than -0.5; for rutting is less than -0.1 and for texture is greater than 0.4.

If we are looking for accelerated ageing, we want to leave in outlying positive values for rut depth and roughness and the negative values for texture. But if we are interested in the decay rates during a period of linear decay then we also want to delete these outliers. The following values have been chosen: 0.8 for rut depth, 0.1 for roughness and -0.6 for texture.

The following two graphs for rutting and roughness show the histograms where blue indicates sites with roadworks that have been judged relevant to texture but not to rutting or roughness – that is, essentially reseals.





The graphs with a substantial number of high positives of the differences are associated with reseals. Apparently reseals cause a temporary increase in rutting and roughness.

We cannot tell for sure the direction of causality. Possibly, when the road is beginning to fail, but before an increase in rutting and roughness is apparent, a reseal is scheduled. Then the rutting and roughness become apparent at the same time the reseal is carried out.

For these analyses, it is assumed the reseal causes the increase in rutting and roughness.

Since these high values are not of interest in the present study it seems best to regard reseals as affecting all three of the variables – not just texture.

To simplify the analyses, rather than assuming some kinds of road work affect only one or two of rutting, roughness and texture, no distinction was made between types of road work and it was supposed all might be affected.

B2.2 Selecting the data

In the linear ageing data analyses the focus was on stretches of data with at least an eight-year range (ie eight points if data was collected every year) with no road works and with between year differences within the ranges identified in section B2.1. The same limit was also applied to the two-year difference. This was primarily to handle missing years but the analysis seemed to give slightly better results if the procedure was applied to all two-year differences.

But when looking for accelerated ageing, only the observations that could be attributed to road works were deleted – that is where we know there are road works or there are low outliers for rut depth and roughness and high outliers for texture.

B2.3 Linear ageing

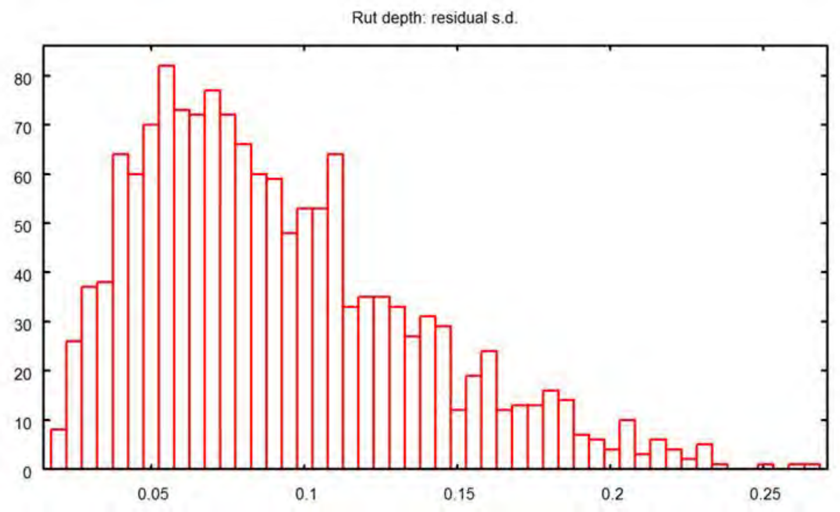
A simple linear regression model was fitted to each of the 12 road segments at each site where we had at least an eight-year range and where there were no outliers in the differences and no relevant road works.

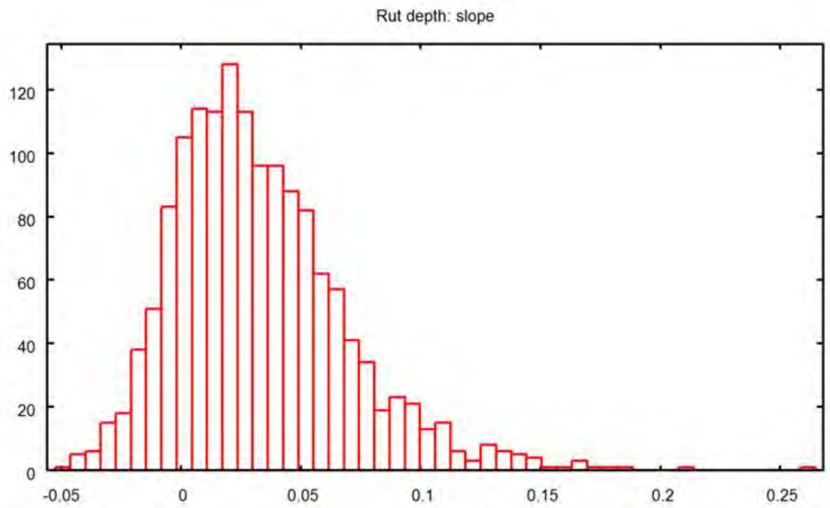
For each of the three transformed variables graphs are provided of a:

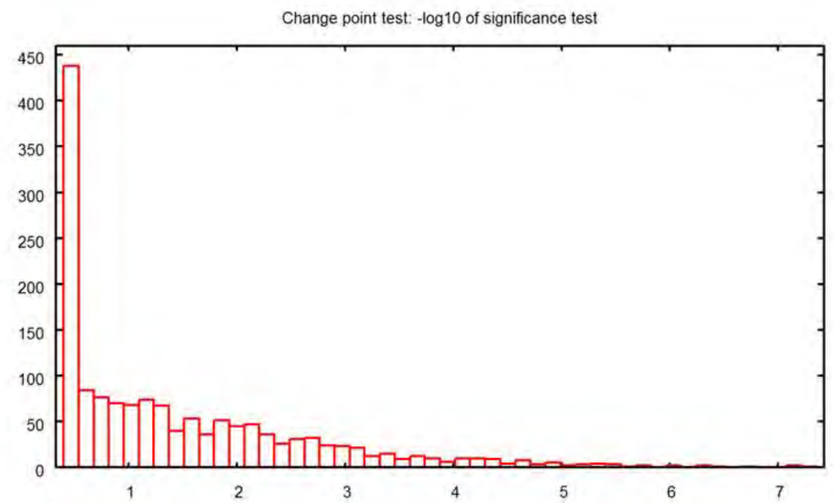
- histogram of the residual standard deviation
- histogram of the slope (trend)
- histogram of the results of a change point test
- plot of slope versus the residual standard deviation.

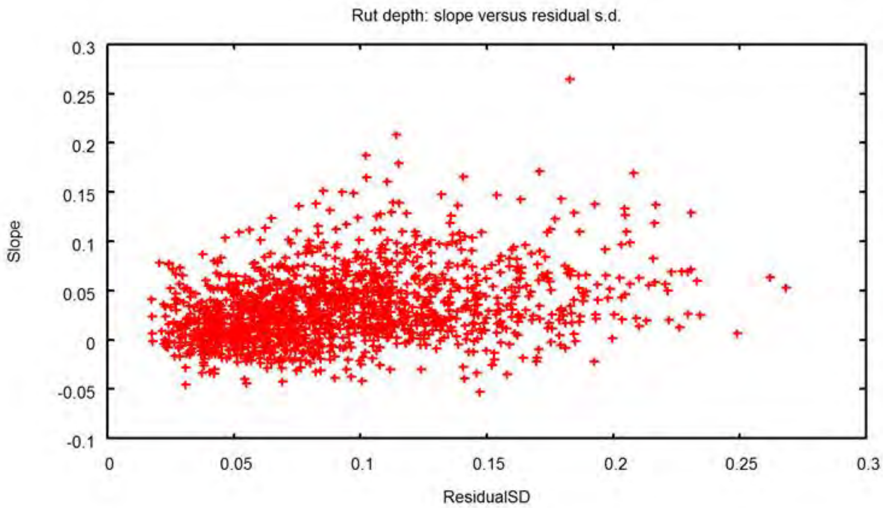
Correlation between successive observations (ie from one year to the next) has not been allowed for. Doing so is outside the scope of this study, at least in the present timeframe. Confidence intervals are not provided and results of the change point test need to be treated with care.

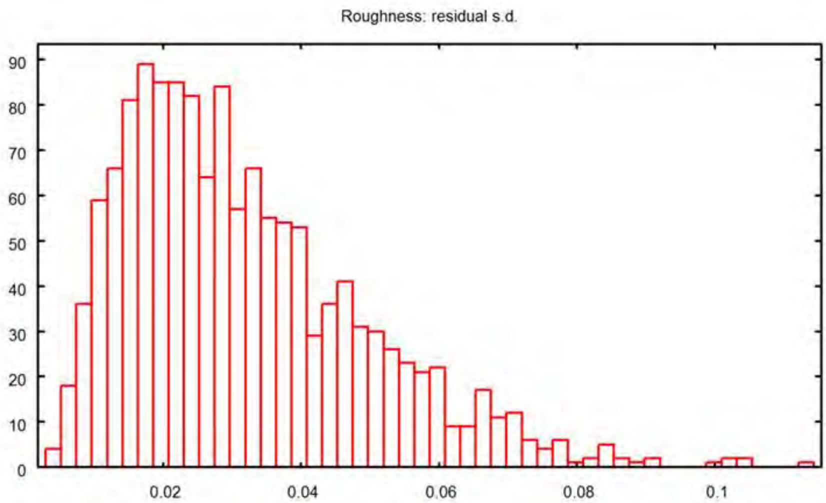
The commentary follows the 12 graphs.

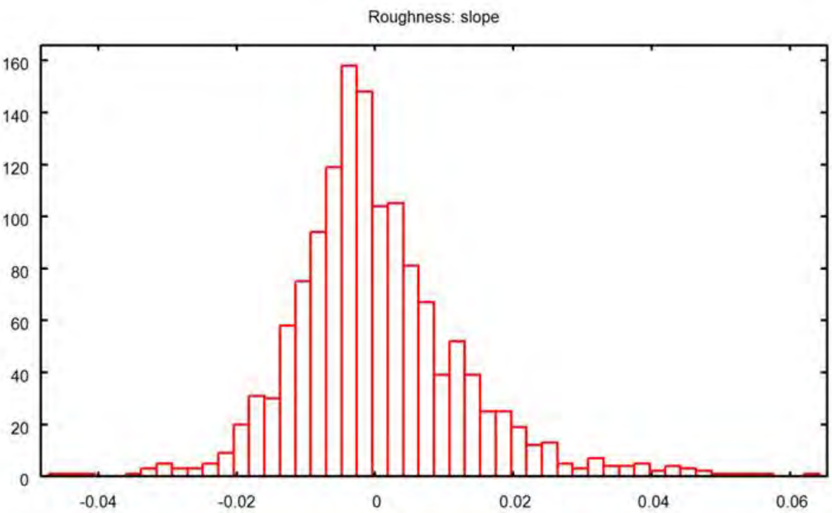

Rut depth: residual s.d.
0
10
20
30
40
50
60
70
80
0.05
0.1
0.15
0.2
0.25

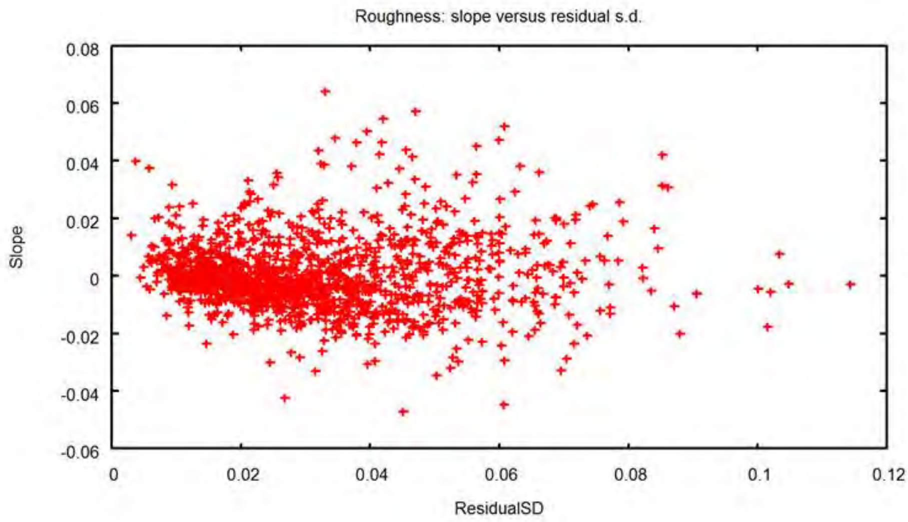

Rut depth: slope
0
20
40
60
80
100
120
-0.05
0
0.05
0.1
0.15
0.2
0.25

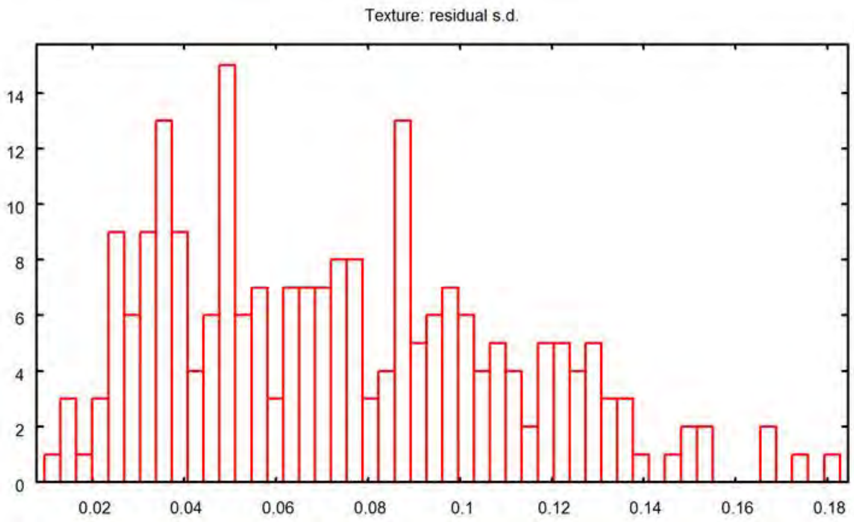

Change point test: -log10 of significance test
0
50
100
150
200
250
300
350
400
450
1
2
3
4
5
6
7

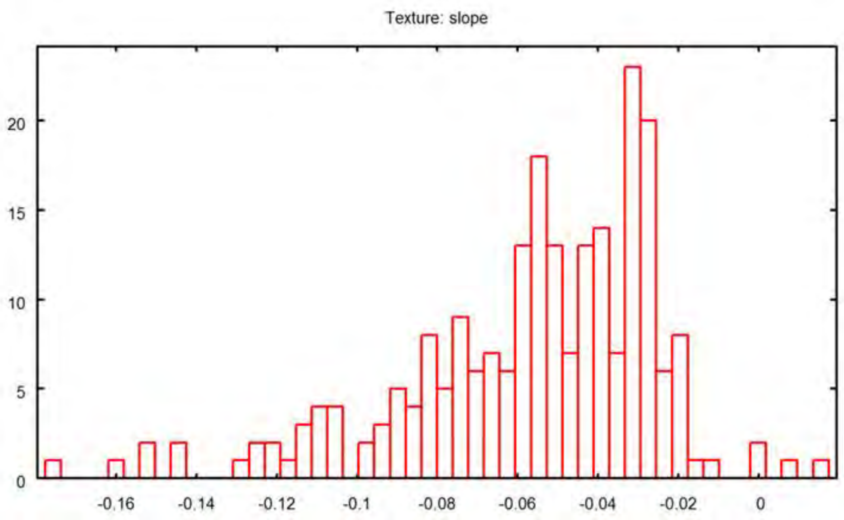

Rut depth: slope versus residual s.d.
Slope
ResidualSD
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0
0.05
0.1
0.15
0.2
0.25
0.3

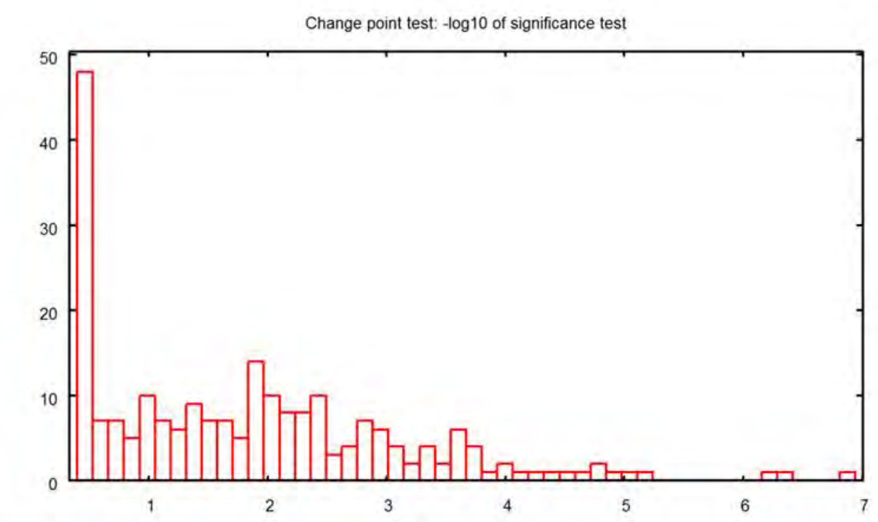

Roughness: residual s.d.
90
80
70
60
50
40
30
20
10
0
0.02
0.04
0.06
0.08
0.1

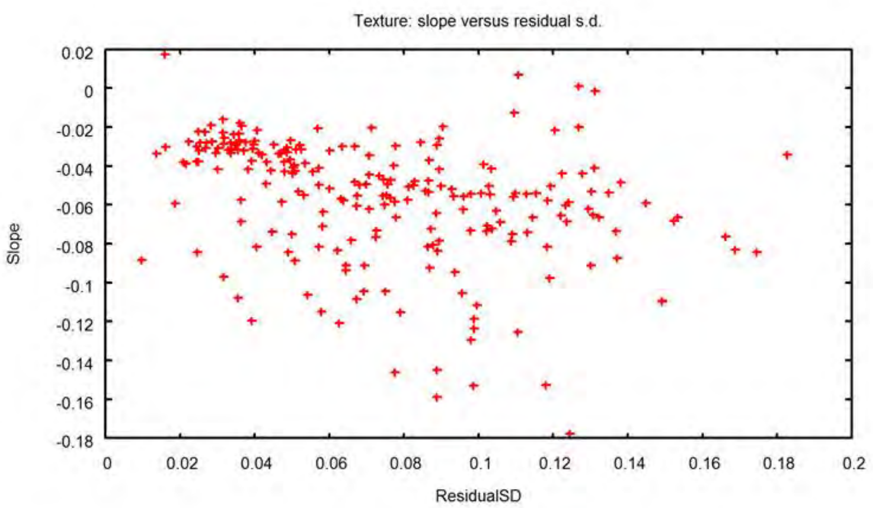

Roughness: slope
160
140
120
100
80
60
40
20
0
-0.04
-0.02
0
0.02
0.04
0.06


Roughness: slope versus residual s.d.
Slope
ResidualSD
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0
0.02
0.04
0.06
0.08
0.1
0.12


Texture: residual s.d.
14
12
10
8
6
4
2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18


Texture: slope
20
15
10
5
0
-0.16
-0.14
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0





The residual standard deviation shows the degree to which the transformed data follows a linear trend. The graphs show there is a lot of variability in the quality of the fit.

The slope (trend) shows how much the variable changes, on average, each year.

For rut depth the slope tends to be positive. Rut depth increases over time, but there is a lot of variability in the values.

For roughness the values seem to be symmetrically distributed around zero, with perhaps a few more very high values.

With texture the values are almost all negative. Texture is decreasing but with a very wide range of values.

The change point test is from Davies (2002). This is used for detecting a change in slope in a linear regression. The graph is of $-\log_{10}$ of the significance probability. If the test is just statistically significant at the 1% level this will return a value 2; if it is just statistically significant at the 0.1% level the value will be 3. Because correlation in the series has not been allowed for, the values are inflated. However, it will be worth looking at the series with the very large values in this graph to see if they show evidence of accelerated ageing. All the variables show some very large values.

The final graph in each sequence is a scatterplot of slope versus standard deviation. This is to see if the sequences with lower residual standard deviation have more consistent slopes. If they do, the points will tend to have an arrow head formation with the arrow pointing left. They do, but the effect is not strong.

There is further analysis of the slopes in the next section. In an attempt to reduce the effect of sites when the trend is not well defined, sequences with the highest residual standard deviations have been removed.

Rut depth sequences with standard deviations greater than 0.15 have been removed from the analyses in the next section. For roughness the value is 0.05 and for texture the value is 0.1. These values have been chosen where the points seem to be 'thinning out' in the slope versus residual standard deviation scatterplots.

B2.4 Linear ageing – further analysis

This section explores whether a relationship can be detected between the slopes found in the previous section and various variables available in the site data. All the analyses are graphical. It should be possible to do a formal statistical analysis, but since few strong results have been found here we should not expect much more from the formal analysis.

The following graphs attempt to find relationships between the slope or, in some cases residual standard deviation, and

- site type
- sensitivity
- AADT
- SNP
- average rainfall.

There is also a box plot of year-by-year difference versus site type using the edited data for comparison with the slope results.

Notes on the predictor variables:

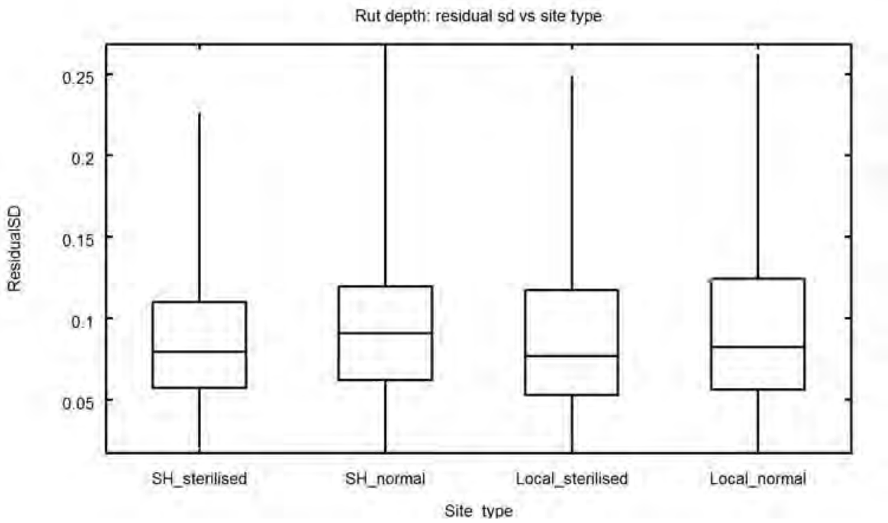
Sensitivity: this is given as one of five categories: *lim*, *low*, *medium*, *mod* or *high*. The number of sites classified in each of these categories is given in the following table:

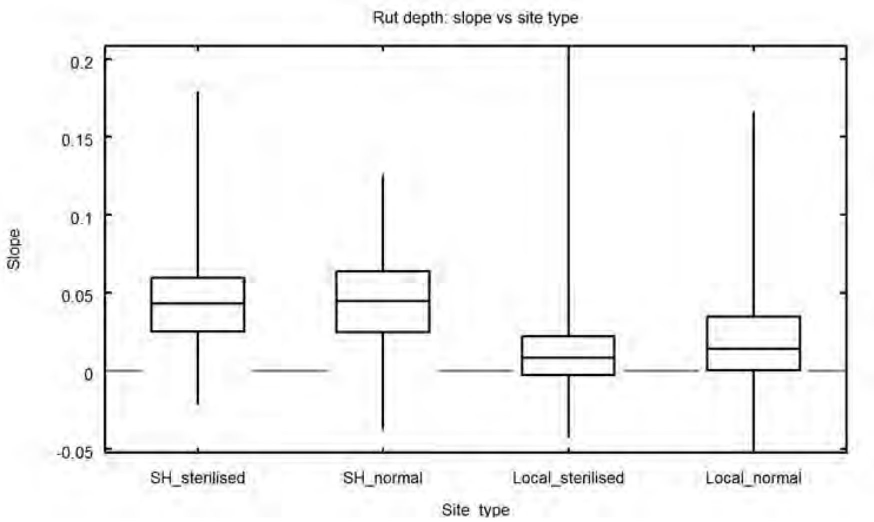
Sensitivity	Number of sites
lim	22
low	45
medium	35
mod	4
high	45

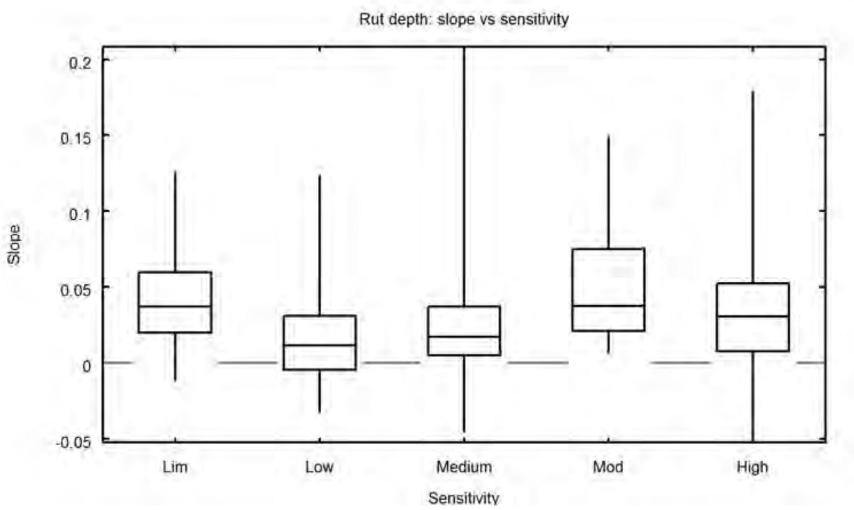
The number of sites classified as *mod* is very small, and *lim* quite small and some of these categories should probably be amalgamated.

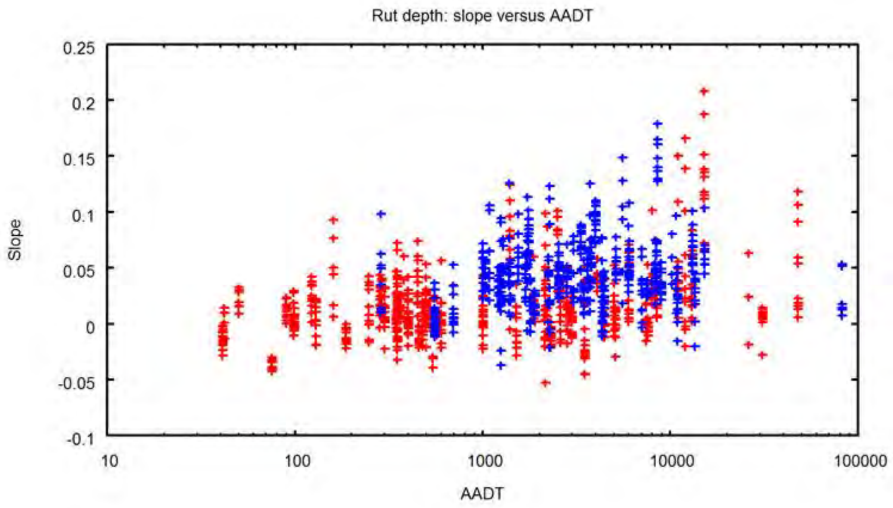
- AADT: The estimate was made on different years for different sites and it is not known if any attempt was made to adjust the AADTs to allow for this.
- SNP: The database generally gives a site value for one year.
- Average rainfall: This is an average over the period from a nearby weather station.

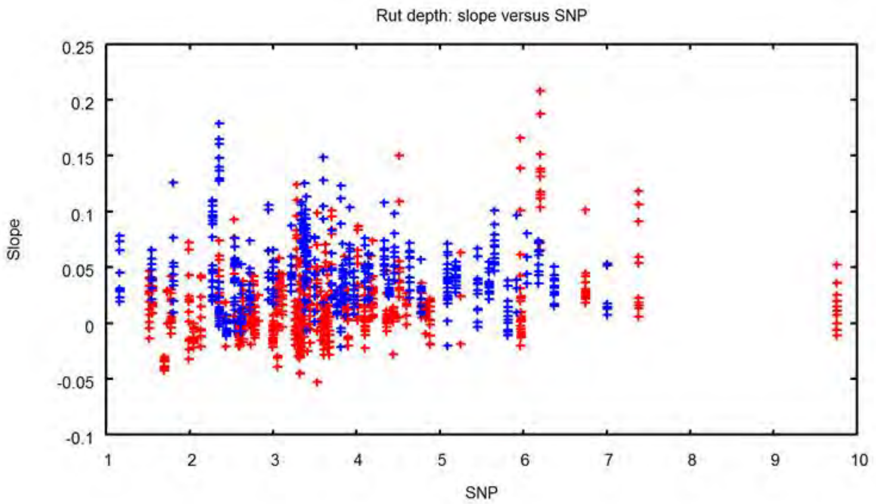
The commentary comes after the following 21 graphs.

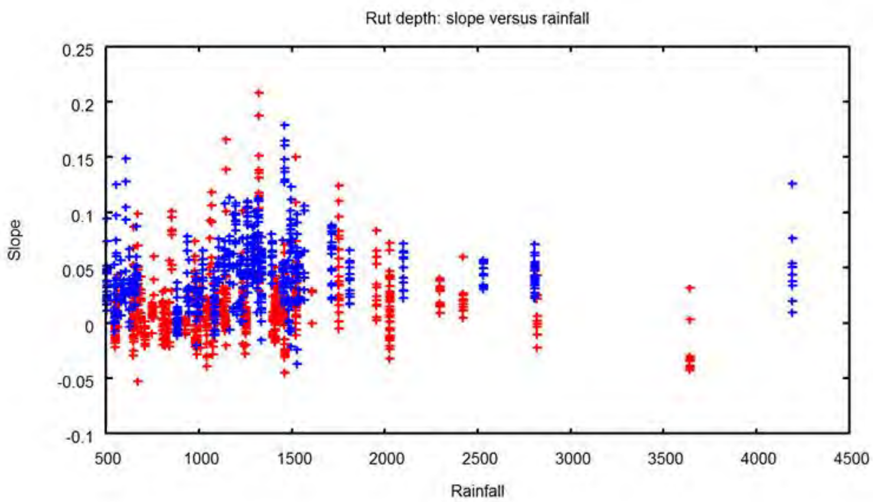


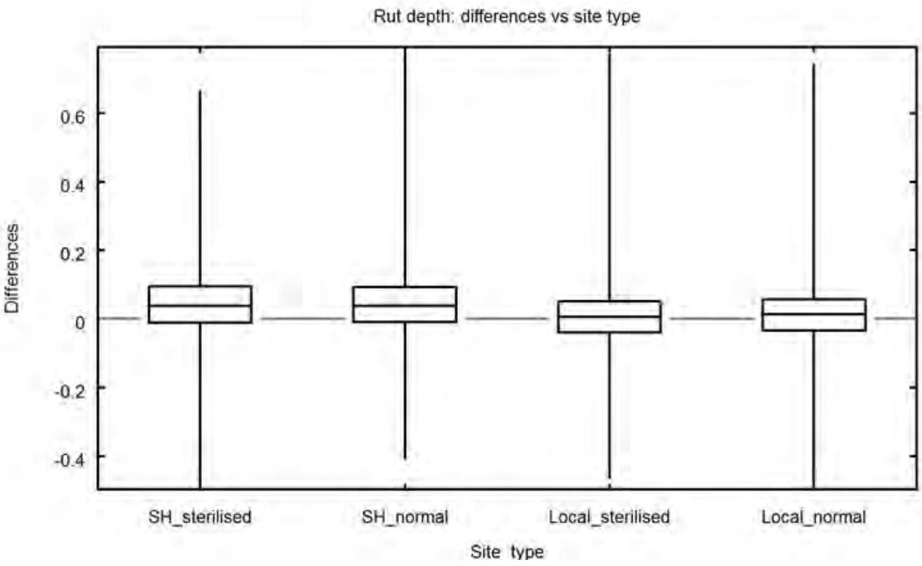


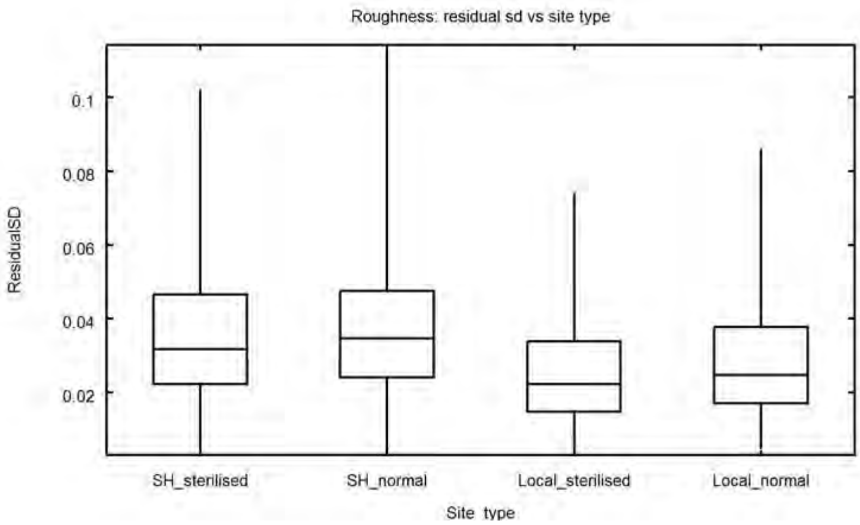


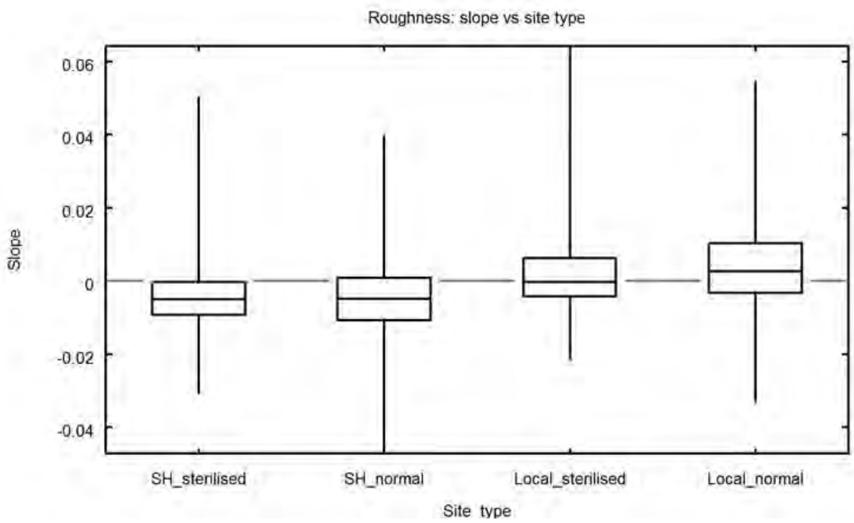

Rut depth: slope versus AADT
Slope
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
10
100
1000
10000
100000
AADT

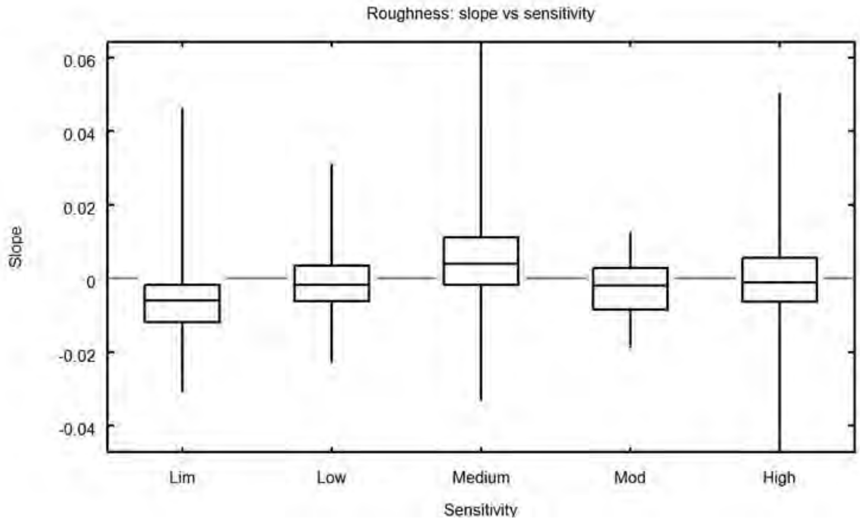

Rut depth: slope versus SNP
Slope
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
1
2
3
4
5
6
7
8
9
10
SNP

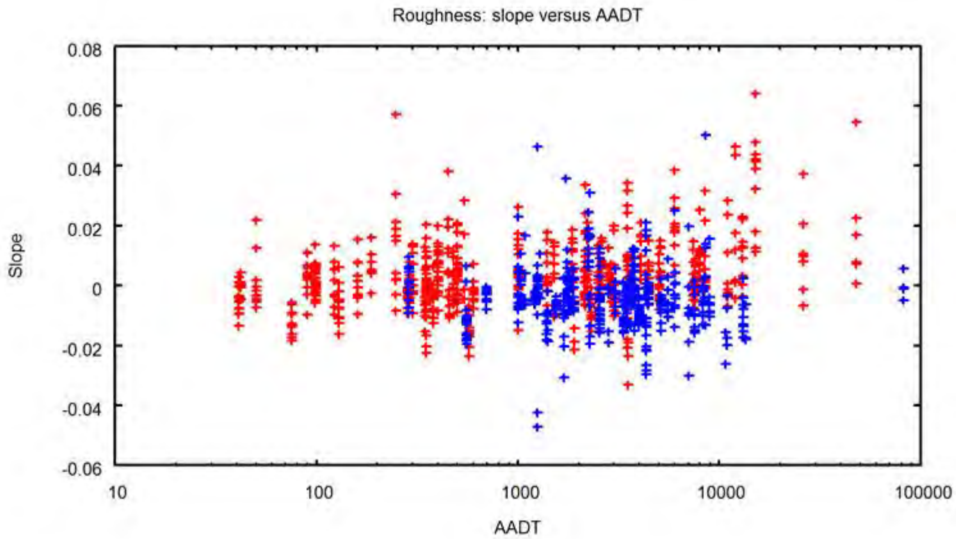

Rut depth: slope versus rainfall
Slope
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
500
1000
1500
2000
2500
3000
3500
4000
4500
Rainfall

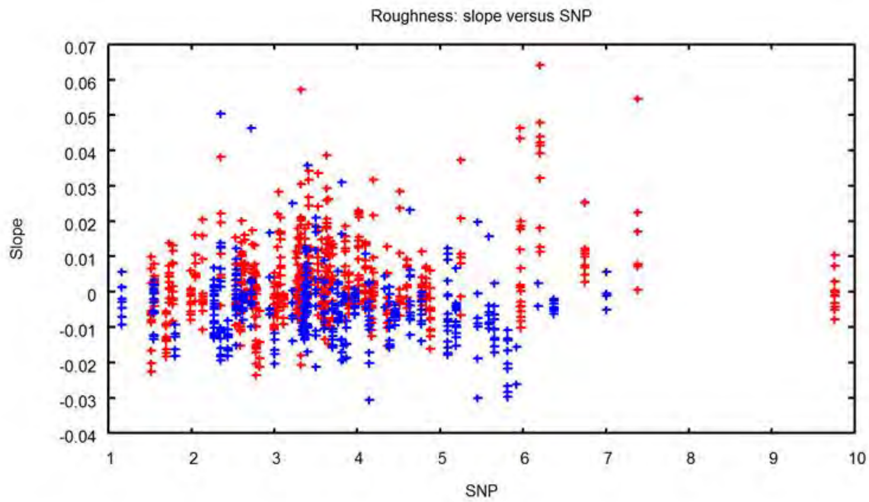

Rut depth: differences vs site type
Differences
0.6
0.4
0.2
0
-0.2
-0.4
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type

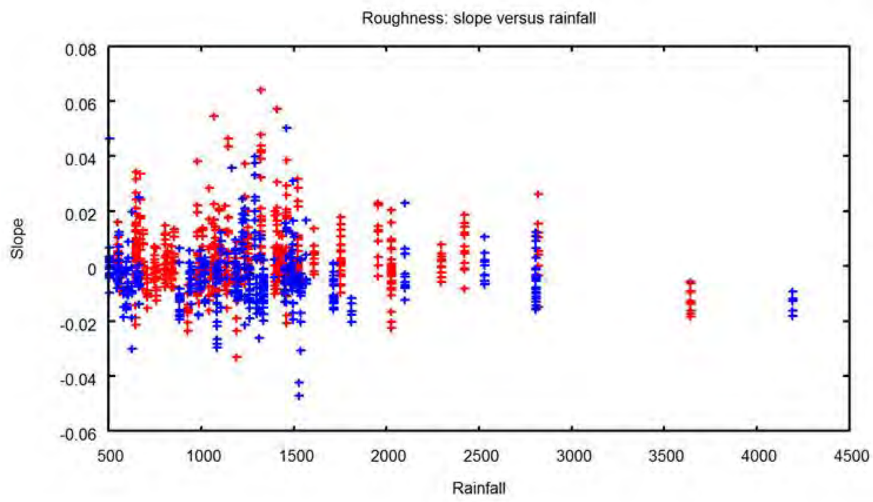

Roughness: residual sd vs site type
ResidualSD
0.1
0.08
0.06
0.04
0.02
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type

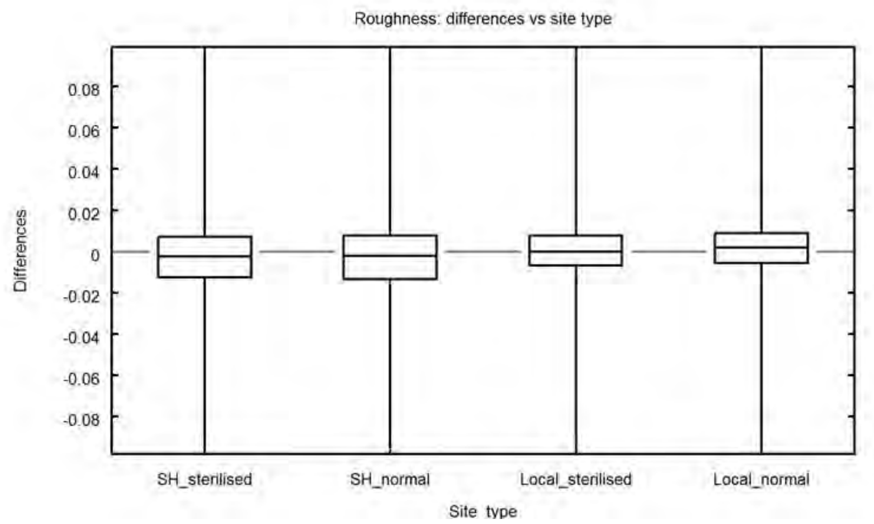

Roughness: slope vs site type
Slope
0.06
0.04
0.02
0
-0.02
-0.04
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type

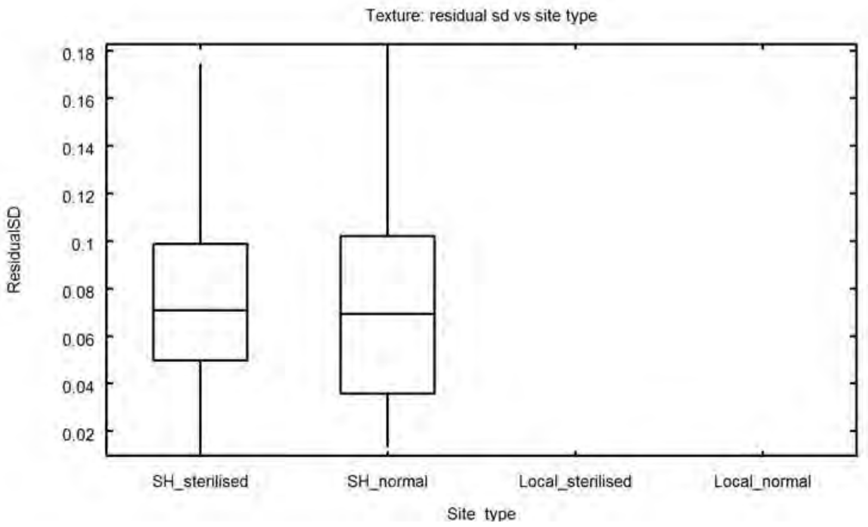

Roughness: slope vs sensitivity
Slope
0.06
0.04
0.02
0
-0.02
-0.04
Lim
Low
Medium
Mod
High
Sensitivity

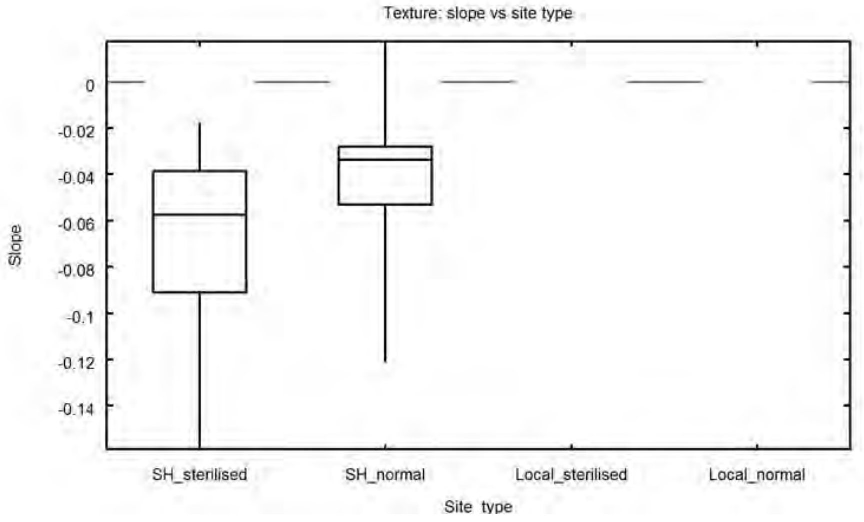

Roughness: slope versus AADT
Slope
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
10
100
1000
10000
100000
AADT

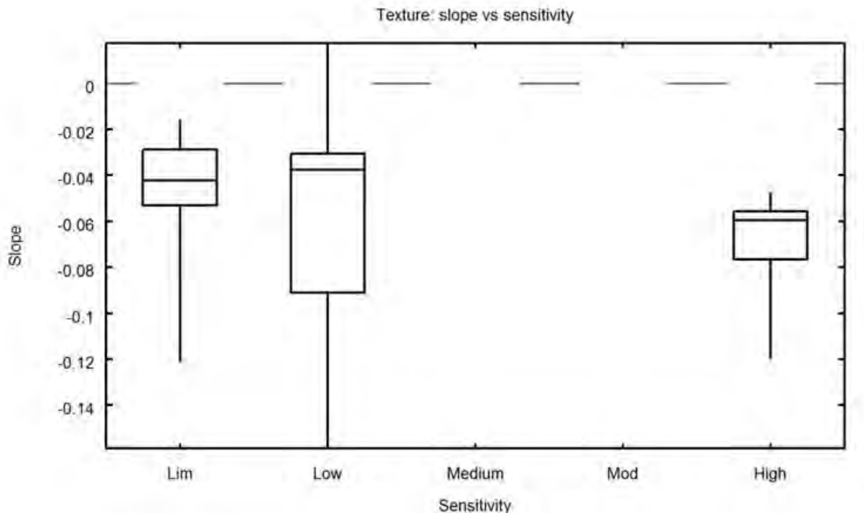

Roughness: slope versus SNP
Slope
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
1
2
3
4
5
6
7
8
9
10
SNP

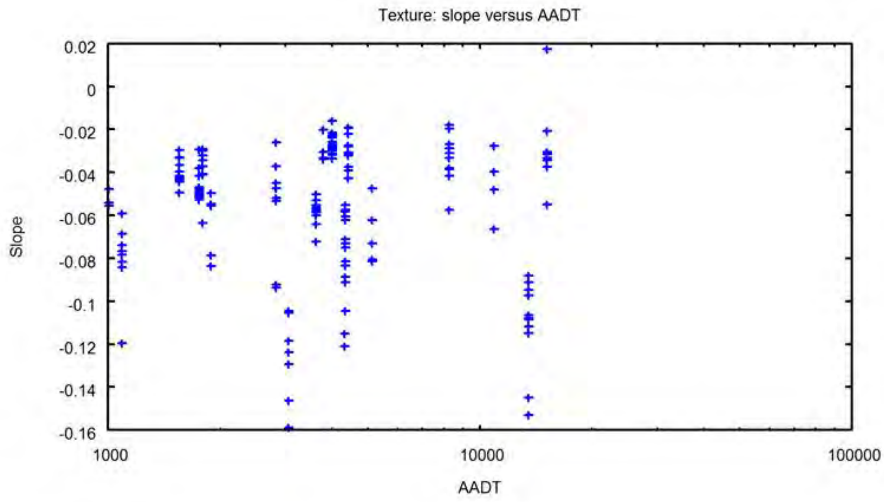

Roughness: slope versus rainfall
Slope
Rainfall
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
500
1000
1500
2000
2500
3000
3500
4000
4500

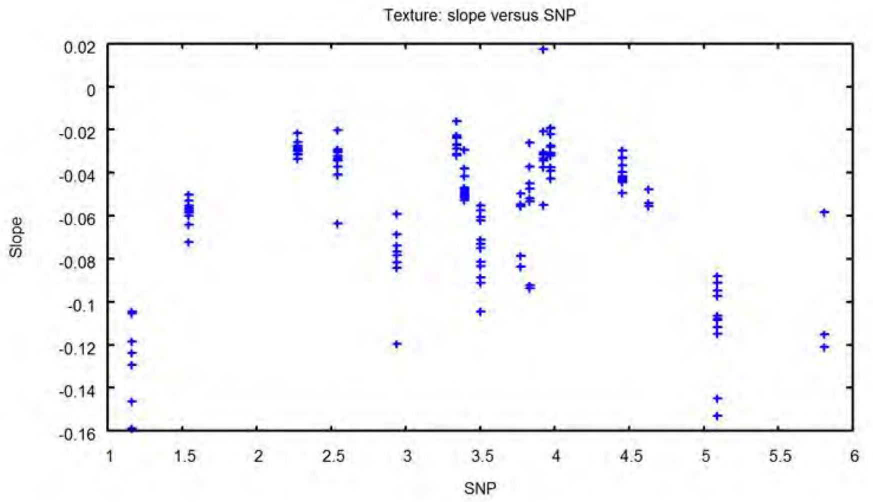

Roughness: differences vs site type
Differences
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type

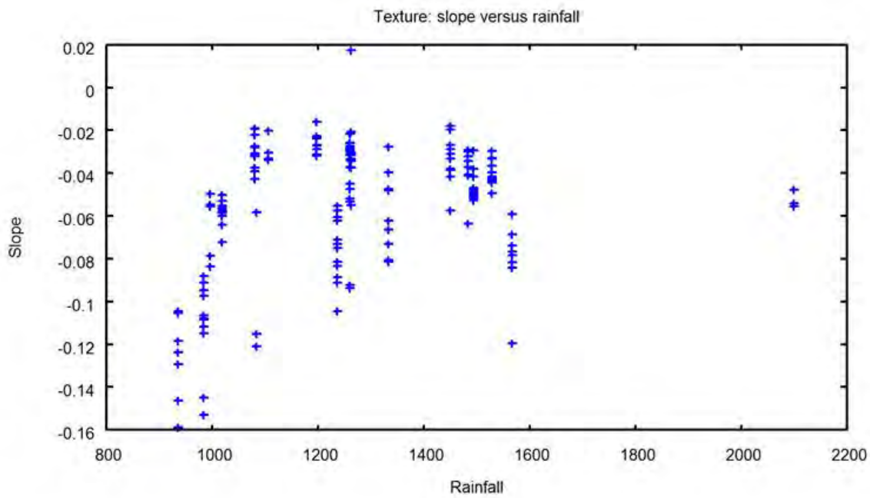

Texture: residual sd vs site type
ResidualSD
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type

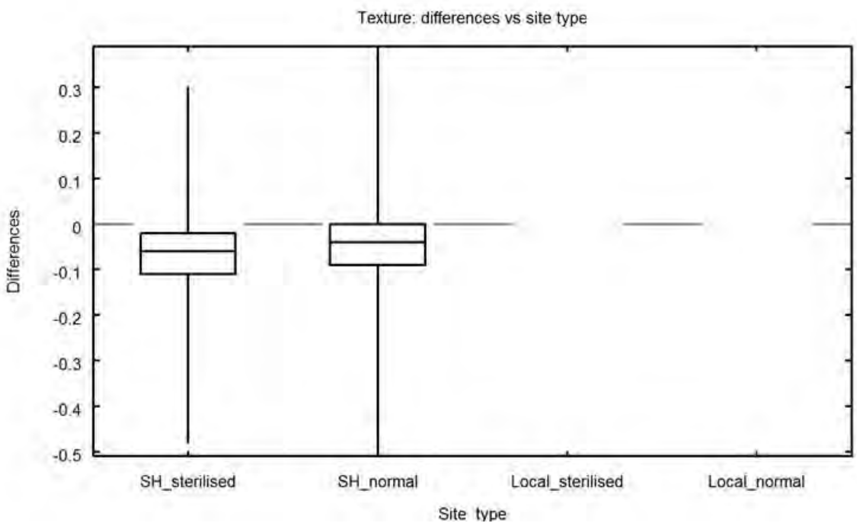

Texture: slope vs site type
Slope
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
SH_sterilised
SH_normal
Local_sterilised
Local_normal
Site type


Texture: slope vs sensitivity
Slope
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
Lim
Low
Medium
Mod
High
Sensitivity


Texture: slope versus AADT
Slope
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
1000
10000
100000
AADT


Texture: slope versus SNP
Slope
SNP
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Texture: slope versus rainfall
Slope
Rainfall
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
800
1000
1200
1400
1600
1800
2000
2200


Texture: differences vs site type
Differences
Site type
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
SH_sterilised
SH_normal
Local_sterilised
Local_normal

Residual standard deviations are much the same for the different site types for rut depth but for roughness the TLA ones seem to be lower. Given the smaller sample sizes one probably cannot make too much meaning from the differences in the box plots for the texture data.

The trends for the rut depth data are much stronger for the SH data than for the TLA data. This may be related to the previously noted higher values of rut depth in the TLA data.

Roughness tends to be *decreasing* on the SH data and shows little trend in the TLA data.

Texture is decreasing and the difference between the sterilised and normal sites may be due to the different surface types.

The trend in rut depth is stronger as the site sensitivity gets higher. The values for *lim* are fairly meaningless because of the small sample size, but otherwise the trend is fairly consistent. The effect of sensitivity on roughness seems inconsistent and is probably small. The trend in the texture data may be stronger for the high sensitivity sites.

In the three scatter plots of slope versus AADT, SNP and rainfall the SH points are the blue ones and the TLA points the red ones. Note that the AADT graphs have a log scale for AADT. There seems to be an increasing slope the graph of rut depth versus AADT, but there is nothing obvious in the others.

The graphs of differences versus site type are for comparison with the graphs of slope versus site type. Given that we are looking at individual differences rather than slopes, which, in effect, represent an average of differences, the two sets of graphs are fairly consistent with each other.

B3 Sites showing signs of accelerated ageing

The results of three computer programs are described in this section. These look for different aspects of accelerated ageing. Graphs of data from the sites where accelerated ageing was detected are then presented.

The actual 50 m section where accelerated ageing was detected is shown in colour (red for increasing direction, blue for decreasing) and the lines for other 50 m sections are greyed out. Note that the scales on both axes vary from graph to graph. Some of the greyed-out graphs also show jumps but these were not large enough to trigger the program.

The shape of the points on the lines shows which 50 m segment is being plotted.

Sequence number	Shape
1	plus
2	times
3	asterisk
4	hollow square
5	filled square
6	hollow circle

The program LTPP14 looks for sudden increases in the case of rutting and roughness and sudden decreases in texture. The jump sizes are the same as those described in section B2.1B2.2: 0.8 for rut depth, 0.1 for roughness and -0.6 for texture over one or two years.

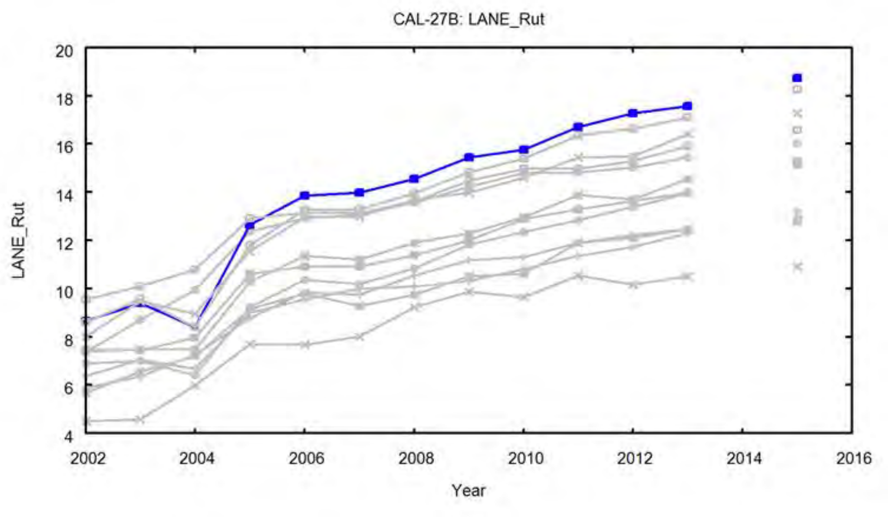
The program LTPP12 looks for sudden changes in trend – the continuous two phase problem. It is more sensitive than the test for a sudden jump but is also more easily fooled. The sudden jump points found in the previous section should have been deleted from the data used here. As in the previous section we are picking up a lot of jumps in 2014 which may be bogus.

The program LTPP11 fits slopes to all the lines and then selects sites where these slopes are inconsistent. Inconsistency may be because one or two lines are maverick or because there are lots of little differences. The interesting cases are where one or two lines are maverick. The program just says there are differences, it does not say which sites are different so there is no greying out of lines in the graphs.

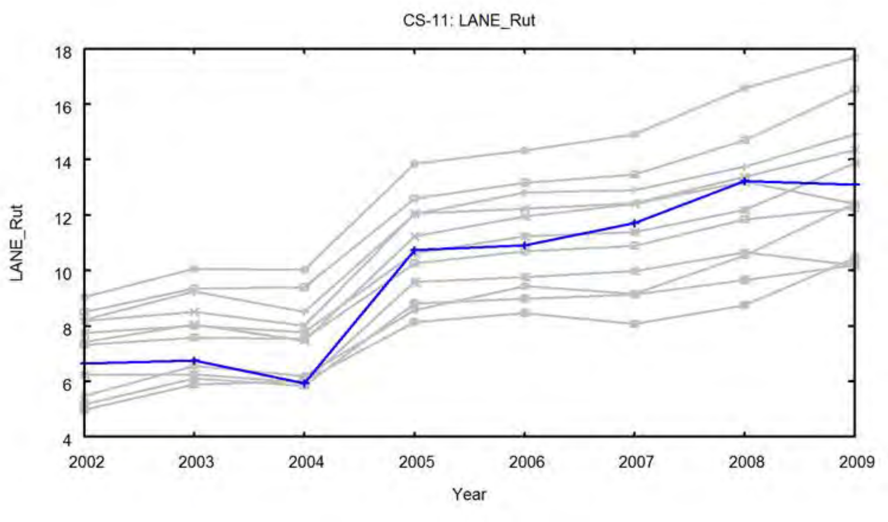
In all cases the choice of the critical points for deciding whether accelerated ageing is present is rather arbitrary since we have not been able to investigate a suitable statistical model.

B3.1 Rutting

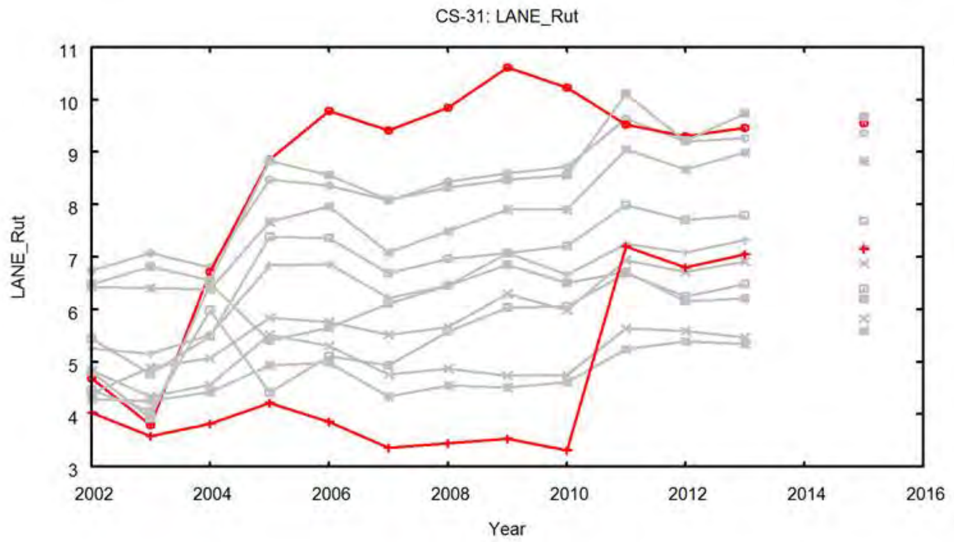
LTPP14 – looking for sudden increases in rutting.



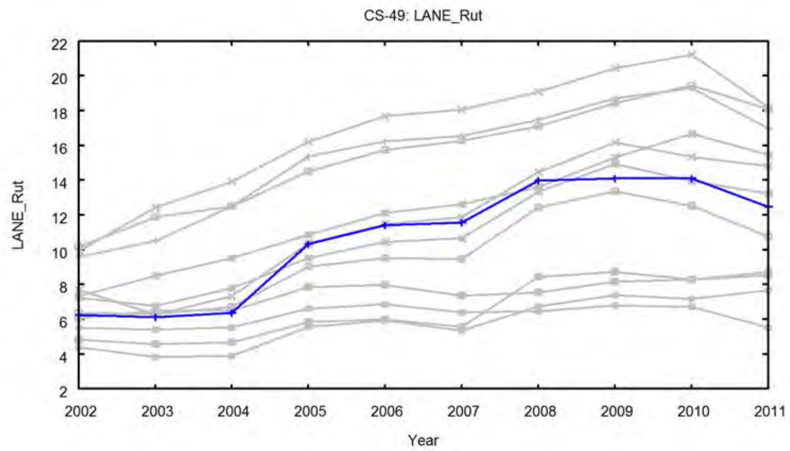
CAL-27B should possibly not be here – the jump may to be due to a bad reading in 2004.



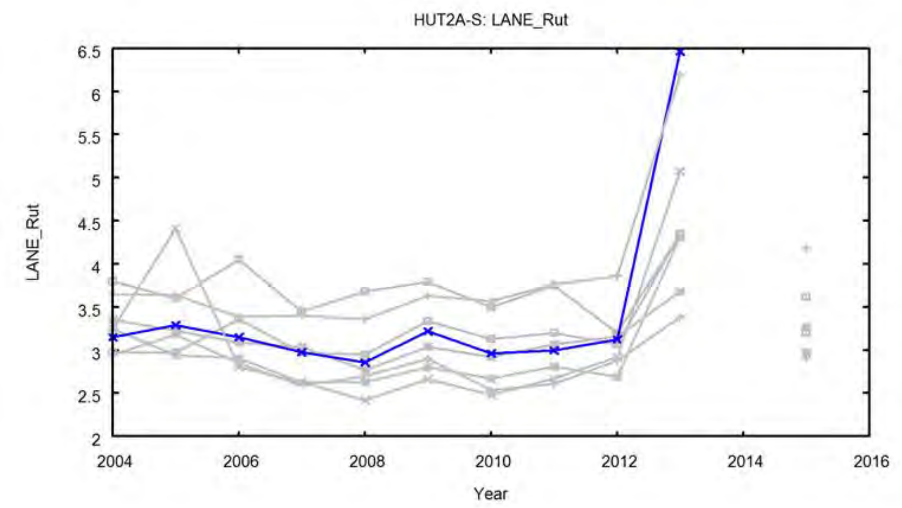
Maybe another bogus jump due to a bad reading?



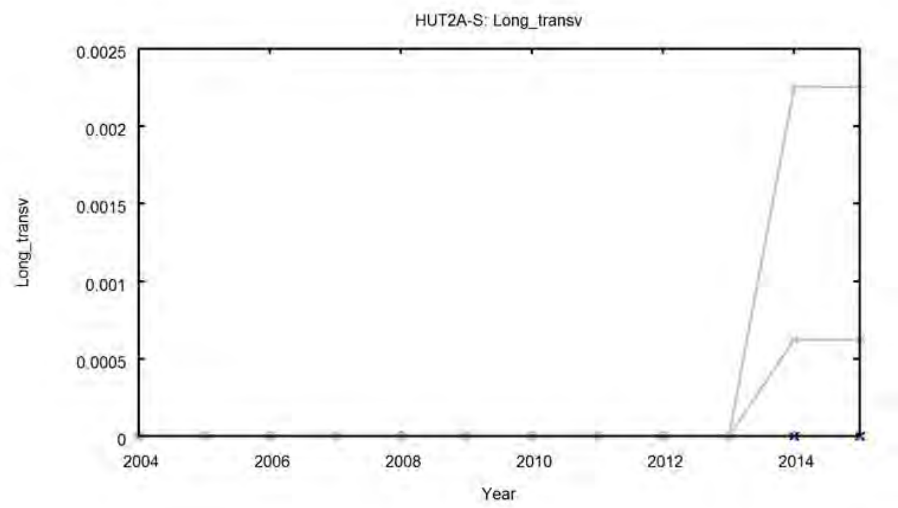
Not sure if these two jumps are real effects or due to realignment of the wheel tracks. There was no cracking reported.



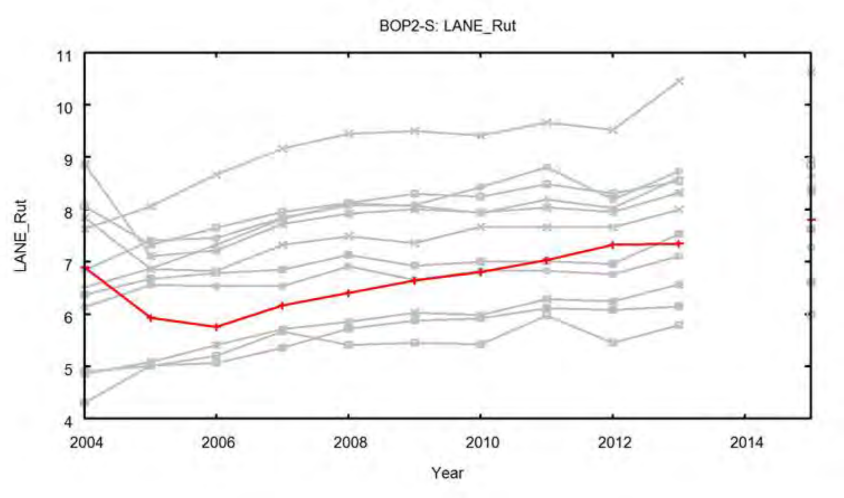
Maybe another bogus jump due to a bad reading?



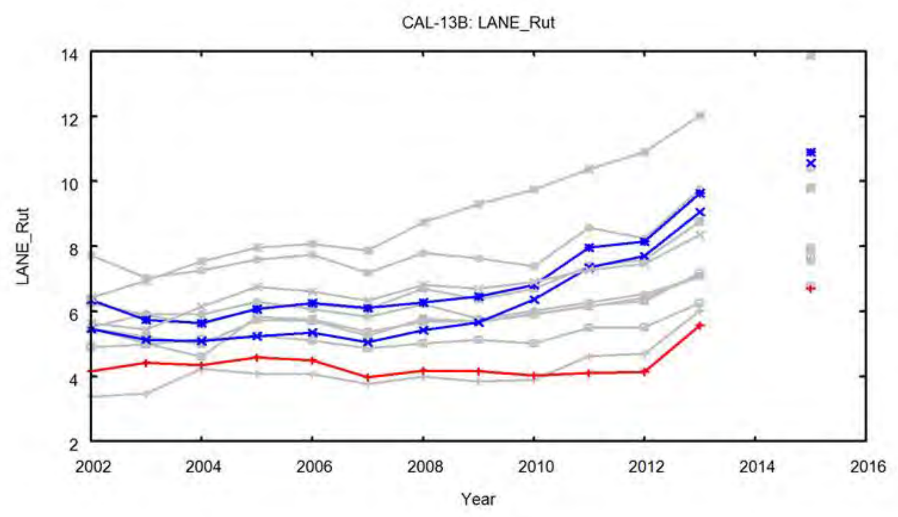
The raters do not provide any explanation for the jump in 2012/3. There was longitudinal or transverse cracking but not corresponding to the segment showing the strongest jump.



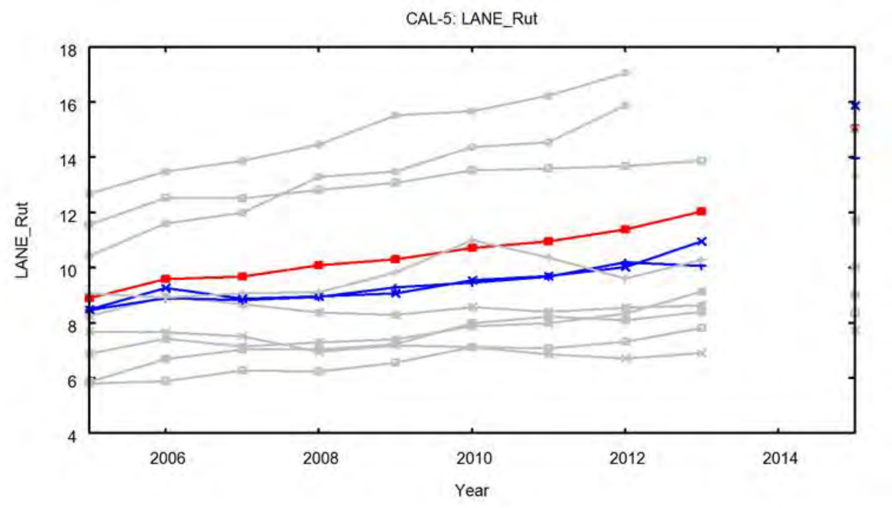
Rutting – program LTPP12 looking for sudden changes in trend.



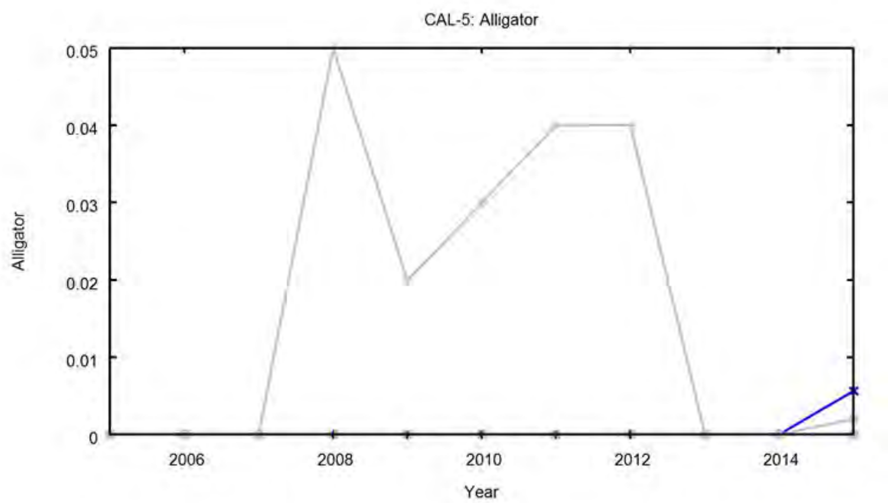
Decreasing trend turning into increasing – probably just settling down after earlier work – not of interest.

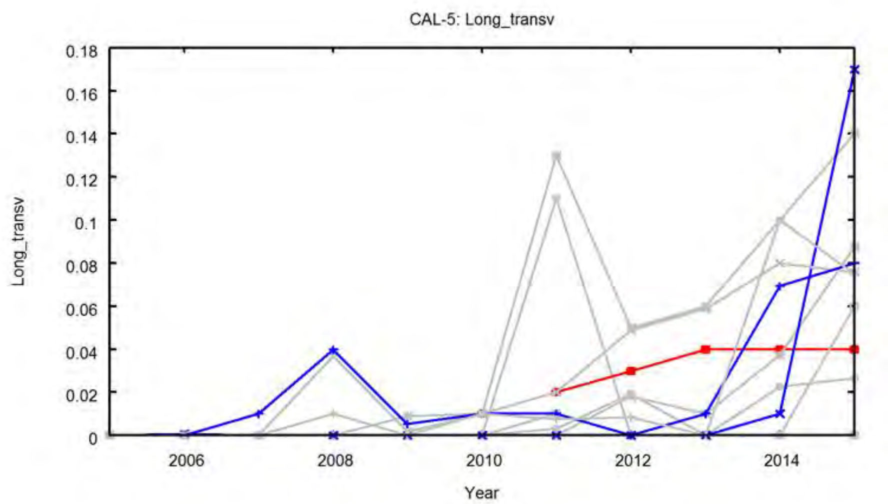


You cannot pinpoint when a change occurs but there does seem to be an increasing upward trend beyond about 2007 in the two blue lines and 2012 in the red line. There was longitudinal or transverse cracking towards the end of the period but not corresponding to the highlighted graphs.

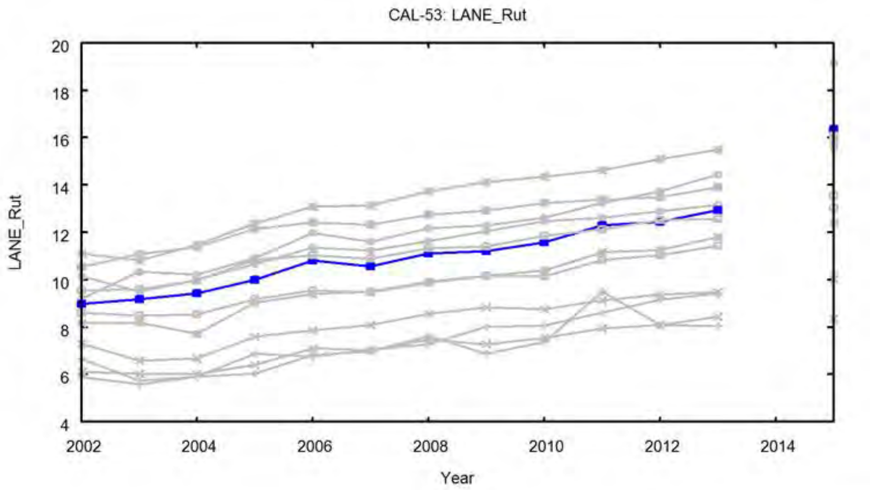


The raters reported the site in bad condition in 2014 and 2015. Here are the graphs of the cracking.

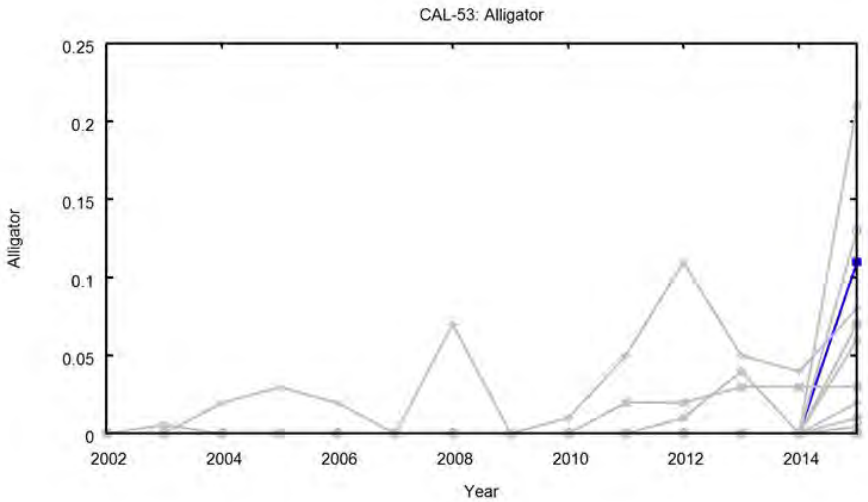


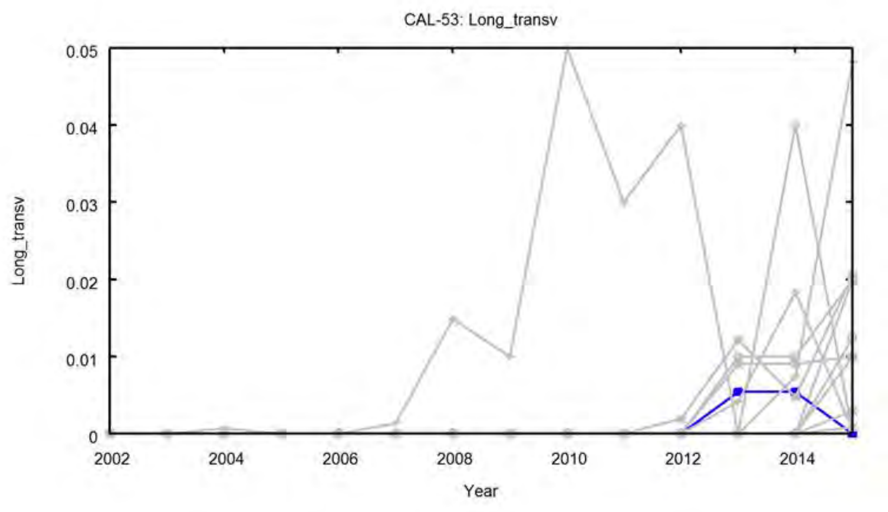


There is longitudinal or transverse cracking in most of the segments including the ones showing the change in slope.

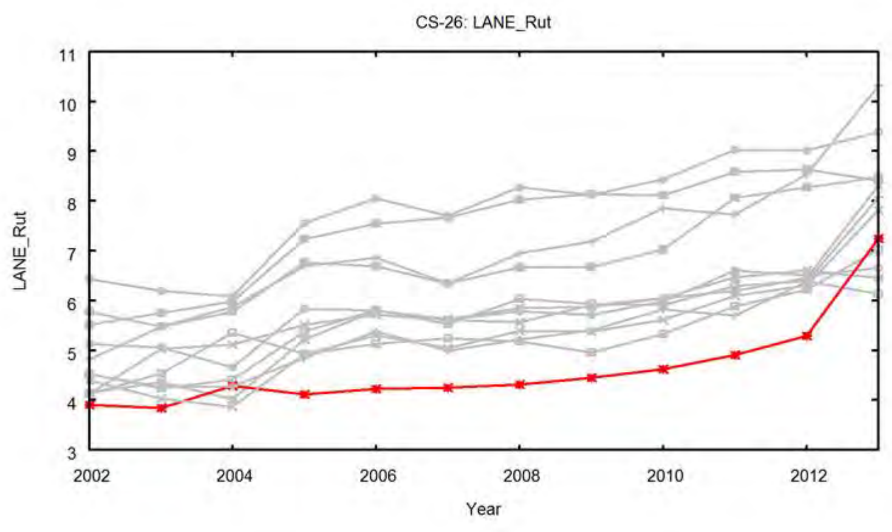


The raters reported the site in poor condition in 2013 and beyond.

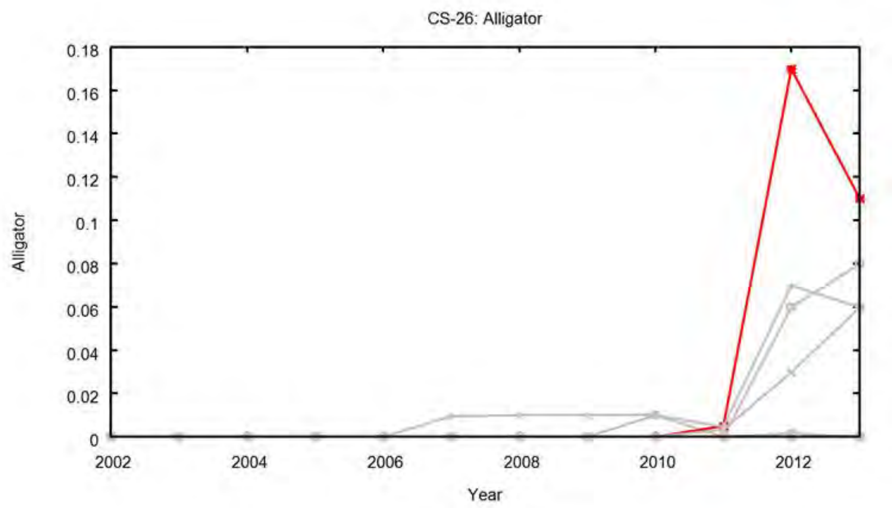


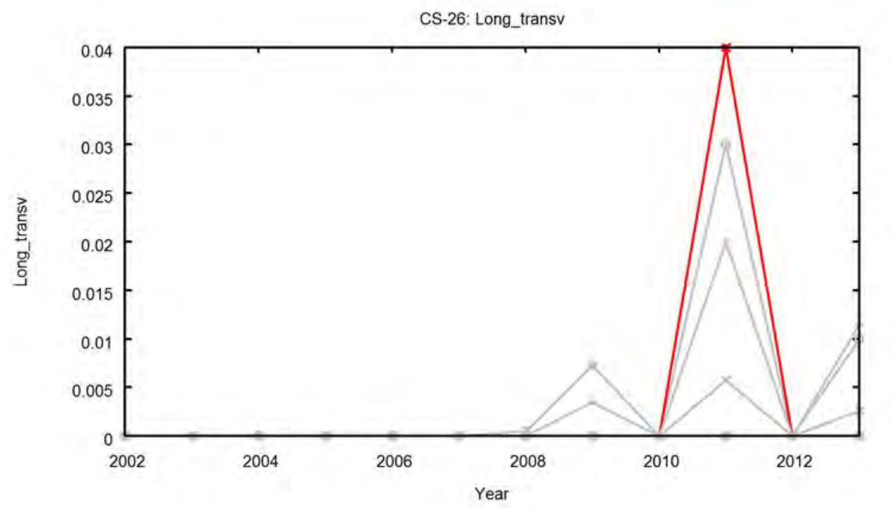


The highlighted lines do not stand out amongst the others.

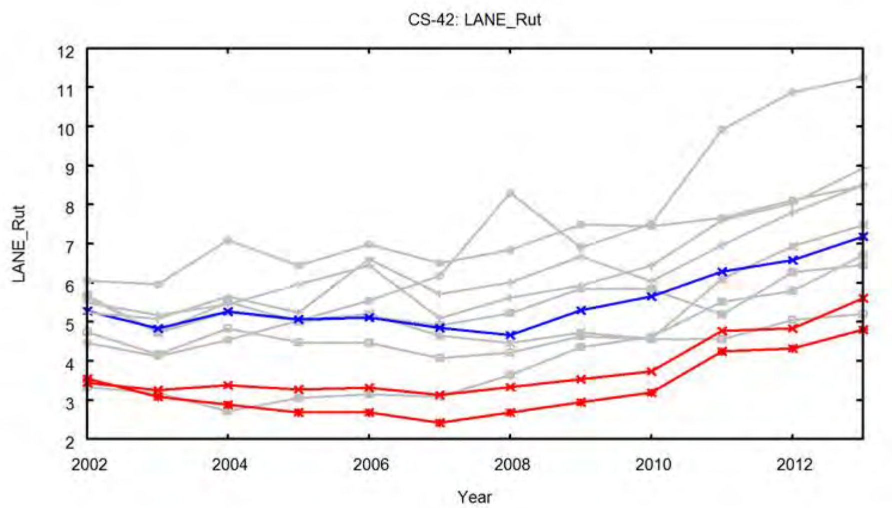


This looks like a site with increasing deterioration towards the end of the period. Here are the cracking graphs.

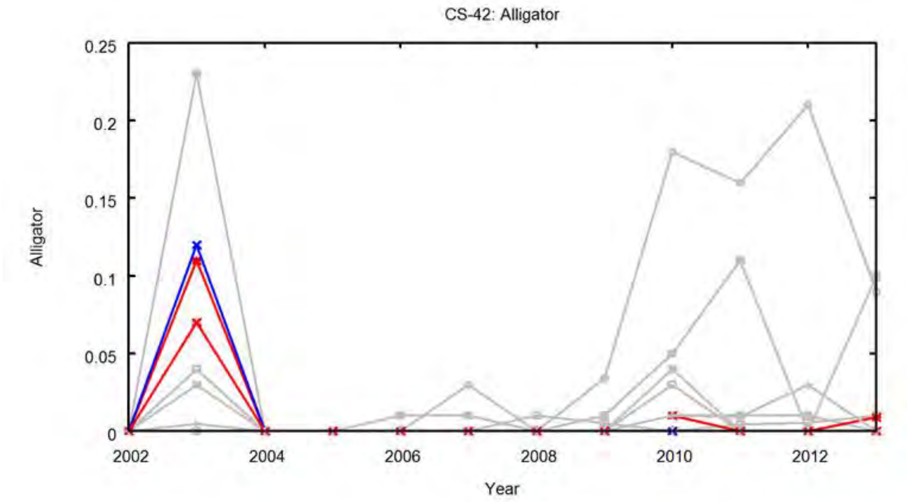


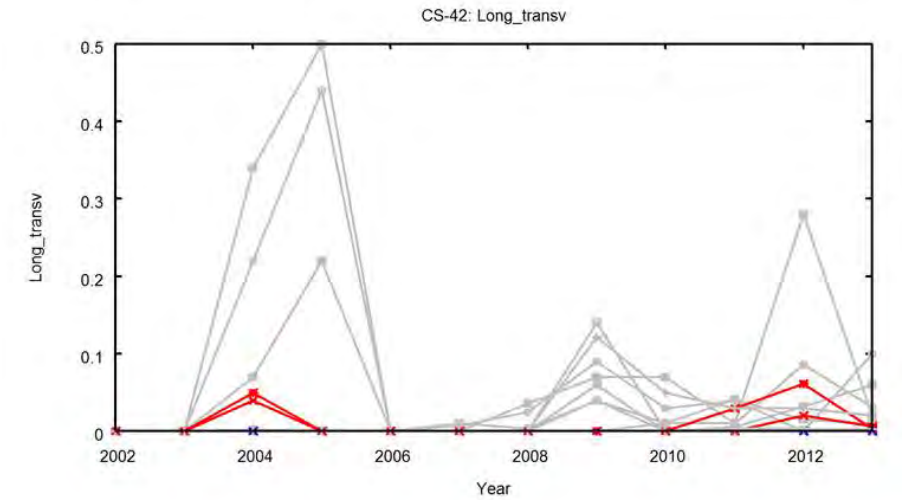


Here, the highlighted graphs do stand out; cracking seems to precede the increase in rutting.



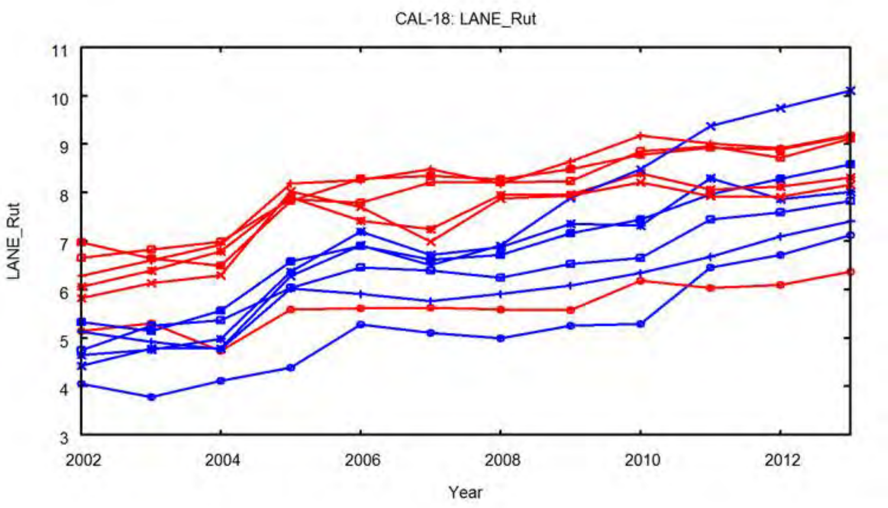
The raters report poor condition towards the end of the period graphed. There was a full rehabilitation in 2014/5 – beyond the point where the data is being graphed. There is not much cracking between 2007 and 2010, when the accelerated ageing seems to be starting.

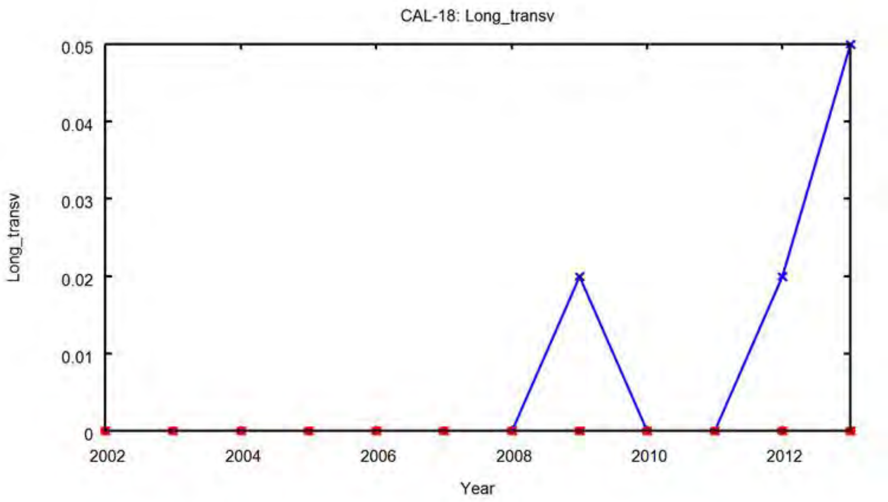




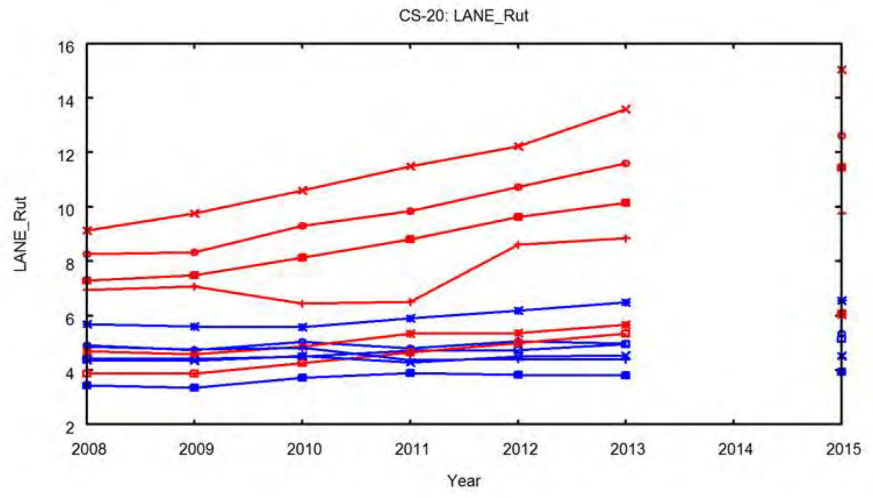
Rutting – program LTPP11 – look for inconsistent slopes.

The program does not pick out which slopes are inconsistent so none of the lines are greyed out. The cracking graphs are indicated where they look interesting.

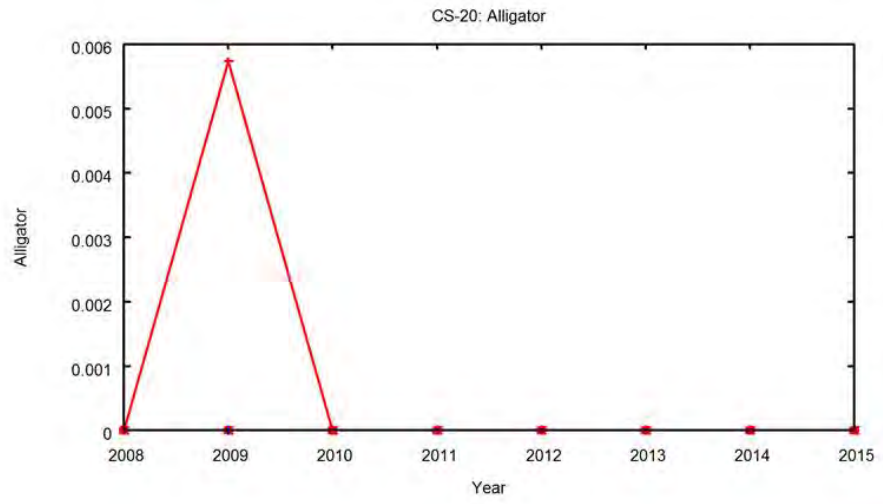


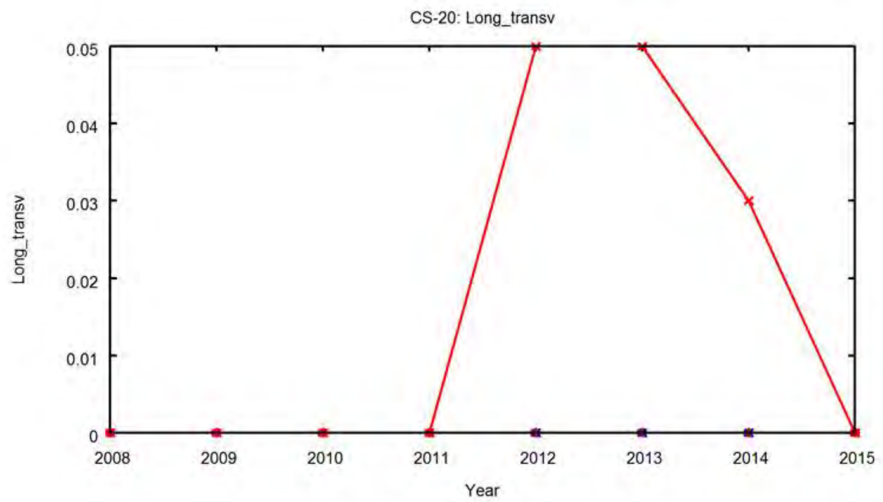


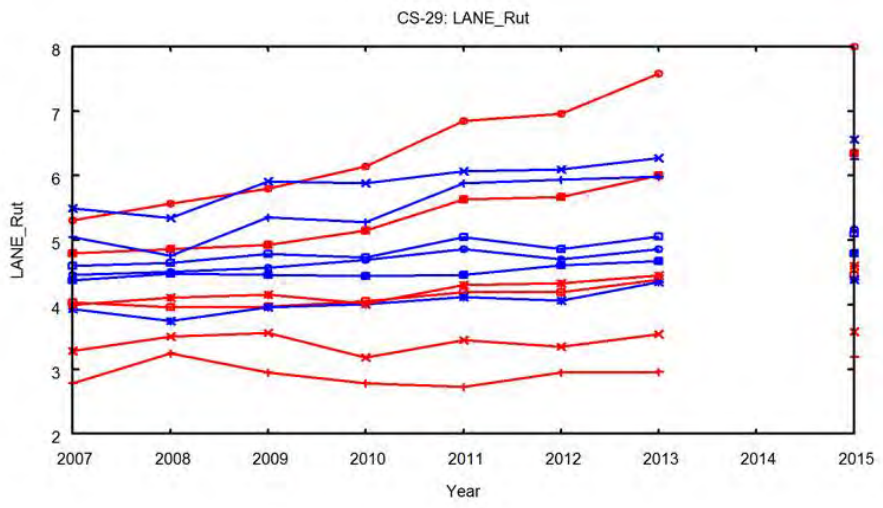
Sequence 2 (times symbol) in the decreasing direction is ageing more rapidly and appears in the longitudinal/transverse cracking diagram.



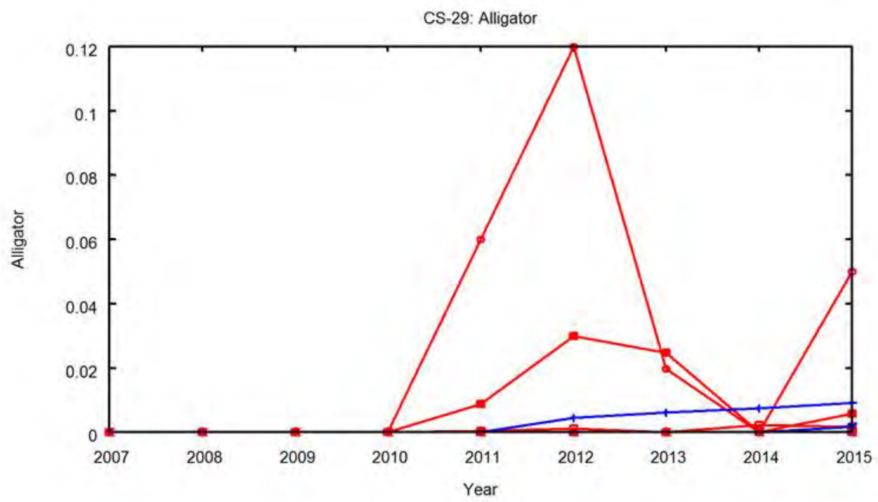
Several in the increasing lane show faster ageing one of them has longitudinal/transverse cracking.

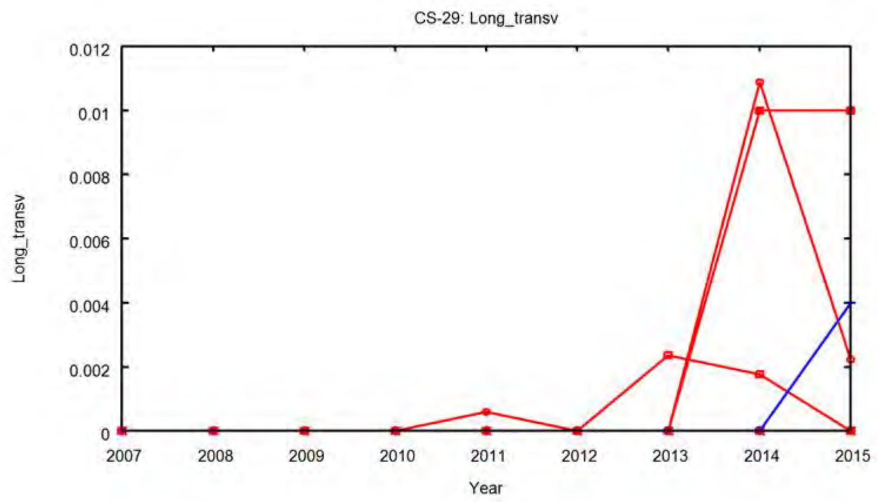


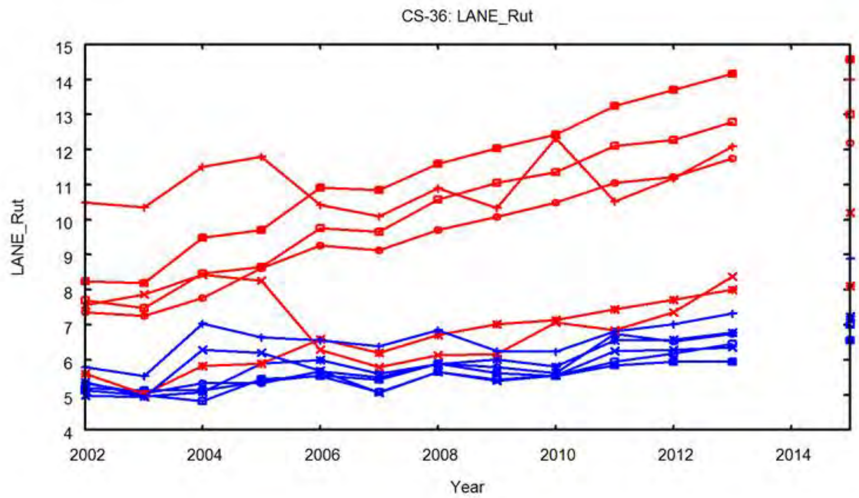




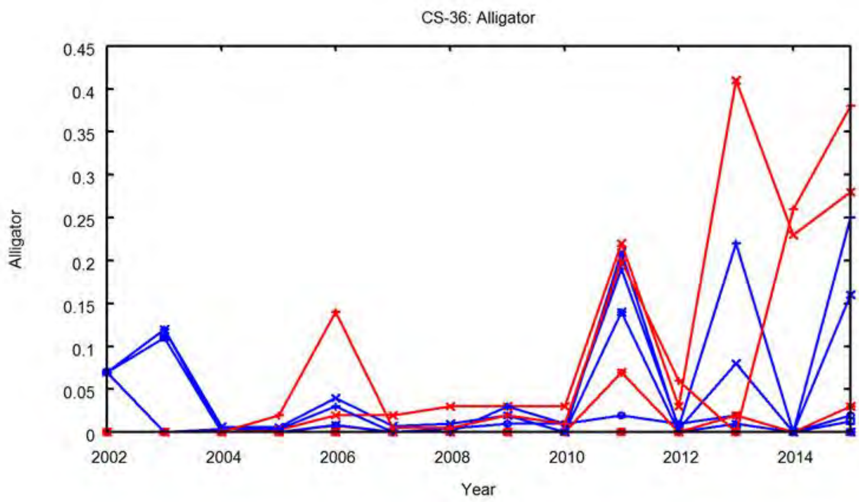
Two segments in the increasing lane and one in the decreasing lane show faster ageing and these appear in the cracking diagrams.

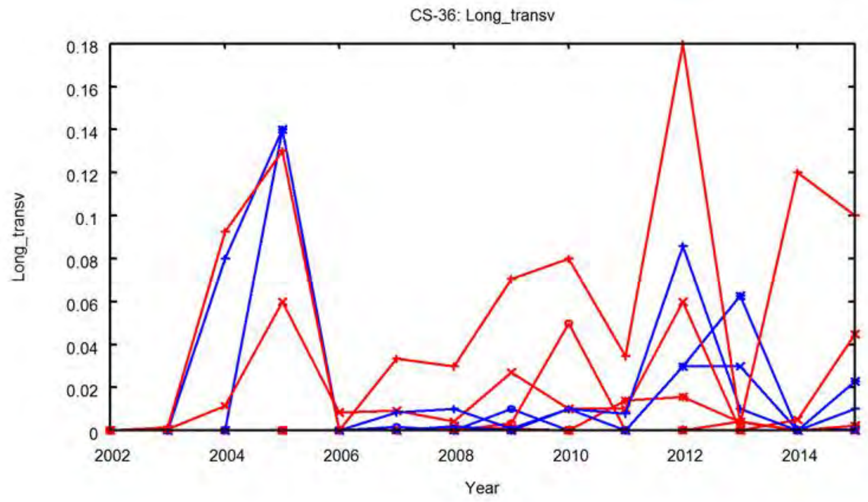


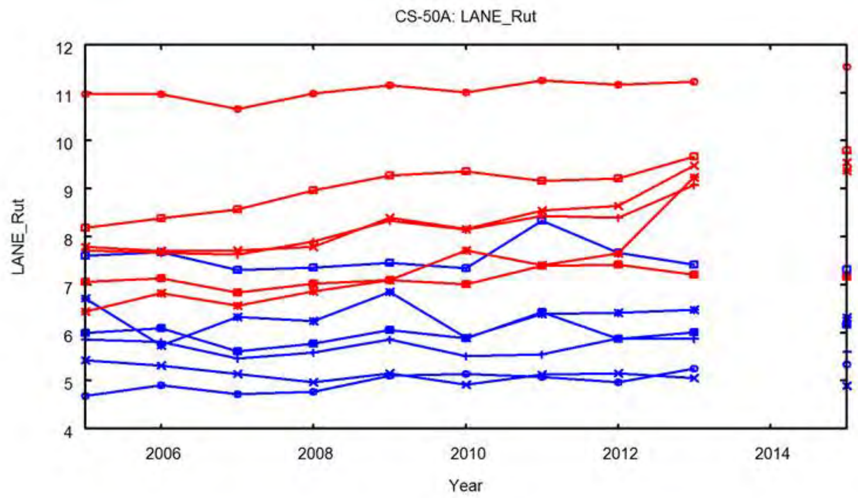




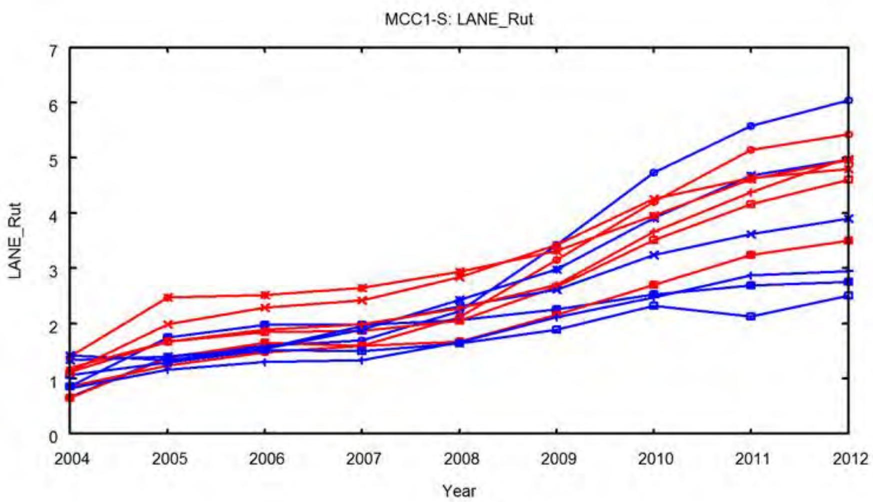
There is considerable cracking but it is difficult to see any relationship between it and the rutting.



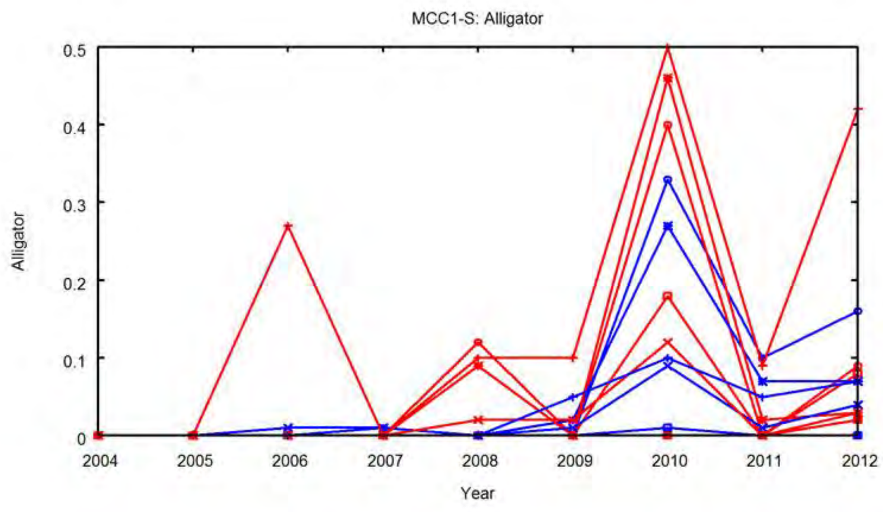


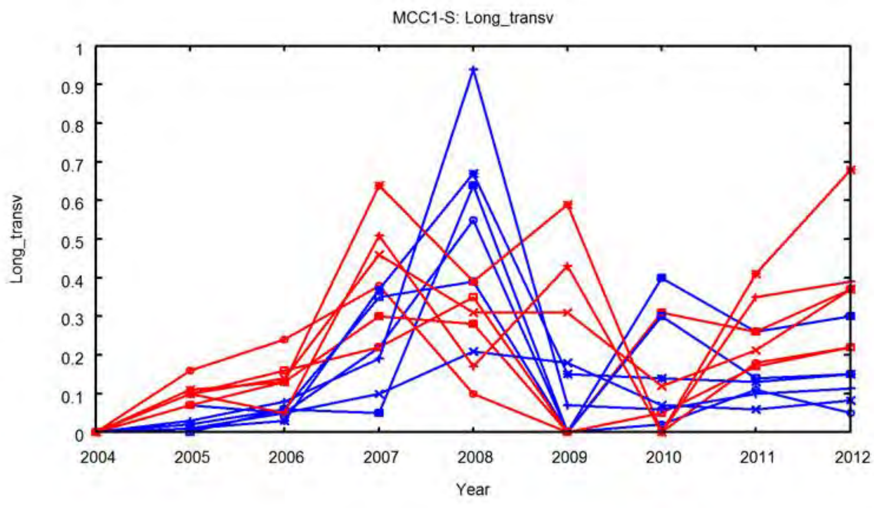


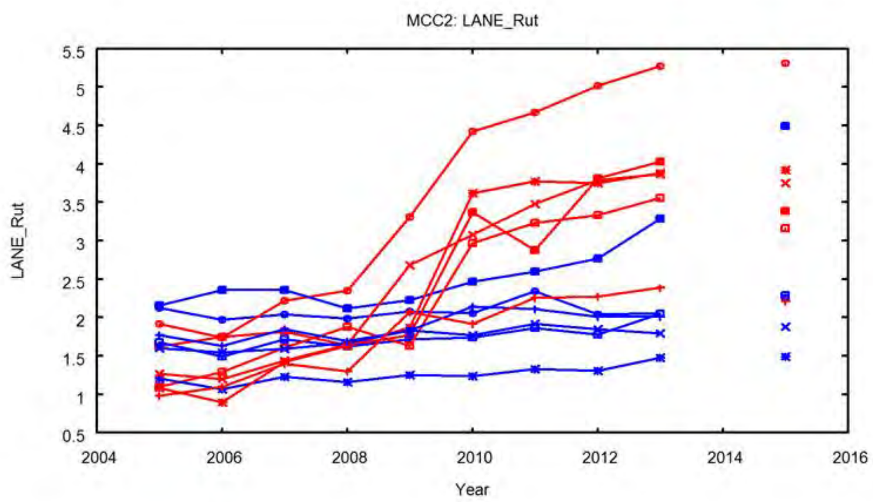
It is not known why this one was selected. There was only slight cracking towards the end of the period.



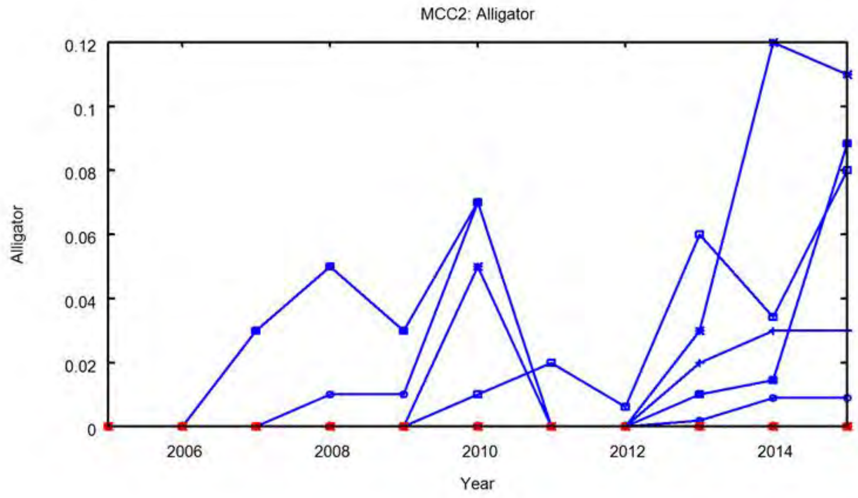
There is strong cracking but it is difficult to see any relationship.

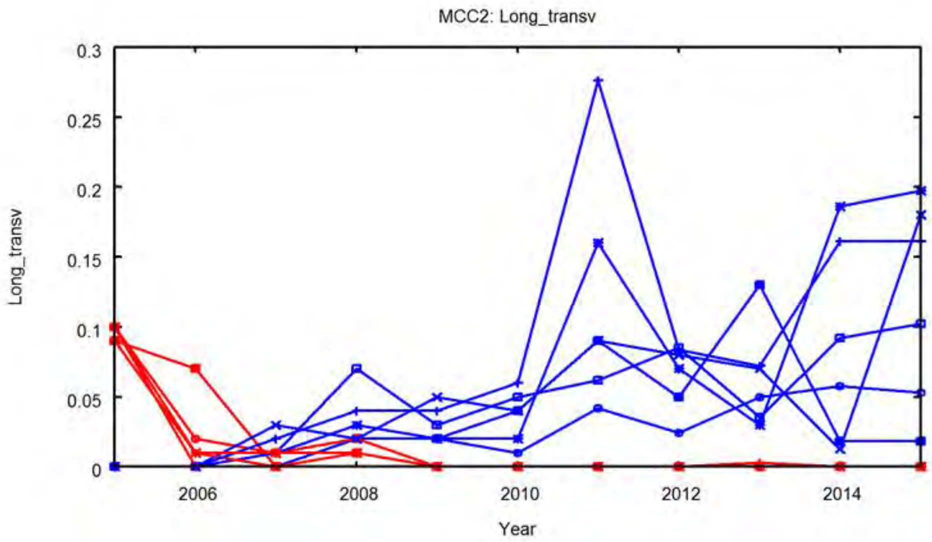


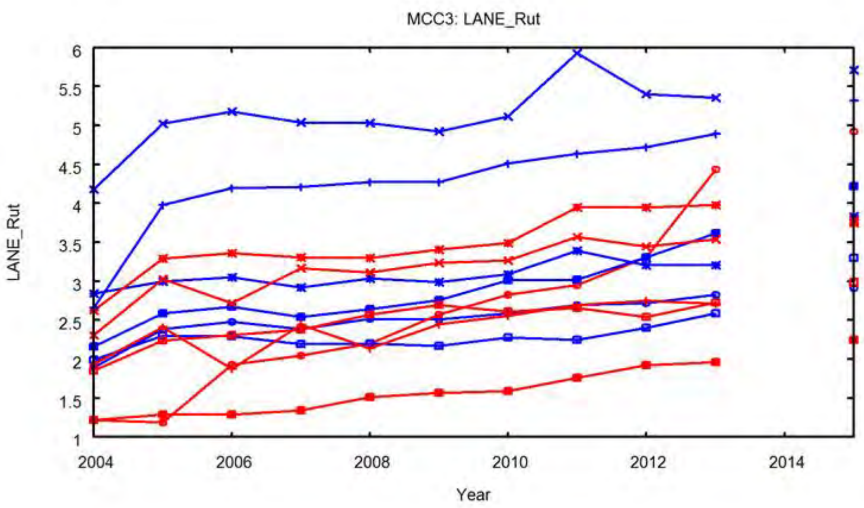




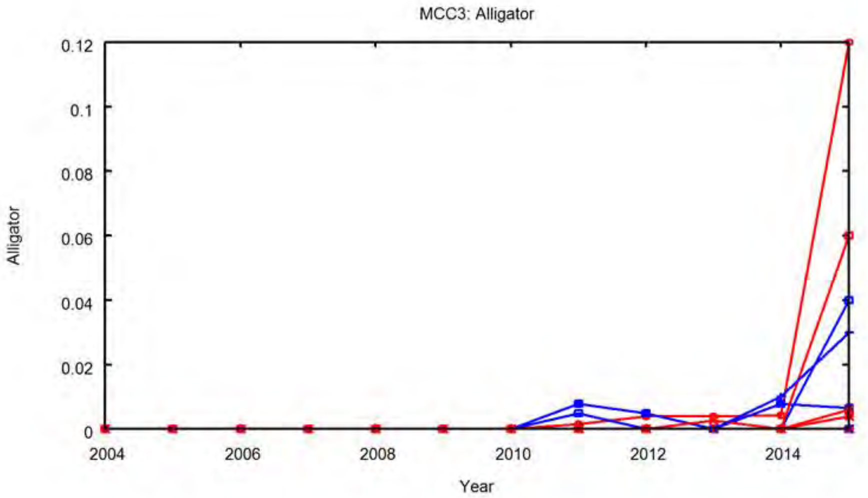
The rapid increase in rutting is in the increasing lanes but the cracking is in the decreasing ones.

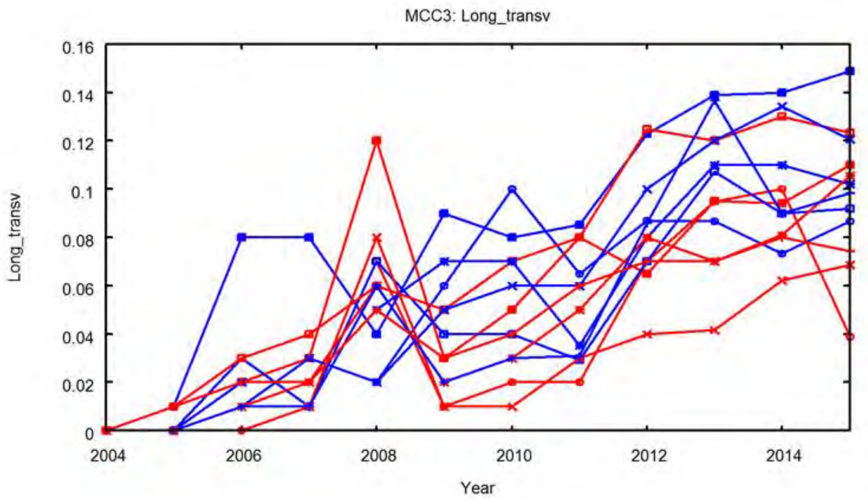


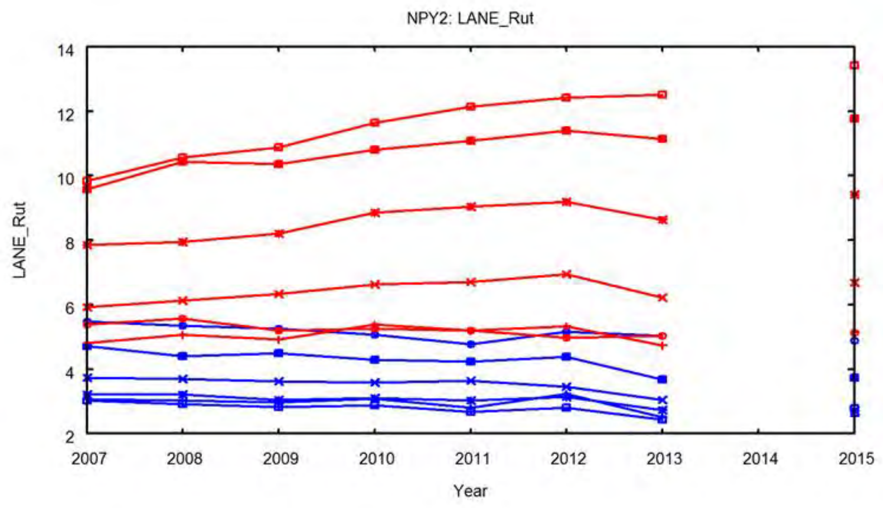




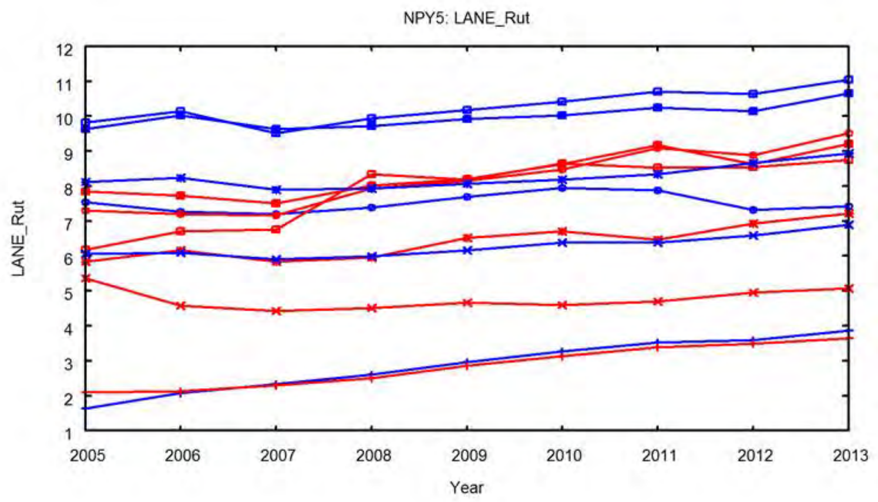
There is a lot of cracking but it is hard to see any relationship with the ageing. The fasted ageing segment (segment 6, open circle in the increasing direction shows the most alligator cracking).



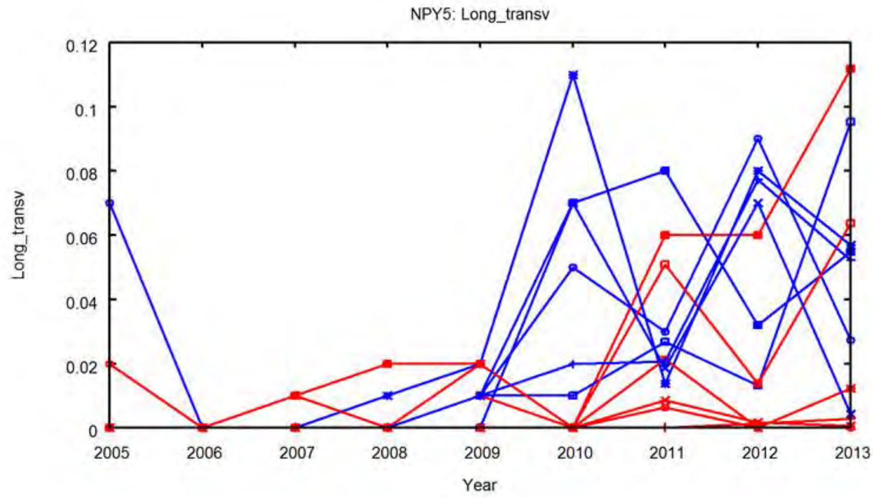


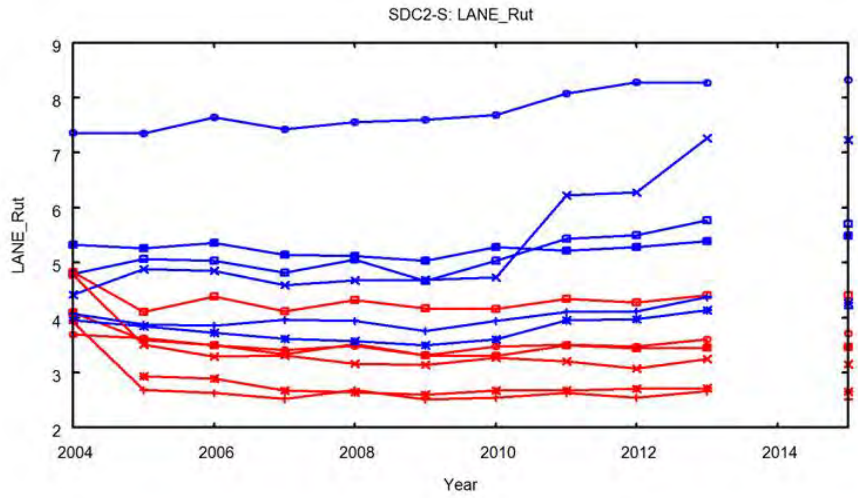


The cracking is very light and does not seem to be related to the ageing.

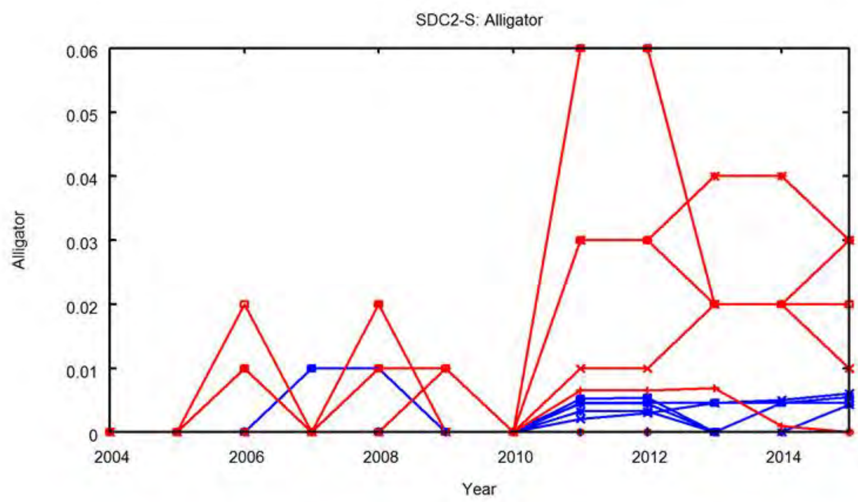


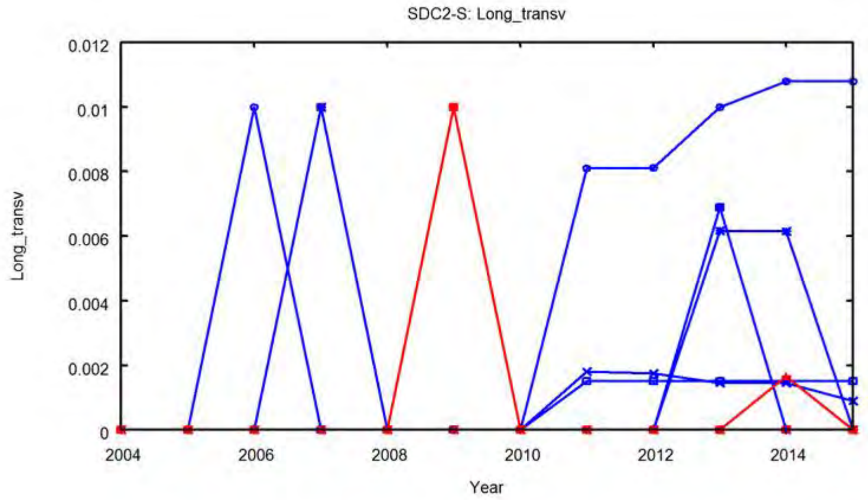
There is only light alligator cracking and moderate longitudinal/transverse cracking that is difficult to relate to the ageing.

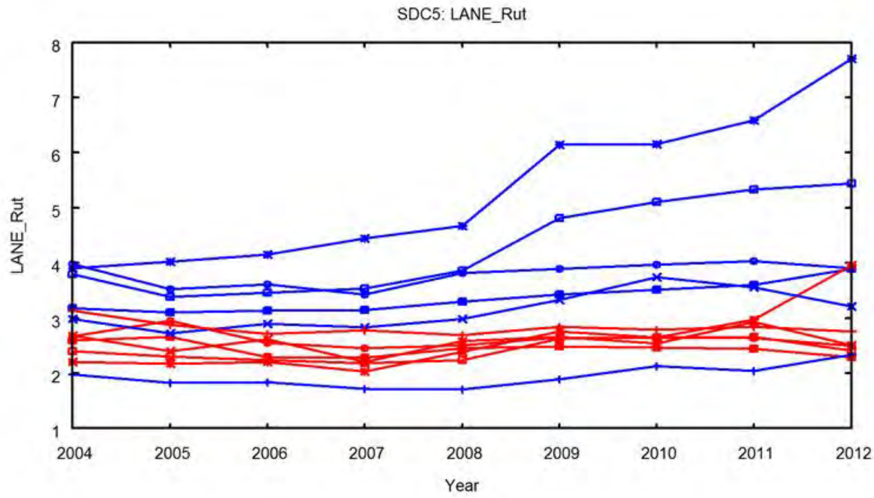




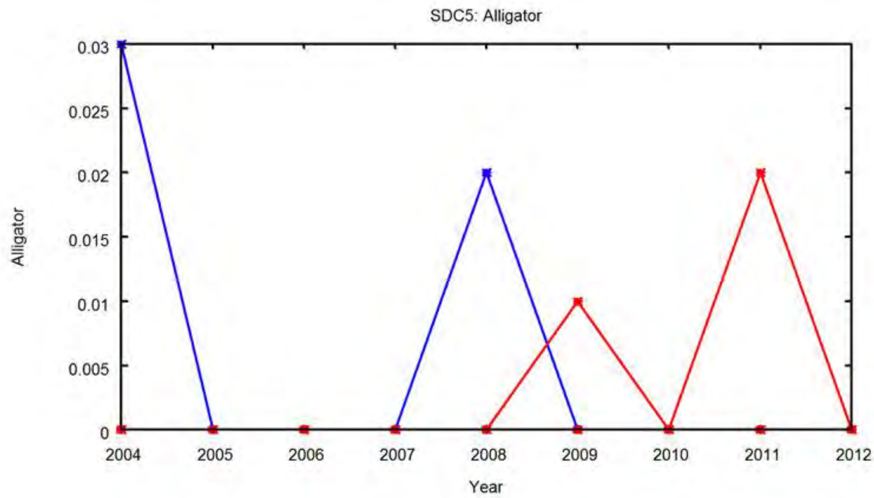
The cracking does not seem to have much relationship to the ageing.

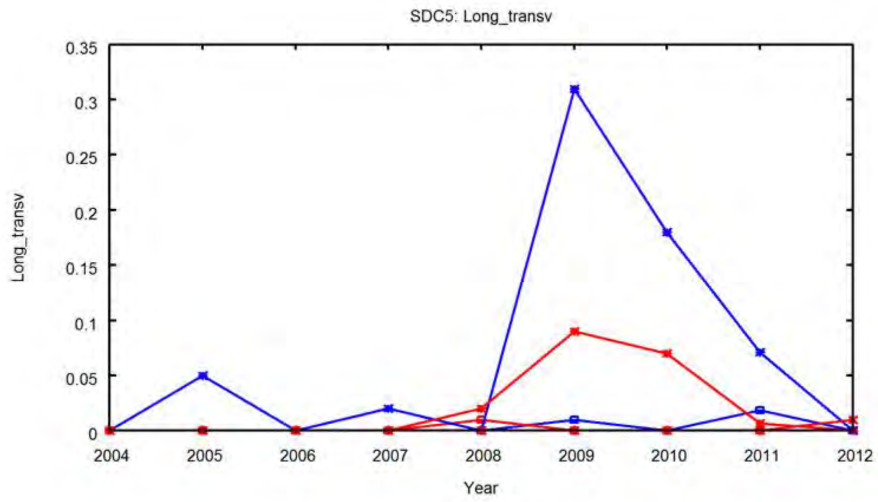


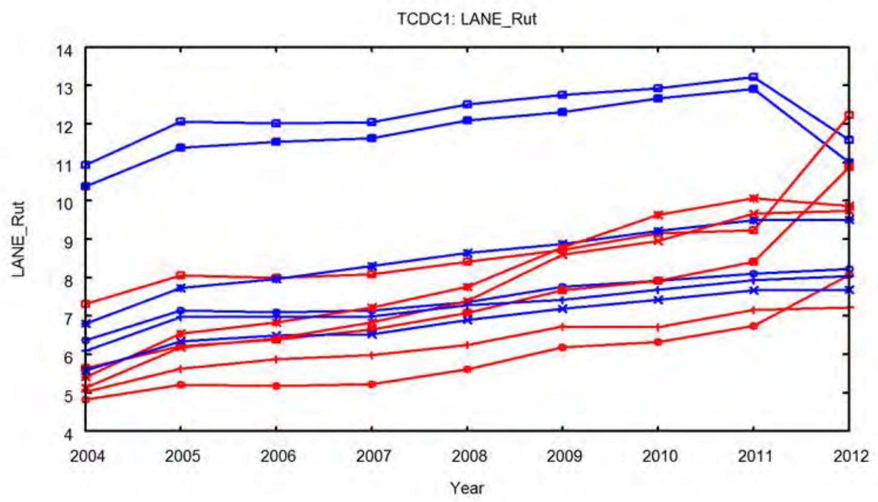




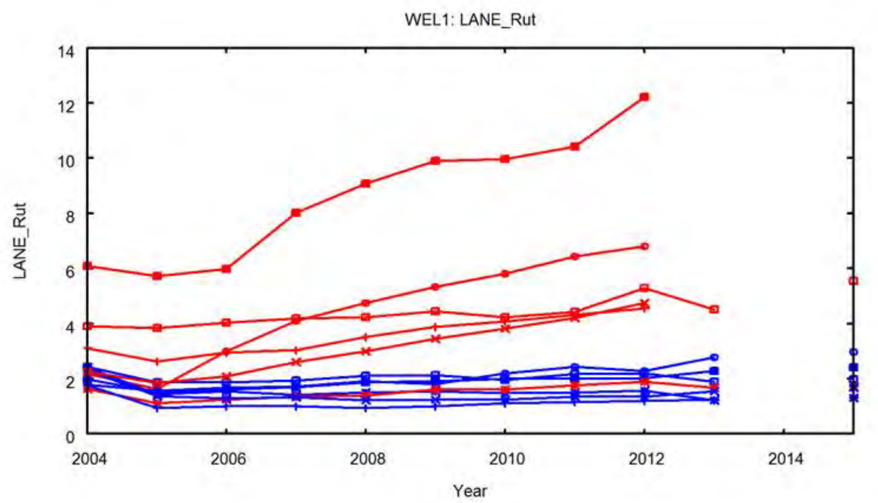
The segment showing the most ageing also has the most longitudinal/transverse cracking.



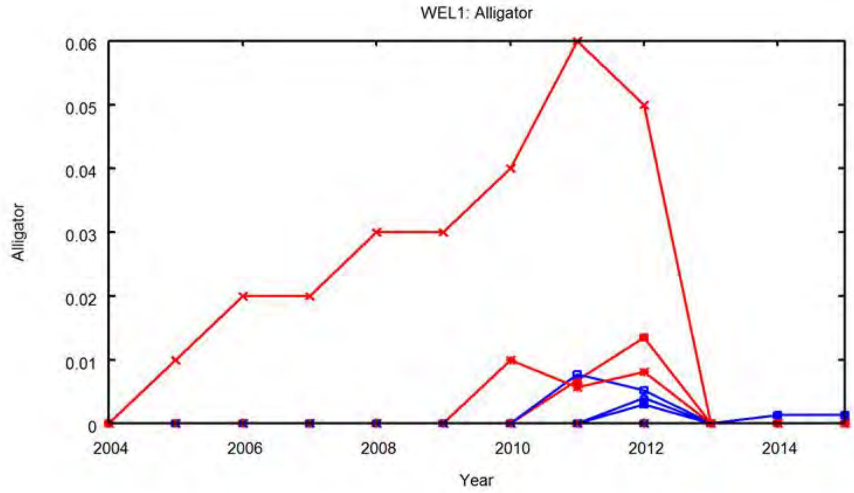


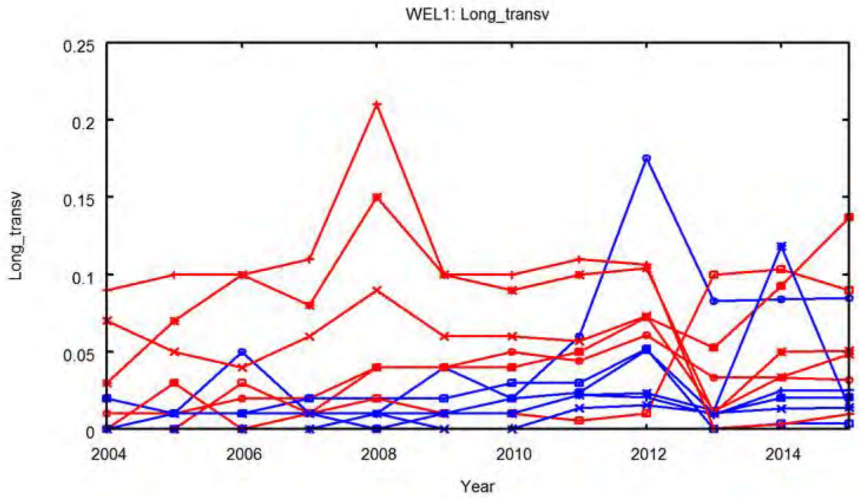


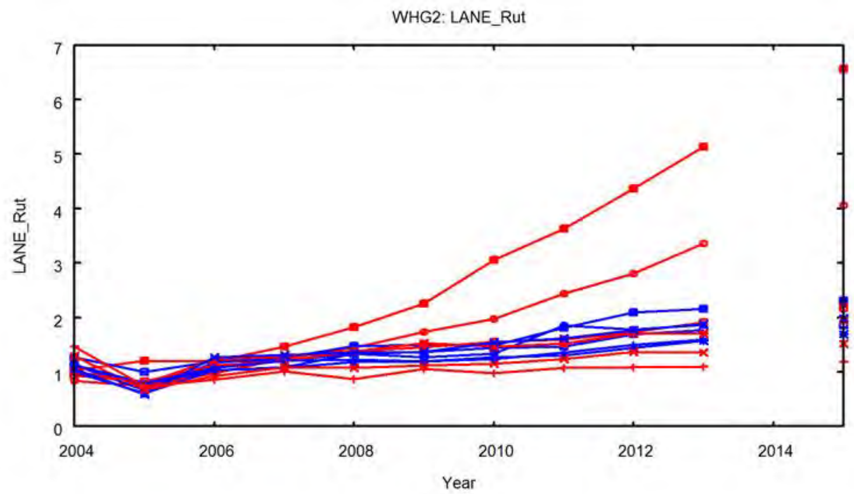
There was no cracking reported.



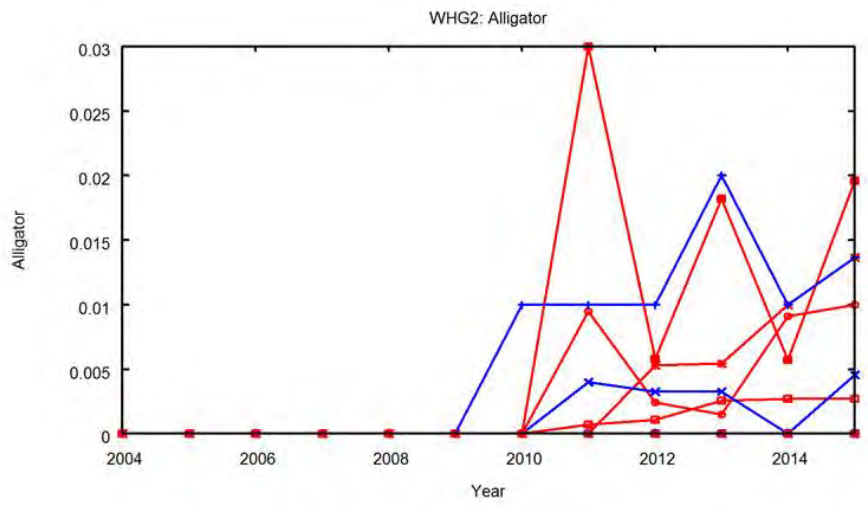
The increasing lanes seem to be ageing more and they have more cracking.

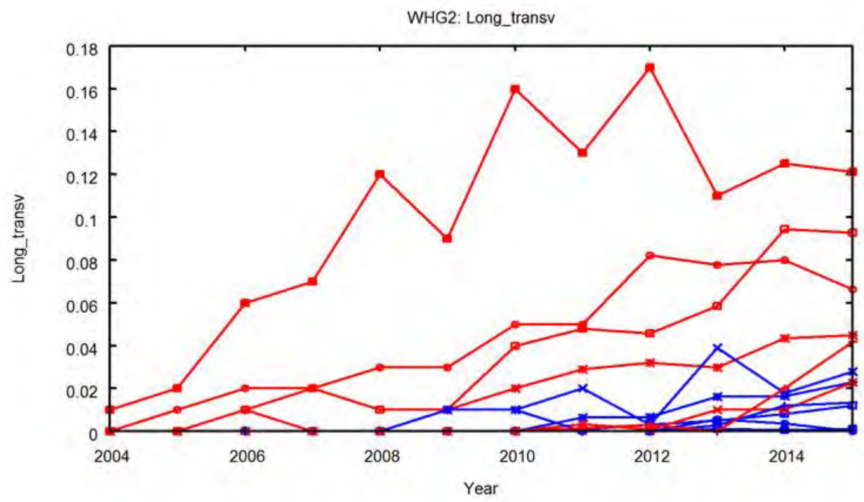

WEL1: Alligator
Alligator
Year
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
2006
2008
2010
2012
2014


WEL1: Long_transv
Long_transv
Year
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014


WHG2: LANE_Rut
LANE_Rut
Year
7
6
5
4
3
2
1
0
2004
2006
2008
2010
2012
2014

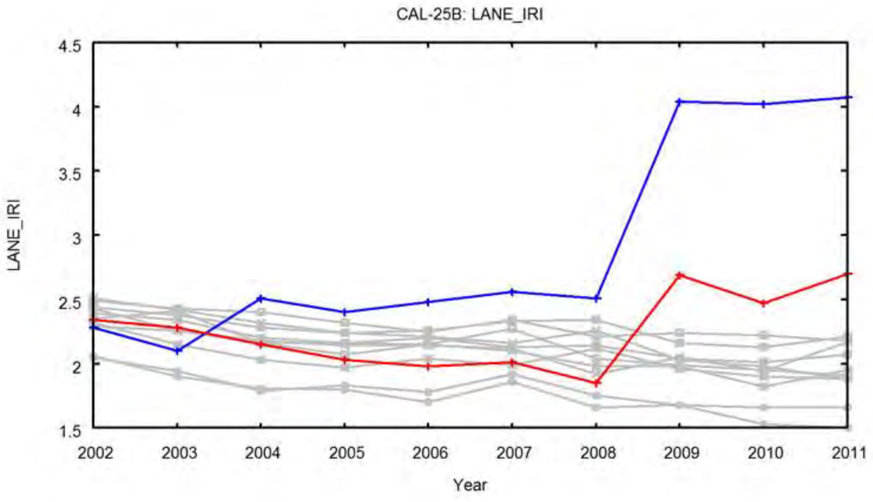
The segment that is ageing fastest is cracking more.



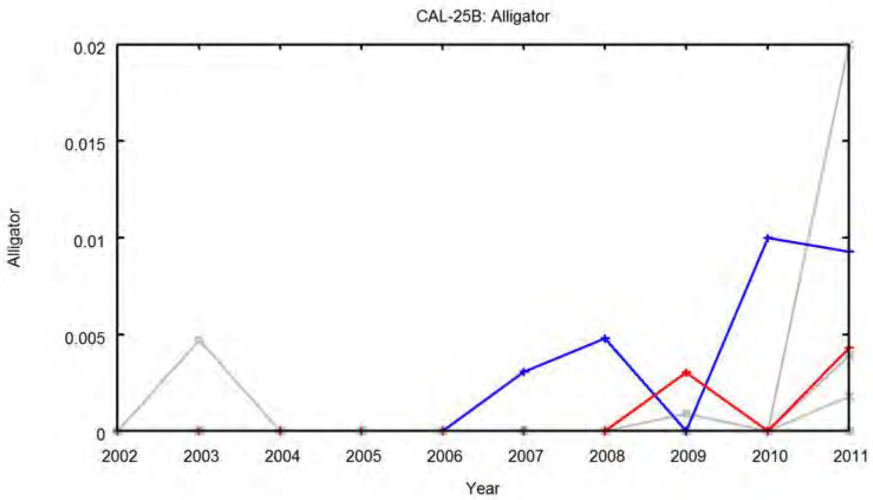


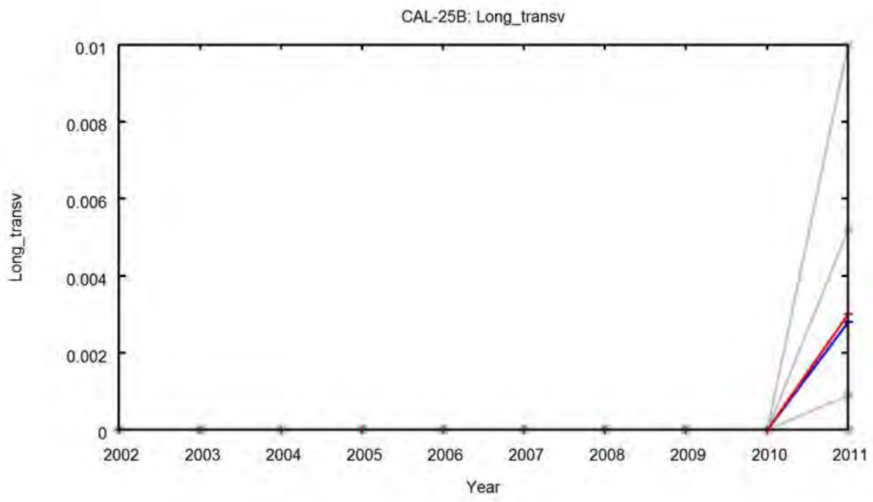
B3.2 Roughness

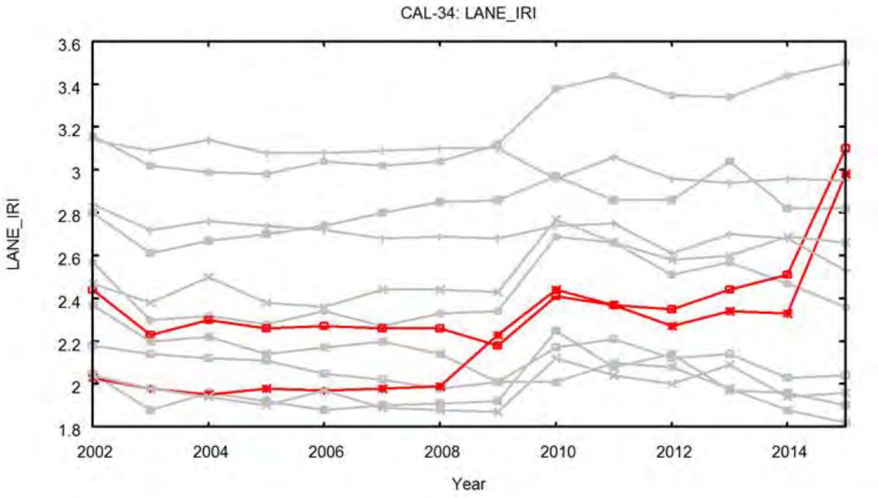
Roughness – LTPP14 – looking for sudden jumps.



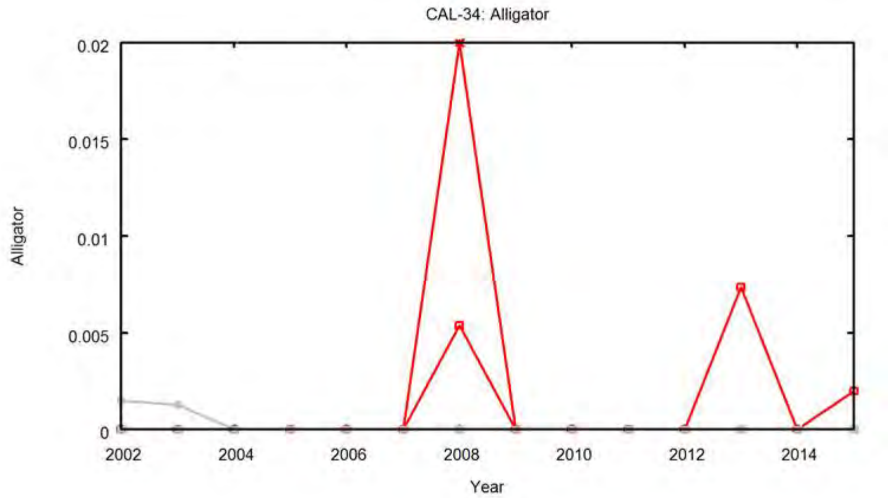
We do not know how much these two jumps are due to maintenance and to what extent they are associated with the cracking.

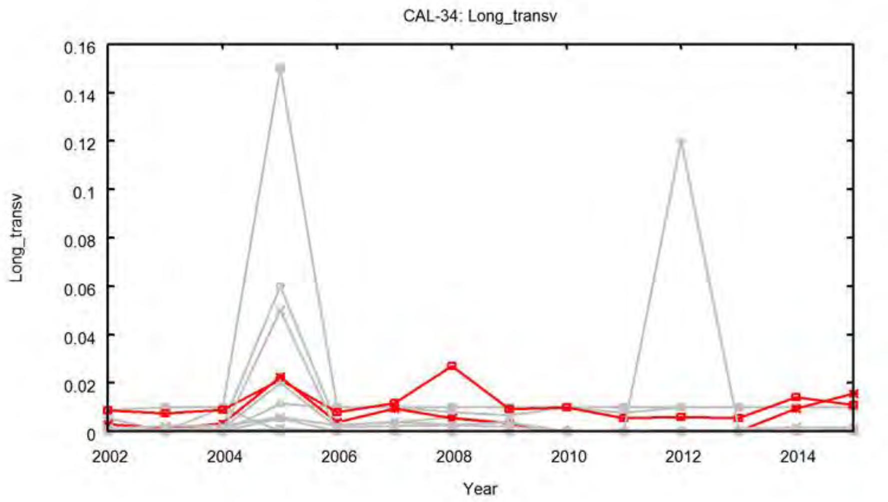


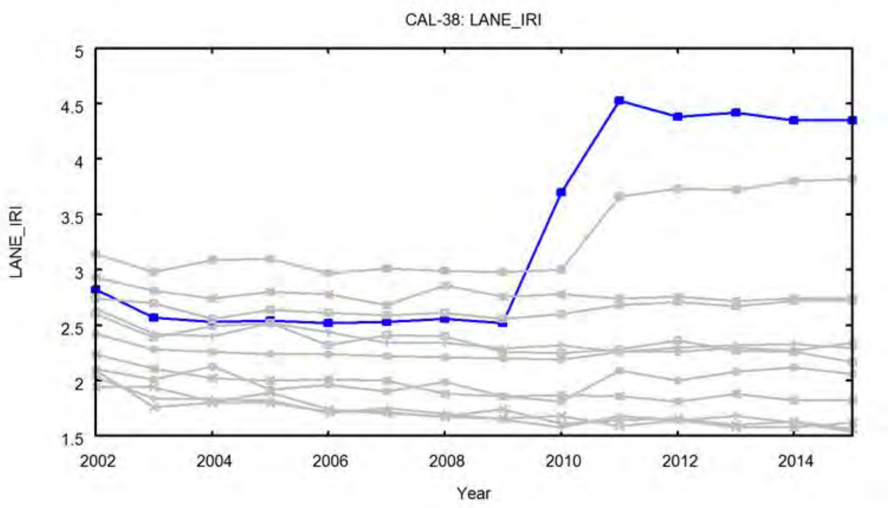




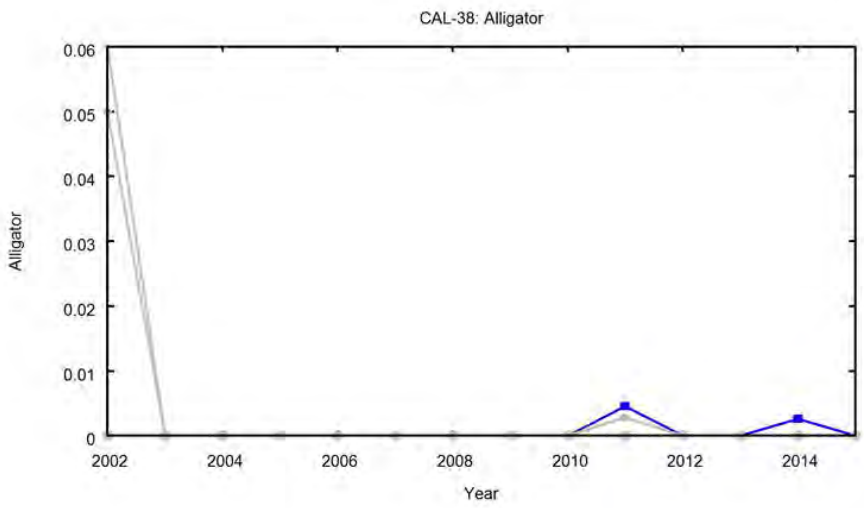
The alligator cracking seems to be associated with the ageing

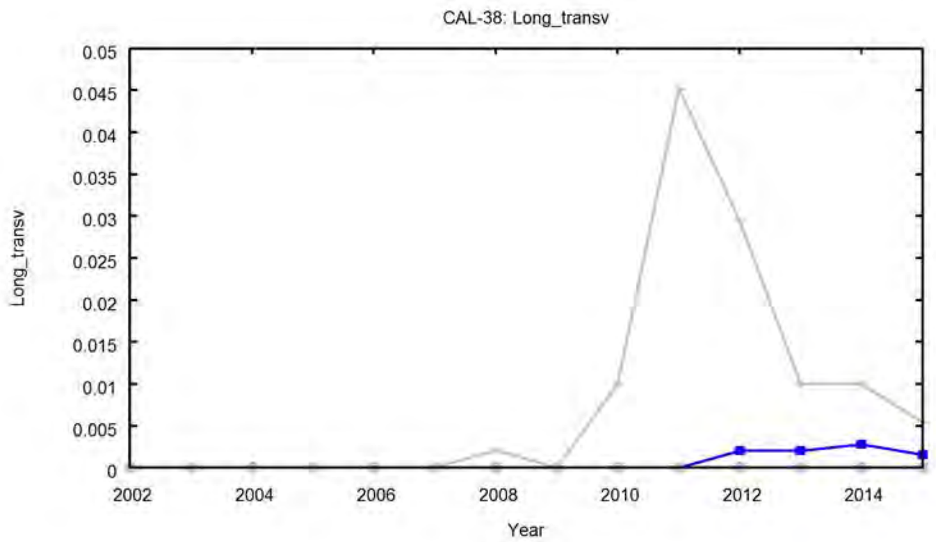


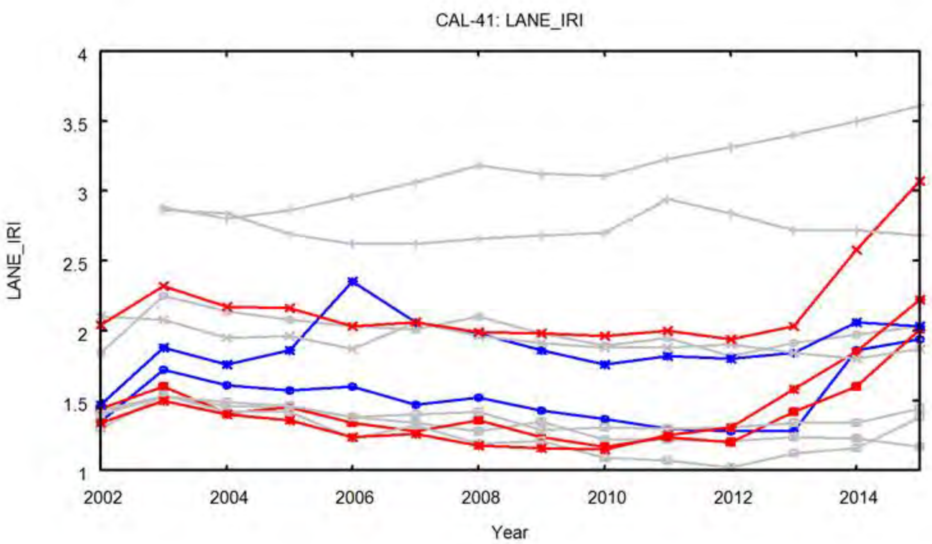




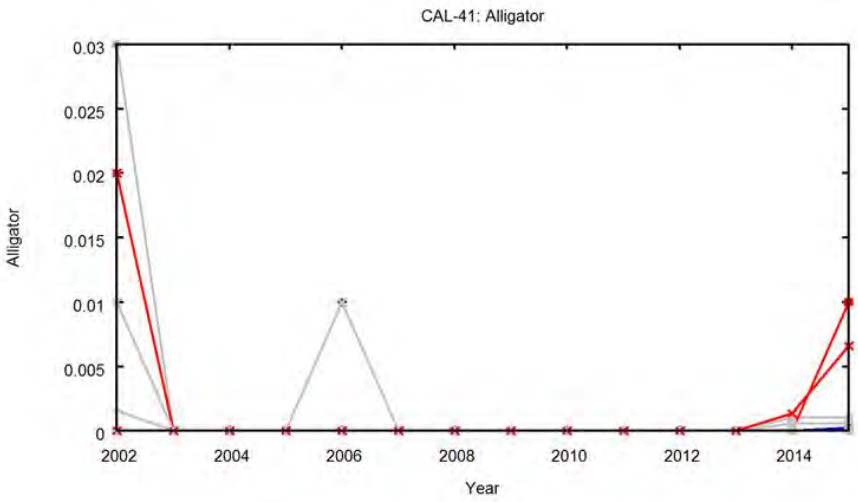
There is little comment to make on the relationships.

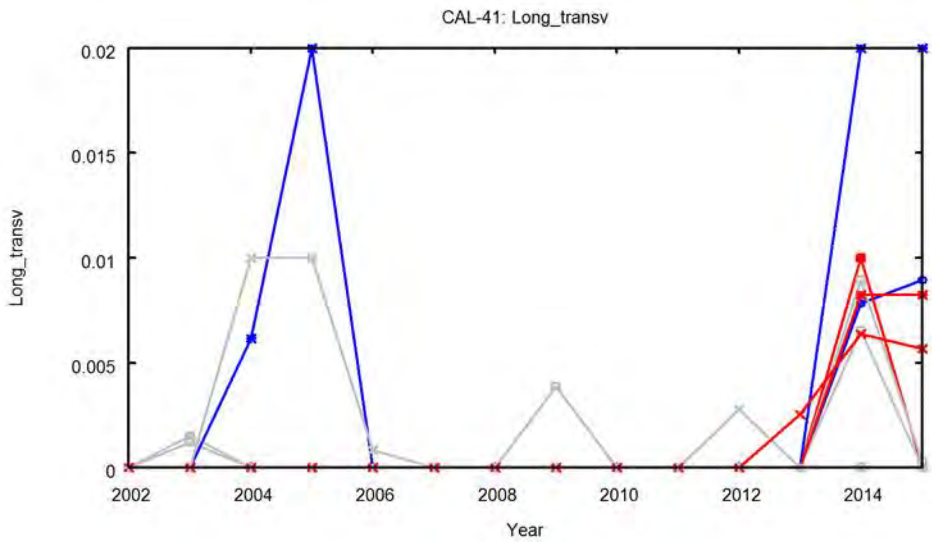


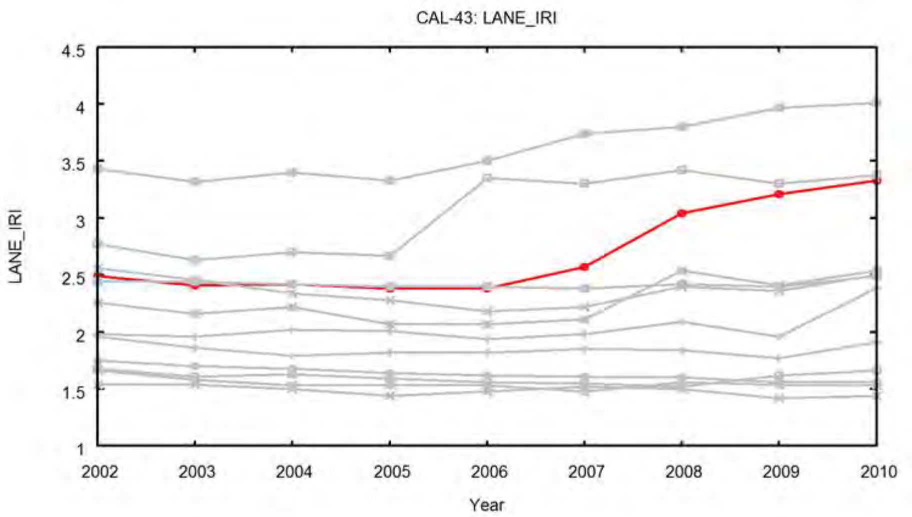




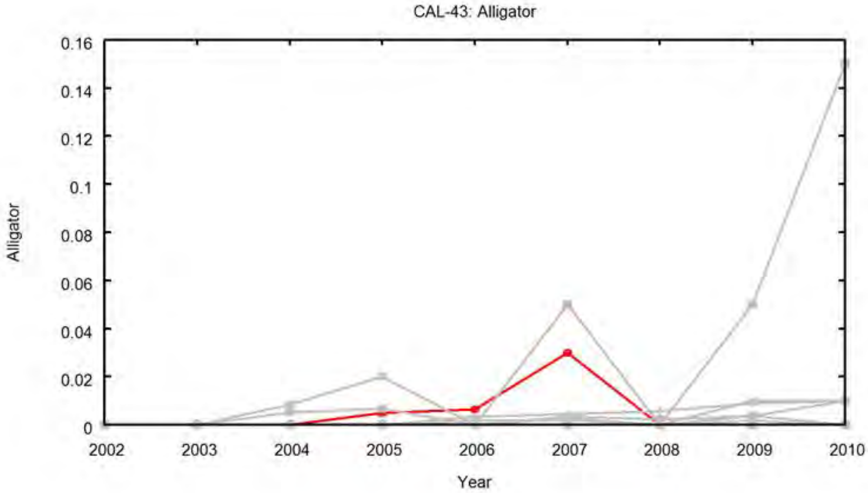
The blue asterisk line probably should not be highlighted, but it is the most prominent one in the longitudinal/transverse line.

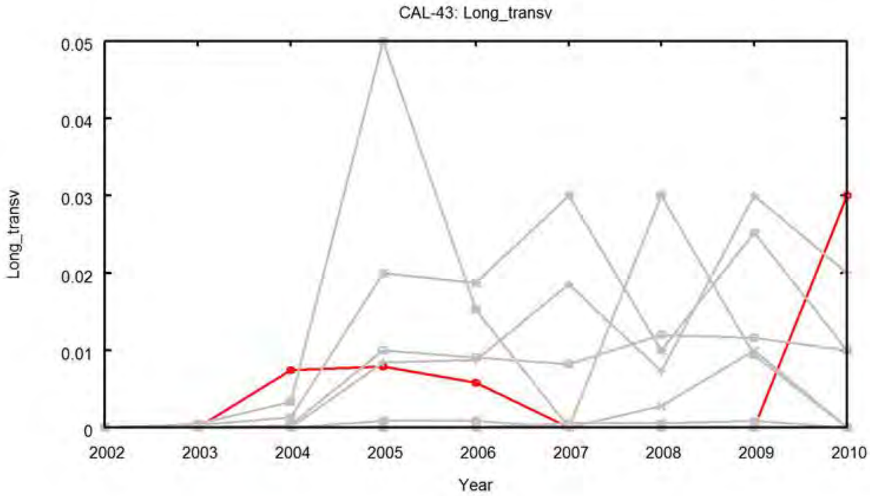


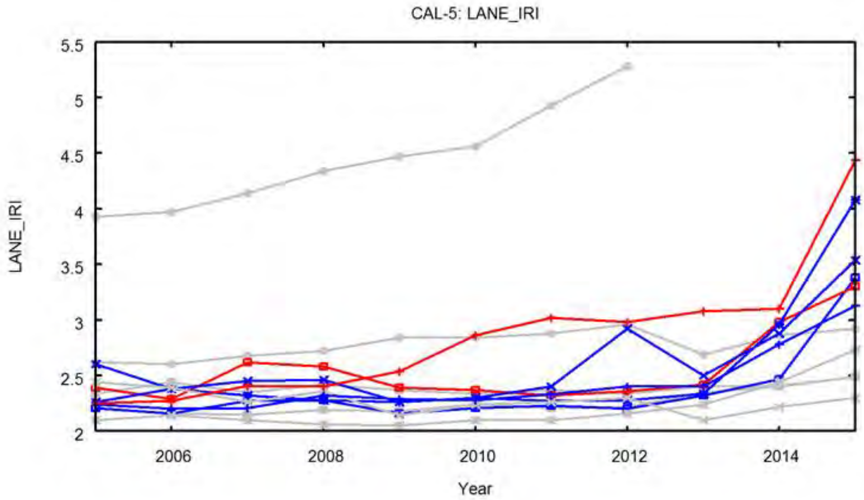




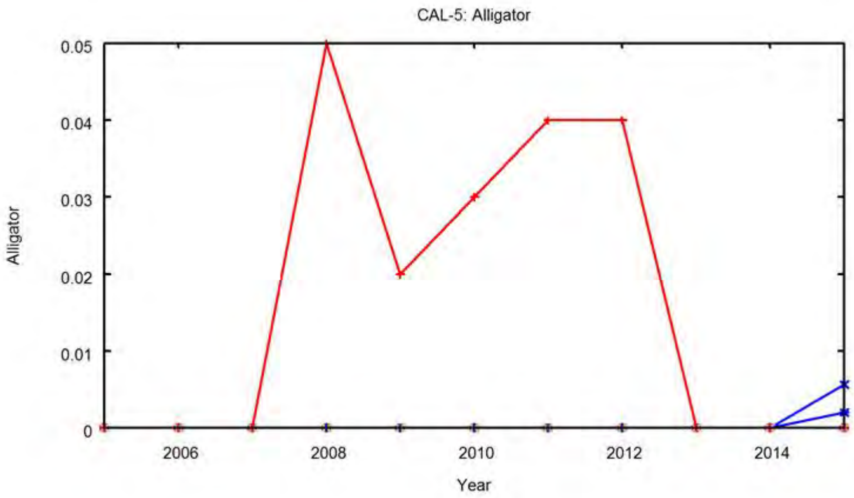
There is not much relationship with cracking here.

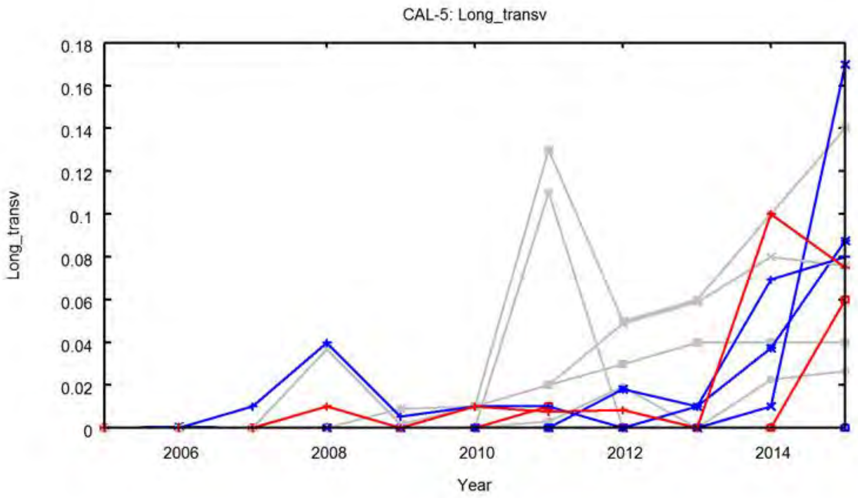


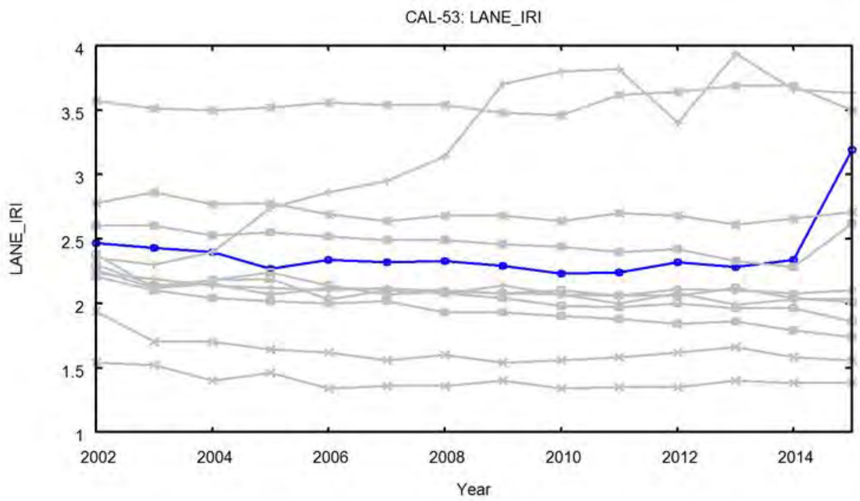




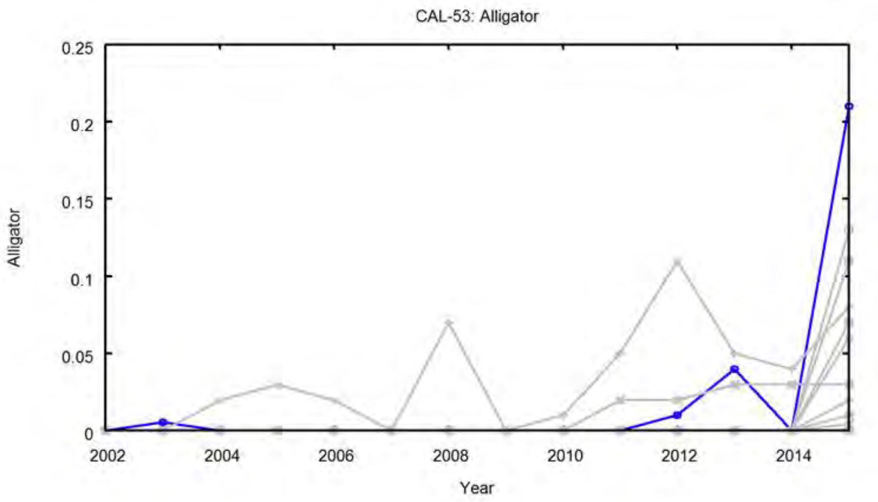
Hard to say if there is a relationship here.

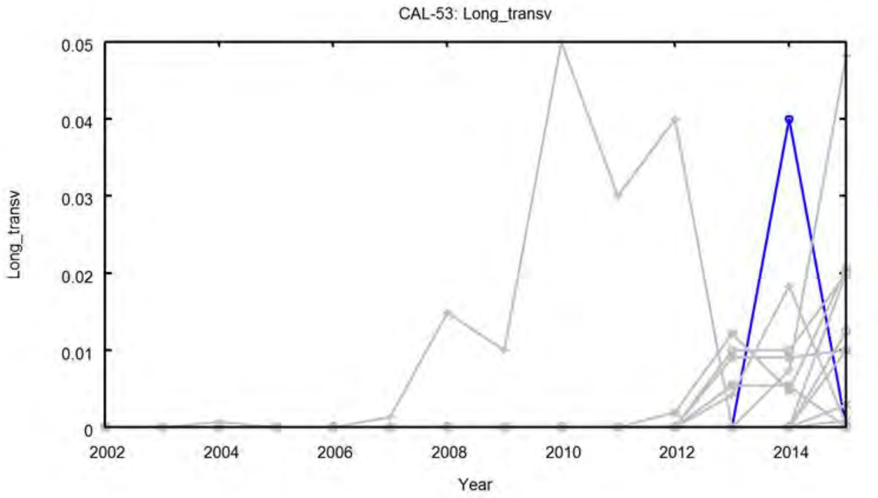


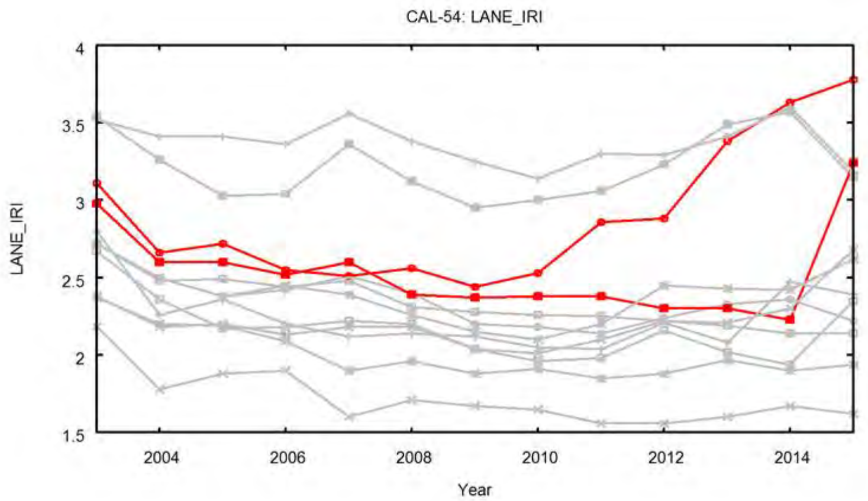




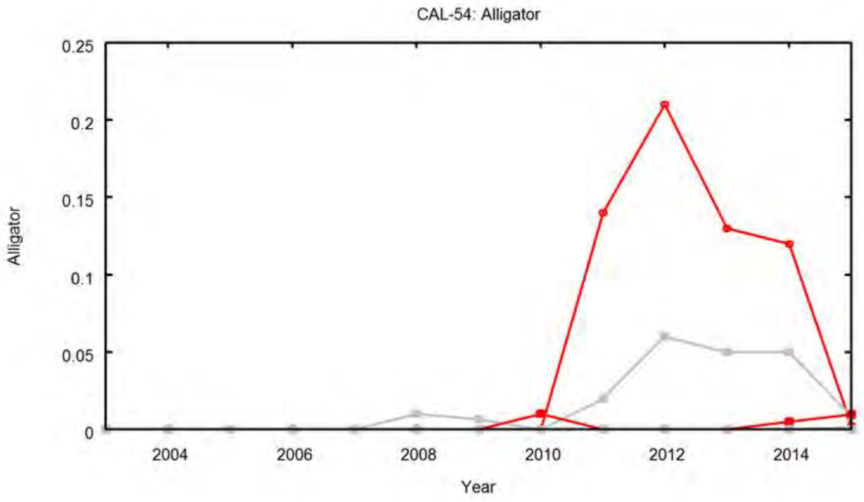
There may be a relationship with cracking here.

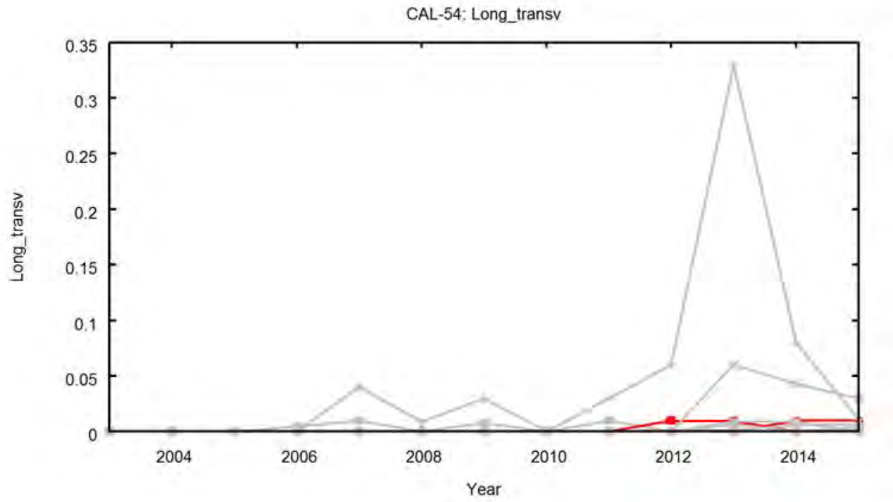


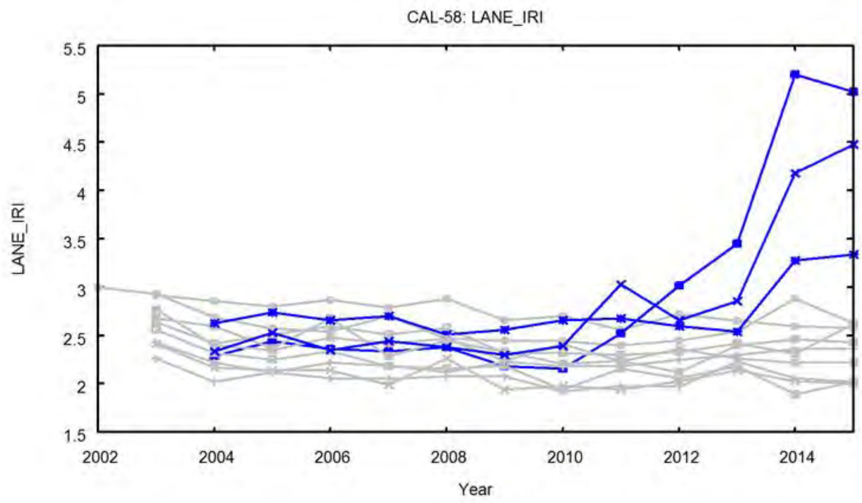




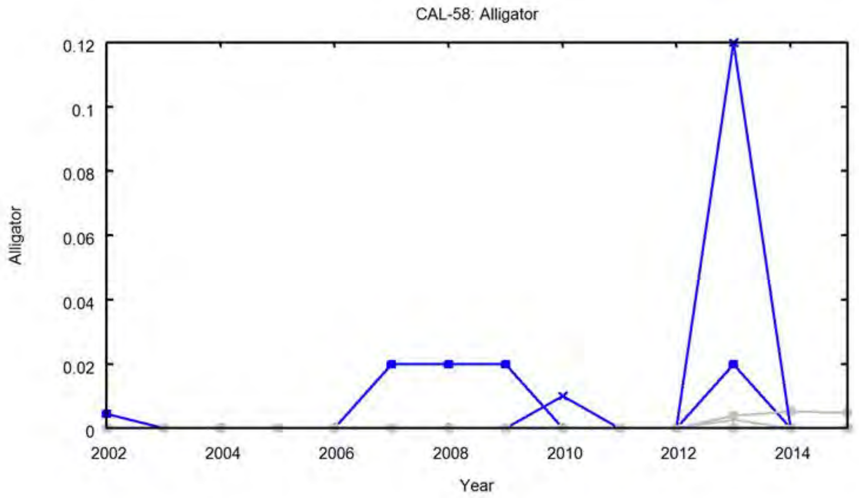
There seems to be a relationship with alligator cracking.

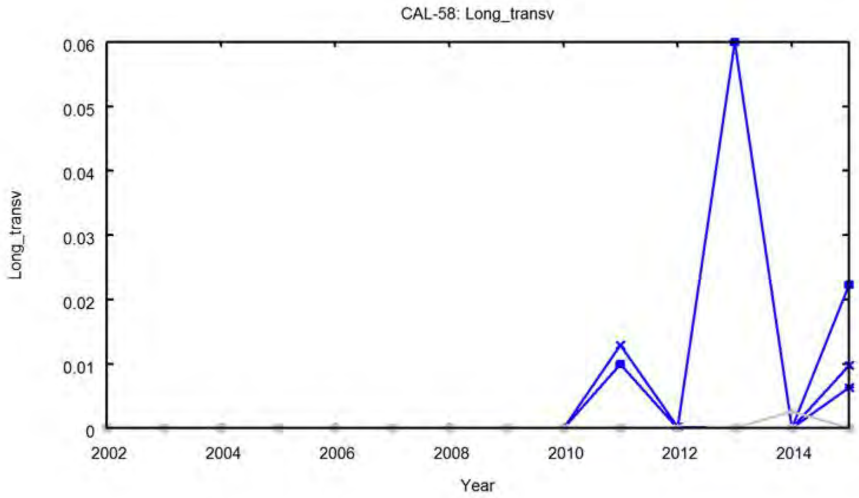


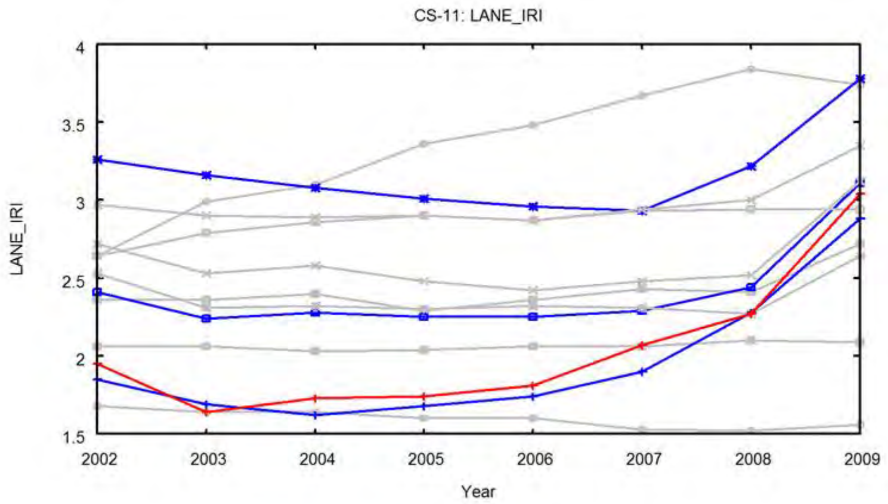




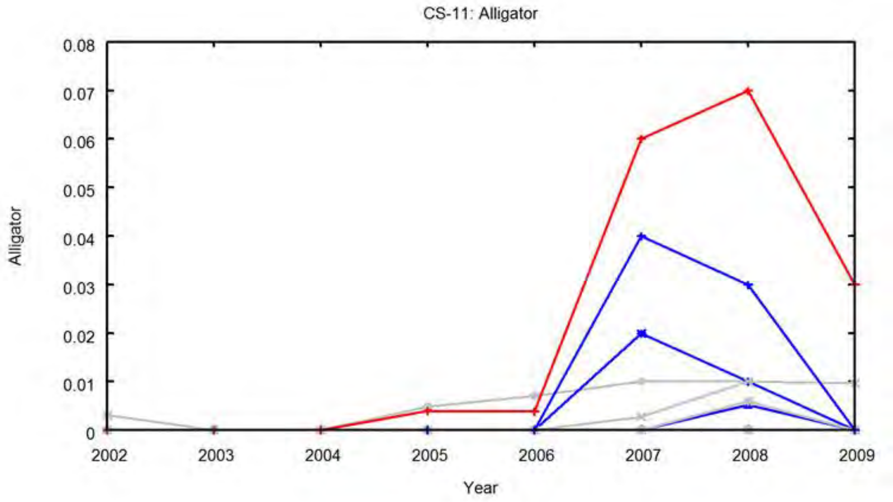
Seems to be a relationship here.

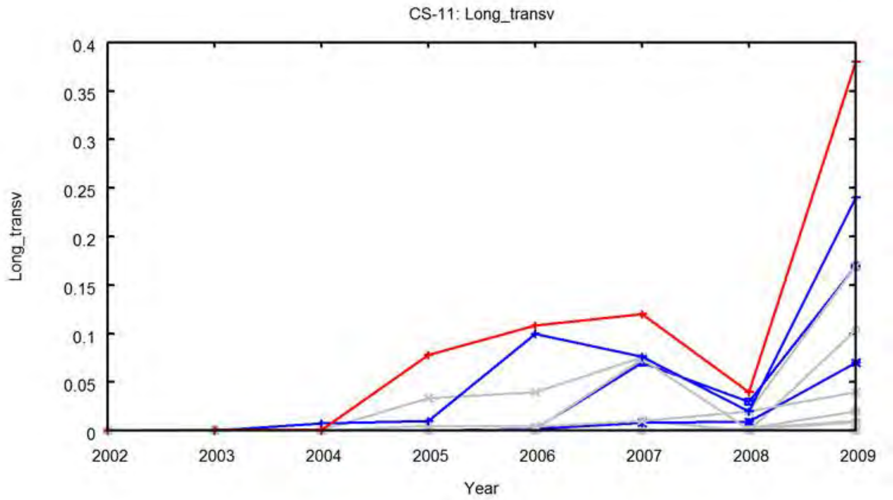


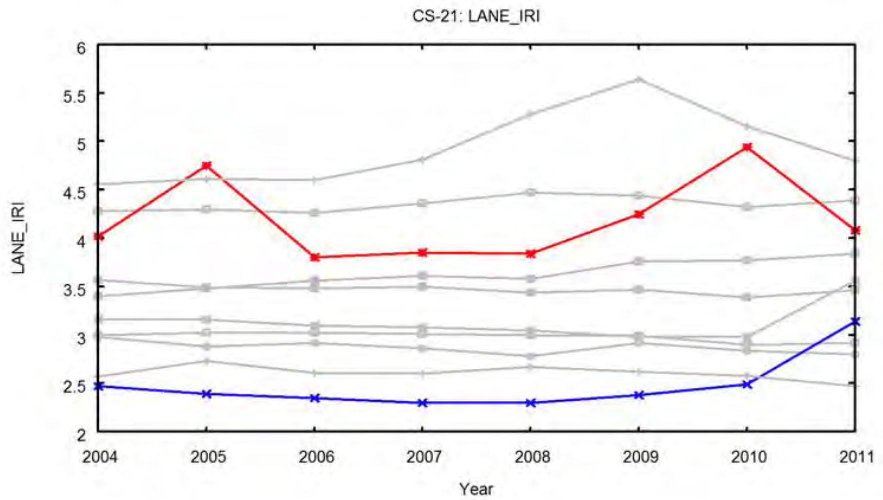




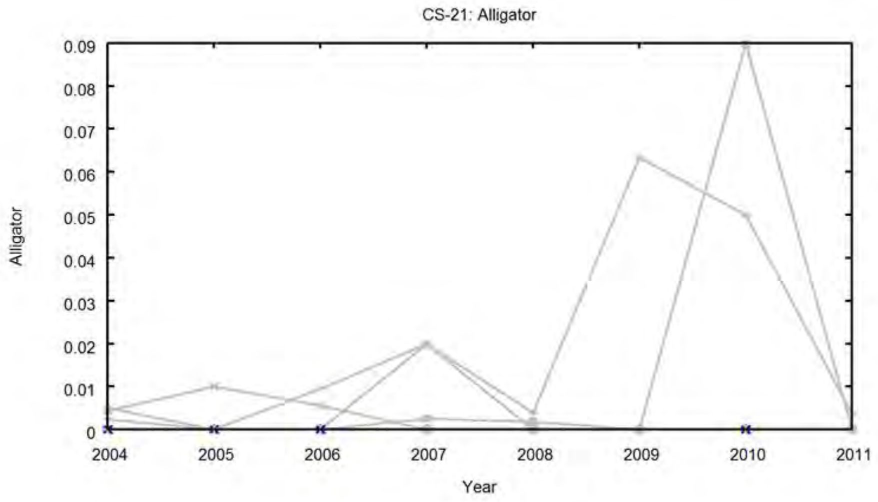
Seems to be a relationship here.

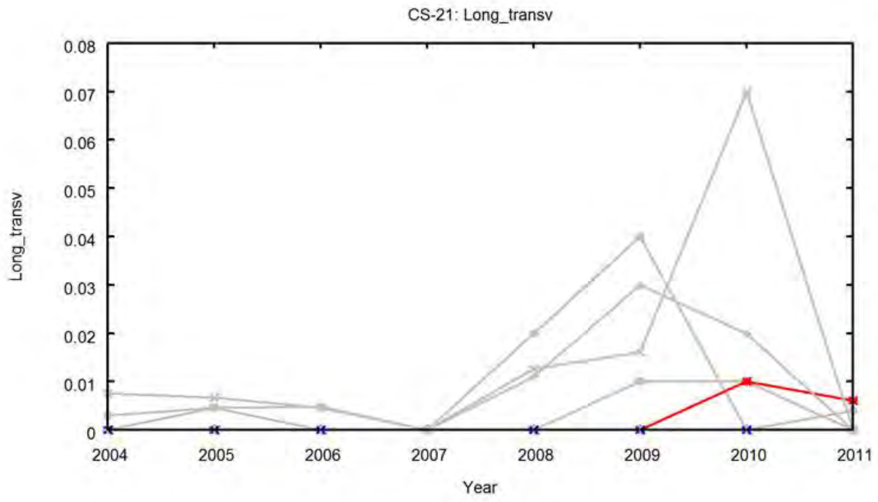


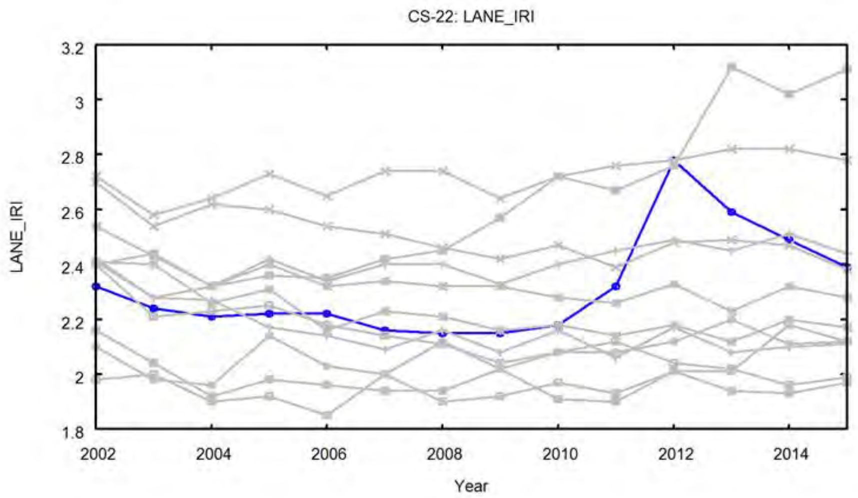




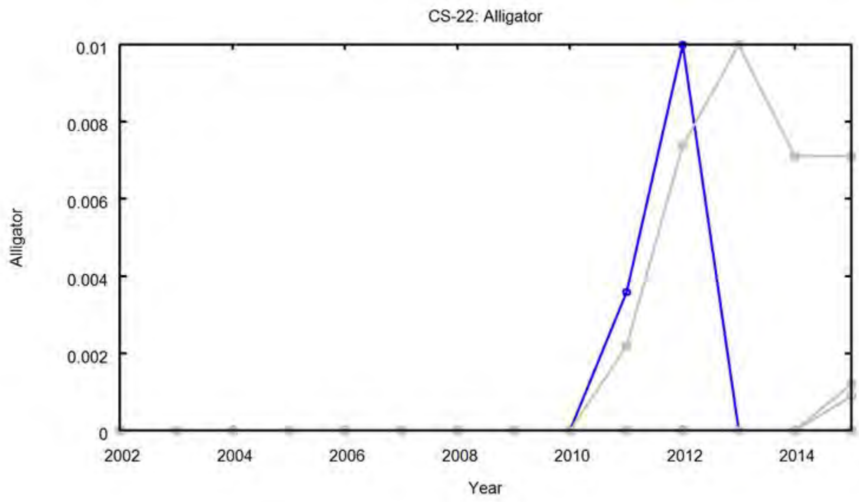
Minimal relationship here.

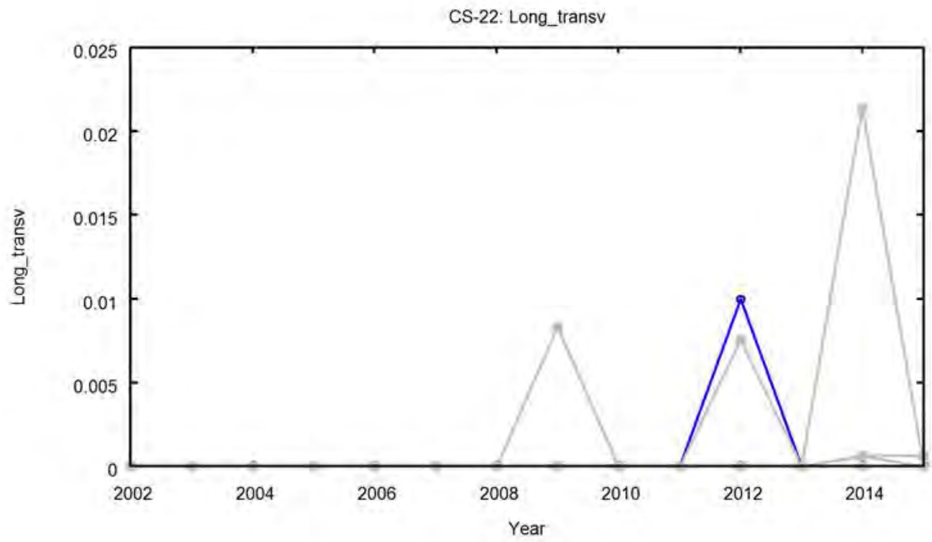


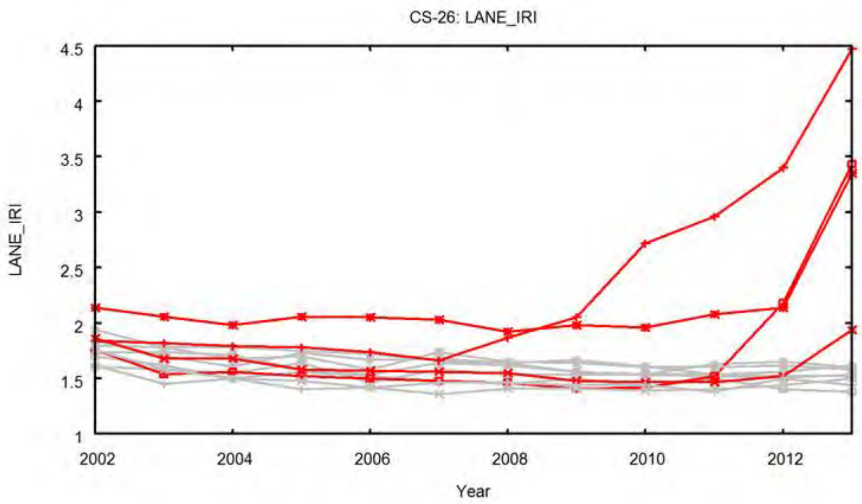




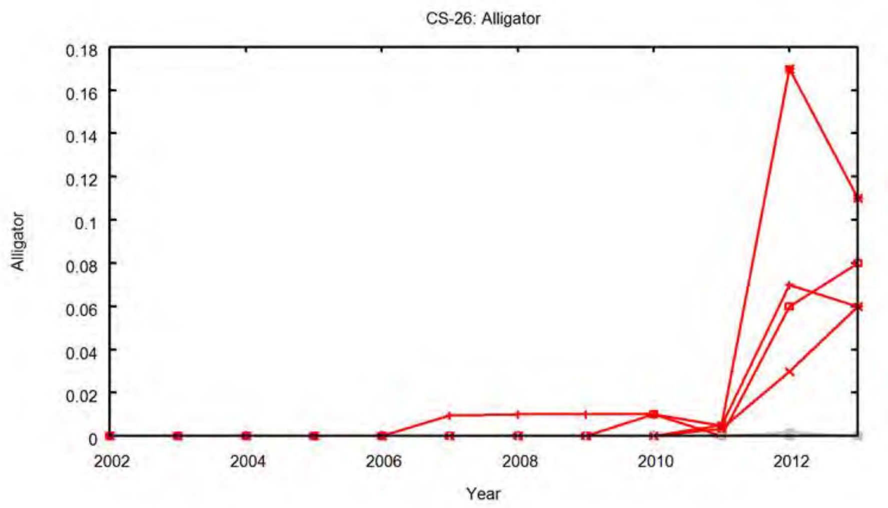
Seems to be a relationship here.

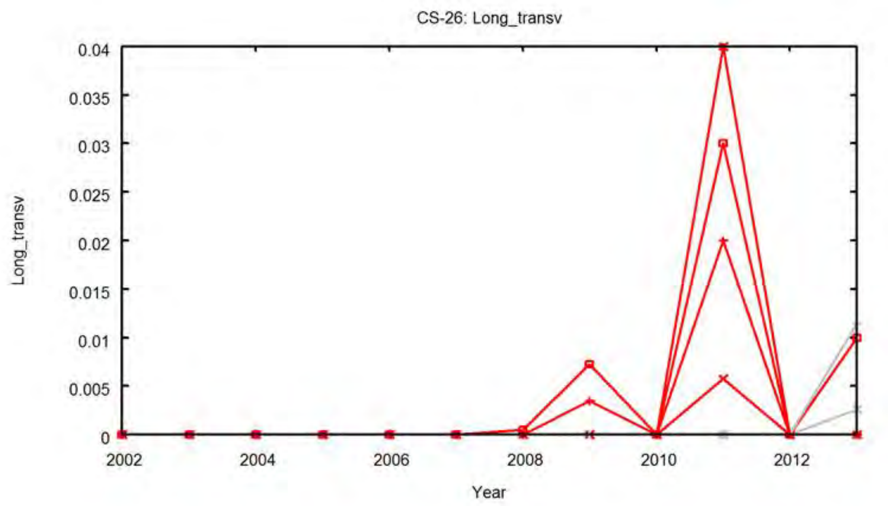


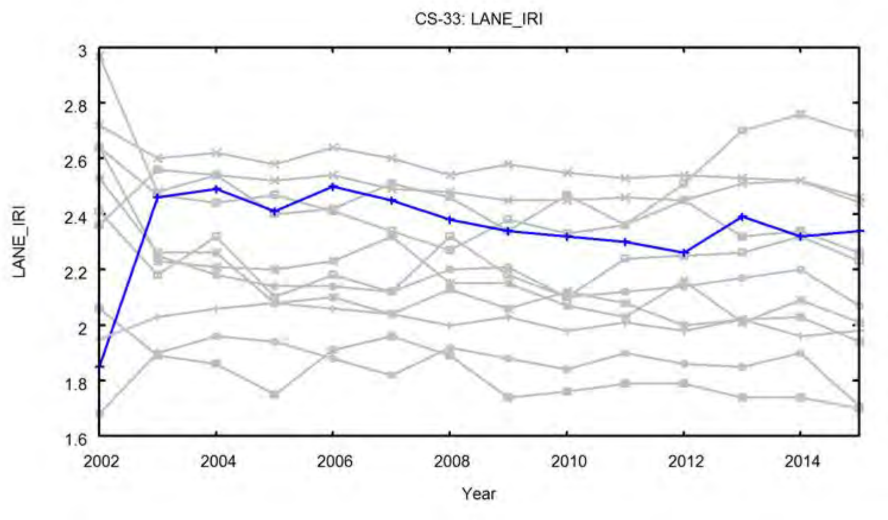




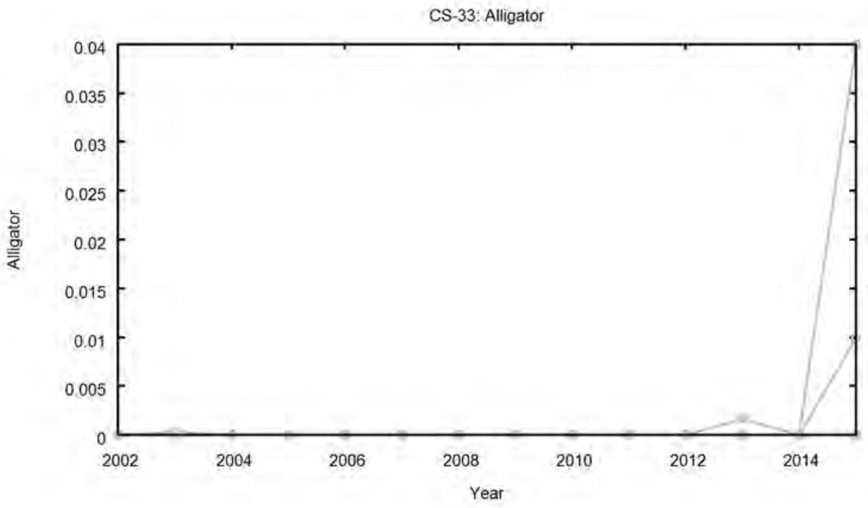
Seems to be a relationship here.

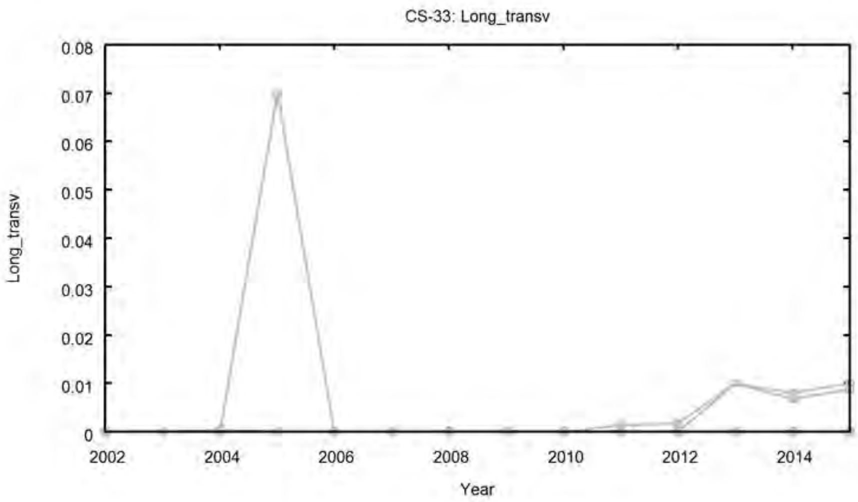


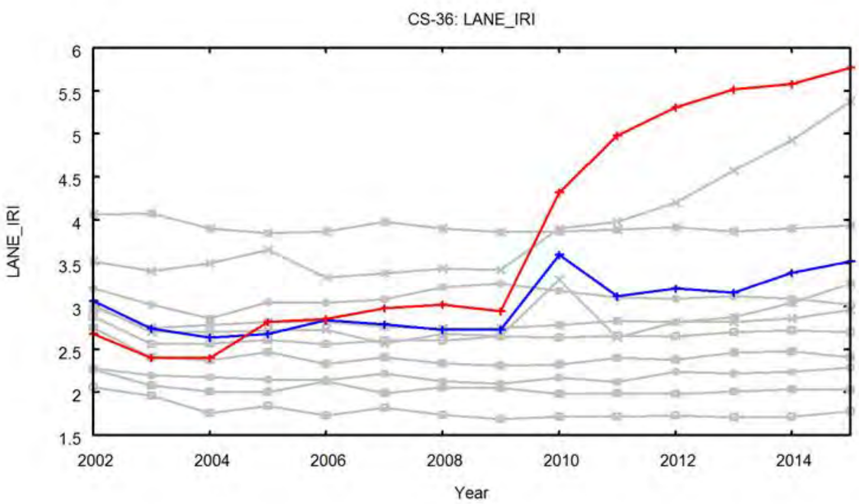




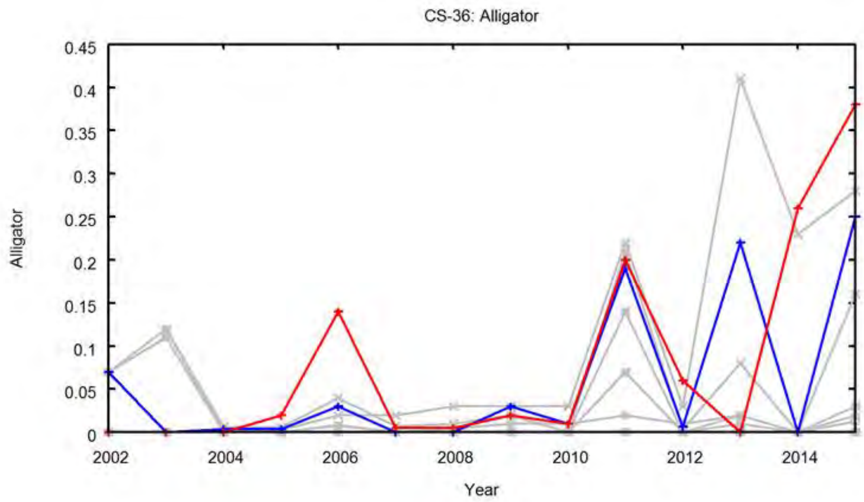
No relationship here and that jump at the beginning may be bogus anyway

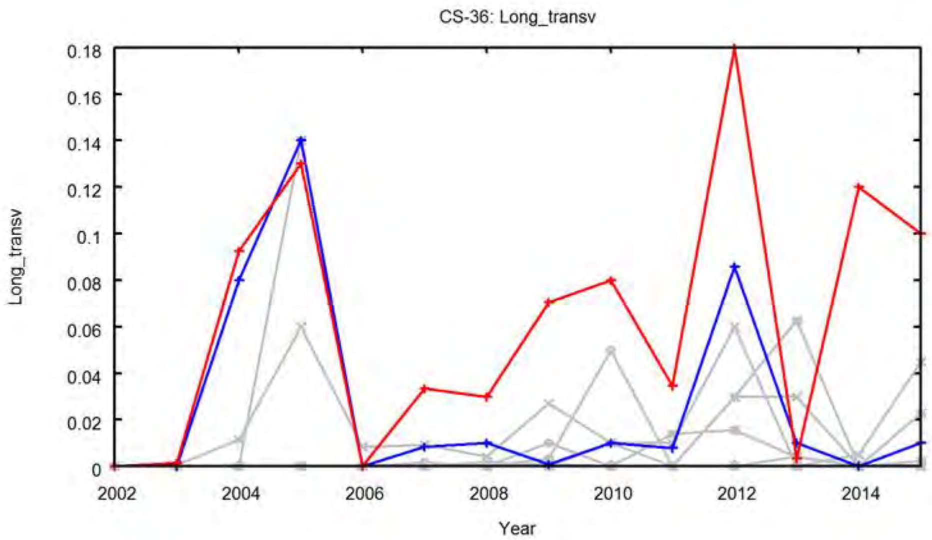


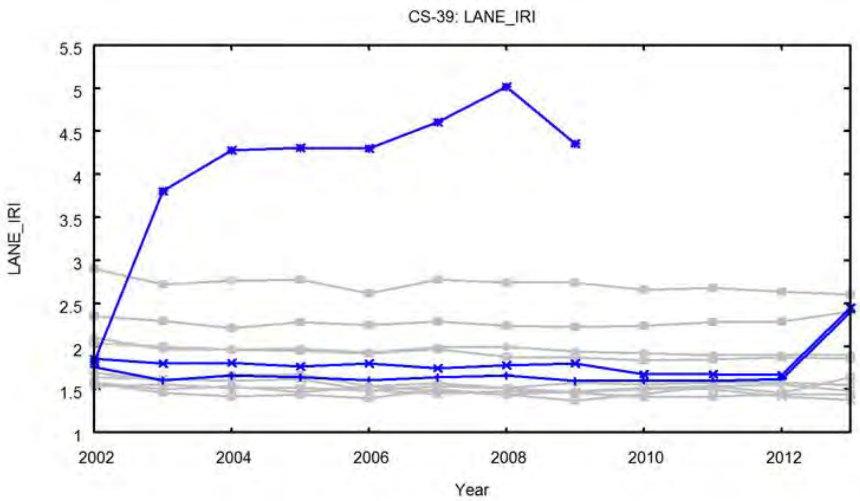




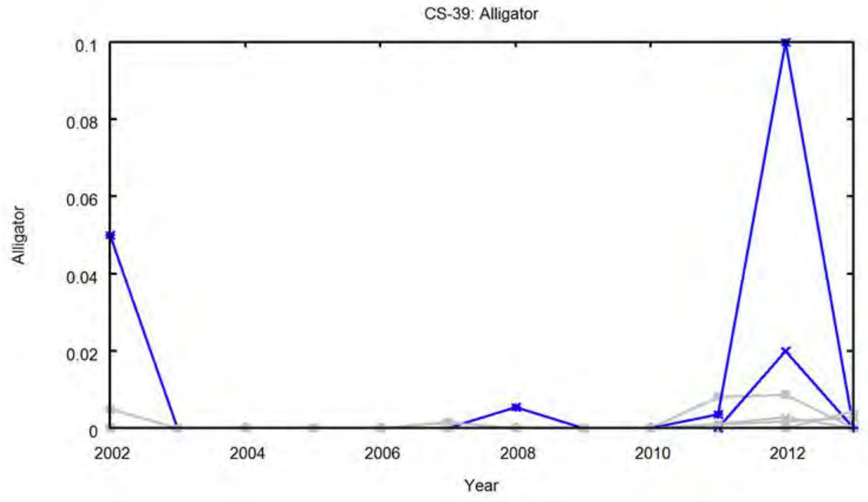
There is a somewhat ambiguous relationship here.

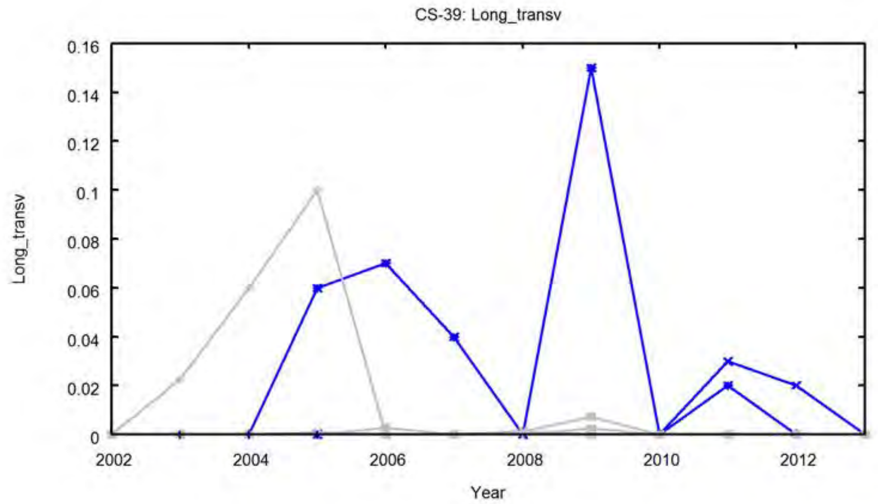


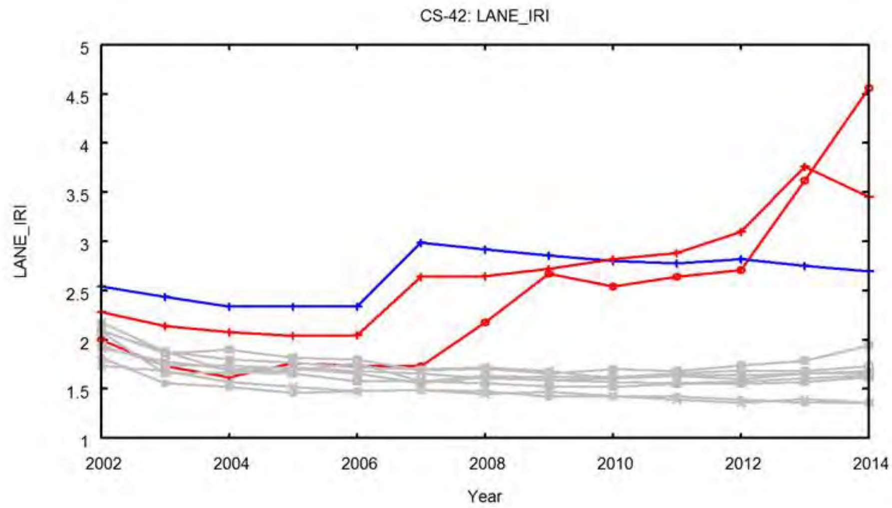




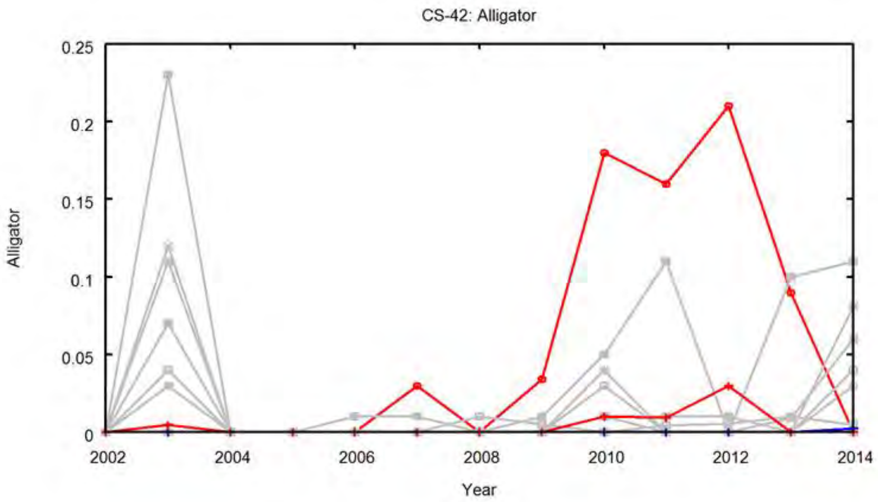
There is a possible relationship here. The blue asterisk line stops in the IRI graph probably because of a sudden drop indicating road work, but the graph still shows the cracking data which might be a little confusing.

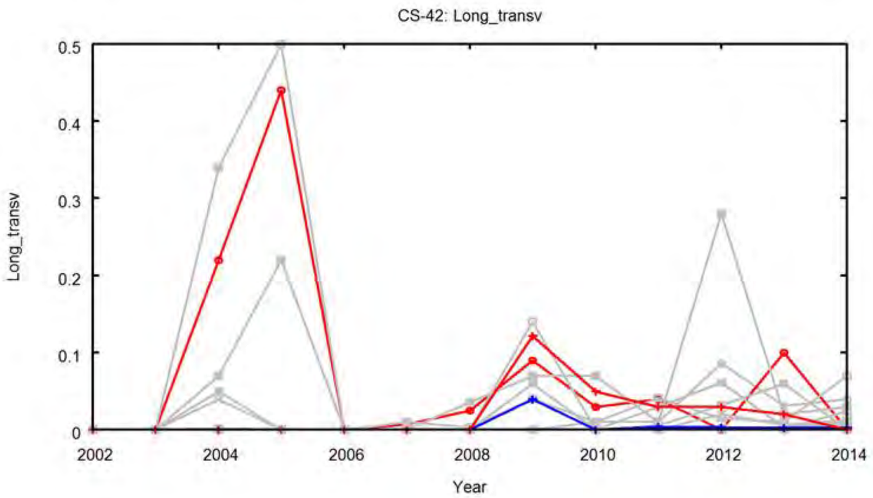


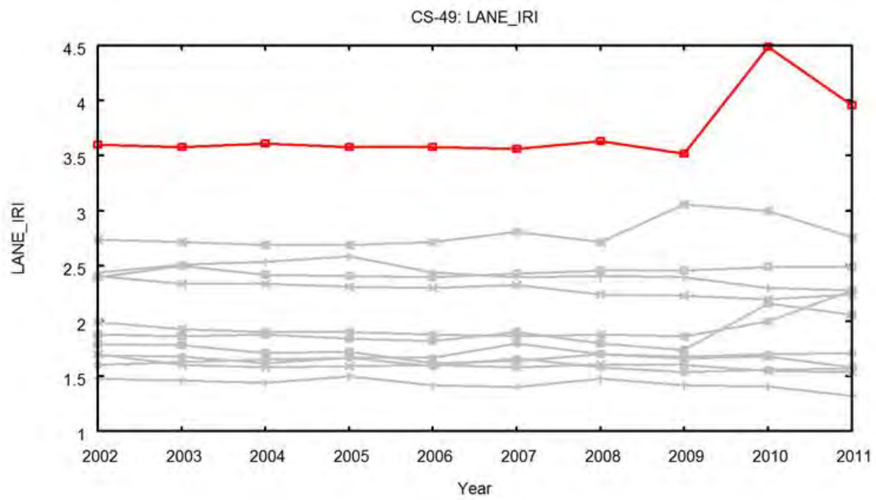


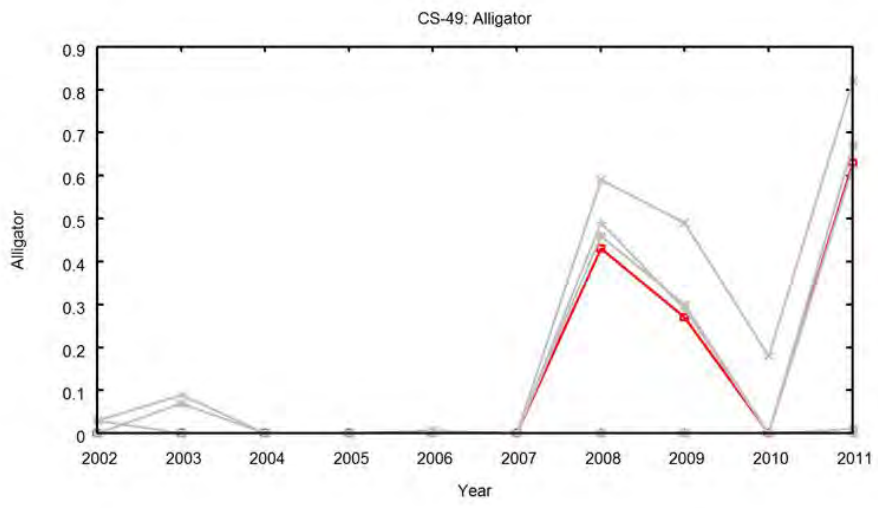


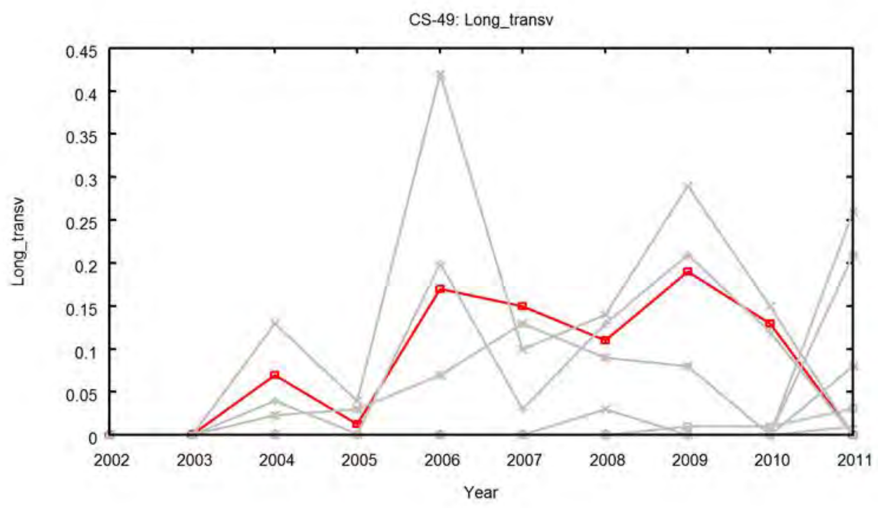
There is a possible relationship with the cracking in the increasing lanes.

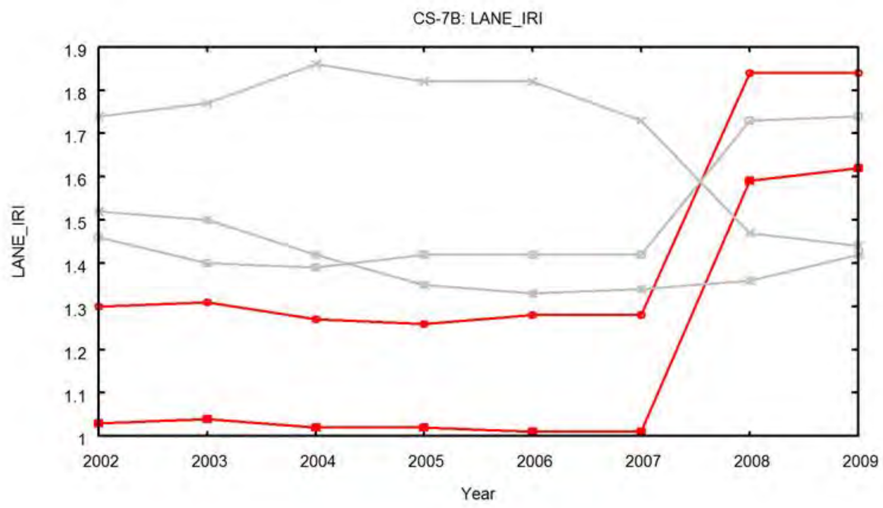

CS-42: Alligator
Alligator
Year
0
0.05
0.1
0.15
0.2
0.25
2002
2004
2006
2008
2010
2012
2014


CS-42: Long_transv
Long_transv
Year
0
0.1
0.2
0.3
0.4
0.5
2002
2004
2006
2008
2010
2012
2014

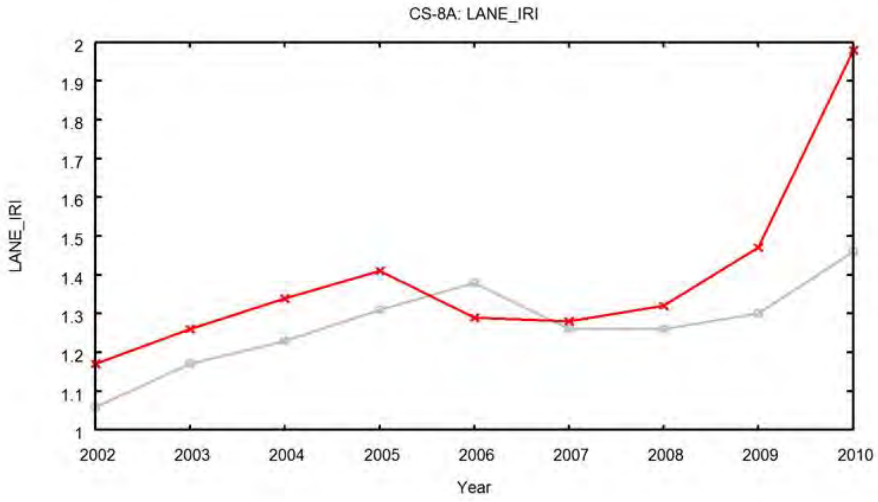

CS-49: LANE_IRI
LANE_IRI
Year
1
1.5
2
2.5
3
3.5
4
4.5
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011


CS-49: Alligator
Alligator
Year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

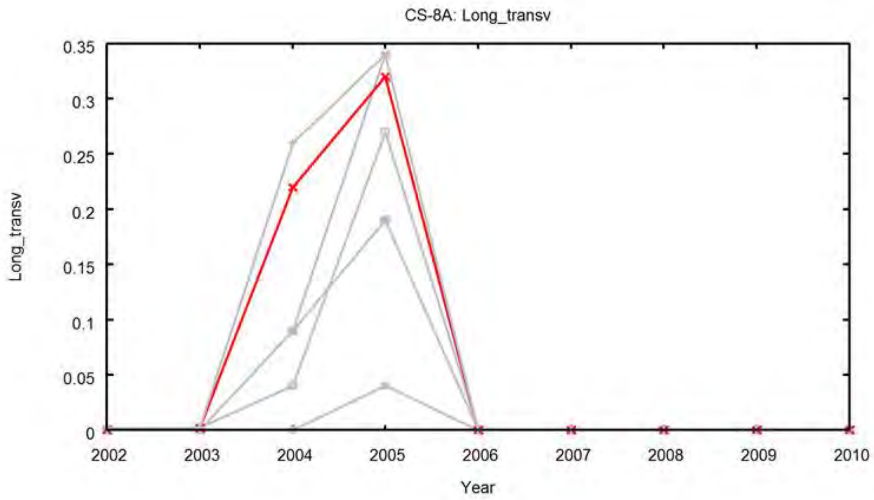

CS-49: Long_transv
Long_transv
Year
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

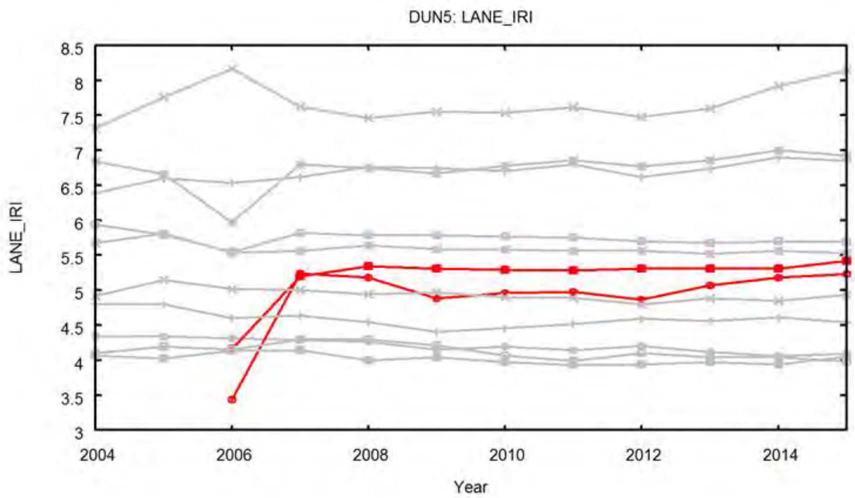

CS-7B: LANE_IRI
LANE_IRI
Year
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2002
2003
2004
2005
2006
2007
2008
2009

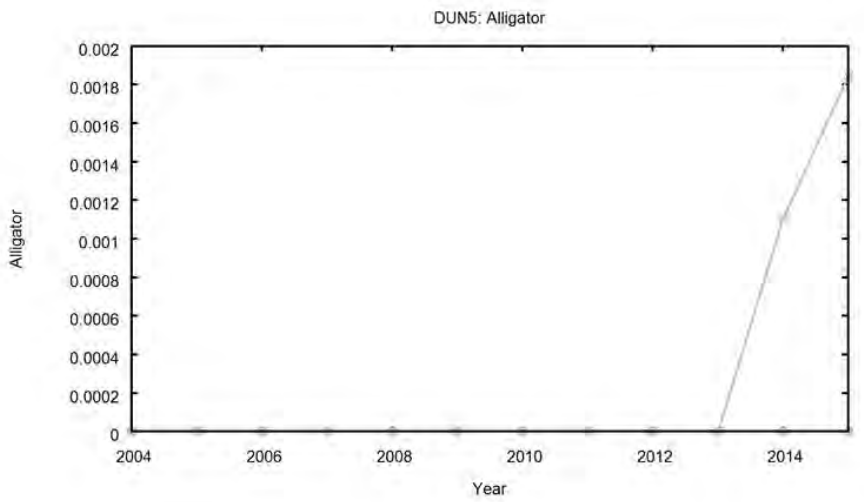
No cracking.

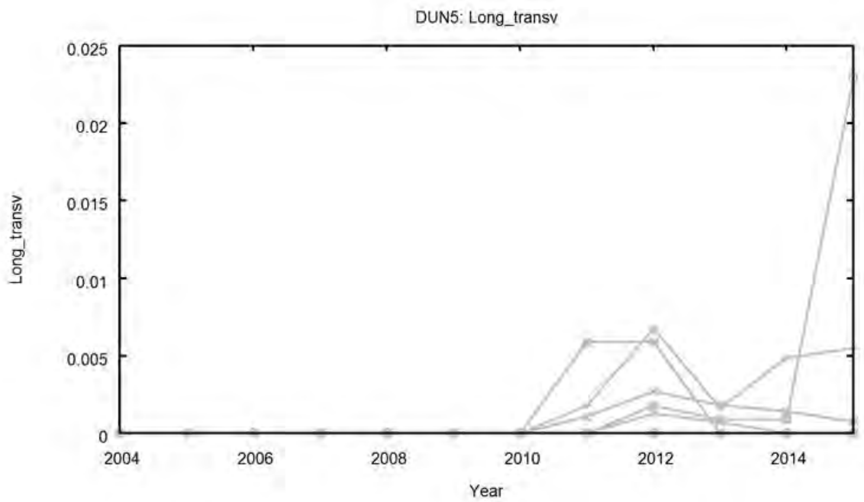


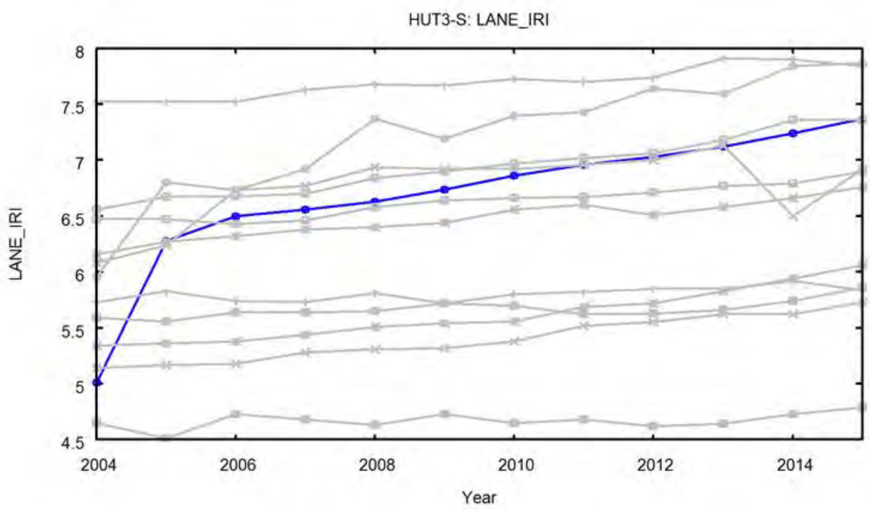
No alligator cracking.

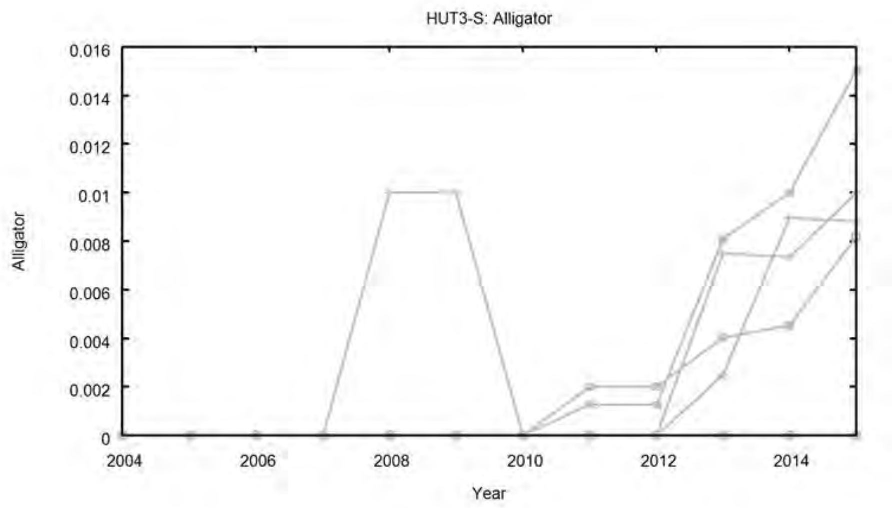


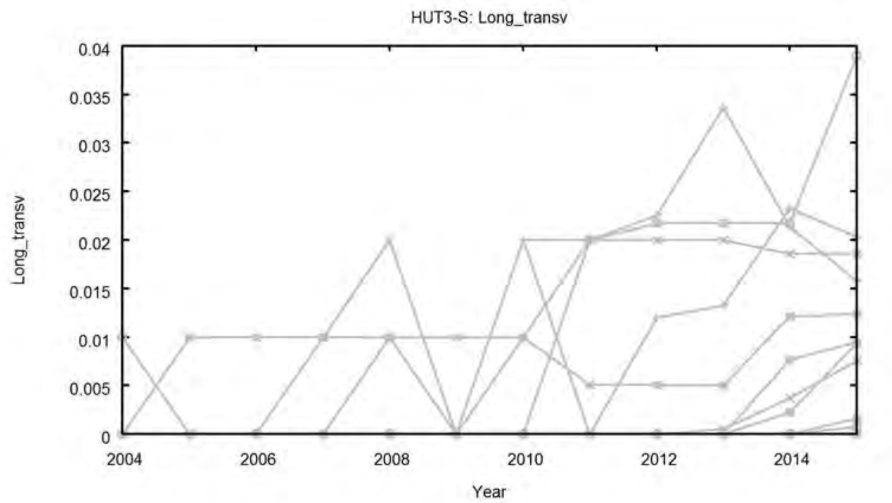


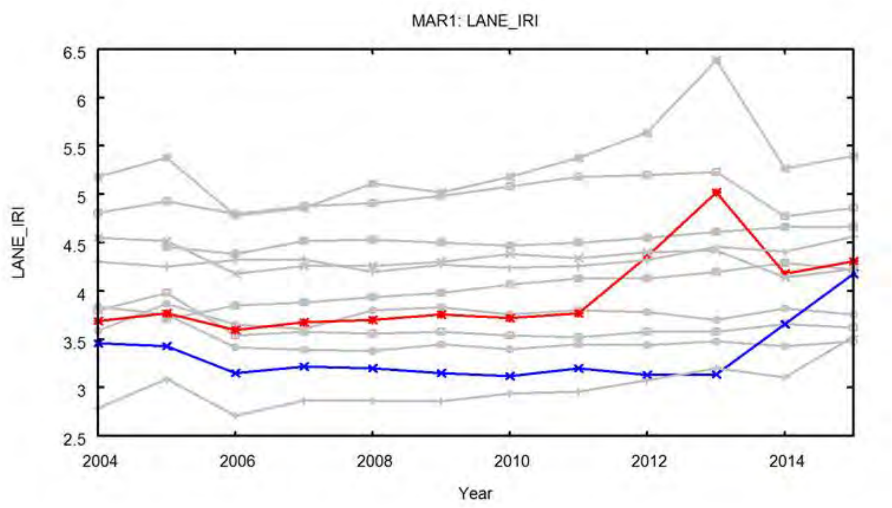

DUN5: Alligator
Alligator
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
2004
2006
2008
2010
2012
2014
Year

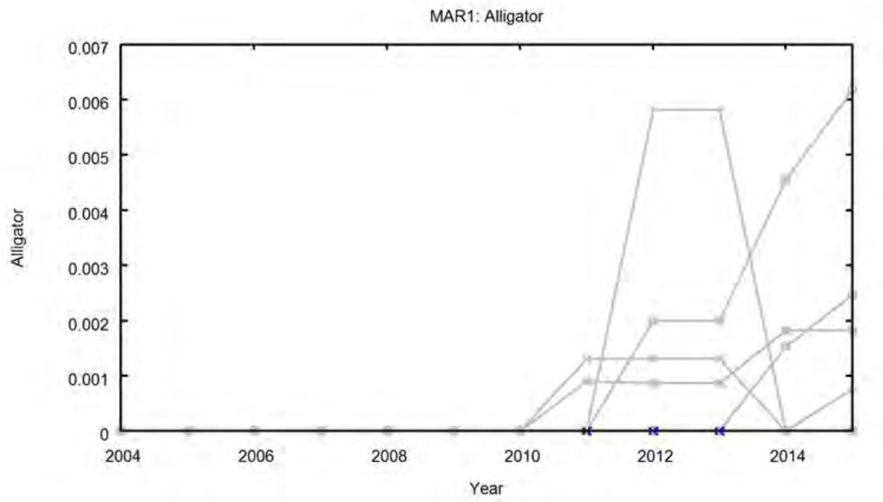

DUN5: Long_transv
Long_transv
0.025
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014
Year

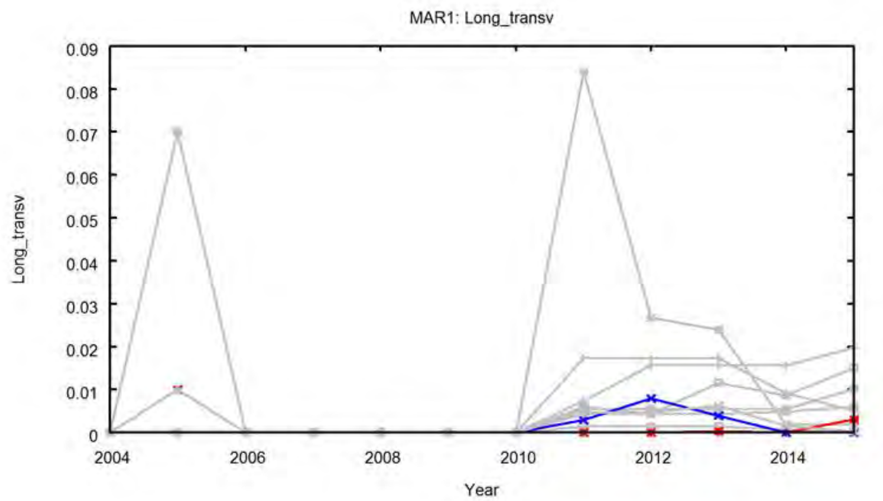

HUT3-S: LANE_IRI
LANE_IRI
8
7.5
7
6.5
6
5.5
5
4.5
2004
2006
2008
2010
2012
2014
Year

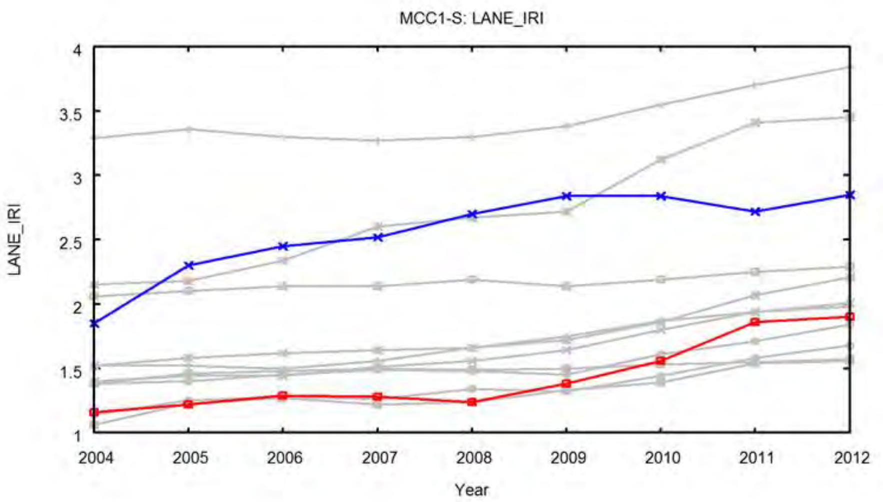

HUT3-S: Alligator
Alligator
Year

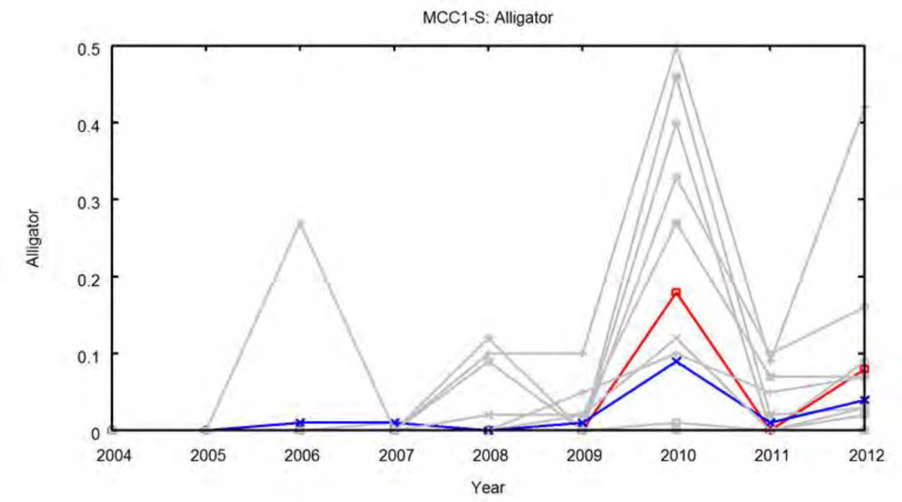

HUT3-S: Long_transv
Long_transv
Year

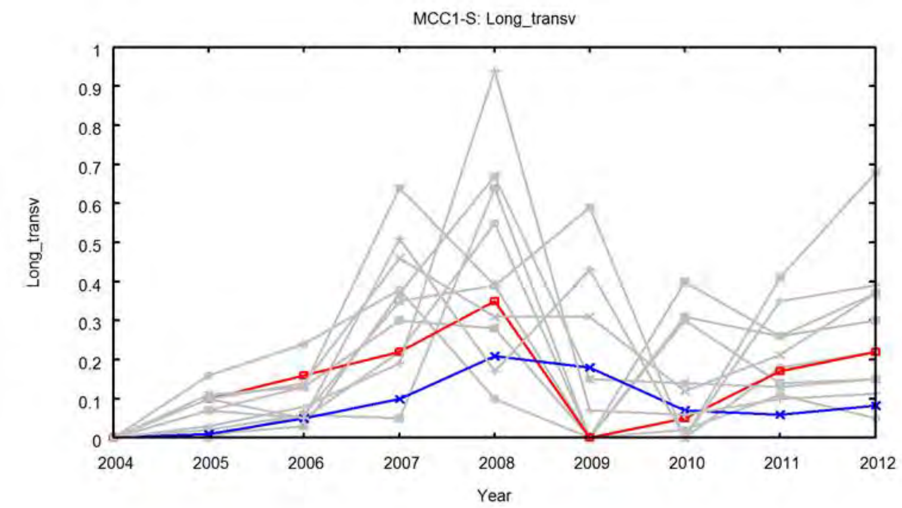

MAR1: LANE_IRI
LANE_IRI
Year

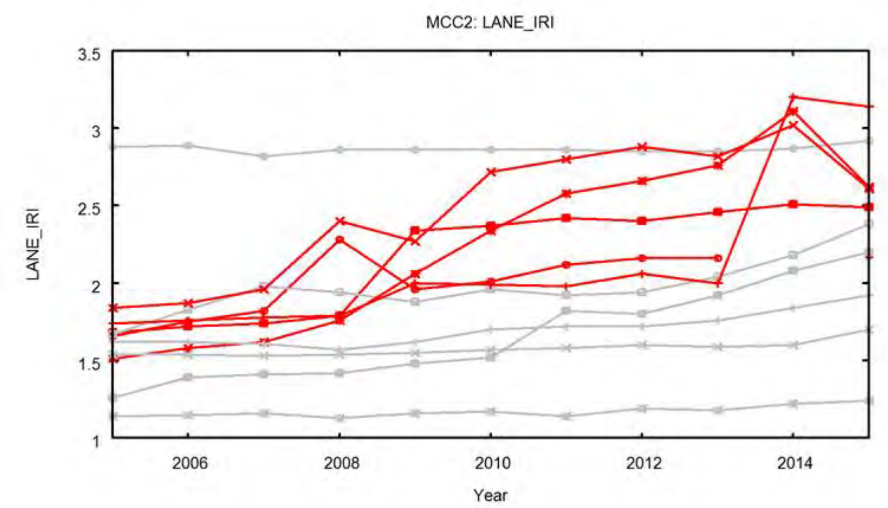

MAR1: Alligator
Alligator
Year
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
2004
2006
2008
2010
2012
2014

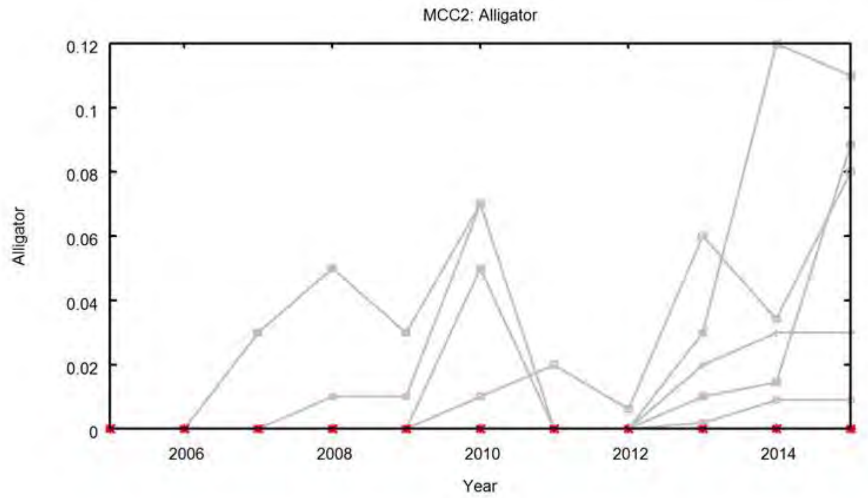

MAR1: Long_transv
Long_transv
Year
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
2004
2006
2008
2010
2012
2014

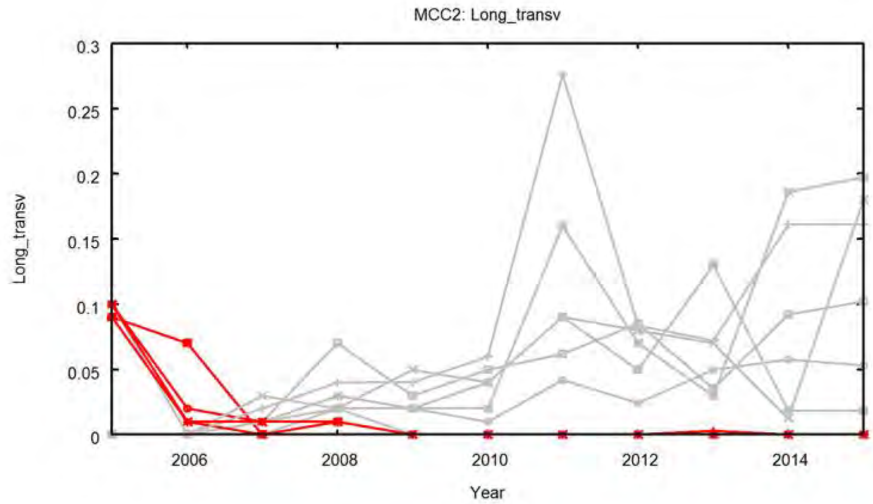

MCC1-S: LANE_IRI
LANE_IRI
Year
1
1.5
2
2.5
3
3.5
4
2004
2005
2006
2007
2008
2009
2010
2011
2012

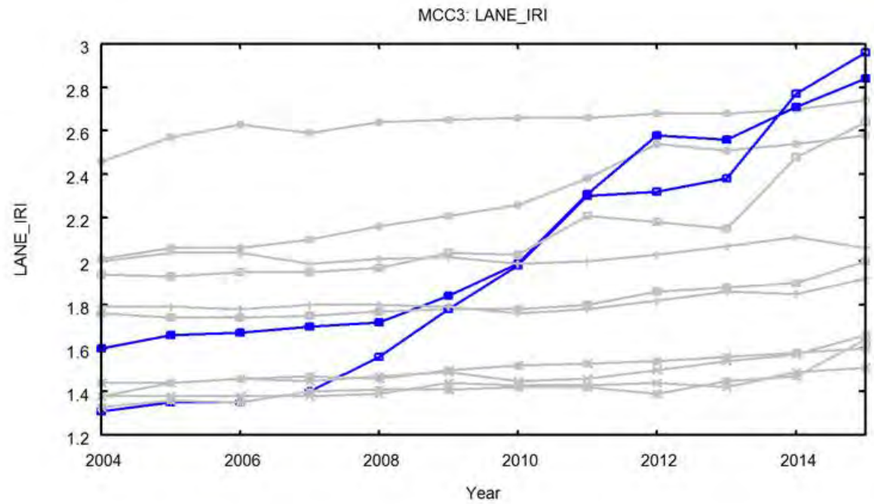

MCC1-S: Alligator
Alligator
Year
0.5
0.4
0.3
0.2
0.1
0
2004
2005
2006
2007
2008
2009
2010
2011
2012

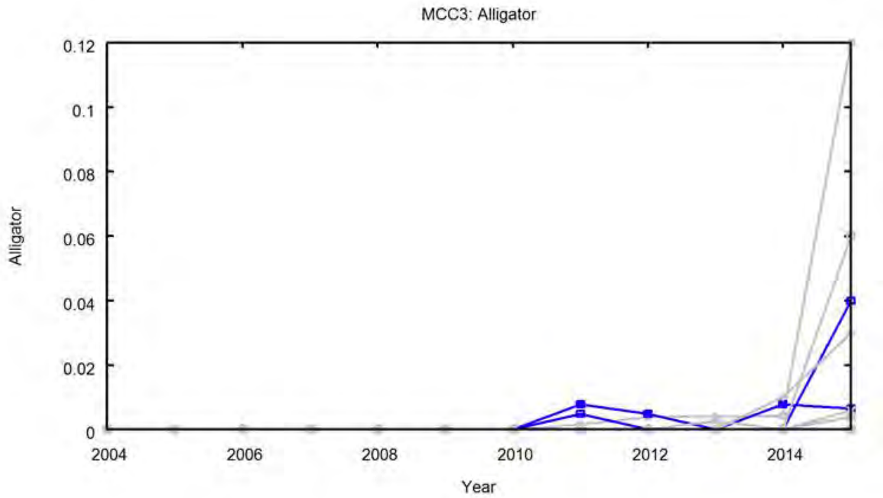

MCC1-S: Long_transv
Long_transv
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2004
2005
2006
2007
2008
2009
2010
2011
2012

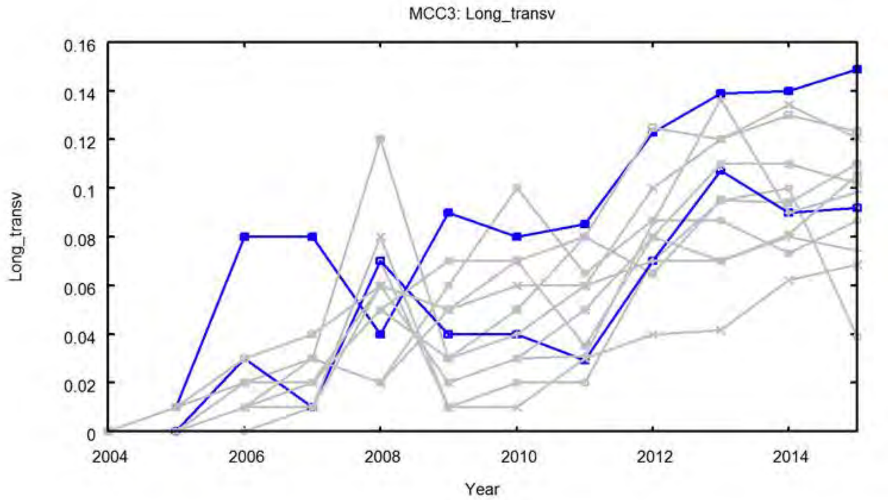

MCC2: LANE_IRI
LANE_IRI
Year
3.5
3
2.5
2
1.5
1
2006
2008
2010
2012
2014

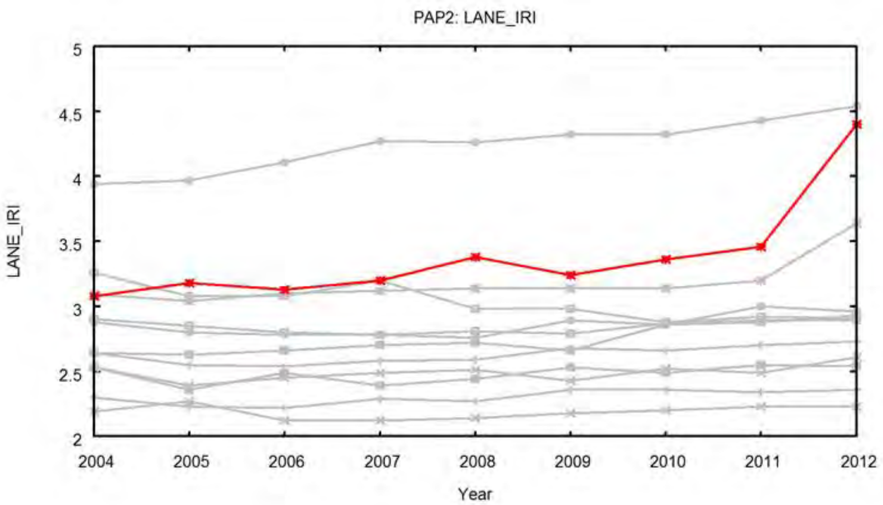

MCC2: Alligator
Alligator
Year
0
0.02
0.04
0.06
0.08
0.1
0.12
2006
2008
2010
2012
2014


MCC2: Long_transv
Long_transv
Year
0
0.05
0.1
0.15
0.2
0.25
0.3
2006
2008
2010
2012
2014

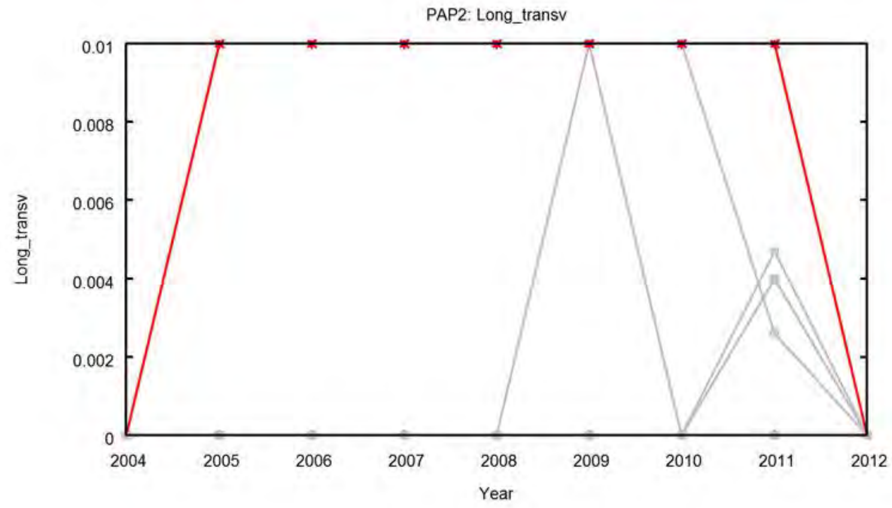

MCC3: LANE_IRI
LANE_IRI
Year
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
2004
2006
2008
2010
2012
2014

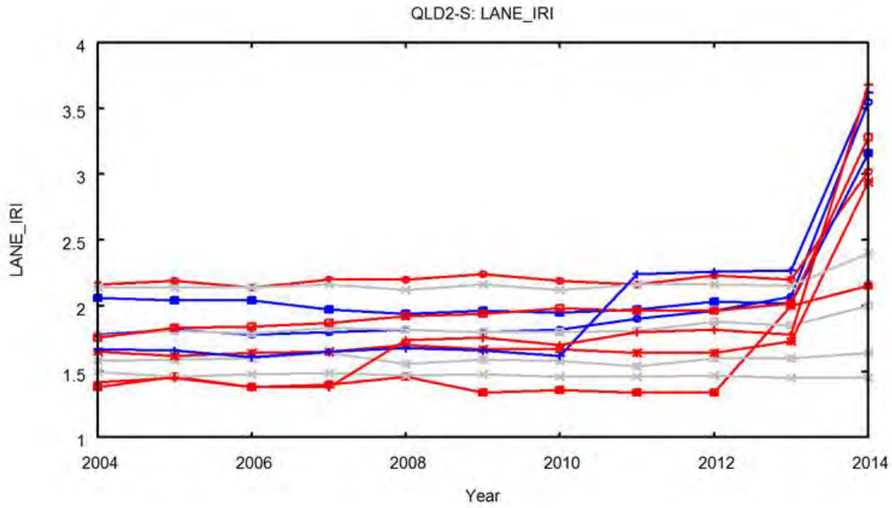


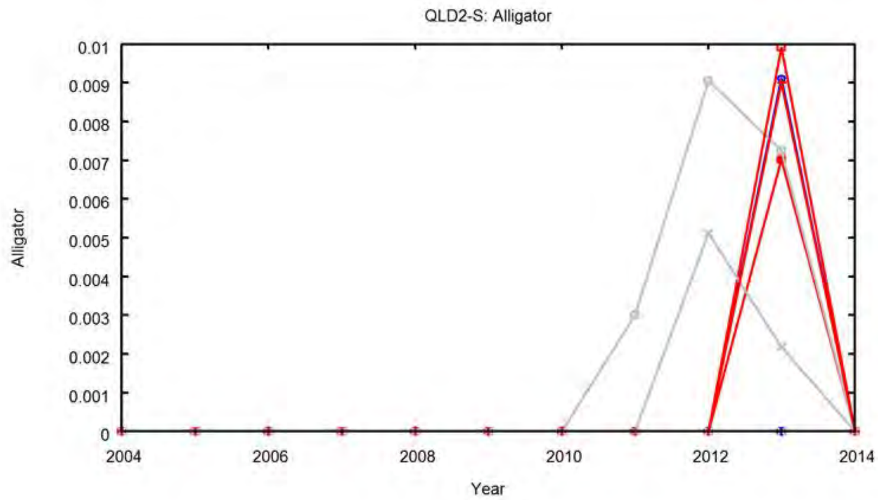


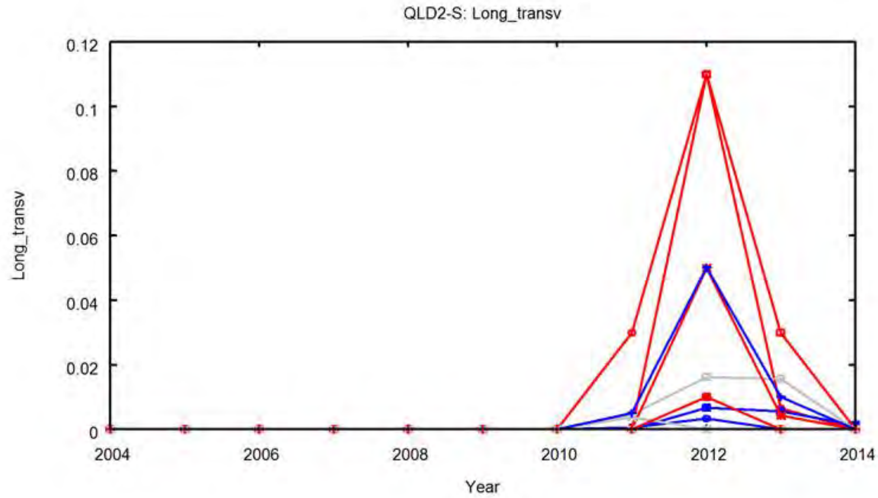


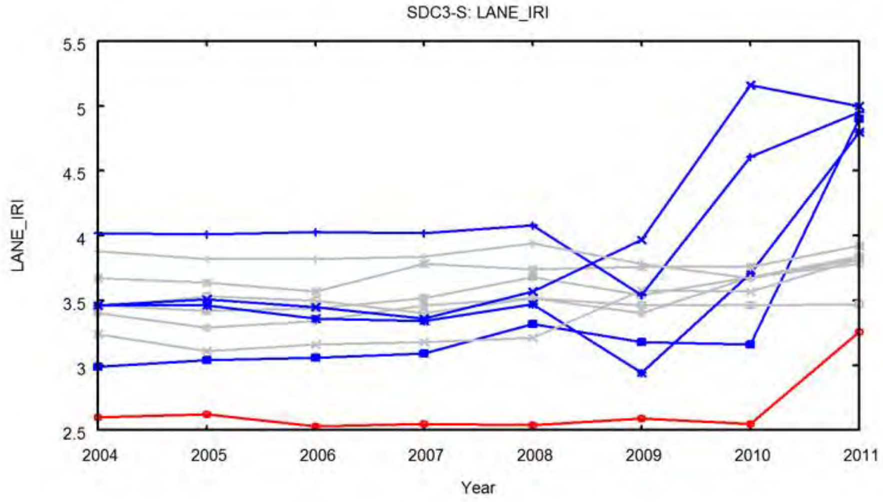
No alligator cracking.


PAP2: Long_transv
Long_transv
0.01
0.008
0.006
0.004
0.002
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

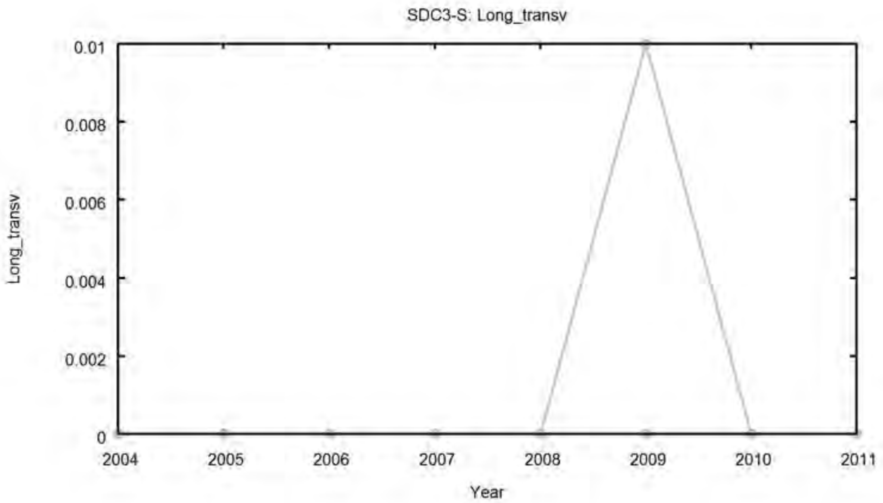

QLD2-S: LANE_IRI
LANE_IRI
4
3.5
3
2.5
2
1.5
1
2004
2006
2008
2010
2012
2014
Year

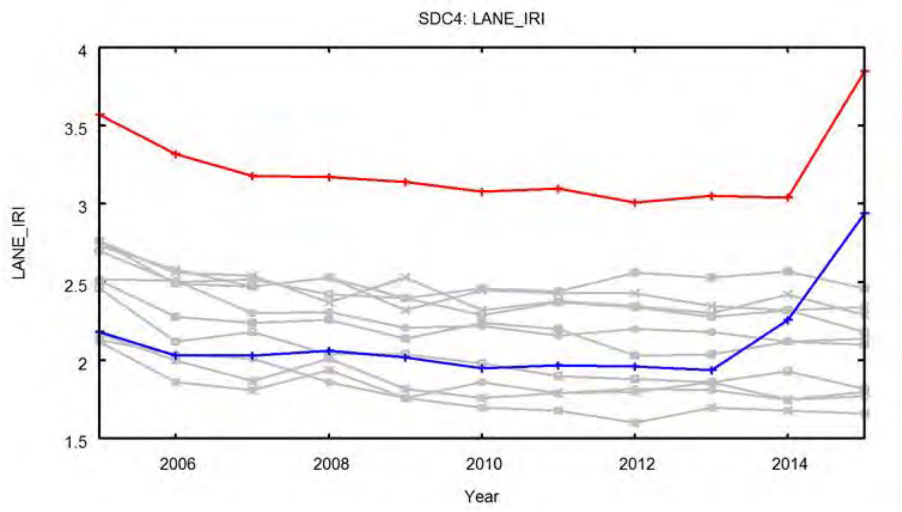

QLD2-S: Alligator
Alligator
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
2004
2006
2008
2010
2012
2014
Year

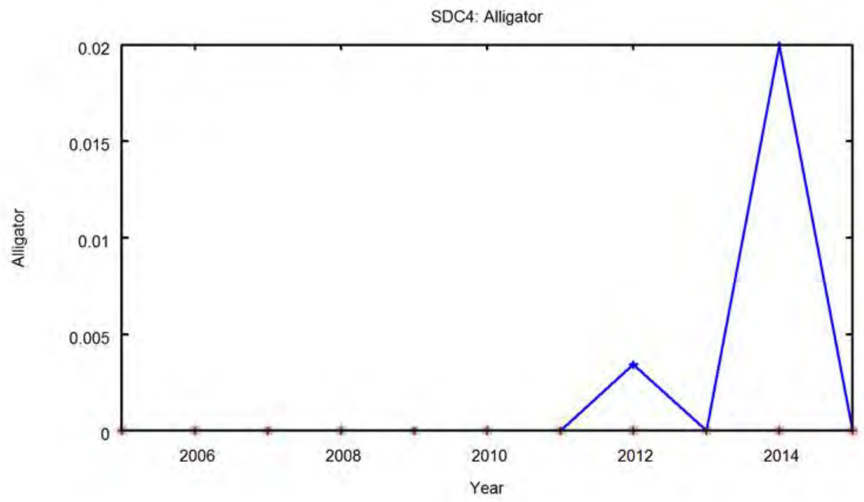


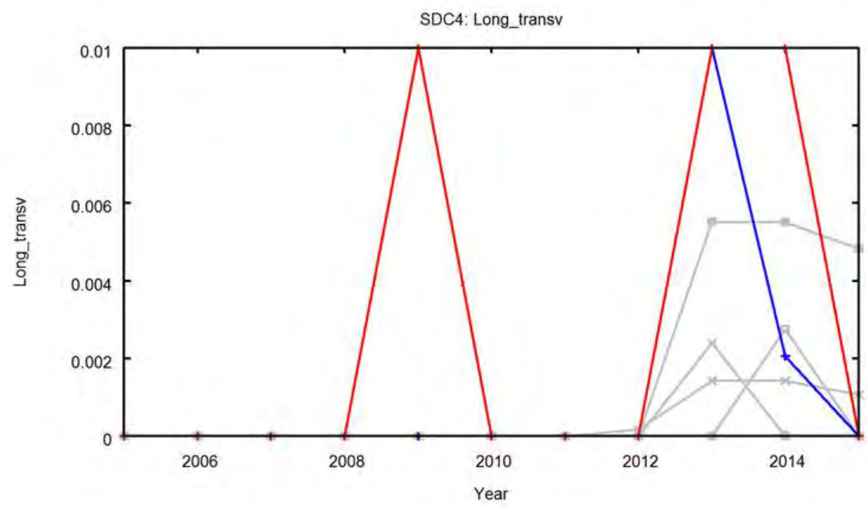


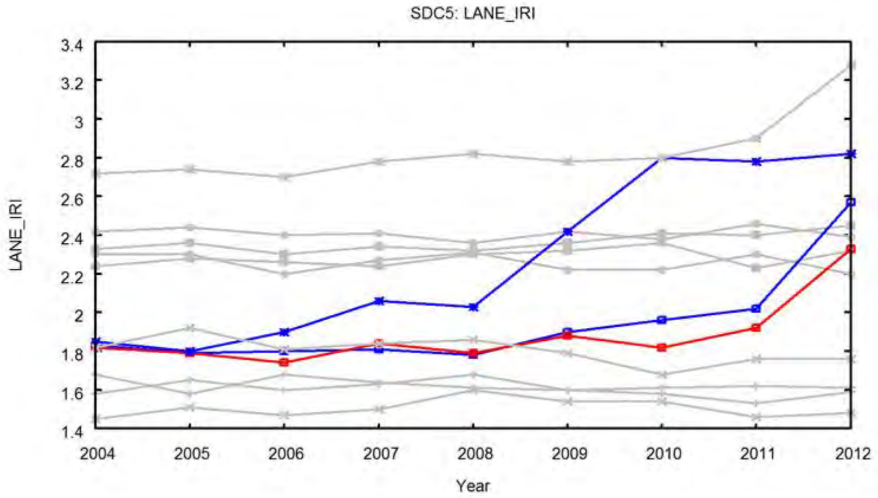
No alligator cracking.

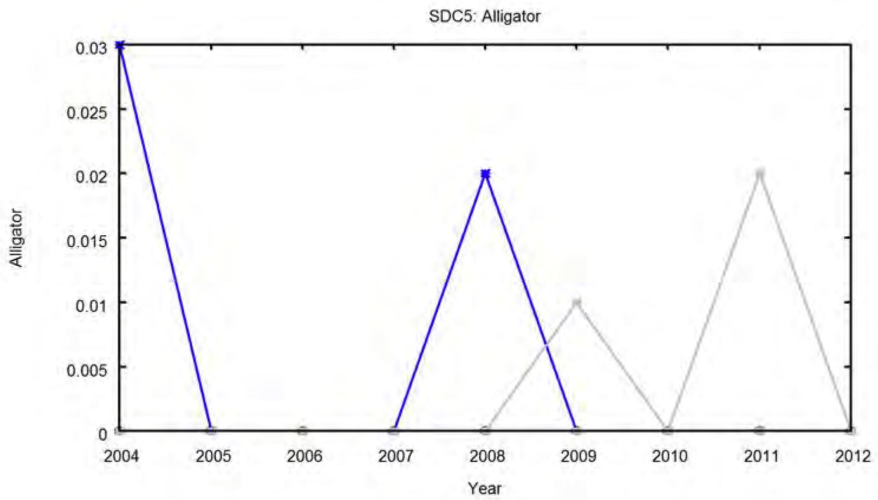



SDC4: LANE_IRI
LANE_IRI
Year
4
3.5
3
2.5
2
1.5
2006
2008
2010
2012
2014


SDC4: Alligator
Alligator
Year
0.02
0.015
0.01
0.005
0
2006
2008
2010
2012
2014


SDC4: Long_transv
Long_transv
Year
0.01
0.008
0.006
0.004
0.002
0
2006
2008
2010
2012
2014


SDC5: LANE_IRI
LANE_IRI
Year
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
2004
2005
2006
2007
2008
2009
2010
2011
2012


SDC5: Alligator
Alligator
Year
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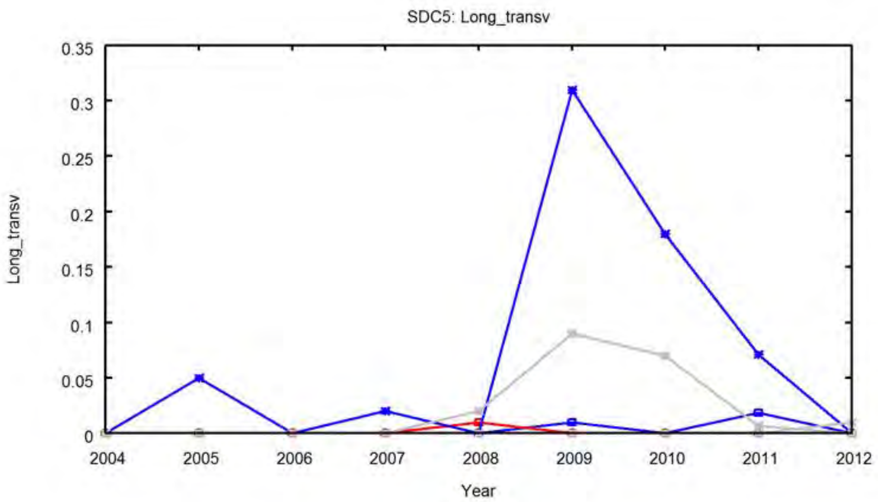
0.025
0.02
0.015
0.01
0.005
0
2004
2005
2006
2007
2008
2009
2010
2011
2012


SDC5: Long_transv
Long_transv
Year
0.35
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0.2
0.15
0.1
0.05
0
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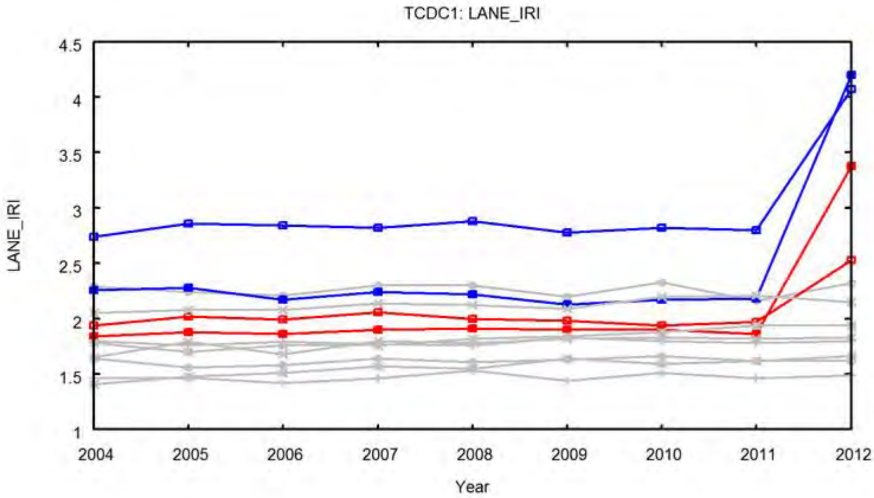
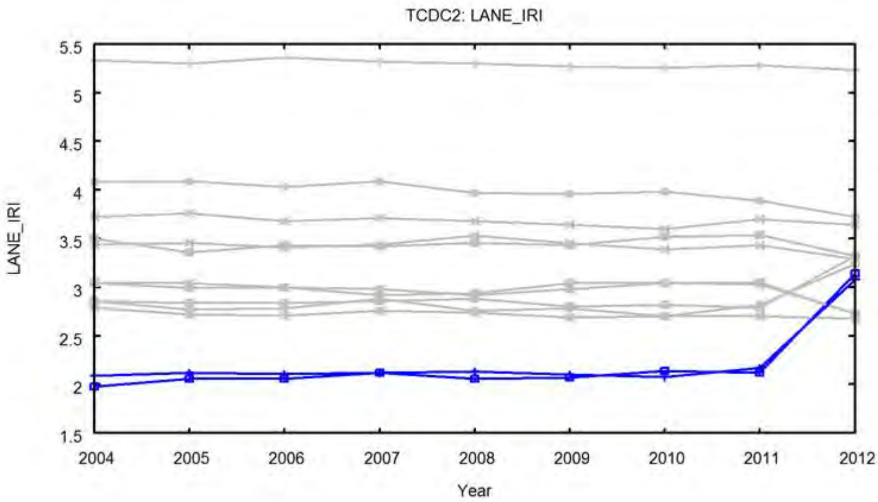
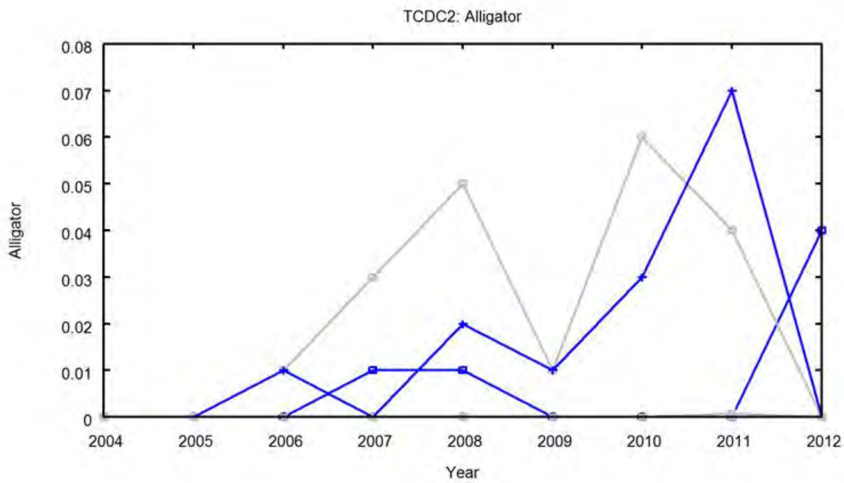
2005
2006
2007
2008
2009
2010
2011
2012


TCDC1: LANE_IRI
LANE_IRI
4.5
4
3.5
3
2.5
2
1.5
1
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


TCDC2: LANE_IRI
LANE_IRI
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


TCDC2: Alligator
Alligator
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
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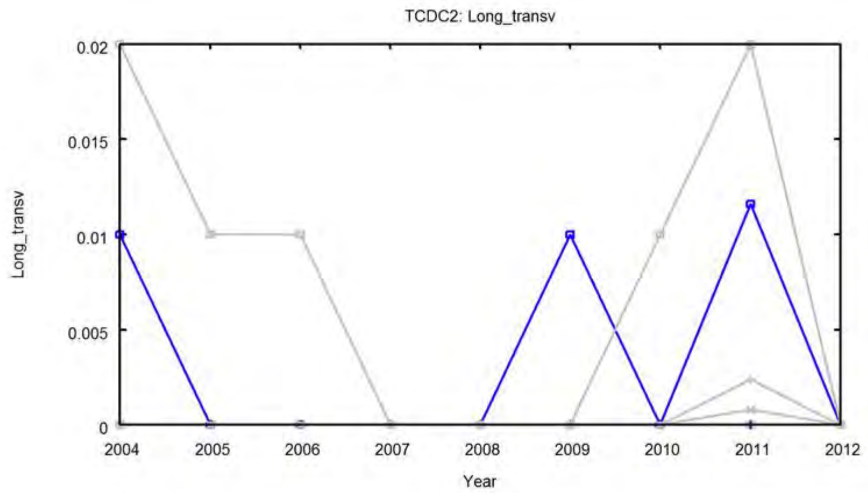
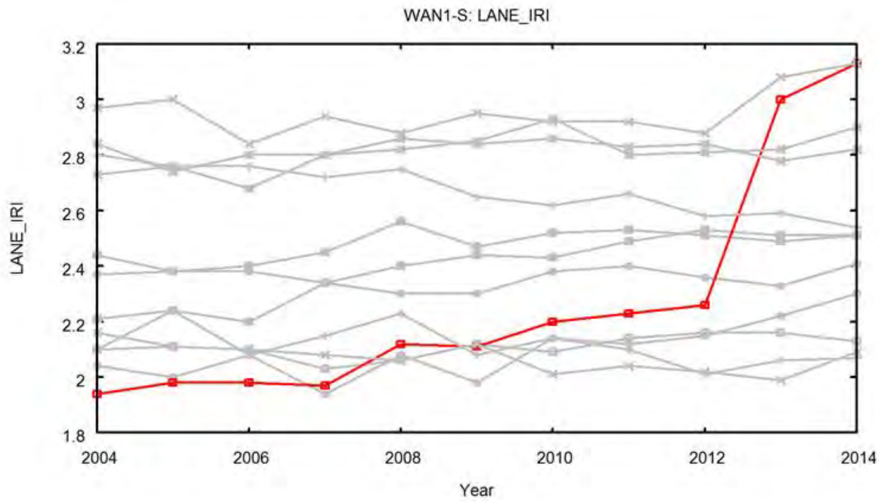
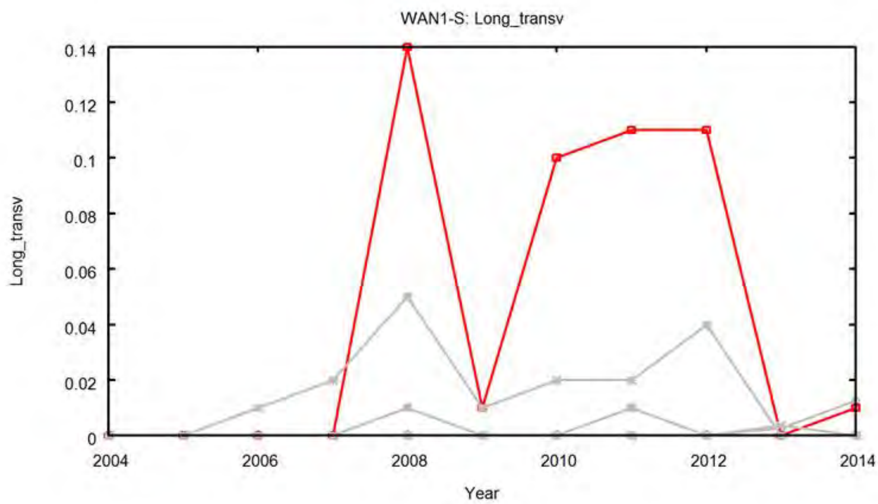
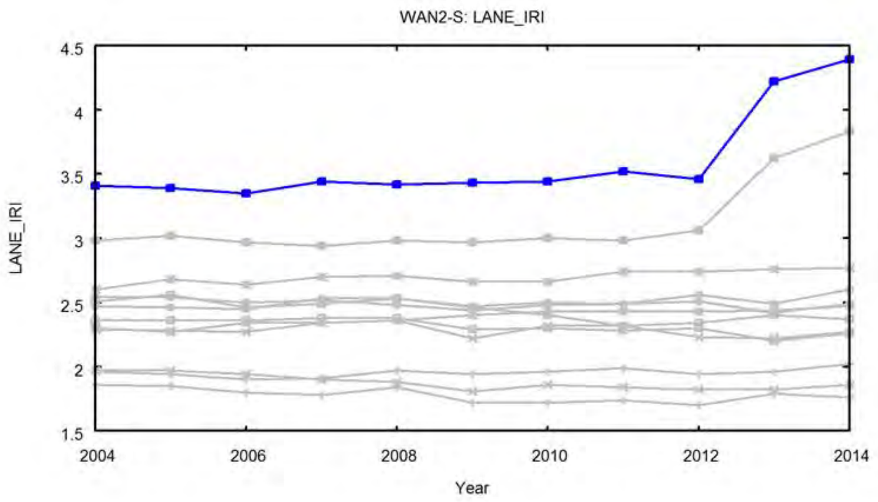
2009
2010
2011
2012
Year

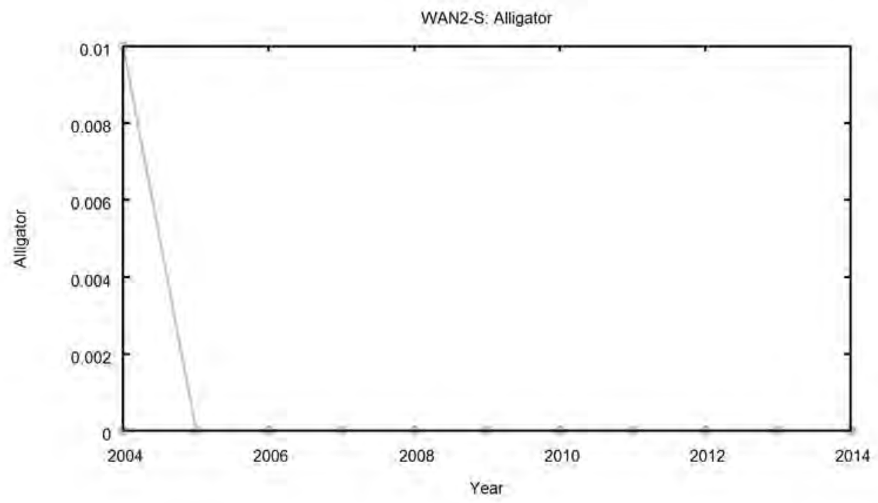


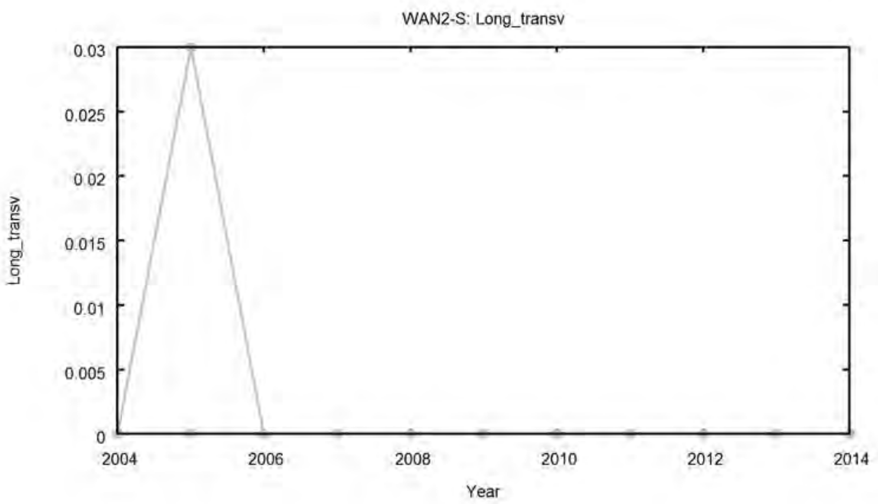


No alligator cracking.




WAN2-S: LANE_IRI
LANE_IRI
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014
Year


WAN2-S: Alligator
Alligator
0.01
0.008
0.006
0.004
0.002
0
2004
2006
2008
2010
2012
2014
Year


WAN2-S: Long_transv
Long_transv
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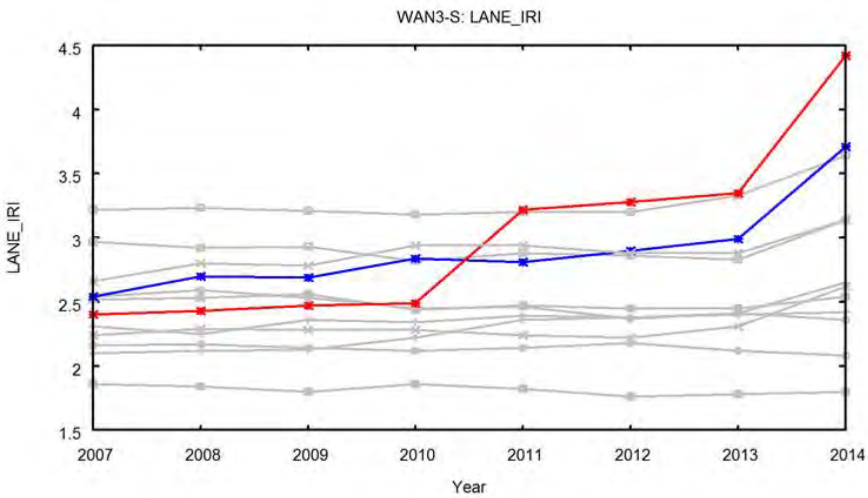
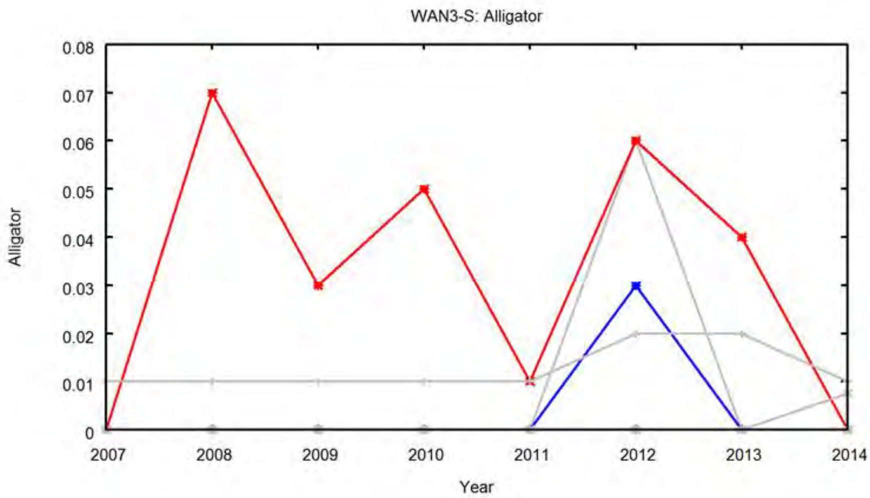
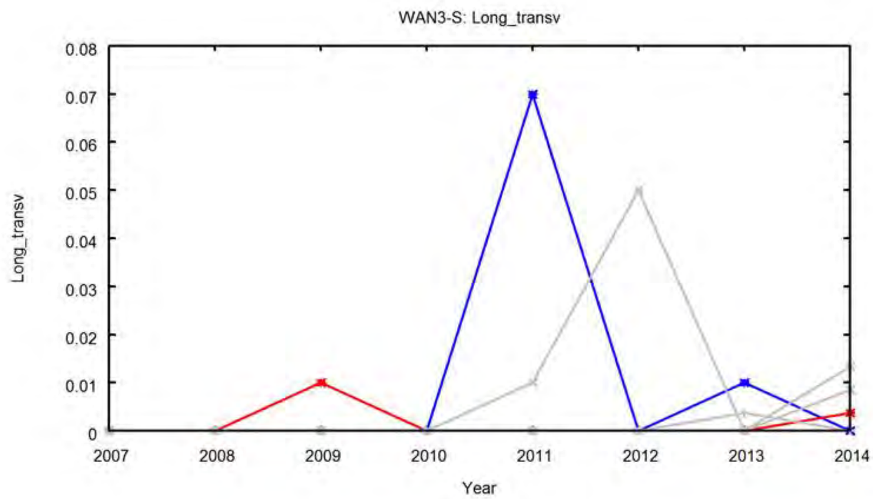
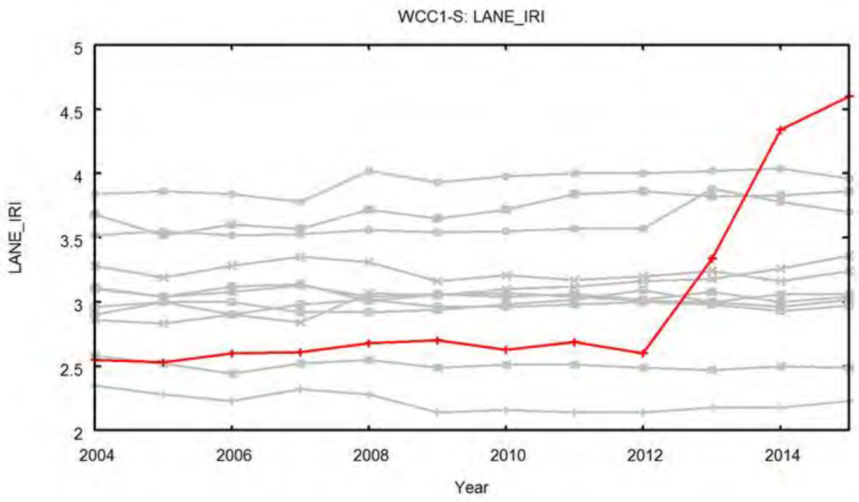
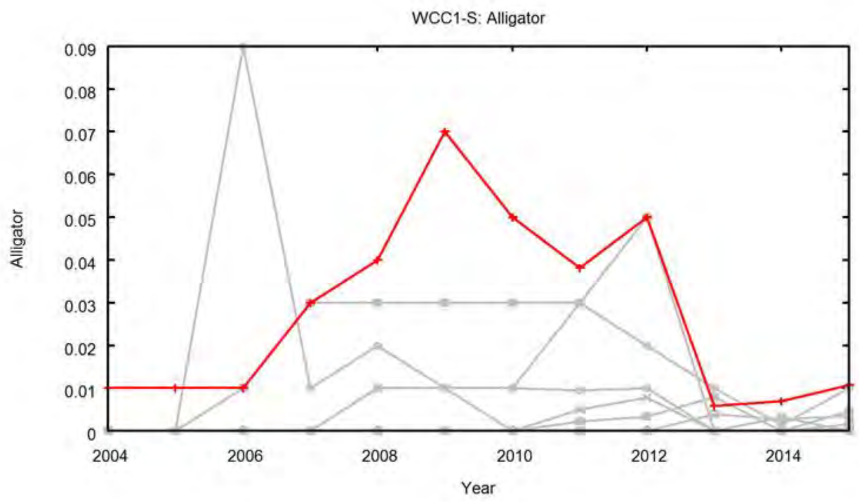
0.025
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014
Year


WAN3-S: LANE_IRI
LANE_IRI
4.5
4
3.5
3
2.5
2
1.5
2007
2008
2009
2010
2011
2012
2013
2014
Year


WAN3-S: Alligator
Alligator
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2007
2008
2009
2010
2011
2012
2013
2014
Year


WAN3-S: Long_transv
Long_transv
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2007
2008
2009
2010
2011
2012
2013
2014
Year


WCC1-S: LANE_IRI
LANE_IRI
Year
5
4.5
4
3.5
3
2.5
2
2004
2006
2008
2010
2012
2014


WCC1-S: Alligator
Alligator
Year
0.09
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0.07
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0.05
0.04
0.03
0.02
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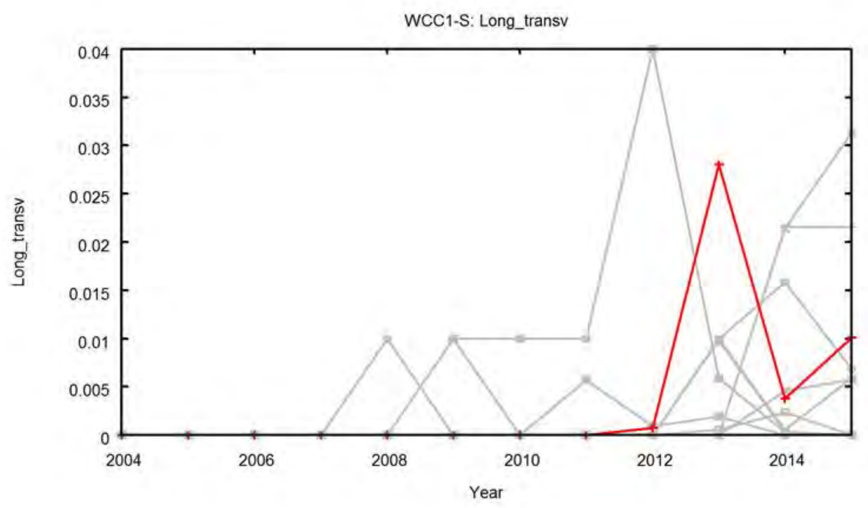
2006
2008
2010
2012
2014


WCC1-S: Long_transv
Long_transv
Year
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0.035
0.03
0.025
0.02
0.015
0.01
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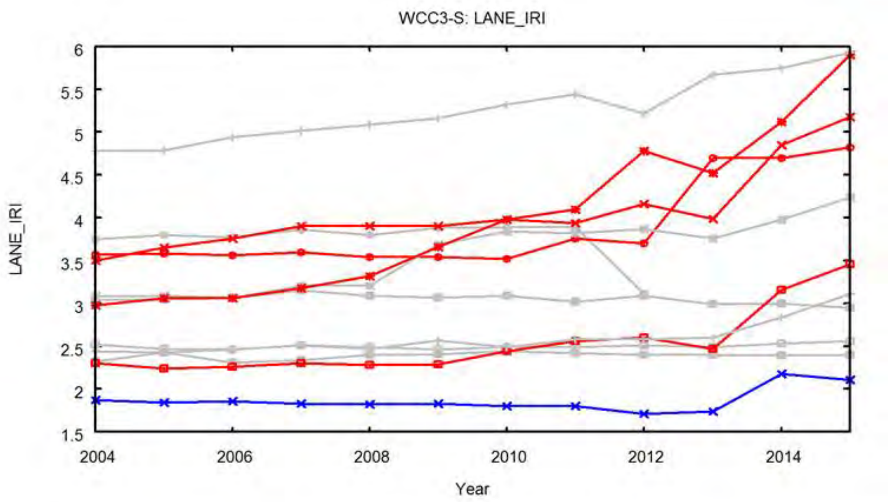
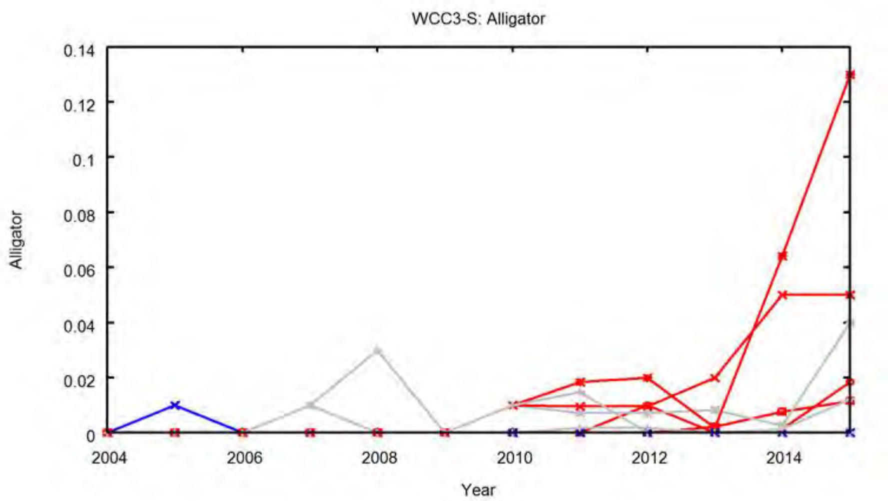
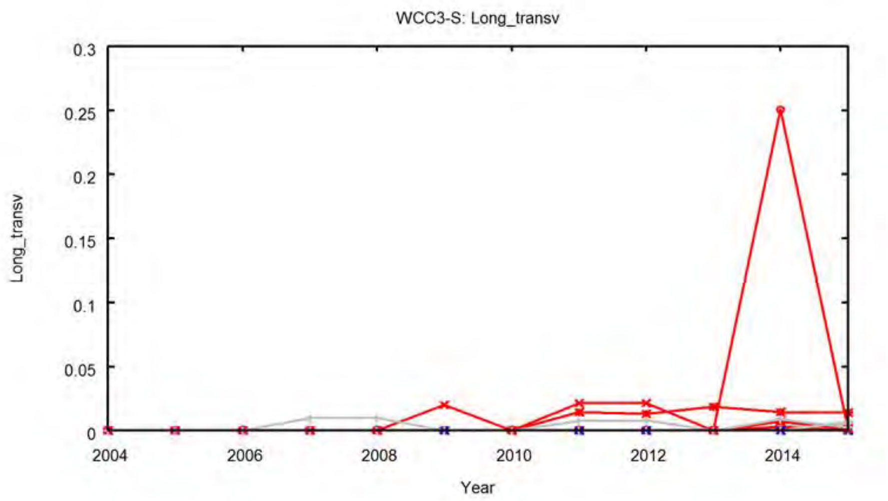
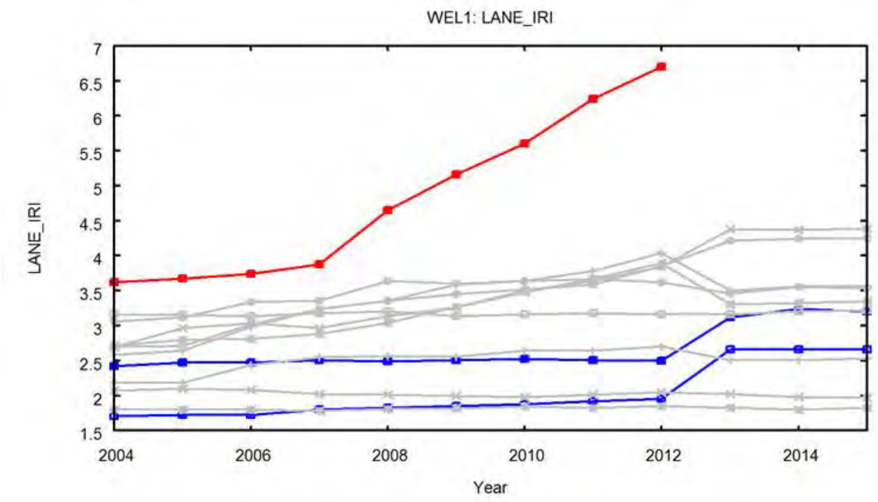
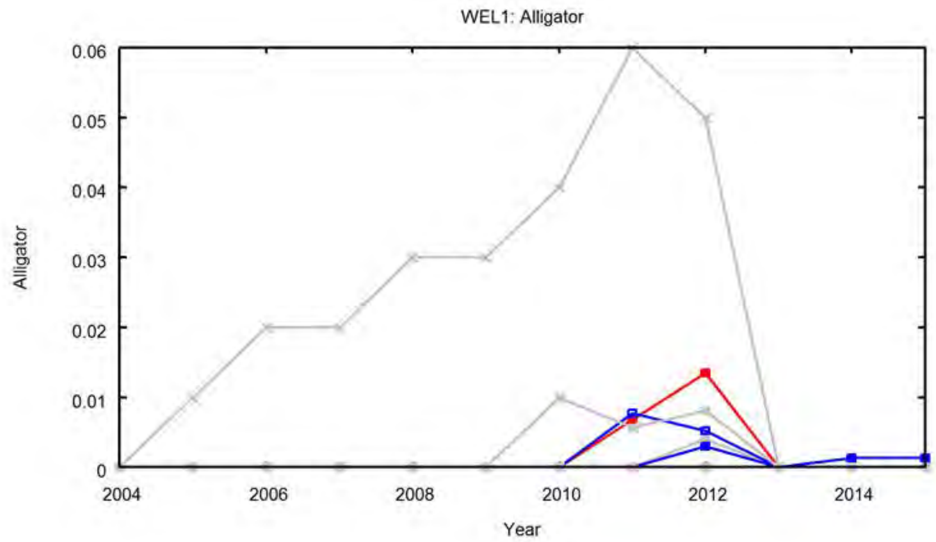
2006
2008
2010
2012
2014

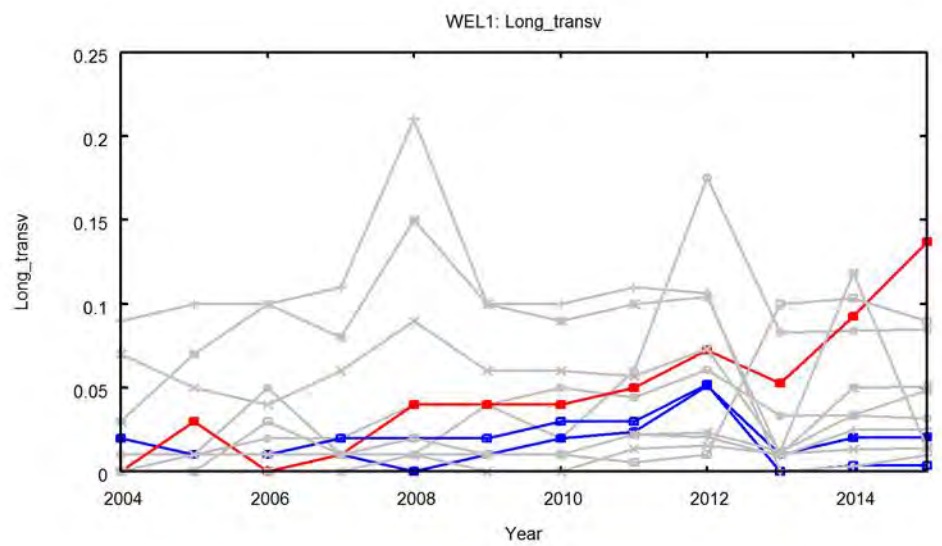

WCC3-S: LANE_IRI
LANE_IRI
Year
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014

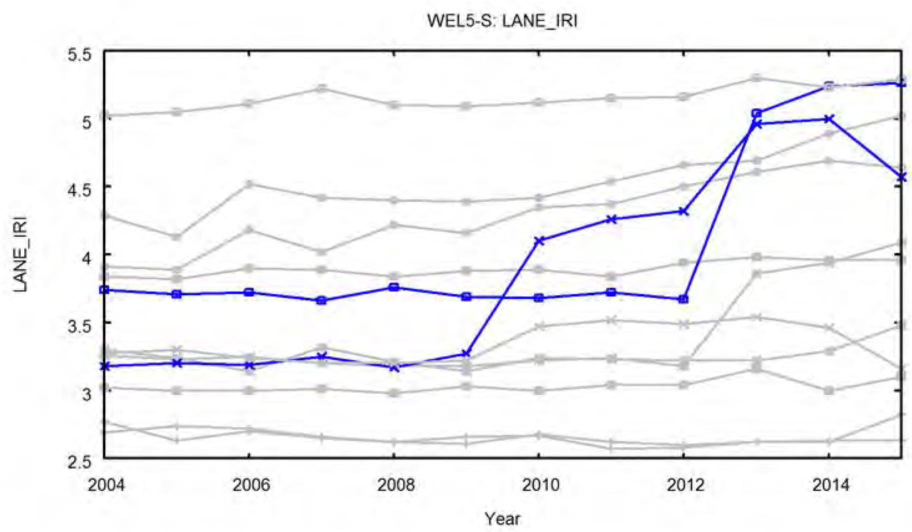

WCC3-S: Alligator
Alligator
Year
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014

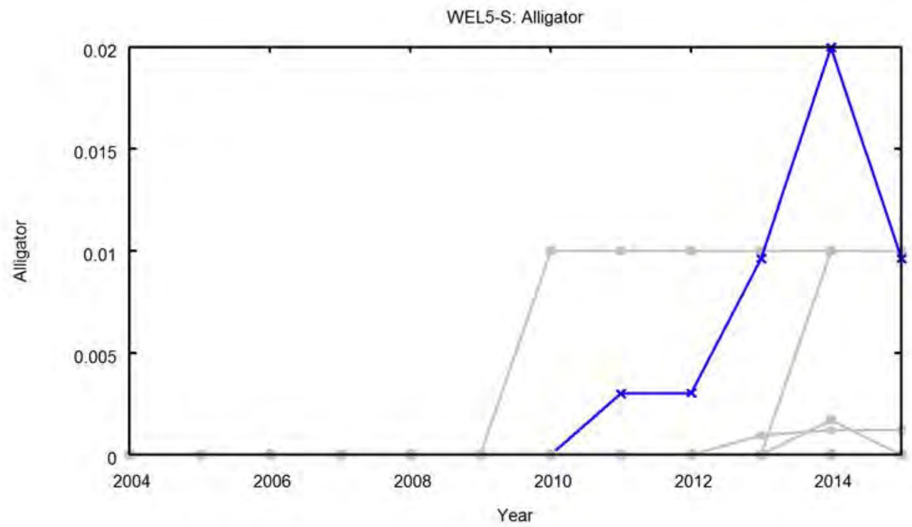

WCC3-S: Long_transv
Long_transv
Year
0.3
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014

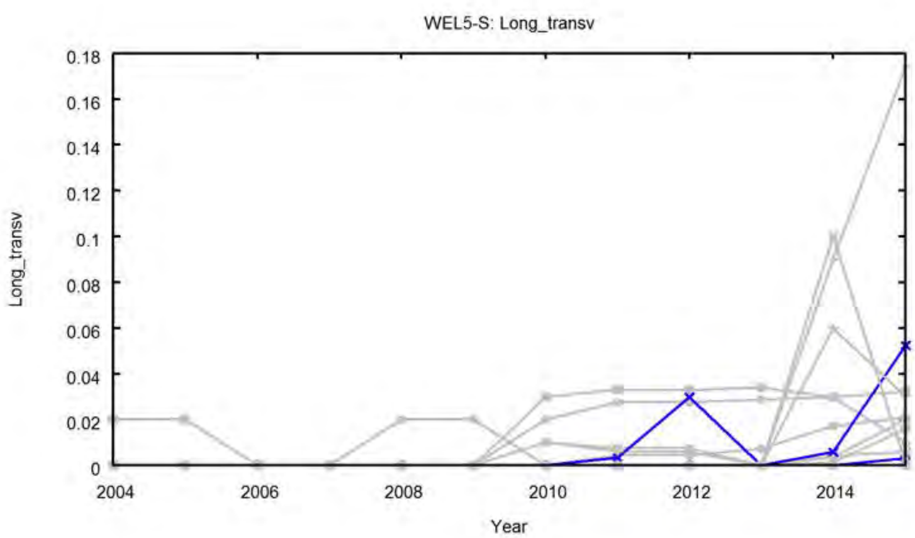

WEL1: LANE_IRI
LANE_IRI
Year
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014

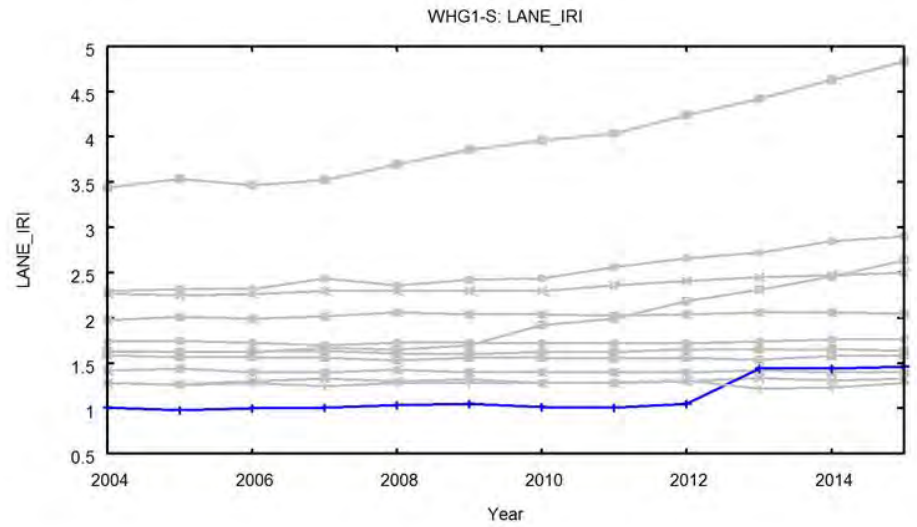

WEL1: Alligator
Alligator
Year
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
2006
2008
2010
2012
2014

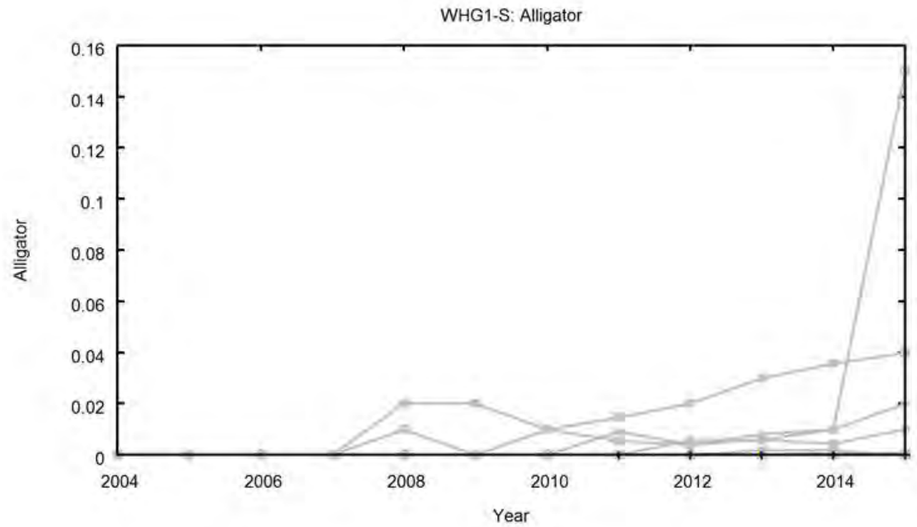

WEL1: Long_transv
Long_transv
Year
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014

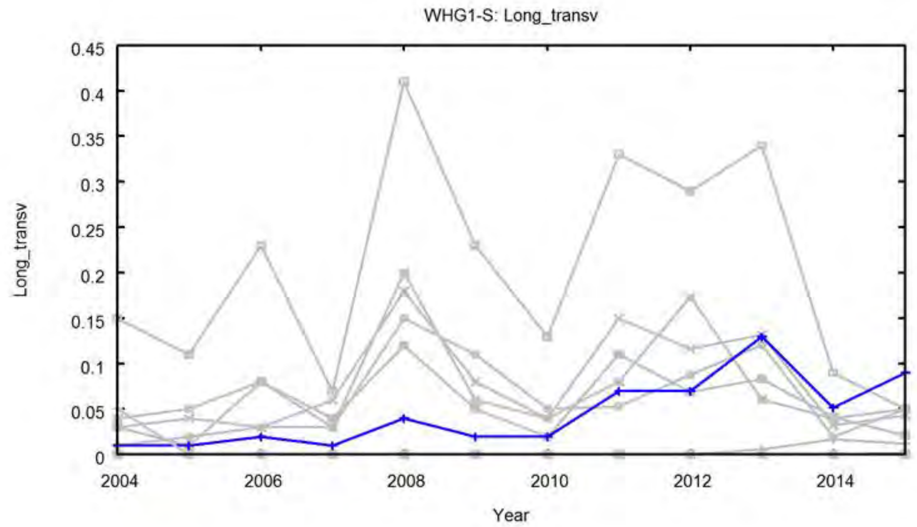

WEL5-S: LANE_IRI
LANE_IRI
Year
5.5
5
4.5
4
3.5
3
2.5
2004
2006
2008
2010
2012
2014

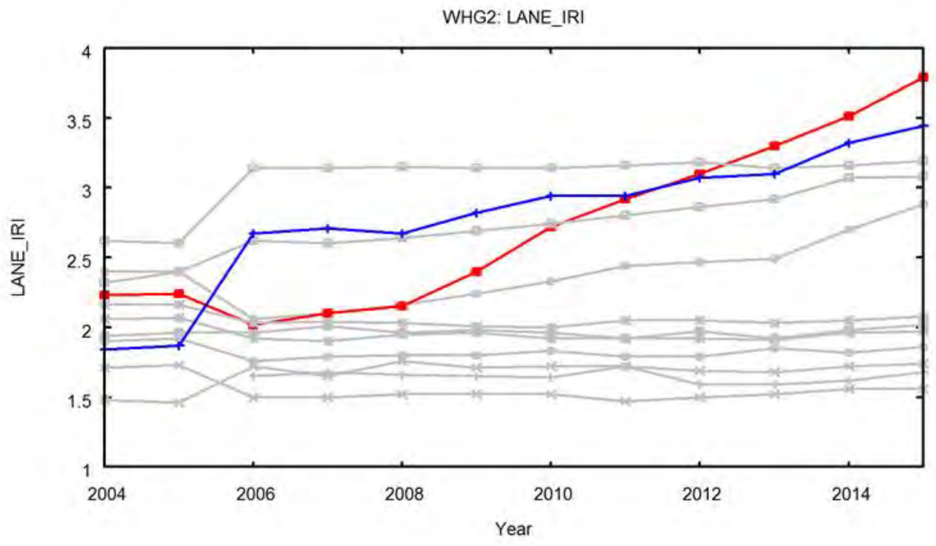

WEL5-S: Alligator
Alligator
Year
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014

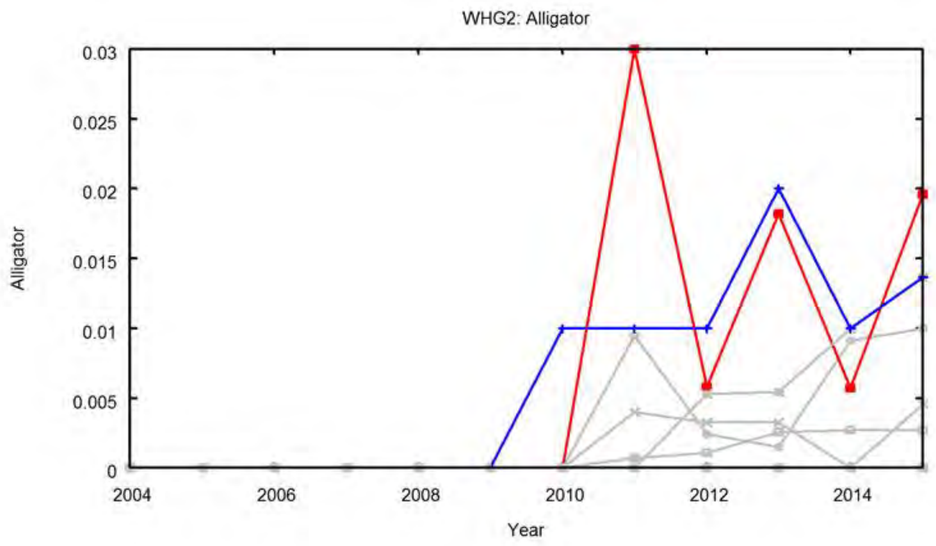

WEL5-S: Long_transv
Long_transv
Year
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014

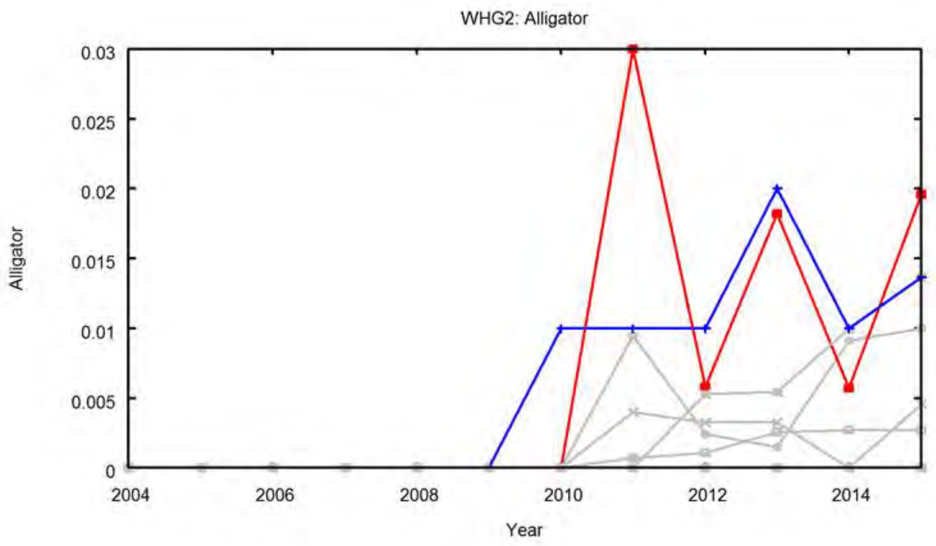

WHG1-S: LANE_IRI
LANE_IRI
Year
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
2004
2006
2008
2010
2012
2014

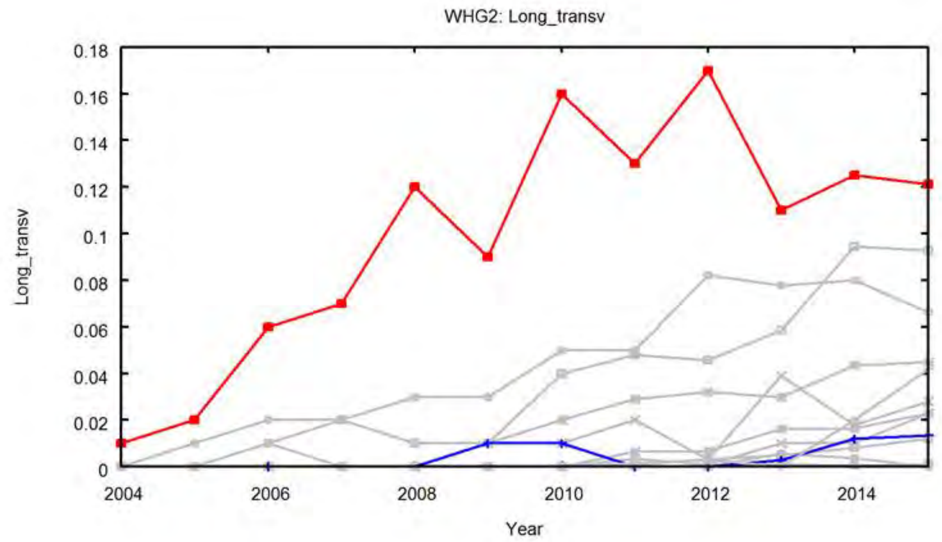

WHG1-S: Alligator
Alligator
Year
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014

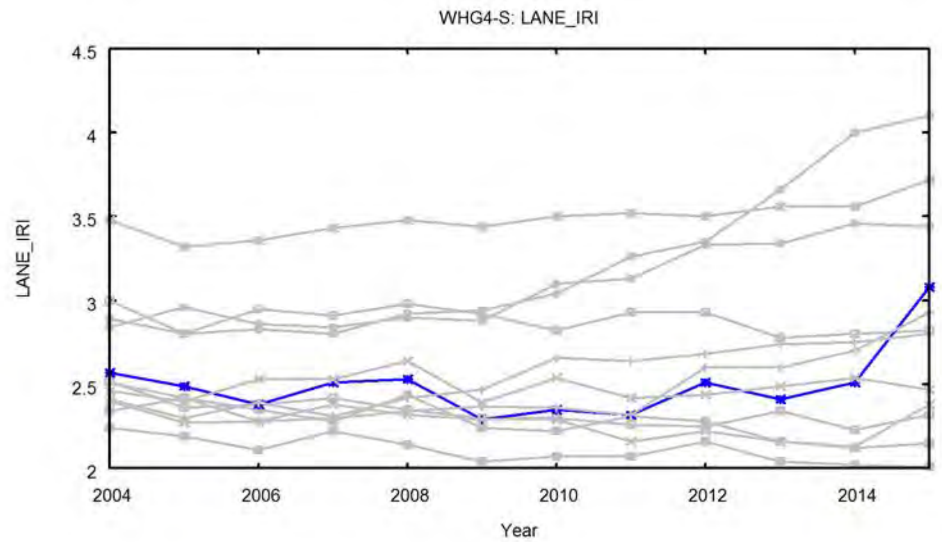

WHG1-S: Long_transv
Long_transv
Year
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014

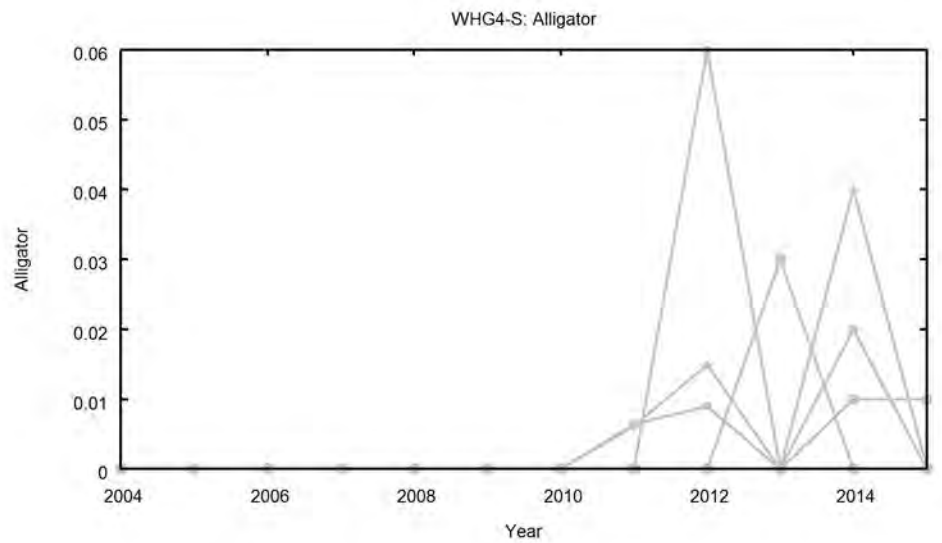

WHG2: LANE_IRI
LANE_IRI
Year
4
3.5
3
2.5
2
1.5
1
2004
2006
2008
2010
2012
2014

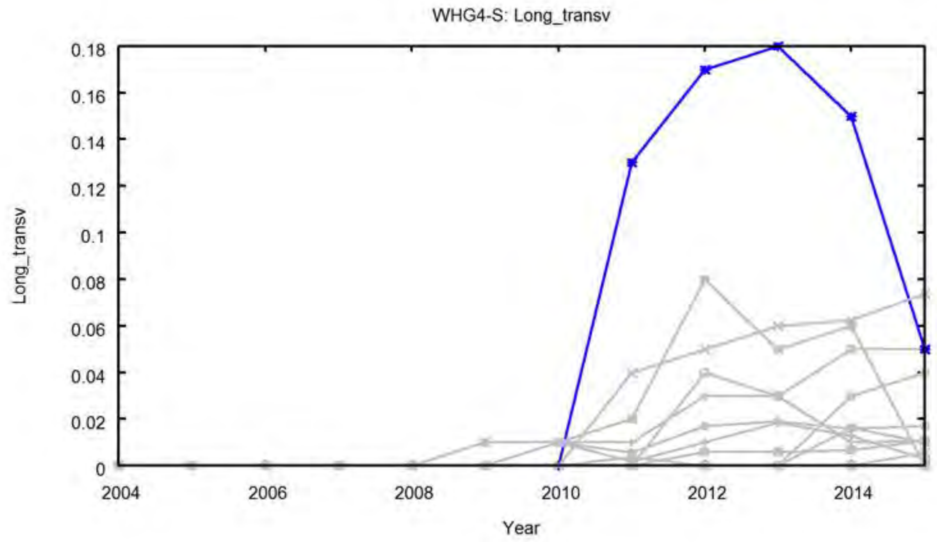

WHG2: Alligator
Alligator
Year
0.03
0.025
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014

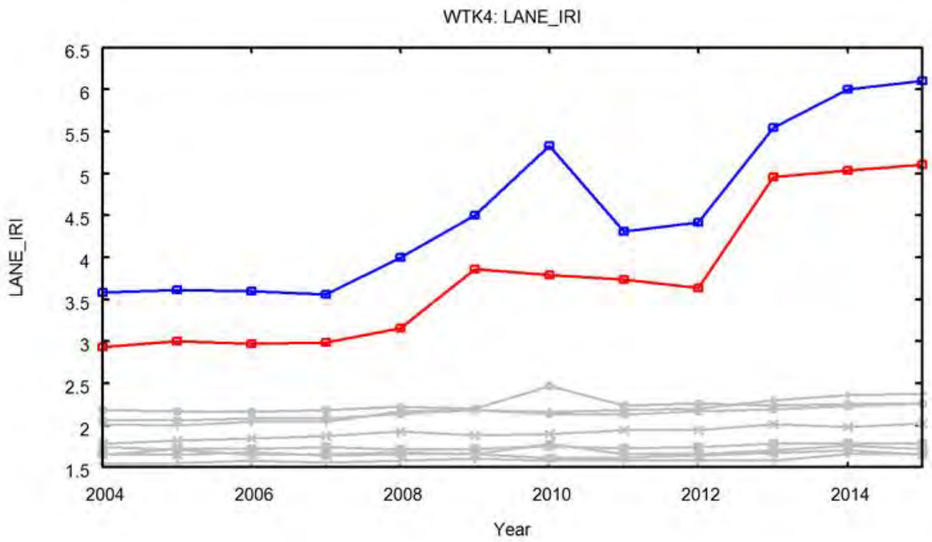

WHG2: Alligator
Alligator
Year
0.03
0.025
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014

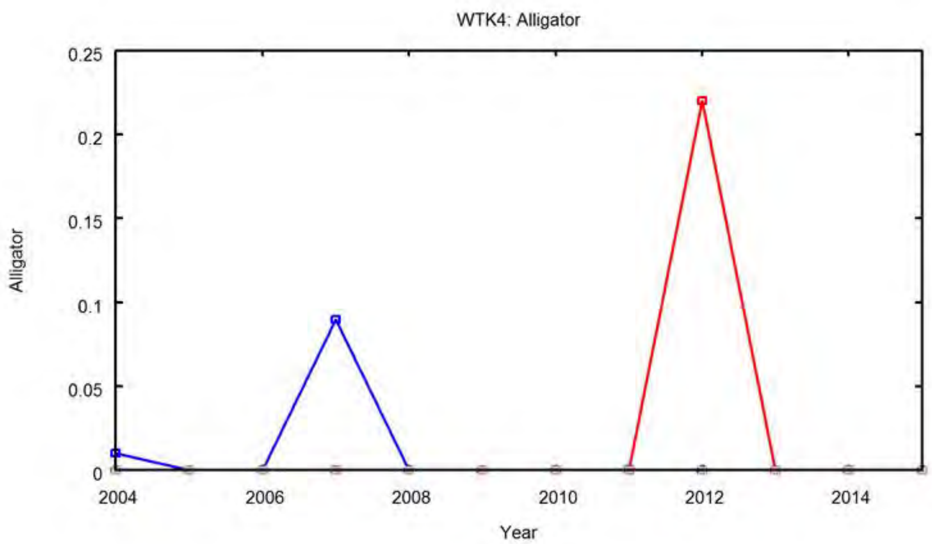

WHG2: Long_transv
Long_transv
Year

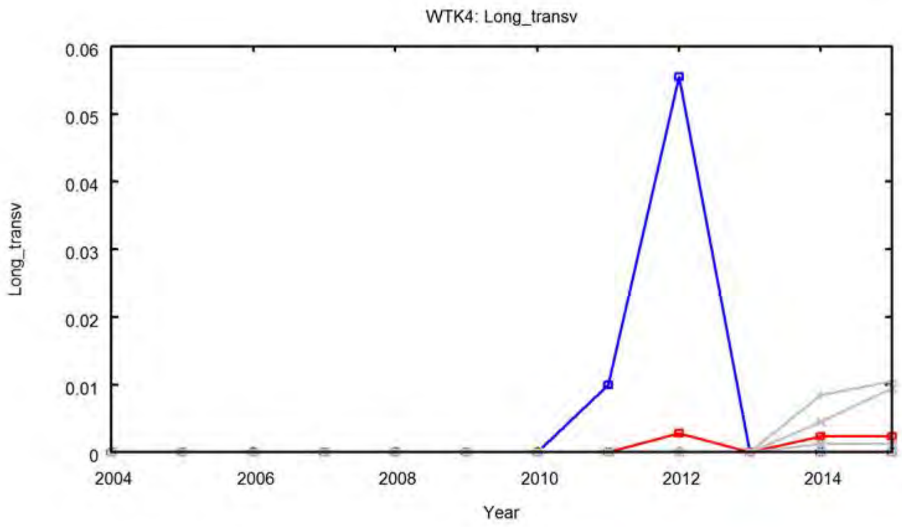

WHG4-S: LANE_IRI
LANE_IRI
Year


WHG4-S: Alligator
Alligator
Year

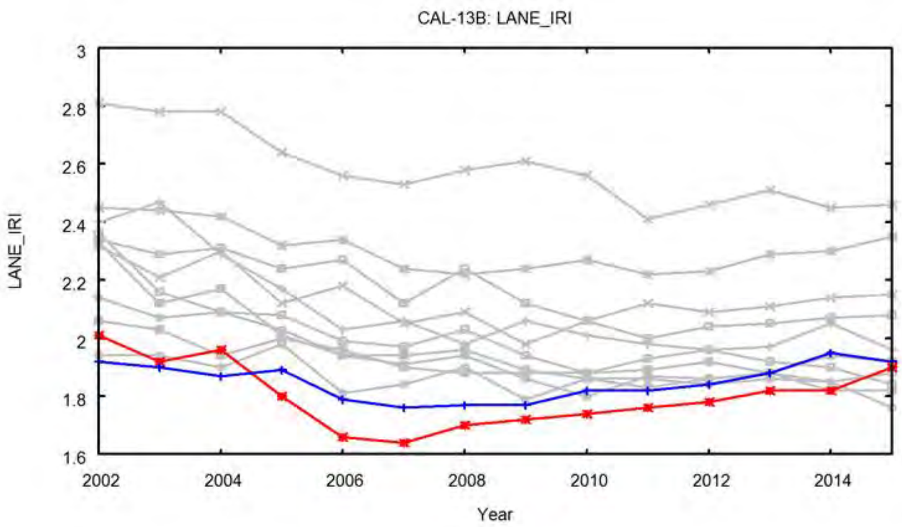

WHG4-S: Long_transv
Long_transv
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014
Year

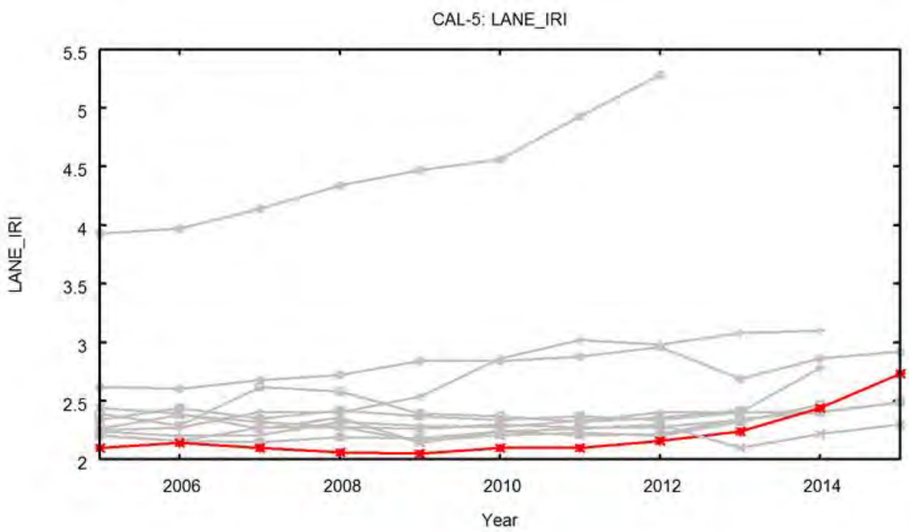

WTK4: LANE_IRI
LANE_IRI
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014
Year

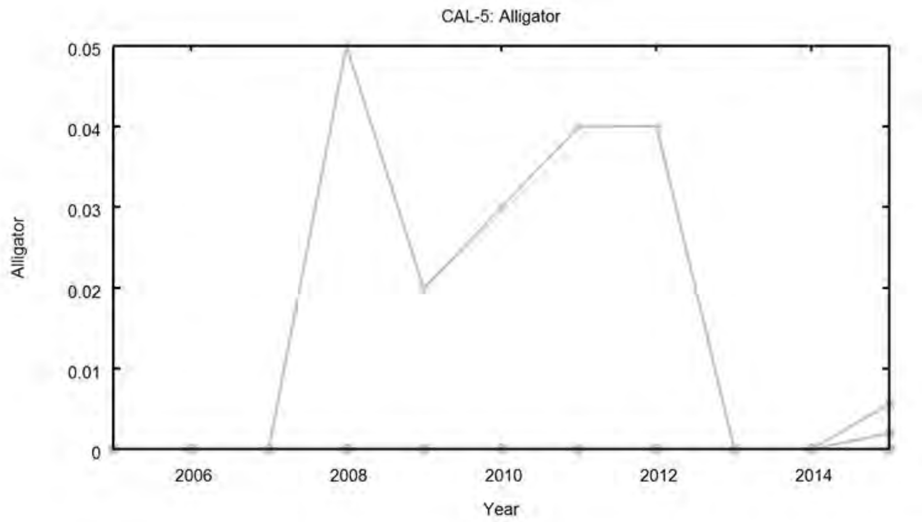

WTK4: Alligator
Alligator
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014
Year

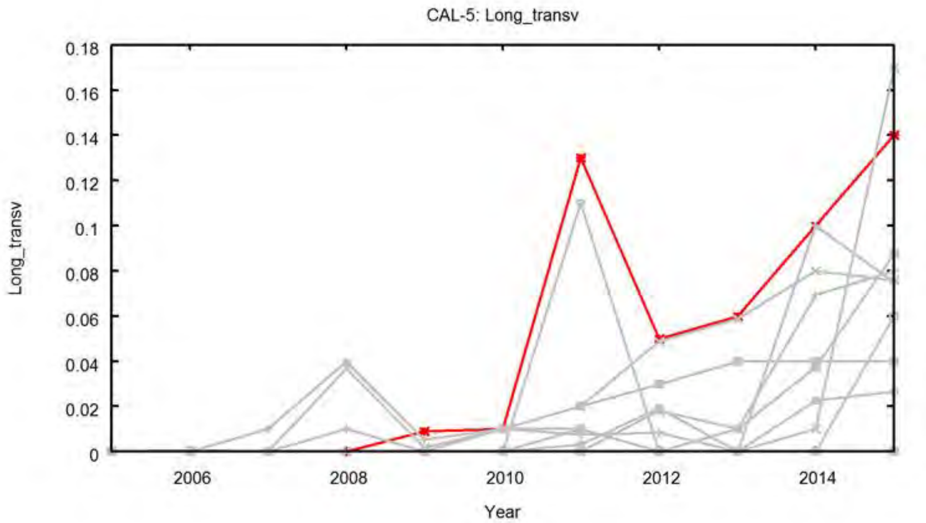


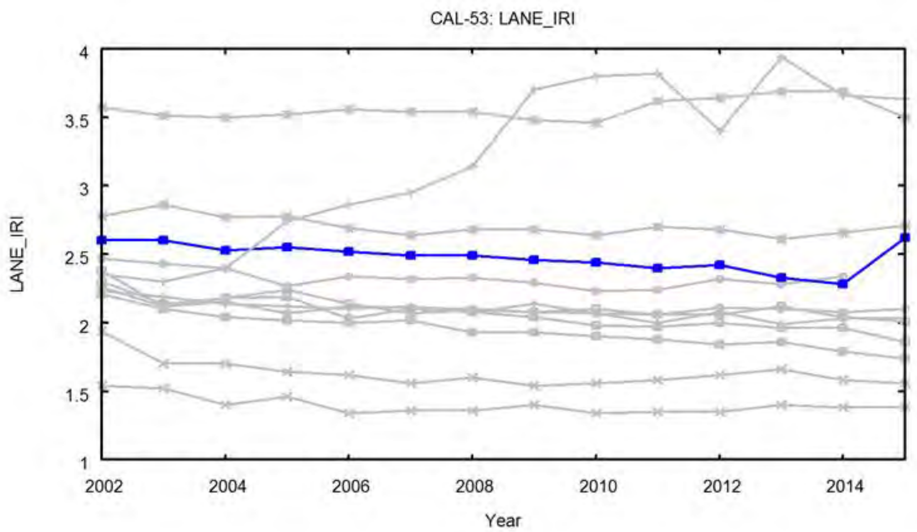
Roughness – LTPP12

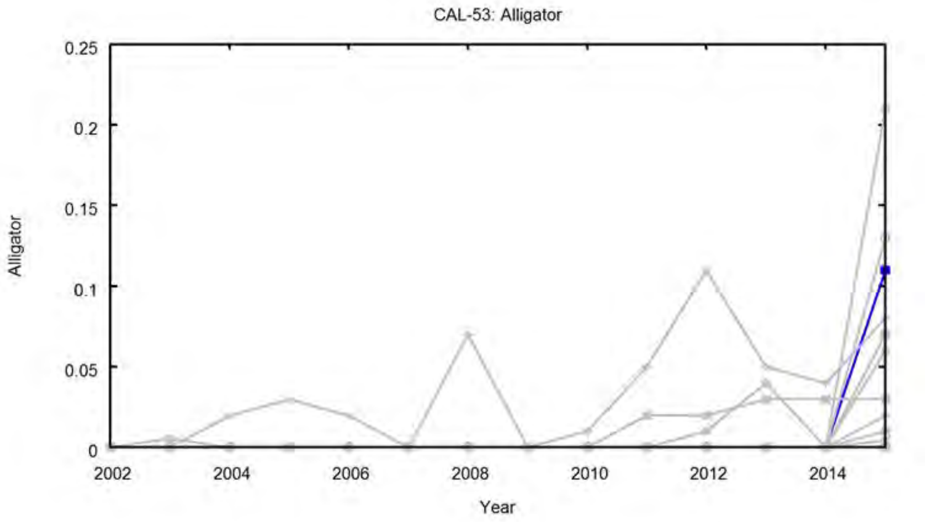


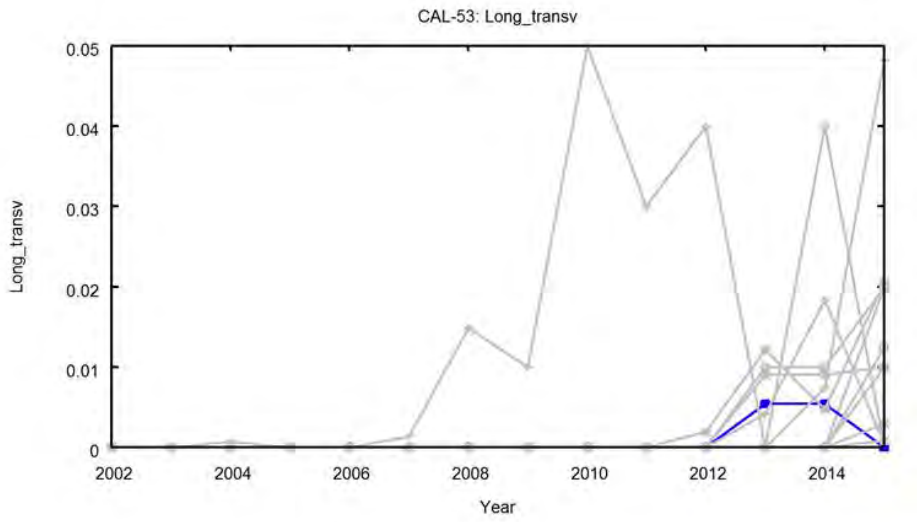


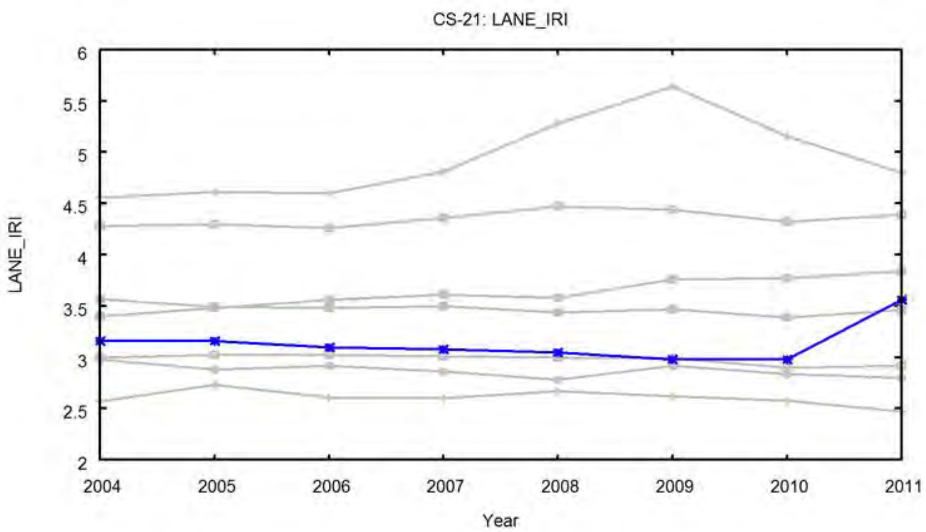

CAL-5: Alligator
0.05
0.04
0.03
0.02
0.01
0
Alligator
2006
2008
2010
2012
2014
Year

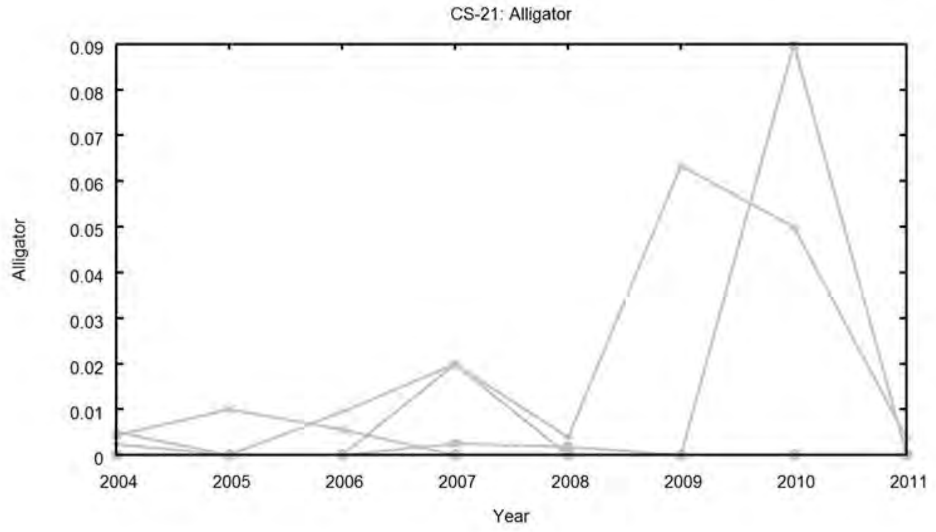

CAL-5: Long_transv
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Long_transv
2006
2008
2010
2012
2014
Year

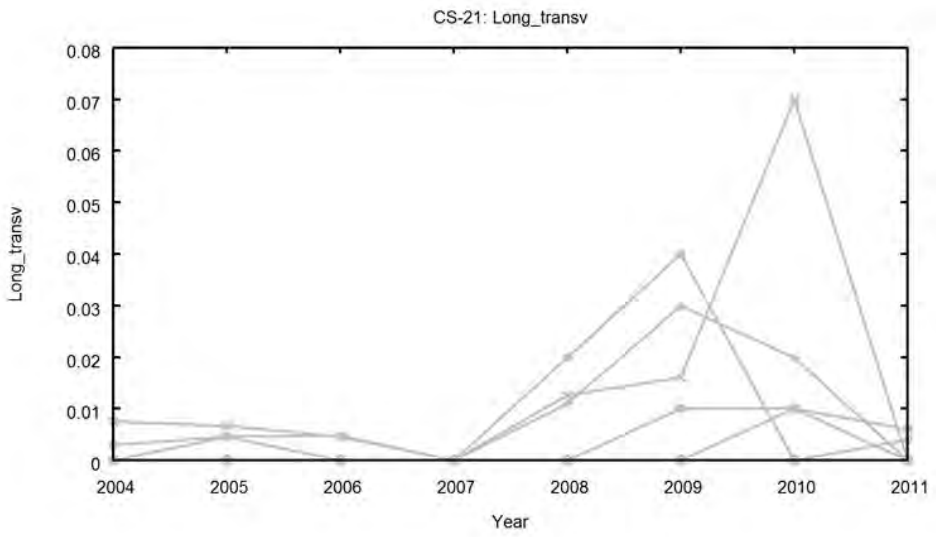

CAL-53: LANE_IRI
4
3.5
3
2.5
2
1.5
1
LANE_IRI
2002
2004
2006
2008
2010
2012
2014
Year

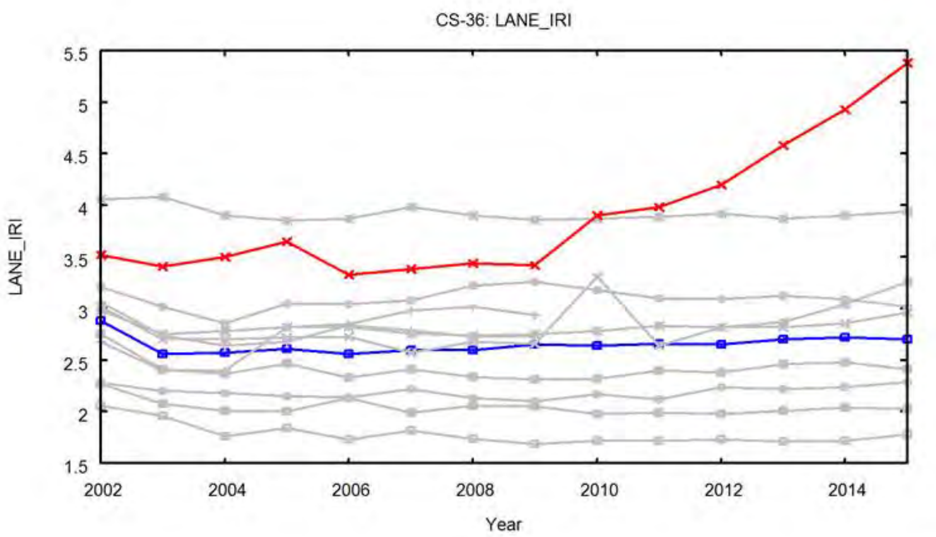

CAL-53: Alligator
Alligator
Year
0.25
0.2
0.15
0.1
0.05
0
2002
2004
2006
2008
2010
2012
2014

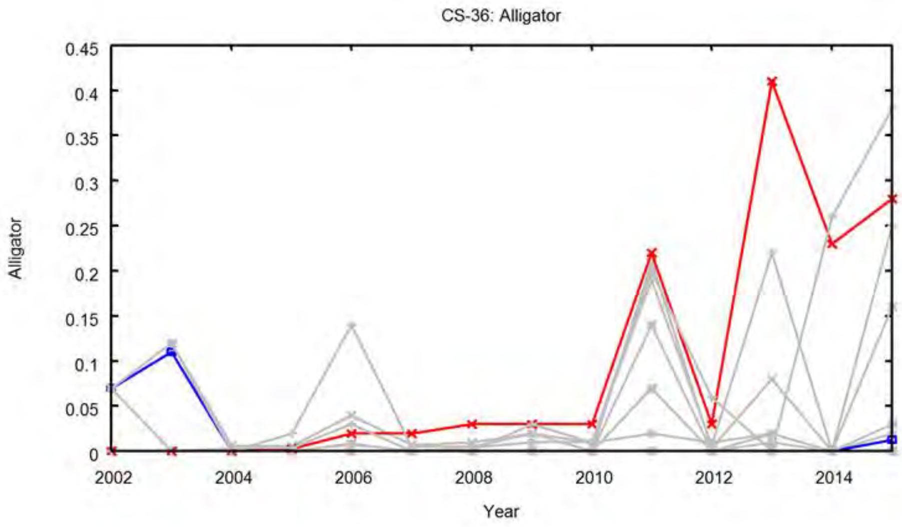

CAL-53: Long_transv
Long_transv
Year
0.05
0.04
0.03
0.02
0.01
0
2002
2004
2006
2008
2010
2012
2014

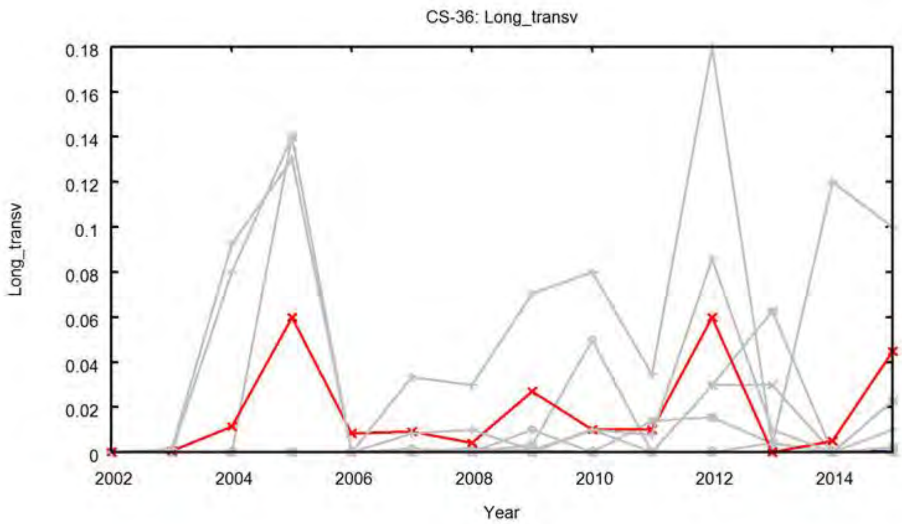

CS-21: LANE_IRI
LANE_IRI
Year
6
5.5
5
4.5
4
3.5
3
2.5
2
2004
2005
2006
2007
2008
2009
2010
2011

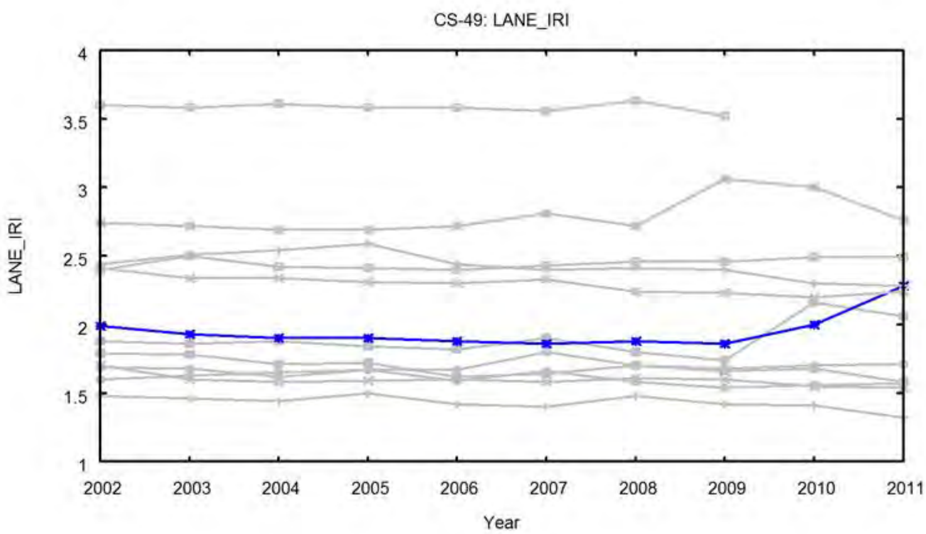

CS-21: Alligator
Alligator
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
2005
2006
2007
2008
2009
2010
2011
Year

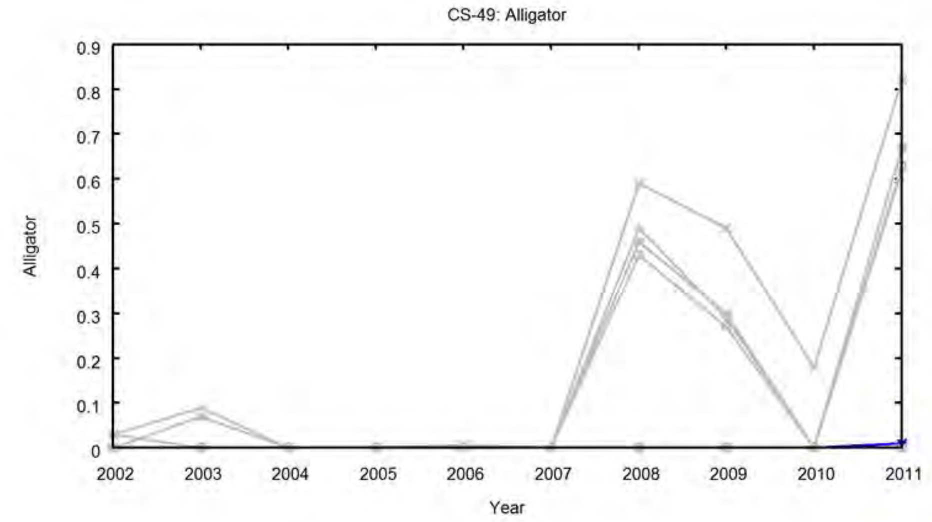

CS-21: Long_transv
Long_transv
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
2005
2006
2007
2008
2009
2010
2011
Year

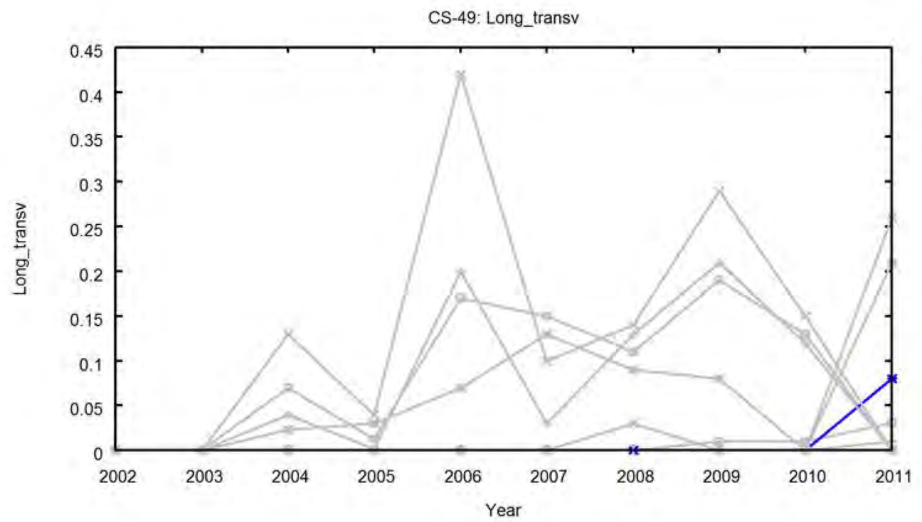

CS-36: LANE_IRI
LANE_IRI
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2002
2004
2006
2008
2010
2012
2014
Year

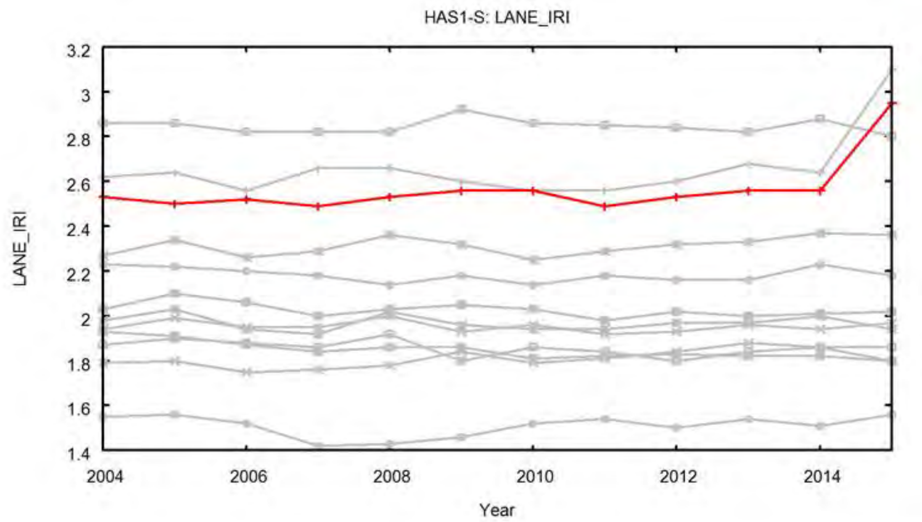

CS-36: Alligator
Alligator
Year


CS-36: Long_transv
Long_transv
Year

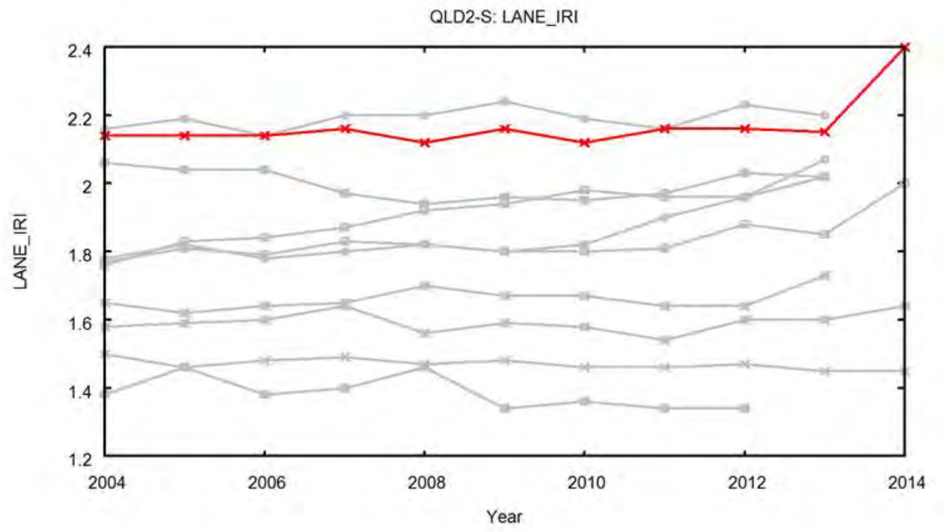

CS-49: LANE_IRI
LANE_IRI
Year

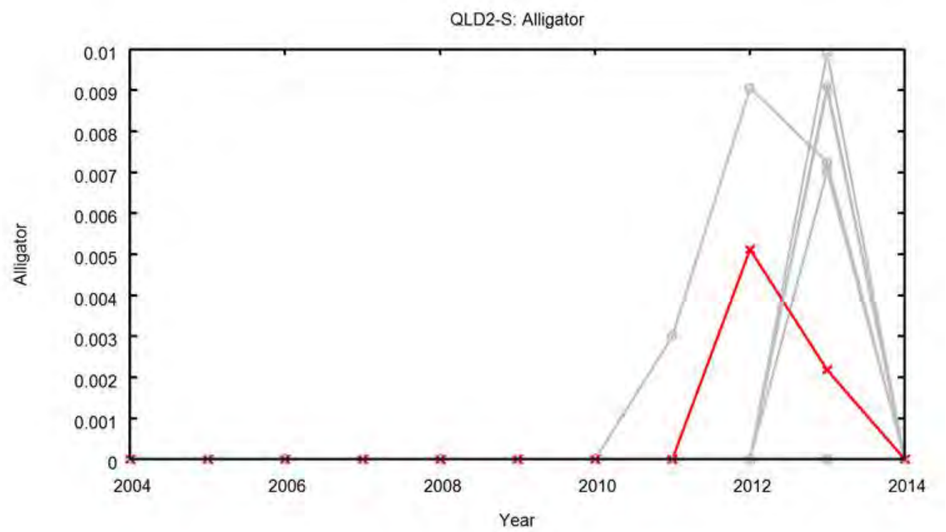


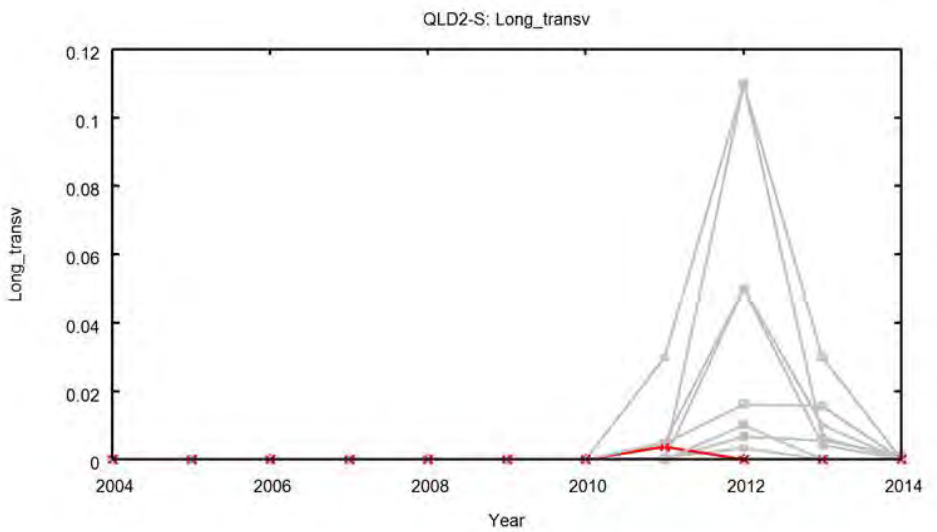


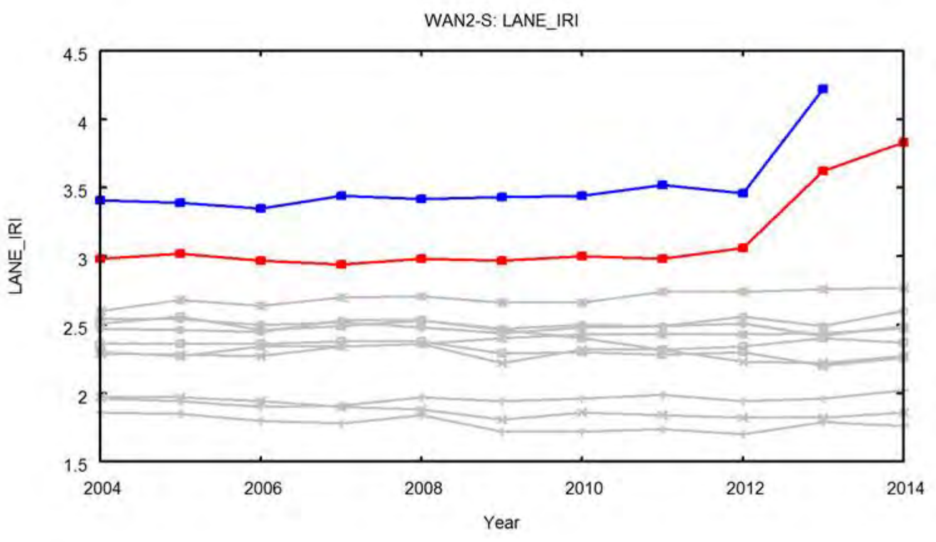


No cracking was reported.

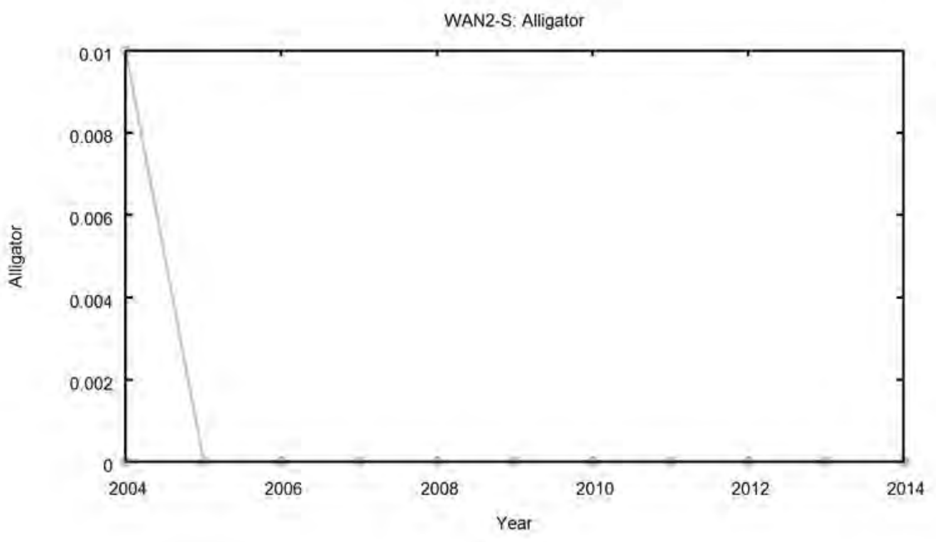

QLD2-S: LANE_IRI
LANE_IRI
Year
2.4
2.2
2
1.8
1.6
1.4
1.2
2004
2006
2008
2010
2012
2014


QLD2-S: Alligator
Alligator
Year
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
2004
2006
2008
2010
2012
2014

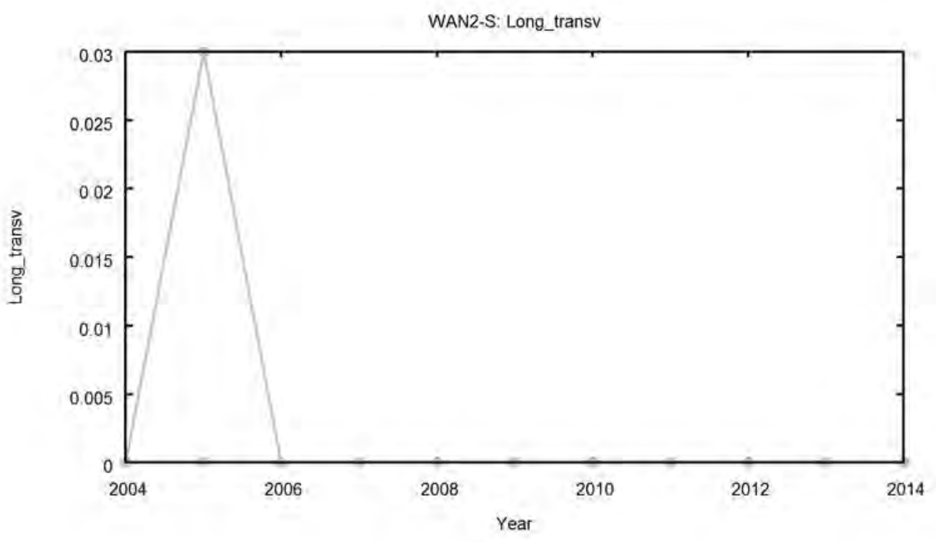

QLD2-S: Long_transv
Long_transv
Year
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014



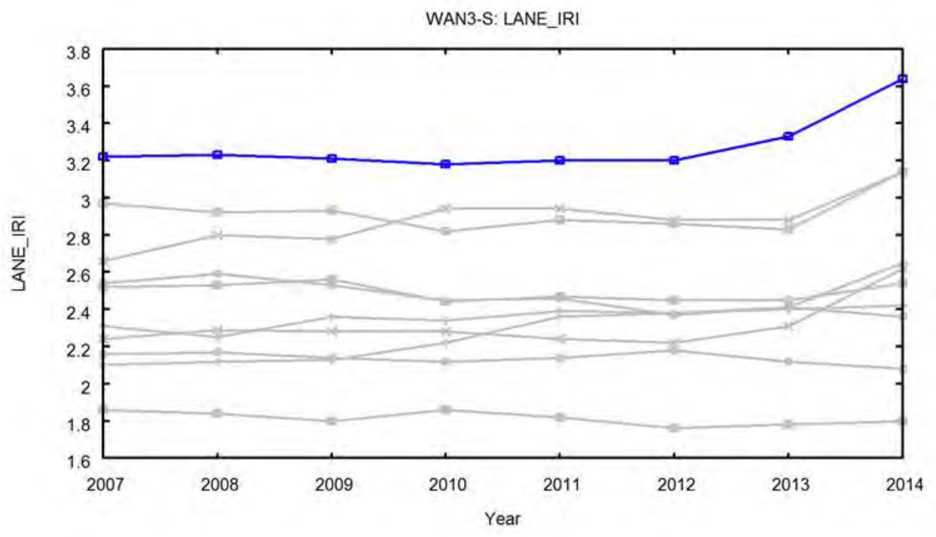
WAN2-S: LANE_IRI
LANE_IRI
Year
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014

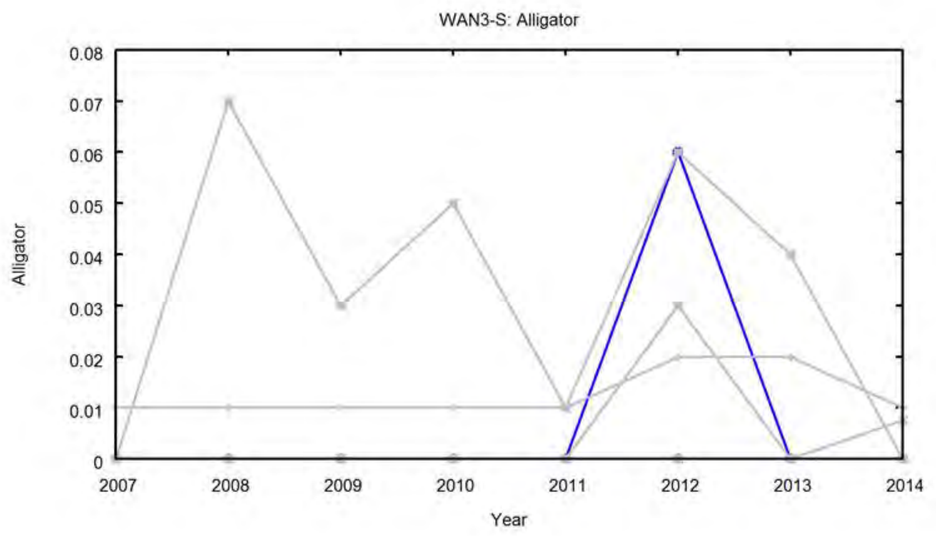


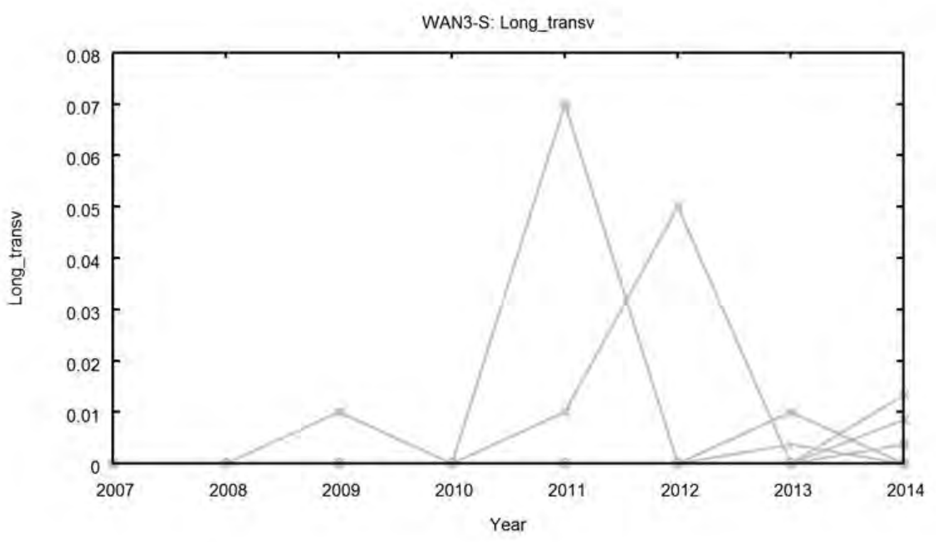
WAN2-S: Alligator
Alligator
Year
0.01
0.008
0.006
0.004
0.002
0
2004
2006
2008
2010
2012
2014

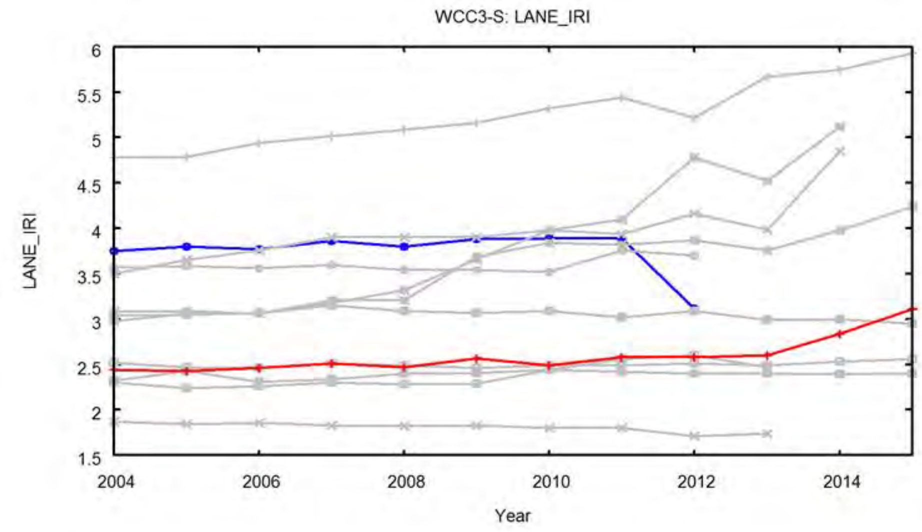


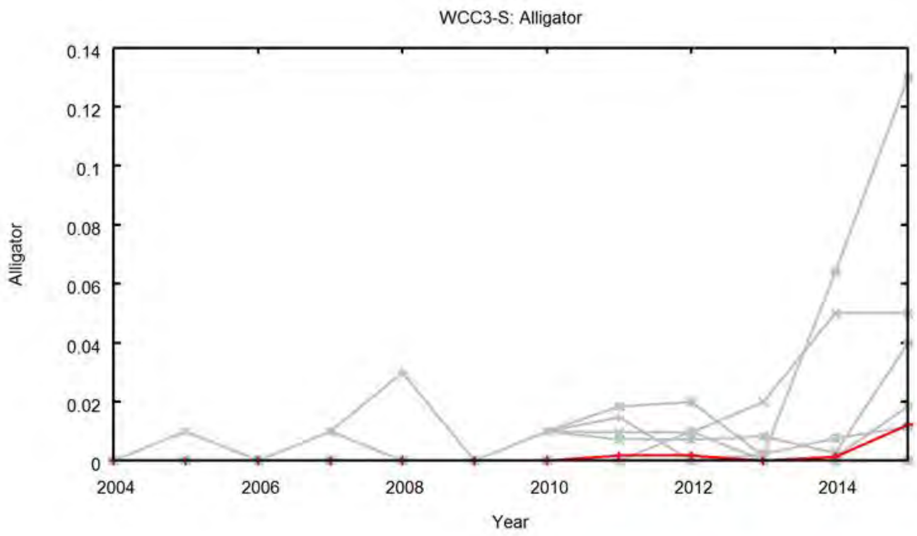
WAN2-S: Long_transv
Long_transv
Year
0.03
0.025
0.02
0.015
0.01
0.005
0
2004
2006
2008
2010
2012
2014

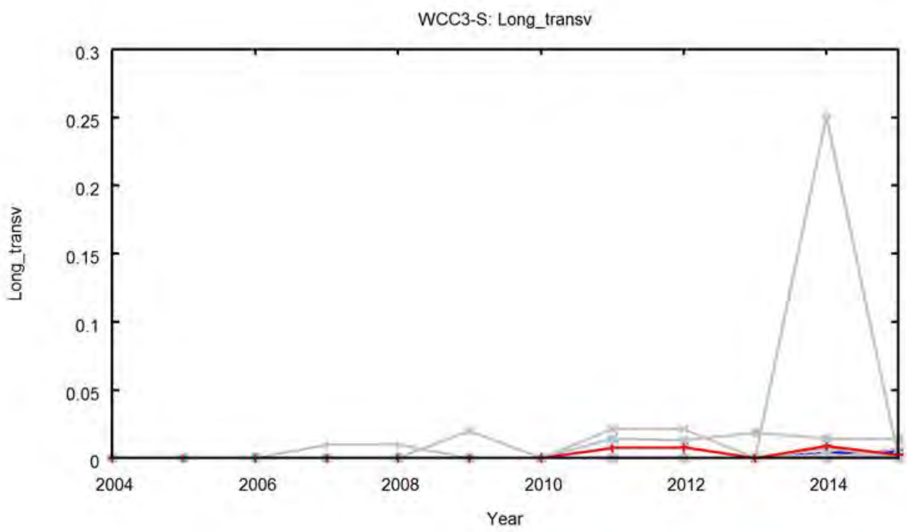

WAN3-S: LANE_IRI
LANE_IRI
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
2007
2008
2009
2010
2011
2012
2013
2014
Year

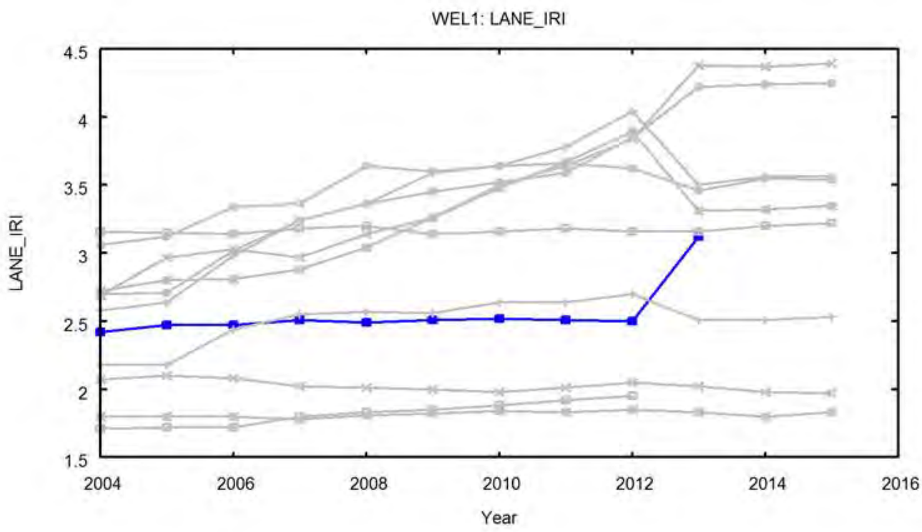

WAN3-S: Alligator
Alligator
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2007
2008
2009
2010
2011
2012
2013
2014
Year


WAN3-S: Long_transv
Long_transv
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2007
2008
2009
2010
2011
2012
2013
2014
Year

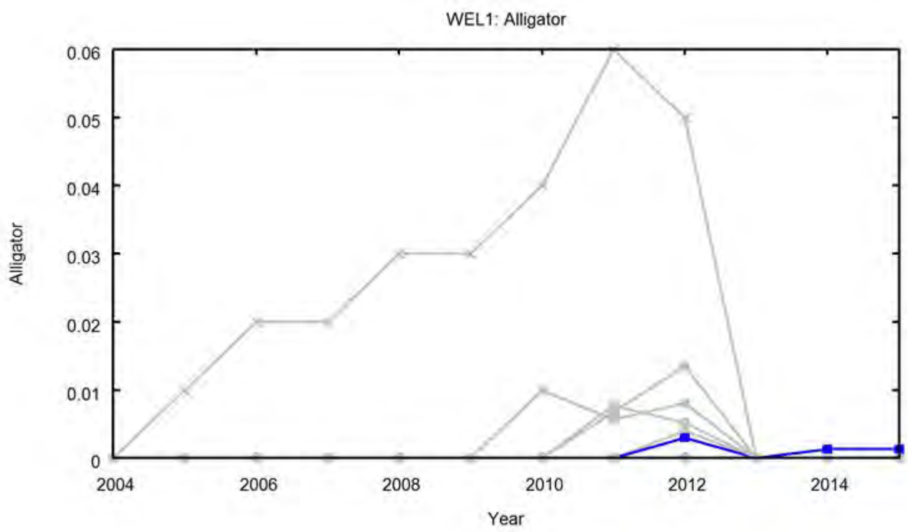

WCC3-S: LANE_IRI
LANE_IRI
Year
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014


WCC3-S: Alligator
Alligator
Year
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014

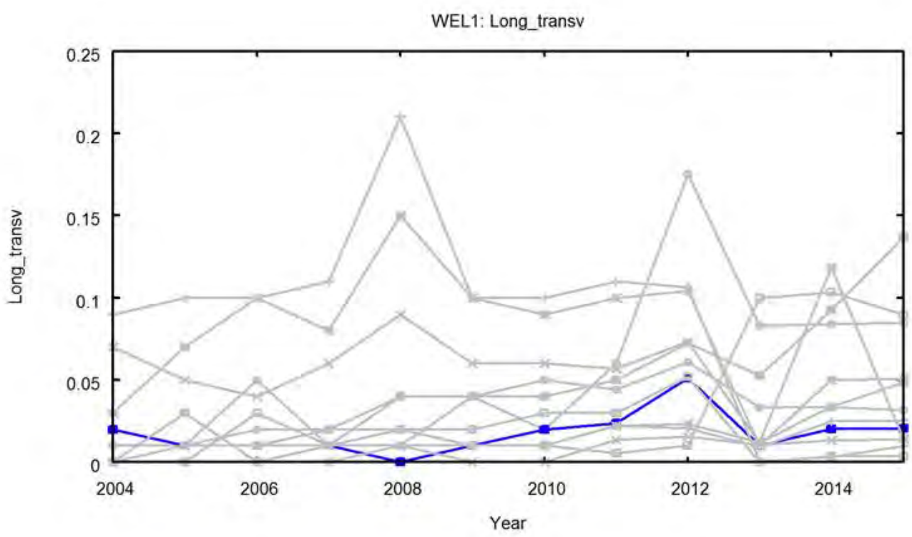

WCC3-S: Long_transv
Long_transv
Year
0.3
0.25
0.2
0.15
0.1
0.05
0
2004
2006
2008
2010
2012
2014



WEL1: LANE_IRI
LANE_IRI
Year
4.5
4
3.5
3
2.5
2
1.5
2004
2006
2008
2010
2012
2014
2016



WEL1: Alligator
Alligator
Year
0.06
0.05
0.04
0.03
0.02
0.01
0
2004
2006
2008
2010
2012
2014



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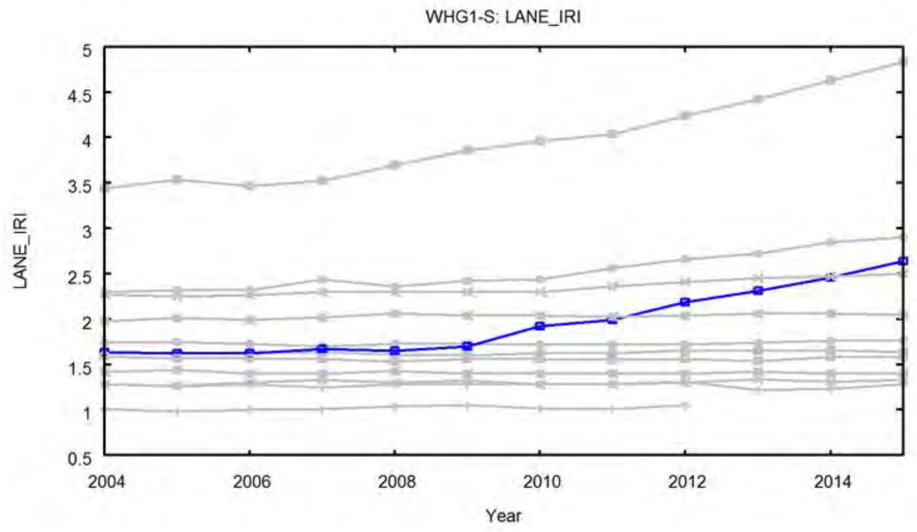
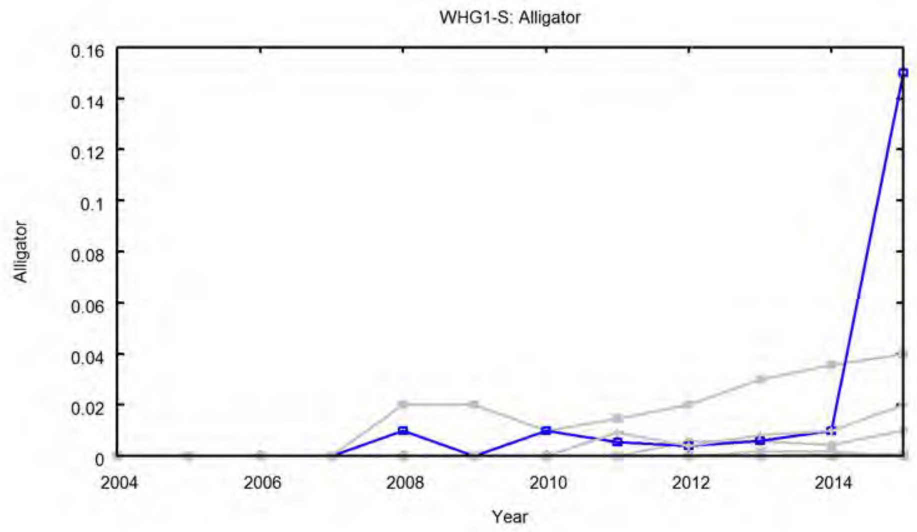
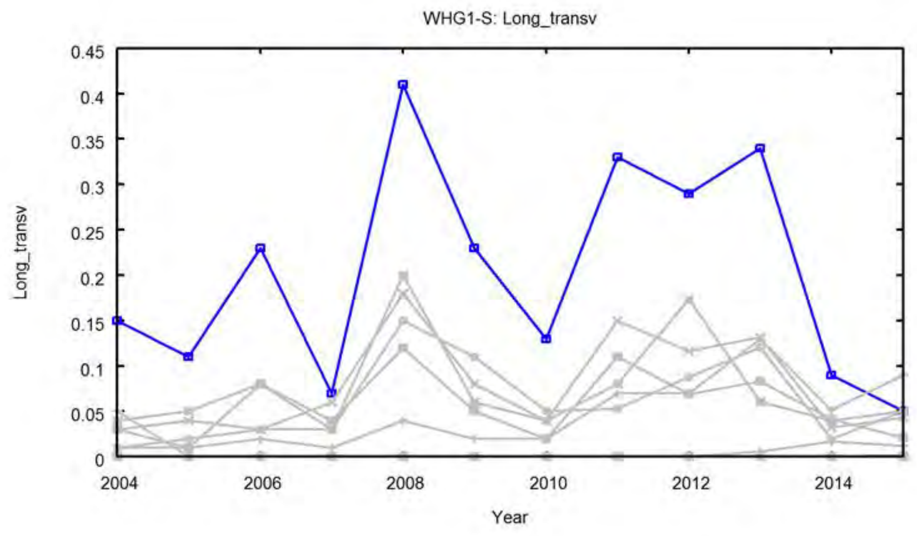
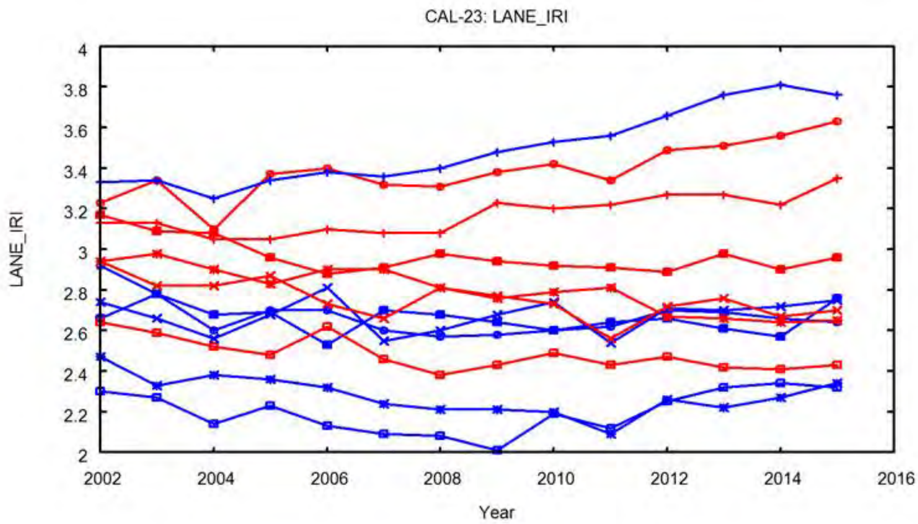






Roughness – LTPP11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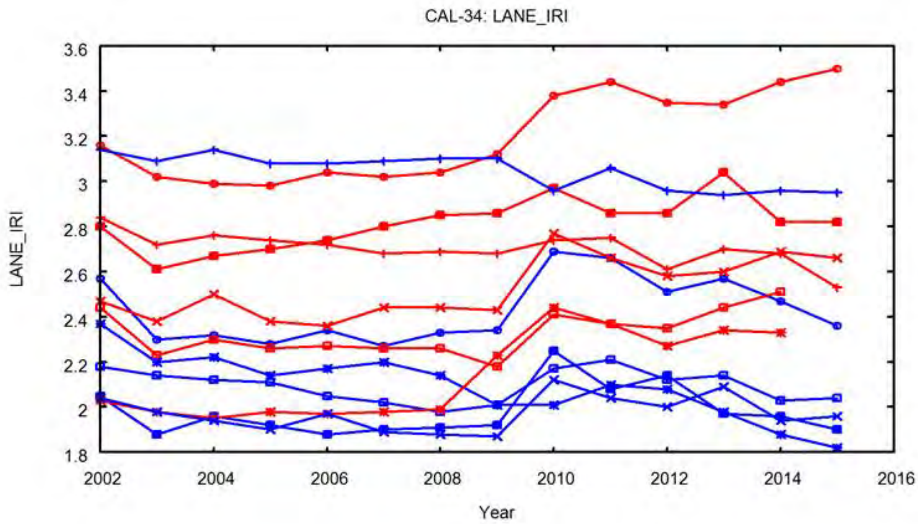
4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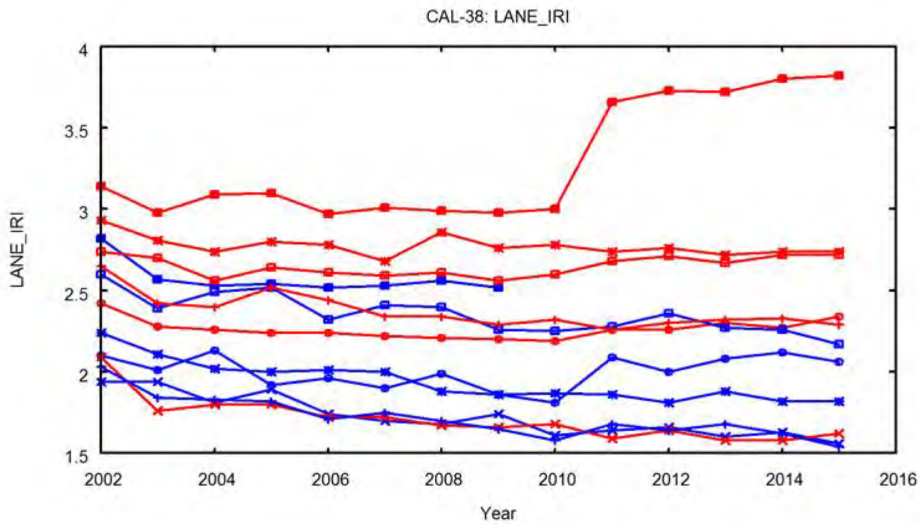
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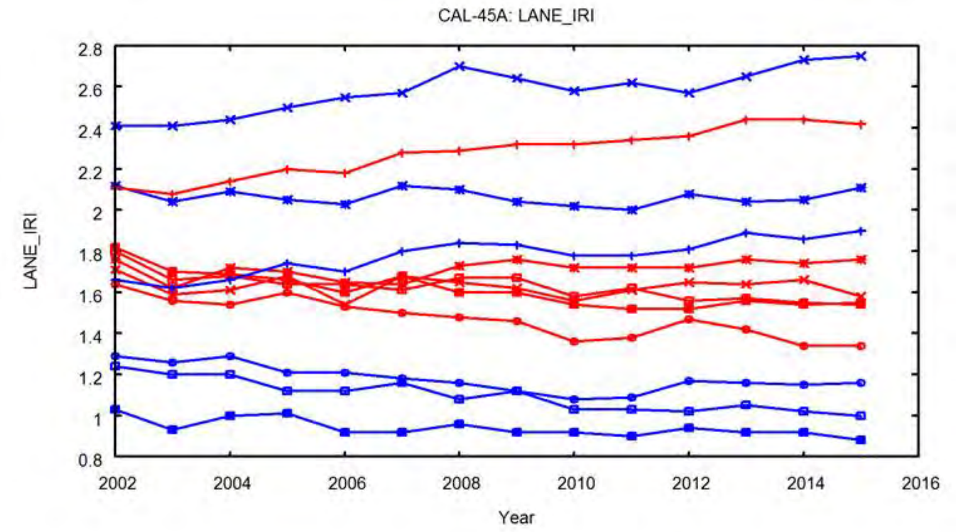
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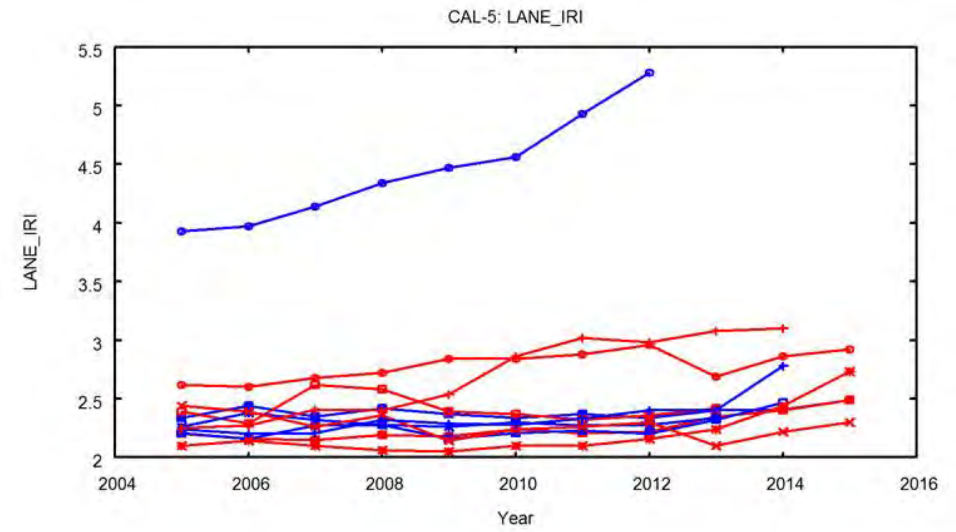
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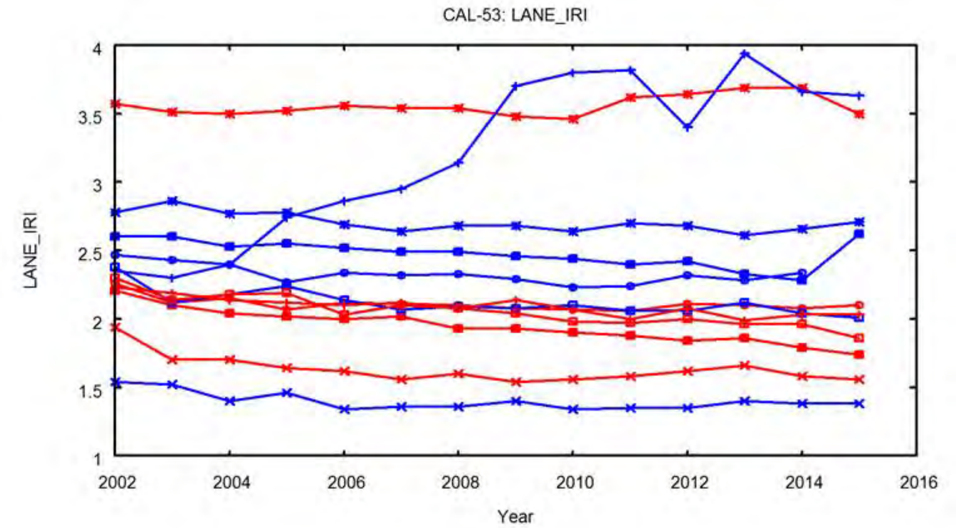
CAL-53: LANE_IRI
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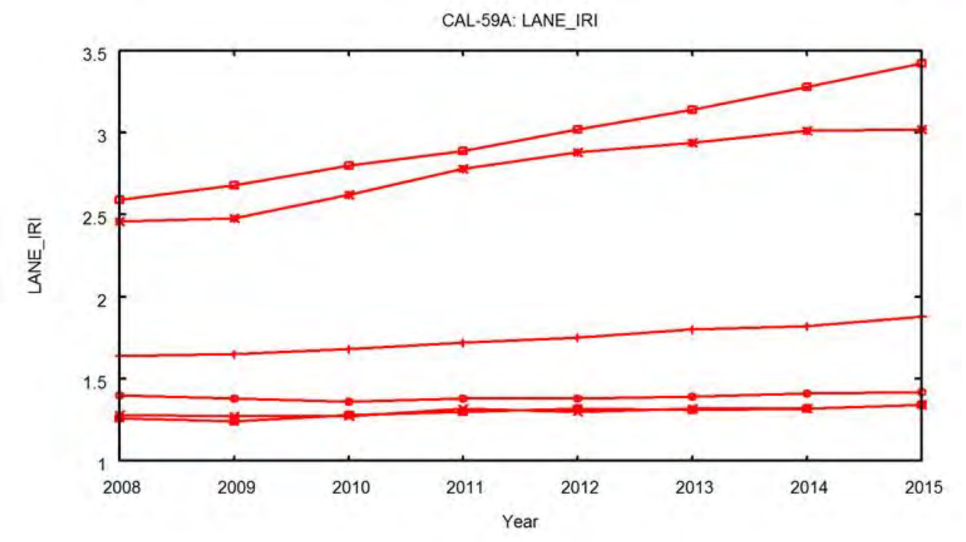
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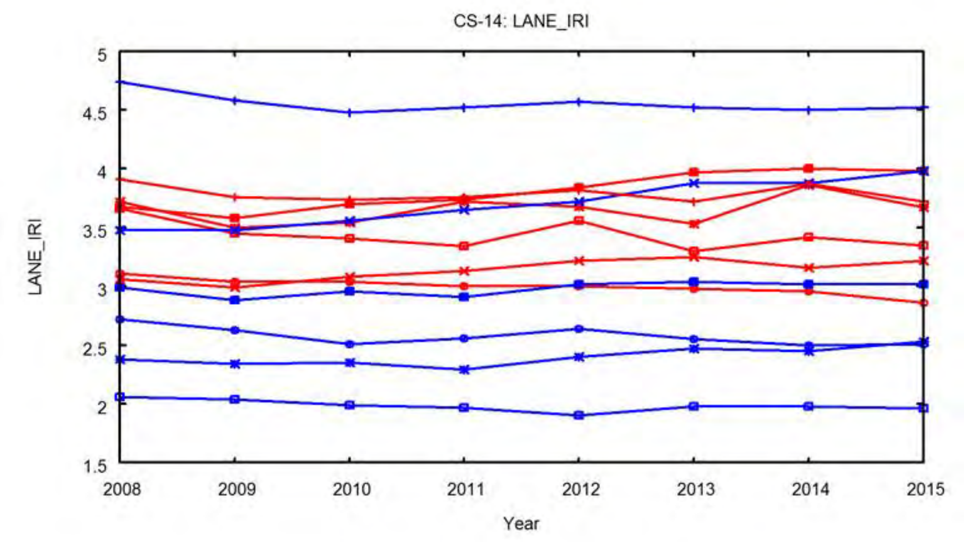
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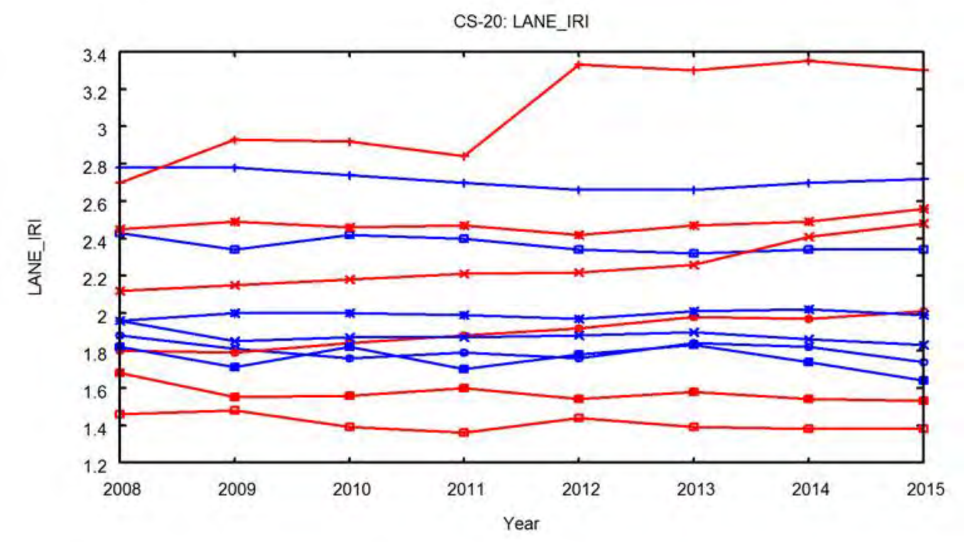
CS-20: LANE_IRI
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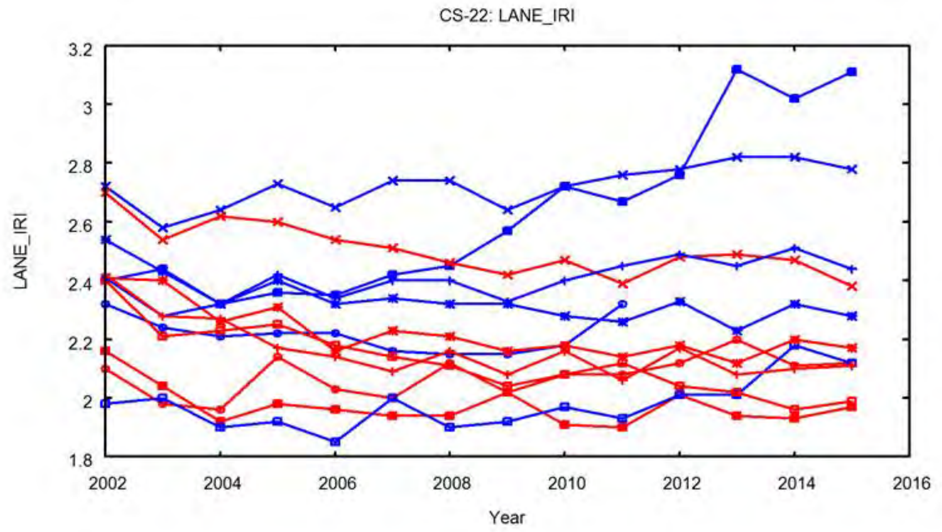
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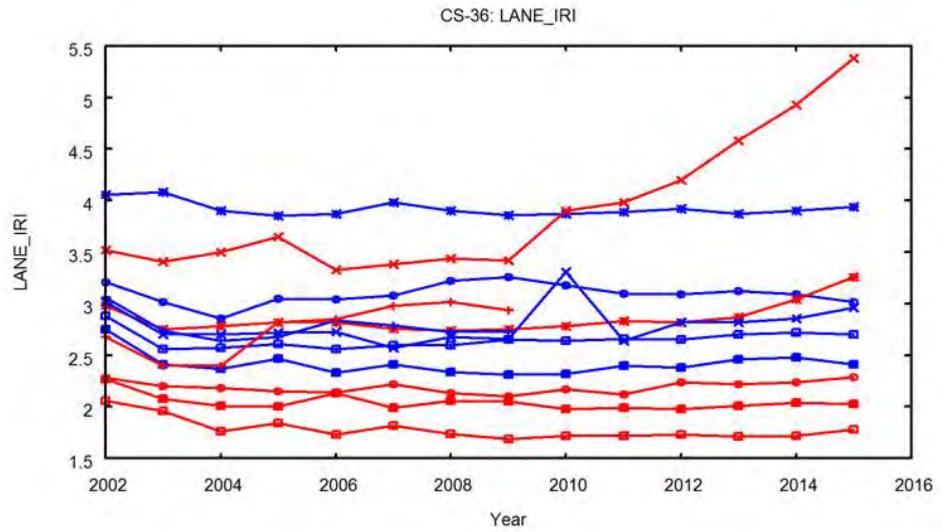
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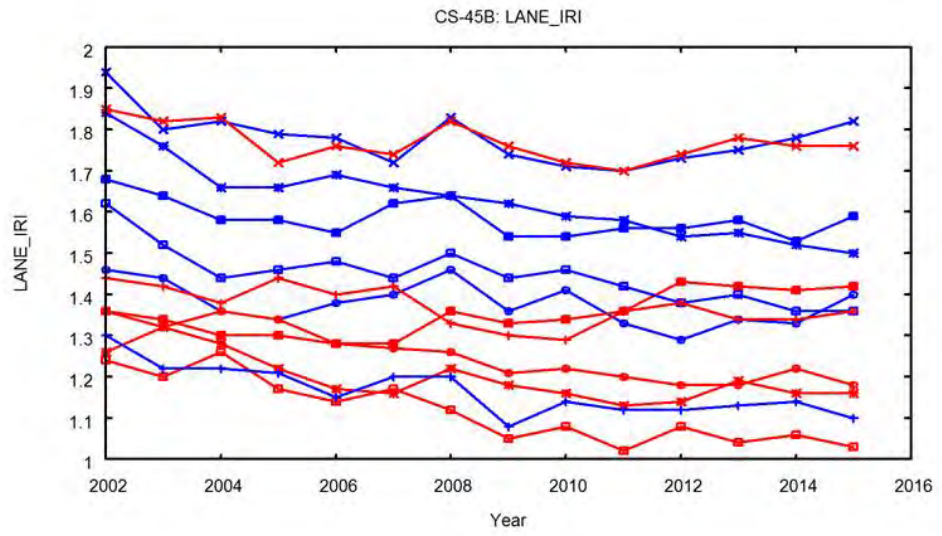
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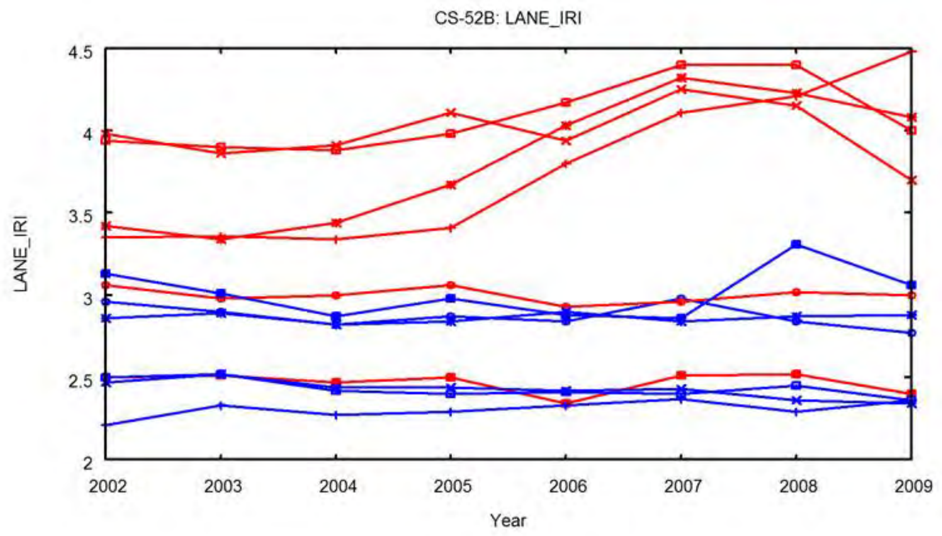
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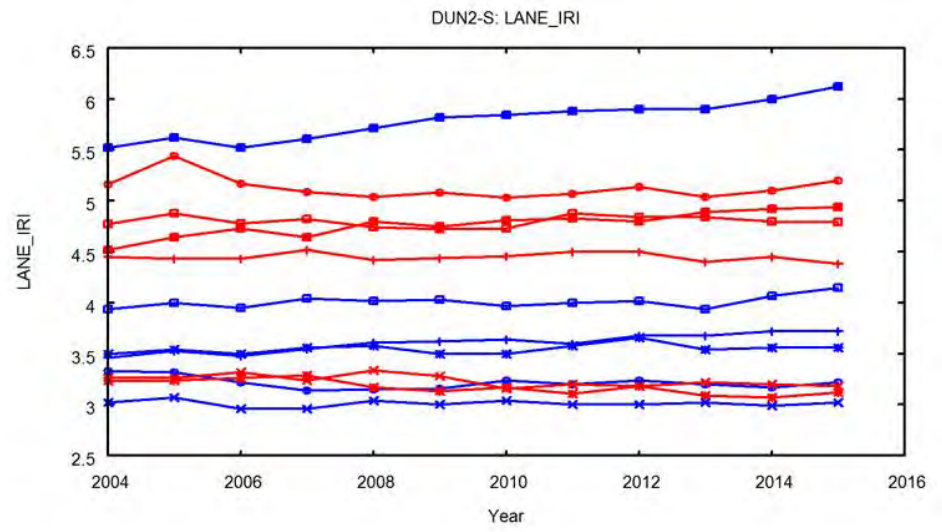
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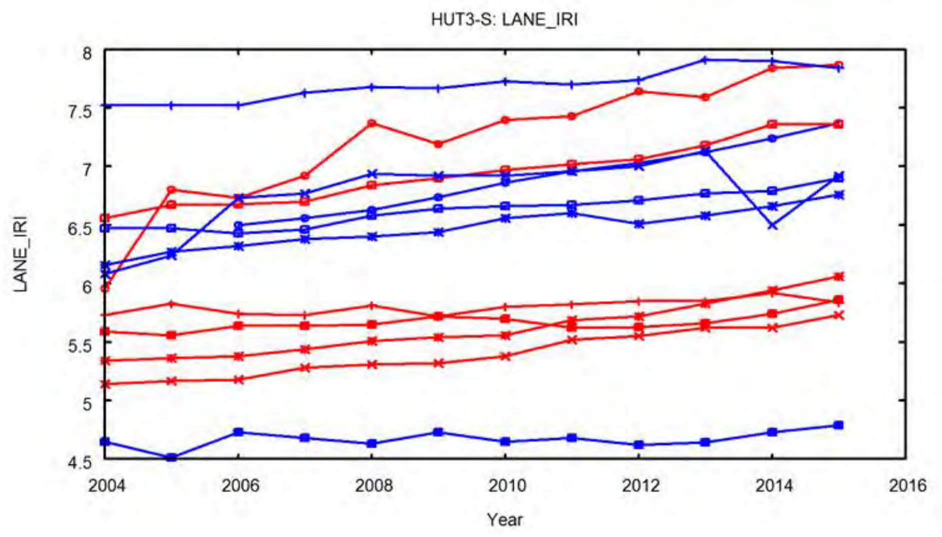
HUT3-S: LANE_IRI
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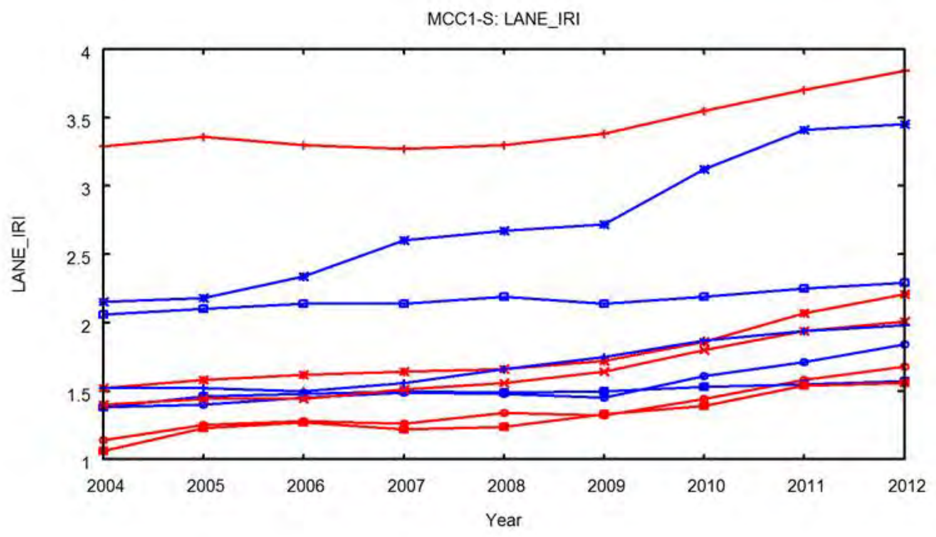
MCC1-S: LANE_IRI
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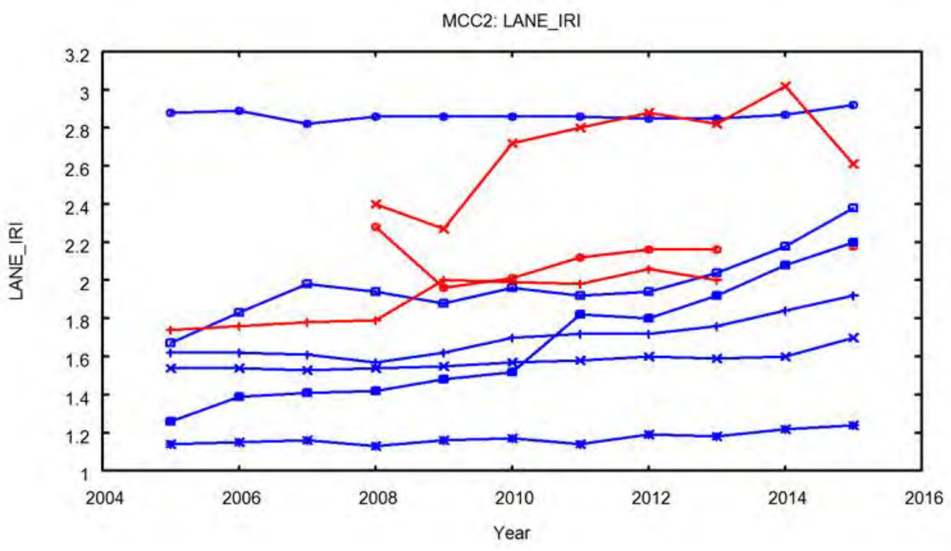
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2014
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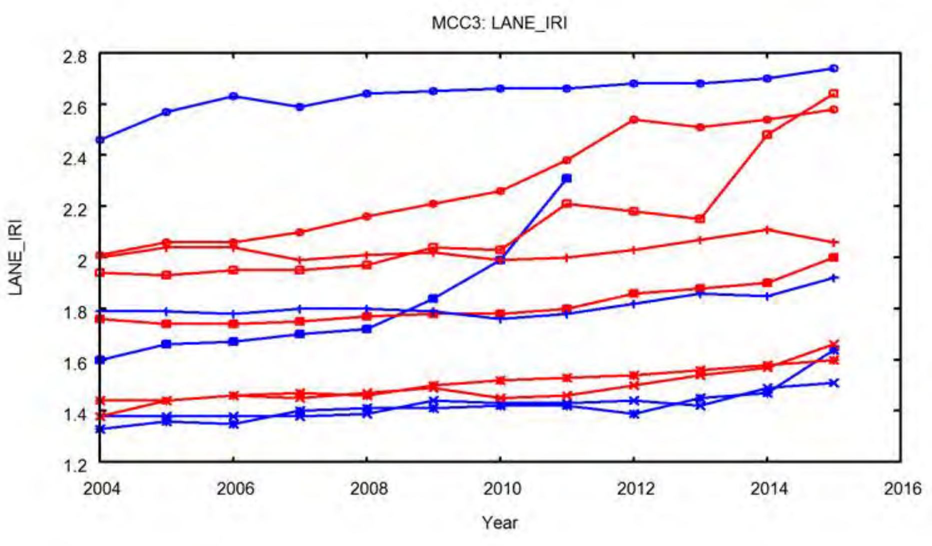
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2014
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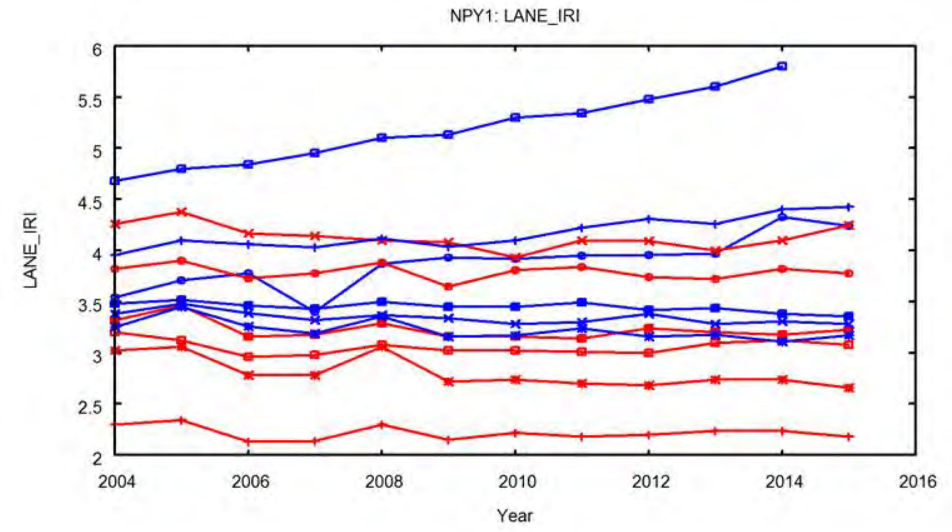
NPY1: LANE_IRI
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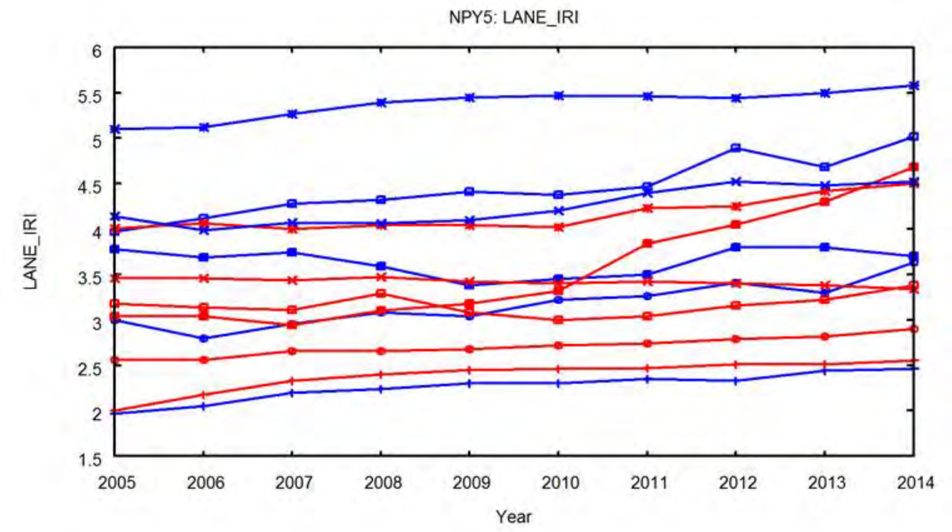
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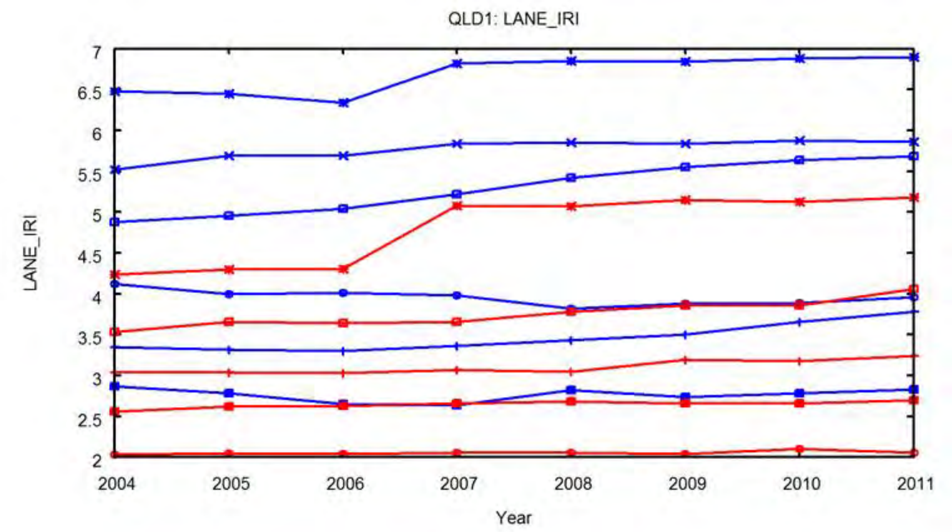
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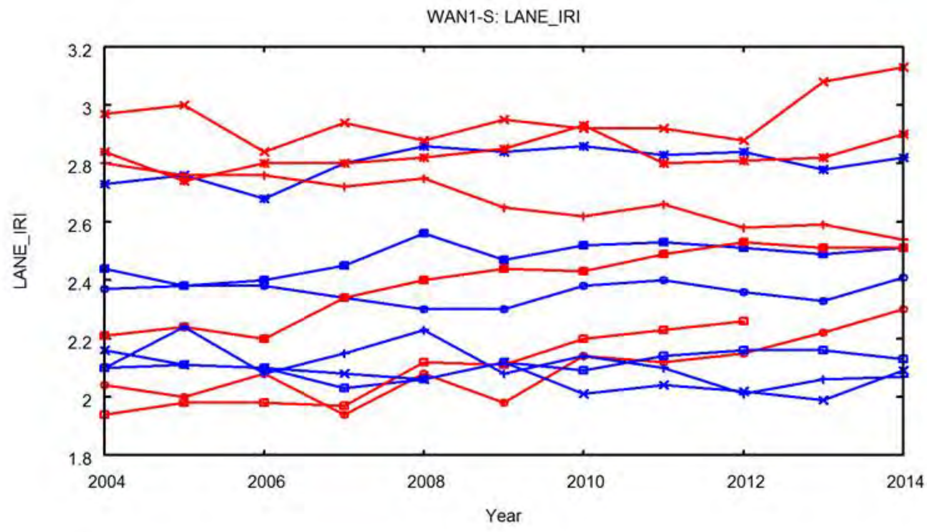
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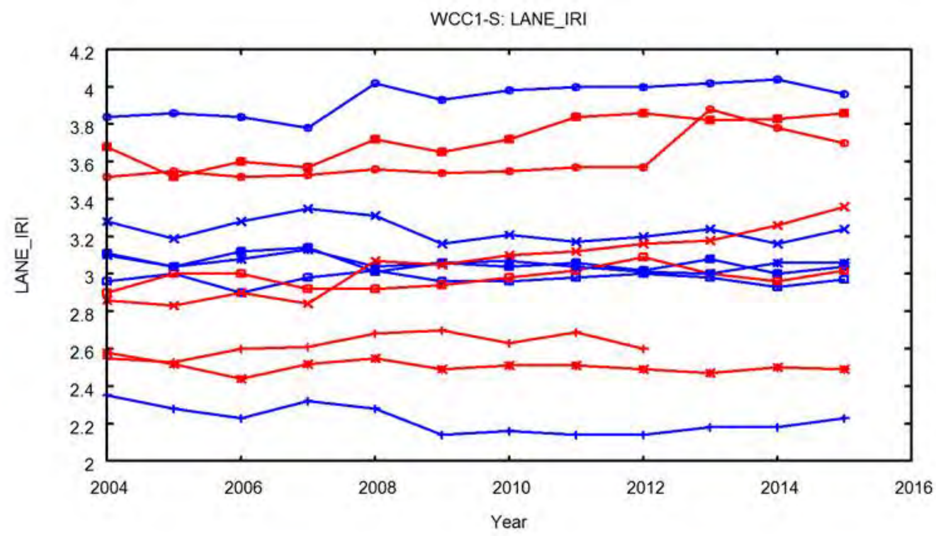
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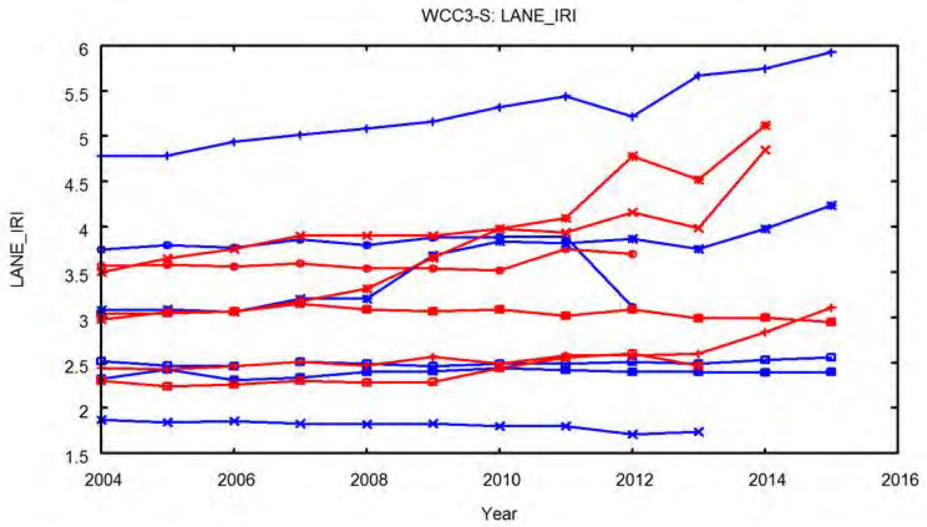
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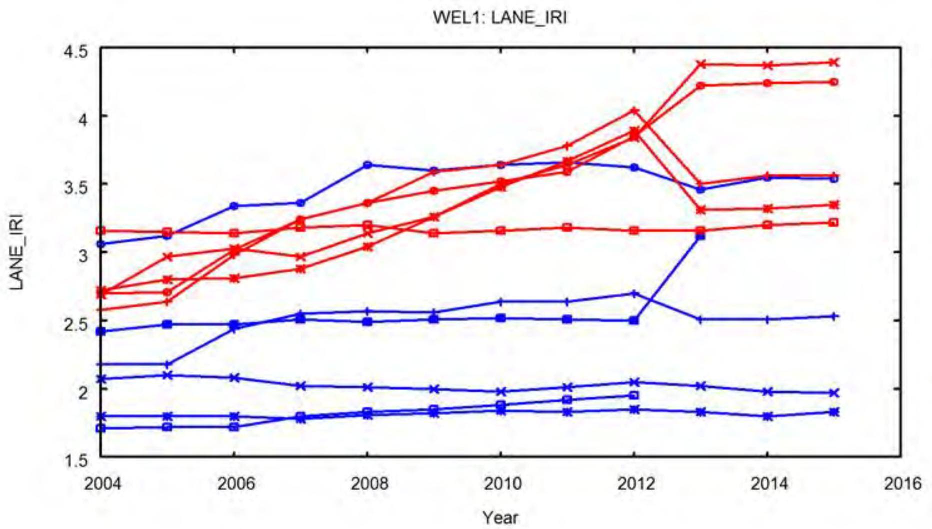
Year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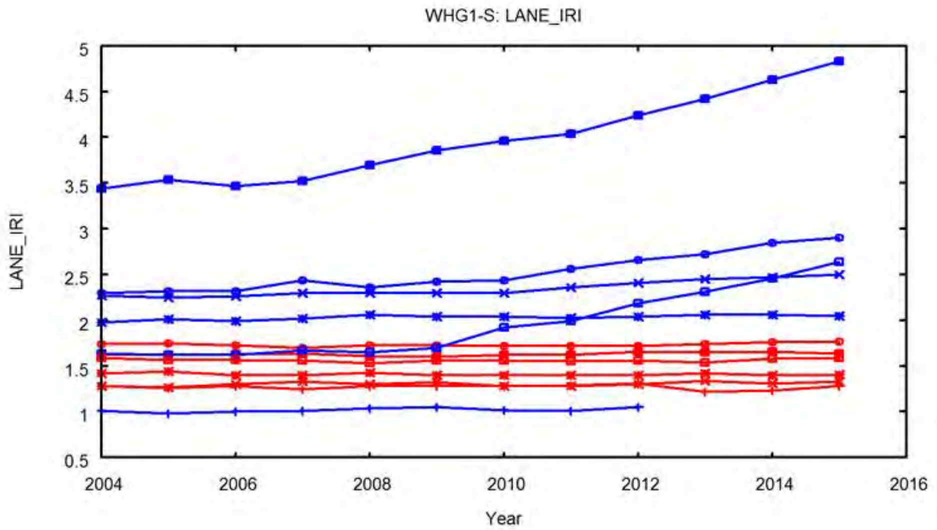
WHG1-S: LANE_IRI
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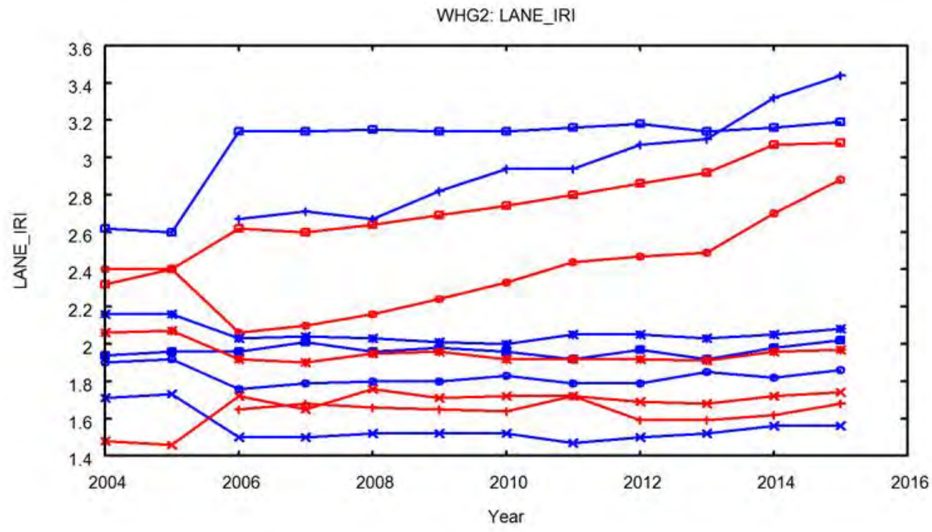
WHG2: LANE_IRI
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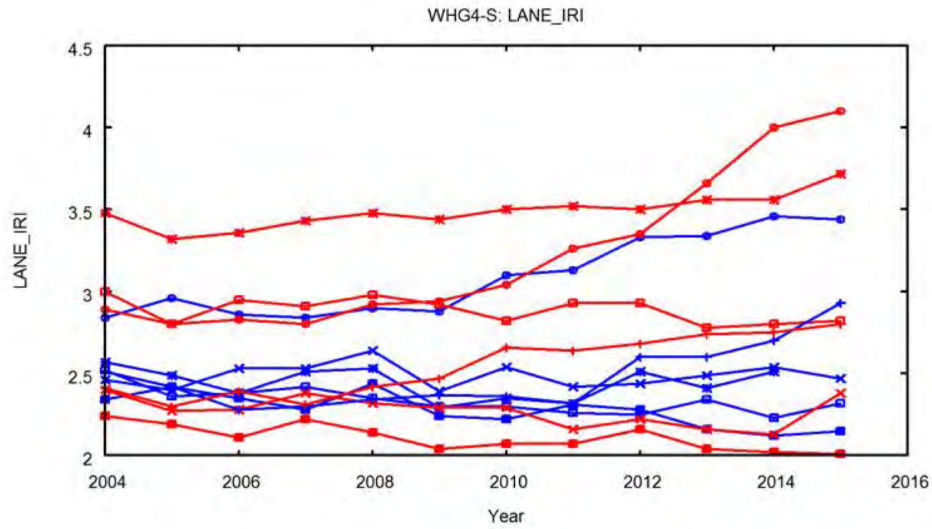
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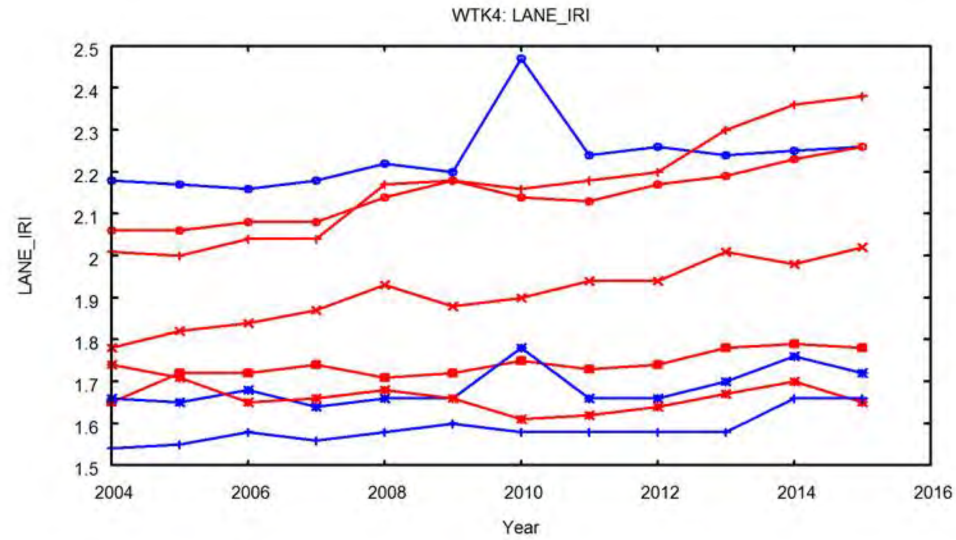
WTK4: LANE_IRI
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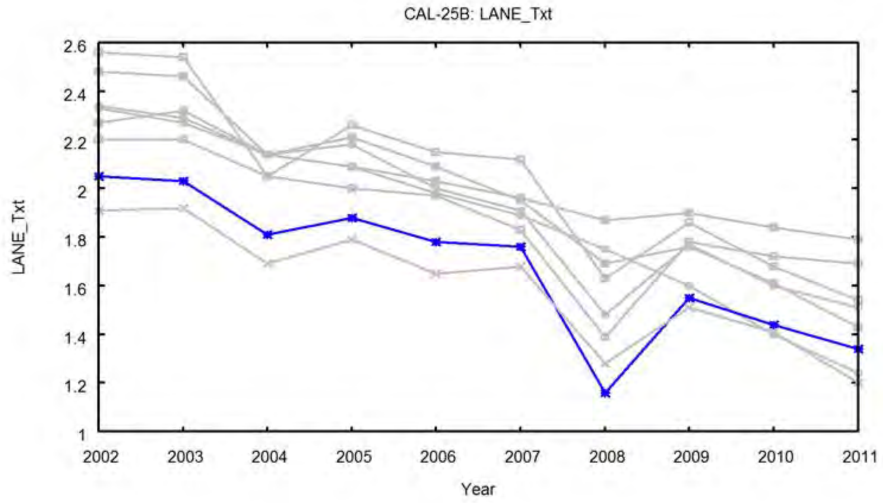
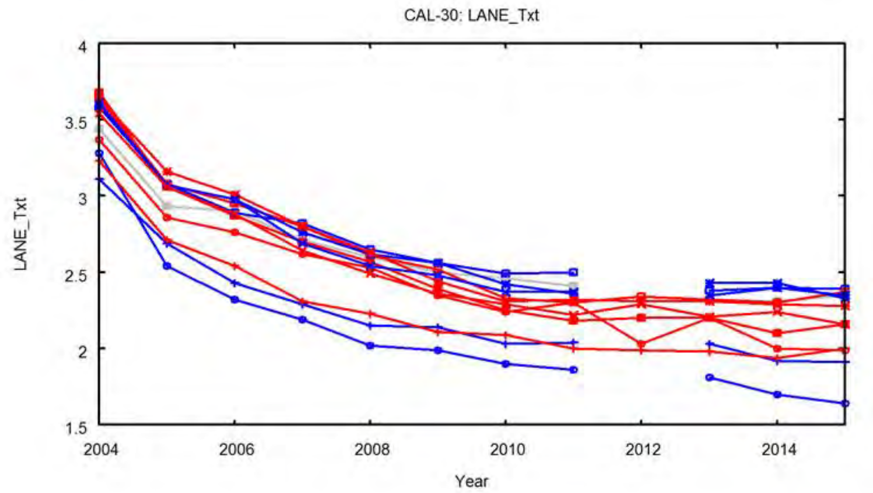
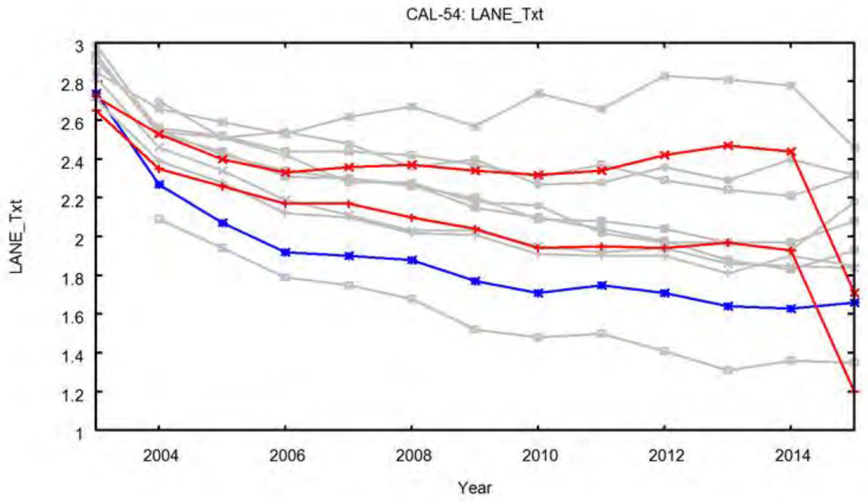
B3.3 Texture

Texture – LTPP14

Not updated yet






CAL-54: LANE_Txt
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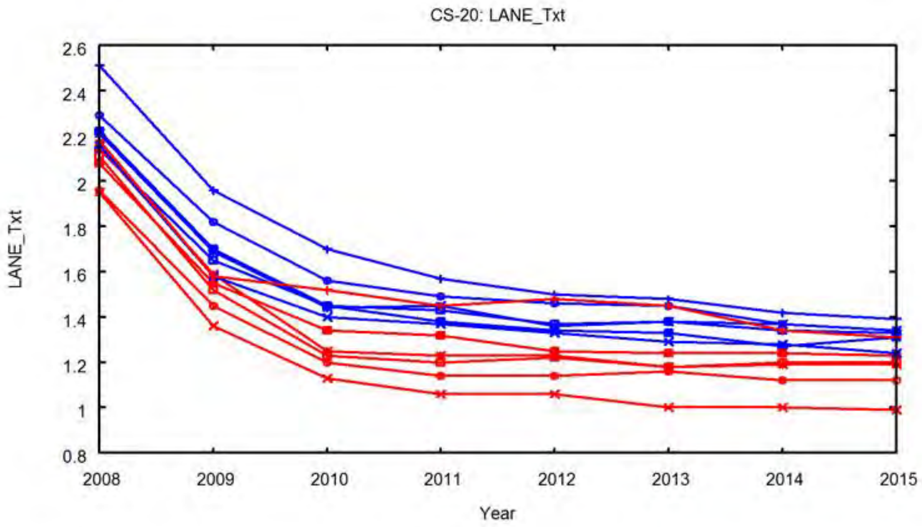
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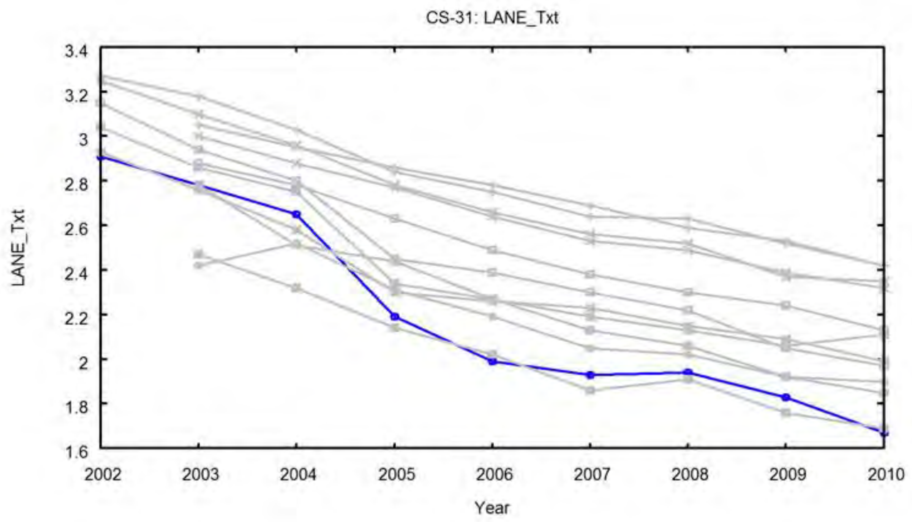
CS-31: LANE_Txt
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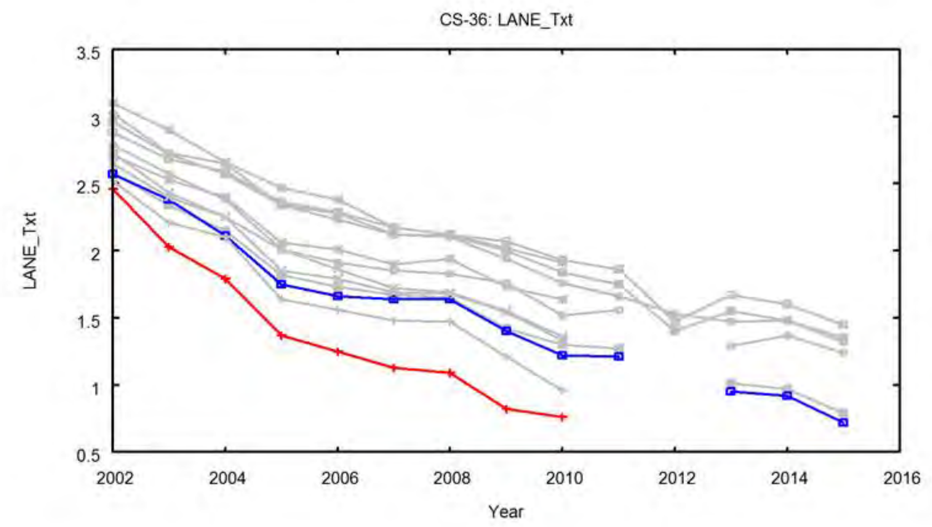
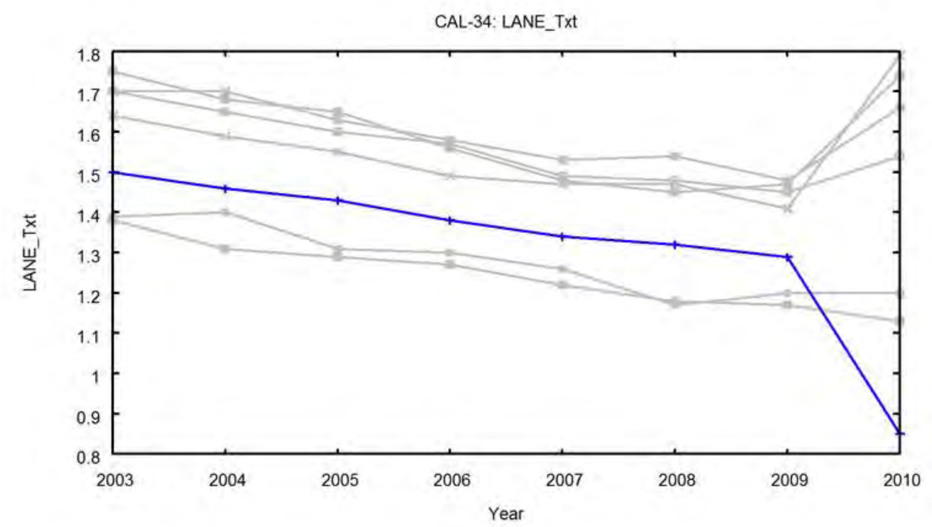
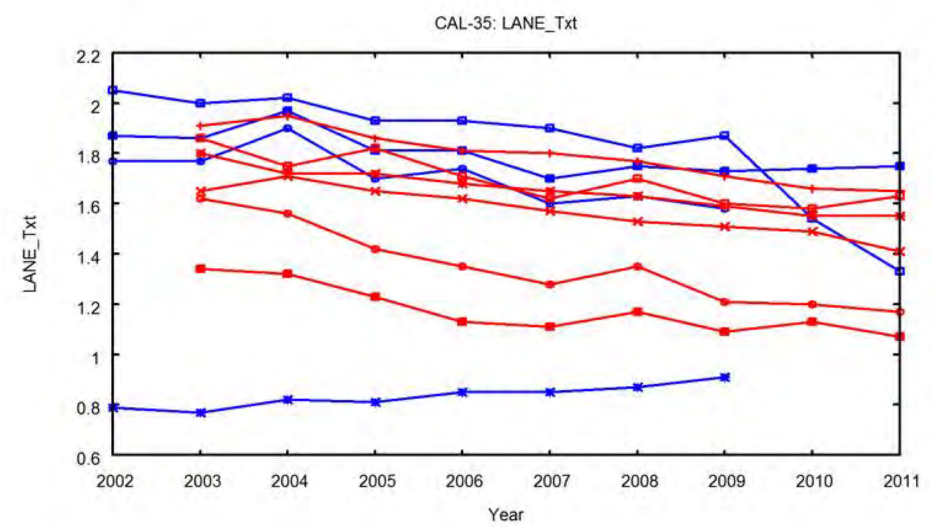


Texture – LTPP12



Texture LTPP11 (cutoff changed to 7)



Appendix C: Glossary

AADT	average annual daily traffic
AAPA	Australian Asphalt Pavement Association
AASHTO	American Association of State Highway and Transportation Officials
AC	asphaltic concrete
ACT	Australian Capital Territory
ADT	average daily traffic
ALF	accelerated loading facility
AWPT	area-wide pavement treatment
CAL	an LTPP calibration/unsterilised site
CCC	Christchurch City Council
CS	an LTPP ‘sterilised’ site
dTIMS	Deighton’s total infrastructure management system (software)
ERP	established route position (a physically fixed point)
ESA	equivalent standard axle
FWD	falling weight deflectometer
FHWA	Federal Highway Administration (US)
G3	grade 3 sealing chip, as specified in Transit New Zealand (2004)
GPS	general pavement studies
HCV	heavy commercial vehicle
HDM	highway development and management (software)
IRI	international roughness index
LTPP	long-term pavement performance
LTPPM	long-term pavement performance maintenance
M4	Transit New Zealand (2006), Specification for basecourse aggregate, TNZ M/4: 2006, Wellington,
MPD	mean profile depth (mm)
OGPA	open graded porous asphalt
PCC	Portland cement concrete
RAMM	Road assessment and maintenance management (database)
RP	route position
RS	reference station

SAS	Statistical Analysis System, a software suite developed at North Carolina State University for advanced analytics, multivariate analyses, business intelligence, data management, and predictive analytics. SAS was developed from 1966 until 1976.
SD	standard deviation
SH	state highway
SHRP	Strategic Highway Research Program (US)
SIP	Stochastic Information Packet
SMA	stone mastic asphalt
SN	structural number
SNP	structural number, as adjusted for the reduced contribution of each pavement layer with depth.
SPS	specific pavement studies
TLA	territorial local authority
TRB	Transportation Research Board (US)