

# Optimum Interventions for Thin Surfacing Maintenance

Final Report  
Highways Agency

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# EXECUTIVE SUMMARY

Thin surface course systems (TSCS), or thin surfacings as they are more commonly described, are proprietary systems in which a hot bitumen bound mixture is machine-laid with a controlled screed paver onto a bond coat to form, after compaction and cooling, a textured surface course less than 50mm in thickness. These materials have been in use on the UK motorway and trunk road network since the mid-1990s. During this time a wealth of information and experience has been acquired about their performance.

Typical service lives of between 7 and 15 years can be expected depending upon the thickness, void content, traffic loading and the underlying pavement structure<sup>[1]</sup>. Experience has shown that as the materials reach the end of their service lives they exhibit deterioration characteristics that can progress to eventual failure over timescales ranging from 6 months to 5 years. This variability results in uncertainty when deciding upon when resurfacing should be undertaken.

This Task was intended to identify the optimum timing or condition stage at which a thin surfacing should be considered for inclusion within the Highways Agency's value management process. This would enable the maximum value to be achieved from the existing asset whilst maintaining safety and reducing the need for expensive unplanned interventions (and the associated network disruption). The objectives were:

- *"To identify the shape and deterioration slope of the end of life phase of TSCS".*
- *"To review the visual and machine based condition data of TSCS approaching the end of their serviceable life".*
- *"To identify the optimum condition of a TSCS when it should be included in a programme of work for scheduled replacement".*

To define the extent of the issue analyses were undertaken to quantify and categorise the existing TSCS materials on the Highways Agency network. Key findings were as follows:

- The total length of TSCS found on the permanent lanes and hardshoulders of the network amounts to 16,855km.
- 39% of the total length of TSCS on the HA network is less than 5 years old.
- Construction records reveal "spikes" in resurfacing activity 6, 9 and 12 years ago. If these materials all deliver similar service lives then peaks in future workload (and investment) may be expected.
- 34% of all TSCS on the HA network was laid in "winter" (November to February inclusive). The majority of this "winter" laid material appeared in the last 5 years.

Thirty, geographically spread, maintenance schemes were selected for detailed analysis. Reviews of the value management (VM) submissions and condition data stored within the Highways Agency's Pavement Management System were undertaken. Key findings were as follows:

- The main driver behind most schemes was the appearance of fretting.
- The visual condition data submitted as part of the VM process was variable in format, quality and completeness.
- Defect records over the last 5 to 6 years indicated significantly different trends for schemes in different maintenance areas. Changes in Service Providers and the Highways Agency's recent introduction of a new form of contract complicated any attempt to analyse historic records on a consistent basis.
- None of the schemes were promoted on the basis of machine condition data. An attempt was made to analyse historic texture data to investigate whether it could be used to illustrate (or quantify) fretting effects as the TSCS materials approached the end of their serviceable lives. The finding was that the acknowledged loss of individual aggregates from the surface of a deteriorated TSCS was generally reflected in an increase in texture. However, neither the rate of increase nor the ultimate texture depth immediately prior to failure could be reliably distinguished.

The conclusion was that none of the existing data sets that are prepared as part of the current VM process could be used to identify the optimum time or material condition at which a TSCS site should be treated (or first introduced into a planned programme of works).

# 1. Introduction

## 1.1. Background

Thin surface course systems (TSCS), or thin surfacings as they are more commonly described, are proprietary systems in which a hot bitumen bound mixture is machine-laid with a controlled screed paver onto a bond coat to form, after compaction and cooling, a textured surface course less than 50mm in thickness. Further background is provided in IAN 157<sup>[1]</sup> – which revised Chapter 6 of HD 37/99<sup>[2]</sup> in December 2011.

Thin surfacings were originally developed in mainland Europe over 20 years ago. The technology was adapted and first transferred to the UK strategic road network in the 1990s. The subsequent success and popularity of these materials is reflected by the fact that it is the only “Permitted Pavement Surfacing Materials for New and Maintenance Construction” which can be used without restriction in England (see HD 36/06<sup>[3]</sup>). It is now estimated that approximately 60% of the Highways Agency (HA) network comprises thin surfacing covered pavements.

The in-service performance of thin surfacings has been subject to review during the last eighteen years and a thorough understanding of their benefits, limitations and behaviours is now emerging. A seminal study on the long term durability of these products was produced by Nicholls *et al*<sup>[4]</sup>. An average service life of 9.9 years was reported for these materials and an analysis of the failure modes was presented. It was concluded that the serviceable life of a thin surfacing is most influenced by the surfacing type, aggregate size and binder content.

IAN 157<sup>[1]</sup> summarised that thin surfacings approaching, or at the end of their serviceable life, generally exhibit three stages of deterioration:

- **Stage 1** - Loss of isolated particles of aggregate.
- **Stage 2** - Substantial loss of aggregate in discrete locations, not necessarily in the wheel track, and surface disintegration at longitudinal and transverse joints.
- **Stage 3** - Loss of integrity of the surface, with fragmentation of the mat.

The time period for deterioration progression from Stage 1 to Stage 3 was reported to vary between 6 months and 5 years.

With such a wide and variable timescale between the onset of visible deterioration and eventual failure of the material there is understandable uncertainty in deciding upon when resurfacing should be undertaken. This, coupled with the fact that the eventual failure can be rapid (necessitating expensive and disruptive temporary repairs until a maintenance scheme can be funded and programmed), poses a threat to the achievement of the HA's Network Delivery and Development Directorate (NDD) required outcomes in relation to the identification, prioritisation and design of schemes<sup>[5]</sup>, namely:

- *“to maximise value for money”*
- *“to prolong the life of the asset by intervention at the most appropriate time”*

Although there is a considerable volume of visual and machine survey data available for the HA network, no recognised parameters or thresholds have been established to indicate to Service Providers when a site should be scheduled for replacement within a works programme. This Task was intended to address this current knowledge gap.

## 1.2. Task

The objectives of this research Task, as defined in the Specification, were:

- “To identify the shape and deterioration slope of the end of life phase of TSCS”.
- “To review the visual and machine based condition data of TSCS approaching the end of their serviceable life”.
- “To identify the optimum condition of a TSCS when it should be included in a programme of work for scheduled replacement”.

These objectives were to be achieved through the delivery of the following sub-tasks.

**Table 1-1 Sub-Tasks defined in the Specification**

Sub-Task	Description
1	“To define the extent of the issue for the Highways Agency by interrogating the Highways Agency Pavement Management System (HAPMS) to determine the length and age of TSCS on the network”.
2	“To review visual condition survey data from a selection of schemes put forward to the value management process in recent years for TSCS replacement”.
3	“To review how long the TSCS lasted after inclusion as a Value Management (VM) scheme and to indicate the rate and number of un-planned interventions or emergency treatments required to maintain the deteriorating TSCS in a safe condition prior to its replacement”.
4	“To identify the critical visual or machine condition factors which lead to the conclusion that the TSCS is due for replacement based upon the schemes reviewed in Sub-Task 2 and the experience of the consultant as an area agent”.
5	“To identify the optimum time and condition for a TSCS to be included in the VM process as a scheme for planned maintenance works”.

## 1.3. Report structure

With regard to the Specification, as summarised in Table 1.1, this report has been structured as follows:

- Section 2 provides network level analyses of construction records for TSCS. It fulfils Sub-Task 1.
- Section 3 analyses data from 30 sample schemes that were promoted through the Agency’s VM process. It fulfils Sub-Tasks 2 to 4.
- Section 4 provides the conclusions from this study. It addresses Sub-Task 5.

## 2. Network level analysis

### 2.1. Introduction

The main objective of this study was to investigate how TSCS behaves as it nears the end of its serviceable life and to identify suitable indicators that would enable maintenance works to be programmed in a timely manner. Before embarking upon this research it was, however, relevant to quantify the extent of TSCS on the Agency's network and to summarise the attributes that are recorded for these materials. This would enable any findings or recommendations to be considered in context.

As shown in Table 1.1, Sub-Task 1 of the Specification required Atkins to:

*“define the extent of the issue for the Highways Agency by interrogating HAPMS to determine the length and age of TSCS on the network”*

Whilst the Specification only required an analysis of the length and age of TSCS on the network, the scope was further extended during meetings with the Project Sponsor (on 24/07/12 and 29/10/12) to include the following attributes:

- Length
- Age
- Geography
- HA Area
- TSCS type (fibre/polymer/generic)
- Season laid
- Cross sectional position (XSP)
- Layer thickness

This Section describes how these requirements were fulfilled.

### 2.2. Data extraction and checking

The surface layer records for the entire HA network were downloaded from HAPMS at the end of August 2012. These encompassed all surface material types (not just TSCS). An initial check was undertaken to verify the completeness of the extracted data. This was achieved by comparing the construction records with section length summary reports from across the network. The findings were as follows:

- The aggregated lane lengths from the construction records totalled 28,652km
- The aggregated lane lengths from the section length summary reports totalled 29,144km

The interpretation from the above was that the construction records - which were to form the basis for all subsequent analyses - accounted for 98.3% of the total lane length across the network. This was deemed to be sufficiently accurate.

### 2.3. Analysis by HA Area and by XSP

The following Tables are presented in Appendix A:

- **Table A.1** - shows the total length of TSCS in each HA Area. Data is presented for all XSPs and both wheelpaths. This analysis is provided for completeness only – in order to fulfil the requirements of the Task Specification. No significant conclusions can be drawn from it.
- **Table A.2** – is a refinement of Table A.1 after filtering it to show only the data for the left wheelpath. The total length of TSCS on the HA network is seen to be 17,106km. This Table again shows all XSPs. It is noted that this includes “additional lanes” – the widths of which vary considerably.
- **Table A.3** – is a refinement of Table A.2 after removing the “additional lanes”. The remaining length of TSCS on the HA network is seen to be 16,855km. This statistic is more meaningful as standard widths can be applied to the permanent lanes and hardshoulders to enable areas to be estimated. All further analyses presented in this report are based on the XSPs shown in this Table (i.e. permanent lanes and hardshoulders only). Excluding the “additional lanes” in this way means that the analyses still represent 98.5% (i.e.  $16,855 \div 17,106$ ) of the total length of TSCS on the network.

## 2.4. Analysis by TSCS type

The following results are presented in Appendix B:

- **Table B.1** – shows the total length of TSCS in each HA Area categorised by material type (i.e. generic/polymer/fibre).
- **Figure B.1** – is a network level summary. 73% of all TSCS on the HA network is classified as being “generic”. The remaining 27% is recorded as being modified with either fibres or polymers.
- **Figure B.2** – is a graphical representation of Table B.1. Areas 4, 12 and 14 record their TSCS materials as being almost exclusively “generic”. Area 1 has the largest proportion of fibre modified material. Area 13 has the largest proportion of polymer modified material.

These analyses demonstrate differences in the way in which Service Providers record data in HAPMS. This is considered to be largely due to the indistinct options for recording TSCS material types. Most “generic” products contain fibres. Polymer modified products may additionally contain fibres. The outcome is that the “material type” records in HAPMS are of limited value. (It is understood that additional fields have subsequently been included within HAPMS since Atkins’ data extraction and analysis was undertaken).

## 2.5. Analysis by age

The following results are presented in Appendix C:

- **Table C.1** – shows the age profile for TSCS materials for individual HA Areas on a length basis. It can be seen that 39% of the total length of TSCS on the HA network is less than 5 years old. 77% of the total length of TSCS on the HA network is less than 10 years old.
- **Table C.2** – is a refinement of Table C.1. It presents the proportion (%) of the total length of TSCS in each HA Area falling within each of the age bands.

It shows that 33% of the TSCS on Area 9 is recorded in HAPMS as being more than 20 years old. This is considered to be unlikely. As instructed by the Project Sponsor, Atkins raised a query with the HAPMS team in October 2012. The following response was provided:

*“The ‘Construction - Surface Layer only’ data source does indeed show a significant proportion of thin surfacing layers with old (in some cases very old) ‘Date Laid’ dates.*

*There is nothing that the HAPMS team can do about this, the data are entered and maintained by the Service Providers and we have no audit role. If the Agency feel that they want the data changed then the appropriate area team would need to contact the Area 9 Service Provider and instruct them to make appropriate corrections”*

- **Tables C.3 and C.4** – show age profiles for the full HA network presented on an XSP basis. This shows that 43% of the total length of TSCS present in CL1 is less than 5 years old.
- **Figures C.1 to C.12** – are graphical representations of Table C.1. They show the age profiles for TSCS materials in each HA Area. The distributions are seen to be variable and reflective of historic fluctuations in maintenance activities.
- **Figure C.13** – combines the age profiles for all HA Areas and demonstrates that “spikes” in future workloads are likely as TSCS materials reach the end of their life.
- **Figure C.14** – is the age profile for all TSCS materials across the network. When produced at this level, “spikes” at ages 6, 9 and 12 years become evident.

## 2.6. Analysis by laying season

Analysis were undertaken to identify the time of year when TSCS materials were laid. The ‘winter’ season was defined, by the Project Sponsor, as being November to February inclusive. The following results are presented in Appendix D:

- **Table D.1** – shows the total length of TSCS in each HA Area that was laid in the ‘winter’ and ‘non-winter’ seasons.
- **Figure D.1** – is a graphical representation of Table D.1. It shows that 34% of all TSCS on the HA network was laid during the ‘winter’ season.
- **Figure D.2** – provides a further analysis on an individual HA Area basis. Area 7 has the smallest proportion of ‘winter’ laid material. Area 9 has the largest proportion. Upon closer inspection of the

HAPMS data, Area 9 appear to have used a default date of 1<sup>st</sup> January for their very old TSCS materials (see also Section 2.5).

## 2.7. Analysis by layer thickness

When reviewing the construction records for all TSCS materials it was noted that some HA Areas record precise thicknesses (to the nearest mm) whereas others used a nominal layer depth. For this reason, the analyses presented in Appendix E consider layer thicknesses in 5mm bands. The following Tables are presented:

- **Table E.1** – shows the length of TSCS in each HA Area falling into each of the thickness bands. 74% of the total length of TSCS on the HA network has a thickness within the range of 26 to 40mm.

At the time of undertaking the data extraction, HAPMS did not record the aggregate sizes used in TSCS. Anecdotally, the majority of TSCS materials use(d) a 14mm sized aggregate. The fact that the HAPMS records suggest that some TSCS materials have been laid as thin as 15mm would give rise to concerns about long term durability.

Areas 2 and 10 are seen to have a large amount of TSCS within the thickness range of 0 to 15mm. Further analysis revealed that the majority of these lengths are more than 12 years old. Some early TSCS products used a 6mm sized aggregate. It is therefore possible that these significant lengths (totalling 185,000m) of thin materials used a 6mm sized aggregate. This cannot be confirmed without further enquiries outside of HAPMS. This was beyond the scope of this Task.

- **Table E.2** – is a refinement of Table E.1. It presents the proportion (%) of the total length of TSCS in each HA Area falling within each of the thickness bands. The most prevalent thickness band in each HA Area is highlighted. Areas 4, 6, 8 and 14 show an apparent preference for a 30mm nominal thick TSCS. Areas 2 and 10 show an apparent preference for a 50mm nominal thickness.
- **Tables E.3 and E.4** – provide an analysis on an XSP basis for the entire HA network. The only noteworthy trend is a slight reduction in TSCS thickness in the hardshoulders.

## 2.8. Cross analysis by age and by thickness

Appendix F provides a cross-analysis of the data previously presented in Sections 2.5 and 2.7. The left hand columns of Table F.1 show the length of TSCS in each HA Area categorised according to thickness and age. The right hand columns instead show the length of TSCS as a proportion of the total length of TSCS in each HA Area categorised according to thickness and age. To improve clarity, values greater than 0.5% have been shaded in blue. Vertically adjacent values of 0.5% or greater have been merged. The following observations arose:

- 5.09% of the total length of TSCS on Area 1 was laid in the last 5 years at a thickness of 0 to 15mm. Further investigation revealed that a large quantity of resurfacing during the summer of 2008 and 2009 was recorded in HAPMS as having a thickness of 1mm. This is considered to be a data error.
- Area 14, who have known durability issues with TSCS, have consistently laid the majority of their surfacing at a thickness of 30mm or less for the last 20 years.
- In most Areas there is a general trend of materials being laid thicker in recent years.

## 2.9. Cross analysis by age and by laying season

Appendix G provides a cross-analysis of the data previously presented in Sections 2.5 and 2.6. Figures G.1 to G.12 show the total length of “winter” laid TSCS material according to its age. The most striking feature of these analyses is that the majority of “winter” laid material that is present on the network appeared in the last 5 years. The influence of laying conditions on the long term durability of TSCS has received significant focus in recent years. IAN 157<sup>[1]</sup> states:

*“In common with other bituminous materials it has been observed that TSCS laid during the winter period are likely to be less durable than those laid in the summer. **Thin surfacings should normally be laid between the months of April to October inclusive** as during these periods the laying criteria given in the SHW are most likely to be met or exceeded [sic].”*

## 2.10. Summary

Whereas the Specification only required an analysis of the length and age of TSCS on the HA network, the following key points arose from this review:

1. The total length of TSCS located in the permanent lanes and hardshoulders of the HA network amounts to 16,855km (Table A.3 in Appendix A). HAPMS records that the total “Lane Length” of the HA network is 29,144km. The “Lane Length” considers only the permanent lanes. If the hardshoulder quantities shown in Table A.3 in Appendix A are removed then the total length of TSCS located in the permanent lanes is 13,077km. The proportion of TSCS in the permanent lanes is therefore approximated to be 45% (i.e. 13,077 / 29,144).
2. 39% of the total length of TSCS on the HA network is less than 5 years old.
3. 43% of the total length of TSCS in CL1 is less than 5 years old.
4. Construction records reveal “spikes” in resurfacing activity 6, 9 and 12 years ago. If these materials all deliver similar service lives then peaks in future workload (and investment) may be expected.
5. 34% of all TSCS on the HA network was laid in “winter” (November to February inclusive). The majority of this “winter” laid material appeared in the last 5 years.
6. Thickness records for TSCS materials are variable within and between HA Areas. Thickness ranges from 30mm to 50mm are typical – although further extremes were also noted.
7. A trend of increasing thickness in recent years is evident in most HA areas.
8. The “generic”/“polymer”/“fibre” classification used within HAPMS was proved to be an unreliable method for distinguishing between TSCS material types.
9. HAPMS data quality issues complicated the analyses that were attempted under this Task.

TRL 674<sup>[4]</sup> concluded that aggregate size, thin surfacing system type and binder content were key parameters in predicting the failure of TSCS based upon visual condition. None of these parameters were recorded in HAPMS at the time of this analysis (although it understood that this issue has now been addressed).

## 3. Scheme level analysis

### 3.1. Introduction

With regard to Table 1.1, the Task specification required the following scheme level analyses:

- **Sub-Task 2** “review visual condition survey data from a selection of schemes put forward to the value management process in recent years for TSCS replacement”.
- **Sub-Task 3** “review how long the TSCS lasted after inclusion as a VM scheme and to indicate the rate and number of un-planned interventions or emergency treatments required to maintain the deteriorating TSCS in a safe condition prior to its replacement”.
- **Sub-Task 4** “identify the critical visual or machine condition factors which lead to the conclusion that the TSCS is due for replacement based upon the schemes reviewed in Sub-Task 2 and the experience of the consultant as an area agent”.

This Section (3) describes how these requirements were fulfilled:

- **Section 3.2** describes the methodology behind the selection process and the drivers behind each scheme (Sub-Task 4).
- **Section 3.3** reviews the visual condition data for each scheme (Sub-Task 2).
- **Section 3.4** analyses the defect histories for each scheme before and after VM (Sub-Task 3).
- **Section 3.5** reviews the machine condition data for each scheme (Sub-Task 4)

### 3.2. Scheme selection

With regard to selecting sample schemes for inclusion in this analysis, the Task specification stated:

*“It is envisaged that at least 30 schemes should be examined and these should have a reasonable geographic spread through out [sic] England”*

At the Task inception meeting in July 2012 three maintenance Areas were proposed for consideration. These were located in the north, west and east of England and were accepted by the Project Sponsor.

It should be noted that the focus of this research Task is to investigate thin surfacing material behaviour across the network rather than the operational procedures or performance of individual Service Providers. For this reason, it was agreed with the Service Providers that the reporting of their scheme data would be done on an anonymous basis.

#### 3.2.1. Selection criteria

The selected Service Providers were requested to provide a list of potential candidate schemes for consideration in this Task. The criteria were as follows:

- Only schemes that had been submitted to the VM process were of interest.
- The main driver for the scheme must have been thin surface course deterioration/disintegration.
- Schemes with underlying structural issues were to be discounted as this would complicate any attempt to analyse the deterioration of the surface course.
- The scheme must have achieved approval through the VM process and progressed to construction funding.

### 3.2.2. Candidate schemes

Each Service Provider submitted lists of Candidate Schemes for initial consideration, as follows:

- The East Area provided an extensive list of 32 Small Works maintenance schemes. A review identified that 16 of these schemes included additional condition factors other than surface course deterioration. These were eliminated from further consideration. The remaining list of 16 schemes was presented to the Agency at a Progress Meeting in October 2012 and accepted for further analysis.
- The West Area provided a comprehensive dataset for 14 Small Works maintenance schemes with each of the schemes outwardly matching the criteria described in Section 3.2.1. The list was presented to the Agency at a Progress Meeting in October 2012 and accepted for further analysis.
- The North Area preferred to deal directly with the Agency. A list of 10 Candidate schemes was submitted in December 2012. It was identified that 5 of these sites encompassed both directions of a dual carriageway. Atkins decided to analyse each direction separately. Therefore, in effect, 15 schemes were selected for further analysis.

### 3.2.3. Data gathering and screening

Having identified 45 Candidate Schemes which were potentially of interest for this Task it was necessary to gather the relevant condition data and VM scheme submissions in order to select the final 30 Sample Schemes that would be most suitable for detailed analysis.

Atkins' quality submission for this Task (dated June 2012) stated "*Atkins assumes that the HA Client will provide the VM scheme submissions from its central source (rather than Atkins having to contact individual Service Providers)*". In the event, Atkins was required to contact the individual Service Providers and request the relevant data.

In addition to the VM scheme submissions, the following information was requested from the Service Providers:

- RMMS pavement related defect data for the three years prior to the VM workshop
- RMMS pavement related defect data for the period between the VM workshop and scheme construction.
- Original construction material detail including the TSCS product name and nominal aggregate size.
- Scheme construction material including the TSCS product name and nominal aggregate size.

Atkins supplemented the above information by extracting the construction records and texture data for each scheme from HAPMS. This download operation was undertaken between November 2012 and January 2013 (to suit the receipt of incoming information from the Service Providers).

For each scheme, checks were undertaken on the data quality and completeness. This provided a final filter and enabled the 30 sample schemes with the most comprehensive data to be selected.

### 3.2.4. Final Sample Schemes

The final selected Sample Schemes are shown in Table H.1 in Appendix H. The following points are noted:

- A total of 30 sample schemes were selected.
- Five of the sample schemes were on dual carriageways and were sub-divided (by Atkins) so that separate analyses could be undertaken for each direction of travel.
- The sample schemes provided the geographical spread (between north, east and west) as required by the Task Specification.
- The schemes were provided with unique references to ensure anonymity. These references were applied consistently throughout the remainder of this Task.
- The scheme selection process was designed to ensure that only the schemes with the most comprehensive available data were selected. However, Table H.1 in Appendix H still shows that for 9 out of the 30 sample schemes there were omissions in the HAPMS data.

### 3.3. Visual condition data analysis

Visual condition data for each of the 30 sample sites described in Section 3.2.4 was requested from the Service Providers. The data that was received was variable:

- One Service Provider produced detailed, annotated strip plans showing visual condition survey data.
- One Service Provider reported that they do not produce strip plans for Small Works schemes but rely on photographs and/or video surveys at VM. Their video surveys were no longer available.
- One Service Provider produced multiple Excel files that were titled “Crack Map.....”. These were found to contain only photographs. Enquiries as to the intended content of these files elicited no response from the Service Provider.

The variability in the supplied data made it impossible to analyse the sample schemes on a consistent basis. Conclusions cannot be drawn about the severity or distribution of defects from unreferenced photographs.

Table I.1 in Appendix I shows Atkins limited review of the visual survey data that was provided. It indicates the presence (or otherwise) of the defect types listed in the HA’s Asset Data Management Manual <sup>[6]</sup> for each of the sample schemes. It can be seen that nearly all of the schemes exhibited cracking and fretting.

The lack of consistency in the visual condition surveys undertaken for VM may reflect a lack of significance that is attached to this subjective data. This would complicate any attempt to identify or introduce a new threshold or indicator for optimum intervention timing.

### 3.4. Defect analysis

Service Provider’s Routine Maintenance Management System (RMMS) data was interrogated to determine the maintenance history for each site from when they were first introduced into the VM process until the planned maintenance works were undertaken (or present day if the works have not been completed). This was intended to assist in determining whether Service Providers are identifying maintenance sites (and promoting them within the VM process) at the correct time.

The VM process is part of a “*continuous 4 year rolling programme*” <sup>[5]</sup>. Frequent unplanned interventions during this period may indicate that the site had deteriorated beyond the optimum condition level before it was introduced into the VM process. Conversely, a total absence of any maintenance during this period may suggest that the asset still retained a proportion of residual life and that it was replaced too soon.

Only Category 1 defects were considered. Category 2 defects were ignored as they were considered, in this context, to be an unreliable measure of condition because:

- they are normally regarded as “wear and tear” issues rather than end-of-life deterioration.
- they can remain within the RMMS for a prolonged period until programmed works are carried out – this would complicate any attempt to analyse their development on a year-by-year basis.
- their generation is normally influenced by cyclical survey programmes as opposed to rapid changes in condition.

Analyses are presented on an individual Area basis in Figures J.1 to J.3 in Appendix J. The defects occurring on each site were normalised by considering their quantity on a “per km” basis.

#### 3.4.1. West Area

Sites in the West Area (Figure J.1 in Appendix J) were noted to have a relatively low intensity of defects. A general trend was noted whereby a comparatively high number of defects were recorded during the early years of the VM process. However, repairing these initial defects appears to have stabilised the condition of the sites and a reduced number of defects were recorded in subsequent years.

60% of the sites exhibited no defects in the year immediately prior to VM. 70% of sites exhibited no defects in the year immediately after VM. This would suggest that the sites were not life-expired at their time of treatment.

5 out of the 10 schemes do not appear to have been constructed or the records in HAPMS have not been updated (see also Table H.1 in Appendix H). It is considered that the latter scenario is more likely – as 4 out

of the 5 schemes have no defects post-VM. Queries with the Service Provider on this issue elicited no response.

It should also be noted that the West Area had a change of Service Provider and a change of contract form during the analysis period. This lack of continuity complicates the assessment of any trends.

### 3.4.2. East Area

Sites in the East Area (Figure J.2 in Appendix J) show a markedly higher intensity of defects in comparison to the other two Areas. Generally speaking, the level of defects reduced in the year immediately prior to VM but increased dramatically in the subsequent year. On this basis it would appear that interventions are occurring a year too late (or the scheme was introduced into the VM process a year too late).

### 3.4.3. North Area

Sites in the North Area (Figure J.3 in Appendix J) generally show a very low level of defectiveness in the early VM years. On approximately half of the sites there were no Category 1 defects in the early years of the analysis period (i.e. 3 or 4 years before VM). This would suggest that un-planned interventions were not the main drivers that lead to the initial identification of a scheme in this Area.

### 3.4.4. Summary

Analysis of the defect histories for the 30 sample sites showed variable, inconclusive trends. Establishing defect thresholds to indicate the optimum condition at which a scheme should be introduced into the Agency's VM process is complicated by a number of factors:

- The analysis periods for the 30 sample schemes will have included recent harsh winters. The effects of these weather events on the defect profiles presented in Appendix J cannot be estimated.
- Considerable variability was noted between the three Areas selected for analysis. Geography, climate, traffic levels, local materials, contractual arrangements and operational approaches will all have an influence on the number of defects recorded. These cannot be discerned within the limitations of the Specification for this Task.
- The recent changeover to the new Asset Support Contract (ASC) has resulted in a risk based approach to defect identification and categorisation. Consequently Service Providers will adopt bespoke, individual approaches. This will prevent the centralised establishment of defect thresholds to indicate when a site is starting to fail.

## 3.5. Machine data analysis

Fretting was previously identified by the Service Providers as being the main driver behind the promotion of schemes (Table H.1 in Appendix H). Fretting was also identified as the most prevalent defect from the limited assessment of visual condition data (Table I.1 in Appendix I). Attempts were therefore made to analyse the machine collected data to determine whether fretting could be determined from texture measurements and whether the onset of failure conditions could be identified.

For all Sample Schemes, texture data was extracted from HAPMS from 2005 to the year when the schemes were constructed. Data was only analysed for a single cross sectional position – the selection of which was governed by the predominant treatment areas identified in the VM documentation. Tabulated 10m average data from successive surveys was presented side-by-side. The data was colour banded according to the thresholds shown in Table 3.1.

**Table 3-1 Texture depth thresholds used for presentation purposes**

Colour	Texture depth (mm)
Grey	< 1.1
Green	1.1 to 1.499
Yellow	1.5 to 1.999
Orange	2.0 to 2.499
Red	>= 2.5

The thresholds shown in Table 3.1 were informed by the following considerations:

- An initial analysis showed that on almost all of the sample sites texture depth increased over the last 4 or 5 years before a site was resurfaced. A banding system was therefore required to highlight graphically the increase in texture depth.  
[Note: TRL 674 <sup>[4]</sup> concluded that the texture depth of thin surfacing *reduces* in the early years after it is laid but noted that “Towards the end of its serviceable life, the texture depth on a site can increase but as a symptom of particle loss rather than as the cause of failure”].
- The lower threshold of < 1.1mm was selected to correspond to with the “Sound” condition category as provided in HD 29/08 <sup>[7]</sup>.
- The subsequent thresholds were determined on an iterative basis. The presented values were found to best illustrate the progressive increase in texture depth as the thin surfacing materials deteriorated. The selected values enabled extremes of performance to be distinguished.

The output from the above exercise extended to over 60 pages. A sample extract is presented in Figure 3.1.

**Figure 3-1 Sample extract from texture depth analyses**

Survey date		Texture depth (mm)								
		Jun-05	Sep-05	Feb-08	Oct-08	Apr-10	Oct-09	Aug-10	Apr-11	Oct-12
Start Ch. (m)	End Ch. (m)									
300	310	1.25	0.98	0.91	1.16	1.03	1.14	1.18	1.19	1.13
310	320	1.13	1.11	1.01	1.25	1.10	1.20	1.33	1.25	1.18
320	330	1.22	1.26	1.18	1.33	1.16	1.46	1.55	1.58	1.21
330	340	1.25	1.17	1.07	1.35	1.47	1.22	1.57	1.27	1.27
340	350	1.03	1.14	1.10	1.31	1.24	1.50	1.36	1.44	1.28
350	360	1.10	1.10	2.08	1.26	1.38	2.16	2.08	1.59	1.16
360	370	1.61	1.53	2.12	1.92	2.17	2.17	2.01	1.68	1.45
370	380	1.69	1.85	2.47	2.03	1.93	2.43	2.44	1.69	1.52
380	390	2.21	2.45	1.93	2.48	2.51	1.95	2.28	1.91	1.38
390	400	1.85	1.97	1.66	2.03	1.81	1.92	1.93	1.73	1.52
400	410	1.55	1.61	1.80	1.95	1.90	2.16	1.90	1.80	1.54
410	420	1.76	1.76	2.23	1.97	1.85	2.20	2.27	1.69	1.47
420	430	2.03	1.84	1.97	2.02	2.31	2.32	2.39	1.65	1.57
430	440	1.87	2.20	1.68	2.39	2.12	1.97	2.22	1.85	1.49
440	450	1.75	1.99	1.70	2.24	1.84	1.92	1.80	1.62	1.65
450	460	1.60	1.65	1.90	2.25	1.77	2.17	2.15	1.67	1.57
460	470	1.87	1.89	2.62	2.60	2.11	2.68	2.52	1.53	1.44
470	480	2.18	2.11	2.19	2.50	2.59	2.31	2.37	1.54	1.46
480	490	2.06	2.17	2.21	2.40	2.25	2.06	2.32	1.49	1.41
490	500	2.01	1.92	1.80	2.76	2.16	2.20	2.22	1.47	1.30
500	510	1.93	1.80	1.87	2.43	2.07	2.16	2.15	1.47	1.42
510	520	1.83	1.88	2.71	2.67	2.08	2.86	2.34	1.29	1.41
520	530	2.20	1.96	2.29	2.58	2.75	2.22	2.94	1.42	1.40
530	540	2.21	2.39	1.85	2.45	2.61	2.18	2.34	1.48	1.33
540	550	2.07	1.84	1.95	2.37	2.04	2.13	2.10	1.38	1.30
550	560	2.06	1.66	1.82	2.43	2.22	2.39	2.26	1.48	1.33
560	570	2.13	1.60	2.19	2.26	2.50	2.31	2.72	1.44	1.41
570	580	2.14	2.18	1.64	2.47	1.93	1.91	2.01	1.63	1.33
580	590	1.77	1.80	1.62	2.12	1.82	1.83	1.88	1.49	1.42
590	600	1.80	1.36	1.69	2.02	2.02	1.88	1.92	1.47	1.39
600	610	2.02	1.34	1.78	2.28	2.03	2.10	1.93	1.57	1.43
610	620	2.00	1.60	2.19	2.22	2.47	2.37	2.39	1.43	1.43
620	630	2.24	2.09	1.76	2.44	2.07	2.03	2.28	1.46	1.61
630	640	1.79	1.83	1.84	2.10	2.31	2.06	2.32	1.51	1.61
640	650	2.02	1.92	1.77	2.30	2.03	2.13	2.19	1.51	1.45
650	660	2.03	2.13	2.22	2.30	2.52	2.62	2.62	1.63	1.47
660	670	1.94	2.00	2.27	2.28	2.54	2.44	2.68	1.50	1.68
670	680	2.20	2.08	1.87	2.38	1.96	1.92	2.16	1.45	1.70
680	690	1.93	1.98	1.73	2.34	2.02	1.93	2.06	1.34	1.42
690	700	1.98	1.92	2.14	2.60	2.58	2.28	2.35	1.36	1.39

When presented in the format shown in Figure 3.1 the texture depths for most schemes showed a general increasing trend over time. Analysis of individual 10m sub-sections however showed fluctuating patterns that could not be corroborated by works records in HAPMS. The fluctuations are therefore thought to be due to measurement issues - such as the survey vehicle following a slightly different line of travel between successive surveys.

Systemic fluctuations were also noted. For example, the sample site shown in Figure 3.1 was resurfaced in March 2012. The widespread reduction in texture depth across most 10m sub-sections in April 2011 remains unexplained.

The conclusion from the above analyses was that, on a broad scale, texture depth measurements may provide a general indication of the changing condition of thin surfacings during their later life. However, when analysed at a localised level, texture measurements exhibit inconclusive behaviour patterns.

Methods were sought to analyse texture measurements over a scheme length and to condense the large volume of data that was generated in the previous analyses. The results are presented in Figures K.1 to K.35 in Appendix K. For each scheme the total length of surveyed carriageway falling within each of the texture bands previously presented in Table 3.1 was calculated and reported in percentage terms. When

analysed at this scale, the general trend of increasing texture over time again became apparent and the effects of localised anomalies were diminished.

It should be noted that Figures K.1 to K.35 in Appendix K will include the effects of localised patching works that may have occurred during the analysis period. Removing the patched areas from the analyses was not considered to be a worthwhile exercise as numerous unexplained anomalies would still have remained in the final Figures.

Whilst the Figures in Appendix K were useful in illustrating general behaviour trends, there was little commonality between the plots for individual schemes. The schemes on the West and East areas were seen to be variable in terms of:

- The initial texture profile
- The final texture profile
- The change in texture profile during the analysis period.

The schemes on the North Area were similarly variable. However, a feature of the plots (Figures K.21 to K.33 in Appendix K) was the prevalence of grey shading indicating a texture depth of 1.1mm or less. With reference to Table H.1 in Appendix H, this Area has historically used 10mm sized TSCS. The inference from these analyses is that the smaller stone sized material retains its lower texture depth over time whereas the 14mm sized materials commonly used on the East and West Areas “open-up” in a more progressive manner leading to higher texture measurements as they near the end of their life. Anecdotal comments however suggest that TSCS material failures (through fretting) on sites in the North Area generally occur in a rapid manner. Analysis of the Figures in Appendix K suggests that the onset of failure cannot be predicted by monitoring texture depth measurements.

Table K.1 in Appendix K was produced to further condense the data previously presented in Figures K.1 to K.35. It compares the texture profile for each site at the start and end of the 4 year VM period. It was hoped that, as a deliverable for this Task, the likely change in texture depth profile during VM could be quantified and enable Service Providers to identify the optimum time to introduce a potential scheme. However, Table K.1 shows that the patterns observed for the 30 sample schemes were highly variable. Furthermore, it has not been possible to establish the texture depth level immediately prior to failure (as none of the sites failed catastrophically and were just resurfaced as part of a normal programme of work). Therefore the objective of using machine condition data to identify the optimum time and condition for replacement could not be achieved.

### 3.6. Summary

The following key points arose from this review of 30 Sample Schemes:

1. **HAPMS data** – 9 out of the 30 Sample Schemes had missing/questionable construction records.
2. **Scheme drivers** – fretting or potholing was cited as being the main driver behind 19 out of the 20 Sample Schemes for which full details were provided.
3. **Service life** – the average age of TSCS materials at the time of their replacement was 8.5 years. The actual ages recorded for individual schemes ranged from 2 years to 13 years.
4. **Visual condition data** – the format, quality and completeness of the visual condition data provided for review was highly variable. This meant that it was not possible to draw comparisons between individual schemes or to identify potential thresholds to indicate when maintenance should be planned.
5. **Category 1 defects** – defect frequencies (/km) varied significantly between the three maintenance Areas. Trends were however noted within each Area.
  - a. The West Area recorded a relatively high number of defects early in the VM process. Repairing these defects appeared to stabilise the condition of the pavement and no/few defects subsequently occurred in the year before or after the VM workshop. This may suggest that surfacing was not life-expired at its time of replacement.
  - b. The East Area recorded the highest frequency of defects. The number of defects also increased significantly in the year immediately after VM. This may suggest that the schemes were introduced into the VM process year too late.
  - c. Schemes in the North area exhibited very few defects in the early years of the VM process. This would indicate that the schemes were not being promoted on the grounds of minimising unplanned emergency works.
6. **Form of contract** – the initial identification and promotion of the schemes included in this review pre-dated the Agency's introduction of the new ASC form of contract. Defect identification and prioritisation is now undertaken on a risk-based approach. This would complicate any attempt to define thresholds for the number or frequency of Category 1 defects that may indicate that a TSCS material should be considered for replacement.
7. **Machine condition data** – since fretting was cited as the most typical driver between the Sample schemes a comprehensive analysis of historic texture data was undertaken. This revealed an expected general trend of increasing texture depth over time as the TSCS approached replacement. Detailed analysis of the 10m texture data proved inconclusive however and unexplained behaviour patterns were apparent. When observed over the final years of the VM period, no consistency or quantifiable trends could be found in the:
  - a. initial texture depth (at the start of the analysis period).
  - b. rate of increase in texture.
  - c. final texture depth in the year before immediately prior to replacement.

Dialogue with two out of the three Service Providers who contributed to this study revealed that the Sample Schemes that they had put forward were typical TSCS schemes that had exhibited normal deterioration and had progressed through the VM process to eventual scheme construction. In order to identify the optimum time/condition at which a scheme should be introduced into the VM process it would be necessary to also include schemes which had deteriorated in an unexpected or catastrophic manner. Anecdotal comments from the Service Providers suggested that such sites do not usually make it through the VM process and were instead treated as emergency schemes. Whilst Service Providers were able to recount examples of TSCS sites that had deteriorated rapidly (requiring emergency intervention) no scheme data or VM submissions were available. Without such information it would be impossible to satisfy the Task Specification and identify the optimum time/condition for maintenance planning.

## 4. Conclusions

With regard to the Specification (as summarised in Table 1-1), the following activities have been undertaken:

- A review of the construction records in HAPMS has categorised the Agency's stock of TSCS in terms of its length, age, geographical location, material type, season laid, cross sectional position and thickness (see Section 2). It was noted that, at the time of undertaking this analysis, HAPMS did not include pertinent details regarding the TSCS materials present on the network. TRL 674<sup>[4]</sup> concluded that aggregate size, thin surfacing system type and binder content were all key parameters in predicting the failure of TSCS based upon visual condition.
- A review of the visual condition survey data that was presented for each scheme at VM was attempted. Variability in the format, quality and completeness of the data by the different Service Providers prevented meaningful conclusions from being made. If thresholds, based on visual condition data, were to be proposed for TSCS schemes then attempts would have to be made to standardise the VM submission requirements.
- Defect records were analysed in the period leading up to the VM workshops and in the subsequent period before construction. Anecdotal trends were identified in the defect patterns within individual Areas but comparisons between Areas were inconclusive. The new ASC arrangements introduced a risk based approach to defect identification and categorisation. This would complicate any attempt by the Agency to define (centrally) defect thresholds to indicate when a site was approaching the end of its serviceable life and should be considered for resurfacing.
- The critical visual factor that lead to the conclusion, by the Service Provider, that most sites were due for resurfacing was the occurrence of fretting. The severity or extent of the fretting that indicated to the Service Provider that a TSCS site was due for replacement was judged on a subjective basis.
- None of the Service Providers cited machine condition data as being a determining factor when deciding when to introduce a scheme into the VM process.
- An analysis of texture data for each site was undertaken to determine whether this could identify fretting. A general trend of increasing texture over time was observed. This was thought to be due to the loss of aggregate particles from the surface (i.e. fretting). The reviewed data for the 30 Sample Schemes was highly variable and no reliable trends or conclusions could be drawn.

On the basis of the above sub-Tasks it was not possible to identify, from the data currently available for consideration at VM, the optimum time and condition for a TSCS site to be included in the VM process as a scheme for planned maintenance works.

## 5. References

Table 5-1 References

Ref	Detail
1	"Thin Surface Course Systems - Installation And Maintenance", Interim Advice Note 157/11. Highways Agency, Dec 2011.
2	"Bituminous Surfacing Materials and Techniques", HD 37/99, DMRB, Volume 7, Section 5, Part 2, Highways Agency, 1999.
3	"Surfacing materials for new and maintenance construction", HD 36/06, DMRB, Volume 7, Section 5, Part 1, Highways Agency, 2006.
4	"Durability of thin surfacing systems, Part 4 Final report after nine years monitoring", J C Nicholls, I Carswell, C Thomas and B Sexton, TRL Report 674, ISBN 978-1-84608-897-1, 2010.
5	"NDD Value Management Requirements - Version 2", Highways Agency, Jan. 2013.
6	"Asset Data Management Manual: Provider Requirements", Highways Agency, Edition 1 (ASC Area 2 issue), Version 1.3, May 2011.
7	"Data for pavement assessment", HD 29/08, DMRB, Volume 7, Section 3, Part 2, Highways Agency, 2008.

## 6. Abbreviations

Table 6-1 Abbreviations

Abbreviation	Expanded
ADMM	Asset Data Management Manual
ASC	Asset Support Contract
DMRB	Design Manual for Roads and Bridges
HA	Highways Agency
HAPMS	Highways Agency Pavement Management System
IAN	Interim Advice Note
NDD	Network Delivery and Development
RMMS	Routine Maintenance Management System
SHW	Specification for Highway Works
TSCS	Thin Surface Course System
VM	Value Management
XSP	Cross Sectional Position

# Appendices

# Appendix A. Network level analysis – by HA Area and by XSP

		Length of TSCS (m) by HA Area											
XSP	Code	1	2	3	4	6	7	8	9	10	12	13	14
Left hardshoulder	LHL	104,292	184,838	261,532	152,617	153,468	344,199	365,152	283,898	205,875	102,242	348,035	39,169
	LHR	104,292	186,102	260,752	152,617	152,679	344,365	364,547	282,858	202,088	103,188	348,347	39,169
Left additional nearside lane(s)	-L2L	~	~	~	~	~	2,191	268	1,516	~	140	677	155
	-L2R	~	~	~	~	~	2,191	268	1,516	~	140	677	155
	-L1L	4,863	415	5,265	7,429	7,944	33,100	31,779	26,000	2,295	12,672	12,598	12,228
	-L1R	4,863	415	5,265	7,429	7,888	33,046	31,805	25,928	2,301	12,722	12,598	12,228
Left permanent lane(s)	CL1L	280,706	493,276	633,636	473,026	626,889	669,882	640,640	506,602	585,467	599,173	401,228	268,913
	CL1R	279,375	494,776	633,034	472,862	627,839	820,706	639,860	506,409	584,135	599,156	401,558	268,870
	CL2L	201,501	302,593	366,417	297,750	373,557	607,901	524,031	452,715	465,511	422,895	229,920	201,971
	CL2R	199,258	302,770	366,521	297,560	375,269	606,836	524,579	452,652	465,788	422,769	229,920	202,144
	CL3L	2,884	214,503	142,086	114,308	58,429	182,030	116,814	186,445	272,146	173,552	128,267	18,834
	CL3R	2,884	202,838	142,086	114,308	58,429	182,030	116,814	186,445	272,080	173,552	128,177	18,834
	CL4L	~	3,581	6,266	30,186	120	47,327	28,386	5,594	34,535	250	445	442
	CL4R	~	3,581	6,266	30,186	120	47,327	28,386	5,594	34,535	250	445	442
	CL5L	~	~	~	~	~	~	~	~	242	~	~	~
	CL5R	~	~	~	~	~	~	~	~	242	~	~	~
Left additional offside lane(s)	+L1L	1,581	~	393	4,875	1,417	14,740	1,273	1,609	253	9,967	8,906	4,151
	+L1R	1,581	~	393	4,875	1,417	14,046	1,309	1,609	253	9,967	8,906	4,151
	+L2L	~	~	~	~	18	1,203	~	152	125	~	65	~
	+L2R	~	~	~	~	18	1,203	~	152	125	~	65	~
	+L3L	~	~	~	~	~	115	~	~	~	~	~	~
	+L3R	~	~	~	~	~	115	~	~	~	~	~	~
Right additional offside lane(s)	+R1R	~	~	~	1,413	1,086	7,586	945	1,793	~	1,886	3,546	538
	+R1L	171	~	~	1,413	1,086	7,586	947	1,793	~	1,886	3,546	538
Right permanent lane(s)	CR2R	2,213	380	~	2,600	576	~	410	1,947	6,736	3,593	~	758
	CR2L	2,213	380	~	2,600	576	~	410	1,947	6,736	3,593	~	758
	CR1R	28,239	87,666	9,894	71,967	98,467	75,293	25,139	43,663	10,091	67,958	95,652	44,321
	CR1L	28,310	87,647	9,939	71,967	99,840	79,373	25,511	43,885	10,091	67,954	95,652	43,765
Right additional nearside lane(s)	-R1R	218	241	197	1,265	1,311	3,425	592	3,672	992	850	4,992	1,214
	-R1L	218	241	197	1,265	1,311	3,425	592	3,672	1,018	850	4,992	1,214
	-R2R	~	~	~	~	~	18	~	~	165	~	~	~
	-R2L	~	~	~	~	~	18	~	~	165	~	~	~
Right hardshoulder	RHR	94,630	783	94,293	109,765	55,147	231,706	302,505	53,477	1,722	8,620	255,740	15,684
	RHL	94,900	783	102,430	109,765	55,381	231,363	303,000	53,477	1,722	8,620	255,740	15,684

Table A.1. HAPMS records for TSCS - All XSPs and both wheelpaths

		Length of TSCS (m) by HA Area													TOTALS	
XSP	Code	1	2	3	4	6	7	8	9	10	12	13	14			
Left hardshoulder	LHL	104,292	184,838	261,532	152,617	153,468	344,199	365,152	283,898	205,875	102,242	348,035	39,169	2,545,318	17,105,727	
Left additional nearside lane(s)	-L2L	~	~	~	~	~	2,191	268	1,516	~	140	677	155	4,947		
	-L1L	4,863	415	5,265	7,429	7,944	33,100	31,779	26,000	2,295	12,672	12,598	12,228	156,590		
Left permanent lane(s)	CL1L	280,706	493,276	633,636	473,026	626,889	669,882	640,640	506,602	585,467	599,173	401,228	268,913	6,179,438		
	CL2L	201,501	302,593	366,417	297,750	373,557	607,901	524,031	452,715	465,511	422,895	229,920	201,971	4,446,762		
	CL3L	2,884	214,503	142,086	114,308	58,429	182,030	116,814	186,445	272,146	173,552	128,267	18,834	1,610,298		
	CL4L	~	3,581	6,266	30,186	120	47,327	28,386	5,594	34,535	250	445	442	157,132		
	CL5L	~	~	~	~	~	~	~	~	242	~	~	~	242		
Left additional offside lane(s)	+L1L	1,581	~	393	4,875	1,417	14,740	1,273	1,609	253	9,967	8,906	4,151	49,166		
	+L2L	~	~	~	~	18	1,203	~	152	125	~	65	~	1,563		
	+L3L	~	~	~	~	~	115	~	~	~	~	~	~	115		
Right additional offside lane(s)	+R1L	171	~	~	1,413	1,086	7,586	947	1,793	~	1,886	3,546	538	18,967		
Right permanent lane(s)	CR2L	2,213	380	~	2,600	576	~	410	1,947	6,736	3,593	~	758	19,213		
	CR1L	28,310	87,647	9,939	71,967	99,840	79,373	25,511	43,885	10,091	67,954	95,652	43,765	663,934		
Right additional nearside lane(s)	-R1L	218	241	197	1,265	1,311	3,425	592	3,672	1,018	850	4,992	1,214	18,995		
	-R2L	~	~	~	~	~	18	~	~	165	~	~	~	183		
Right hardshoulder	RHL	94,900	783	102,430	109,765	55,381	231,363	303,000	53,477	1,722	8,620	255,740	15,684	1,232,864		
<b>TOTALS</b>		<b>721,641</b>	<b>1,288,257</b>	<b>1,528,161</b>	<b>1,267,201</b>	<b>1,380,036</b>	<b>2,224,454</b>	<b>2,038,804</b>	<b>1,569,305</b>	<b>1,586,181</b>	<b>1,403,795</b>	<b>1,490,071</b>	<b>607,822</b>	<b>17,105,727</b>		

Table A.2. HAPMS records for TSCS - All XSPs and left wheelpath only

		Length of TSCS (m) by HA Area												TOTALS	
XSP	Code	1	2	3	4	6	7	8	9	10	12	13	14		
Left hardshoulder	LHL	104,292	184,838	261,532	152,617	153,468	344,199	365,152	283,898	205,875	102,242	348,035	39,169	2,545,318	16,855,201
Left permanent lane(s)	CL1L	280,706	493,276	633,636	473,026	626,889	669,882	640,640	506,602	585,467	599,173	401,228	268,913	6,179,438	
	CL2L	201,501	302,593	366,417	297,750	373,557	607,901	524,031	452,715	465,511	422,895	229,920	201,971	4,446,762	
	CL3L	2,884	214,503	142,086	114,308	58,429	182,030	116,814	186,445	272,146	173,552	128,267	18,834	1,610,298	
	CL4L	~	3,581	6,266	30,186	120	47,327	28,386	5,594	34,535	250	445	442	157,132	
	CL5L	~	~	~	~	~	~	~	~	242	~	~	~	242	
Right permanent lane(s)	CR2L	2,213	380	~	2,600	576	~	410	1,947	6,736	3,593	~	758	19,213	
	CR1L	28,310	87,647	9,939	71,967	99,840	79,373	25,511	43,885	10,091	67,954	95,652	43,765	663,934	
Right hardshoulder	RHL	94,900	783	102,430	109,765	55,381	231,363	303,000	53,477	1,722	8,620	255,740	15,684	1,232,864	
<b>TOTALS</b>		<b>714,807</b>	<b>1,287,601</b>	<b>1,522,306</b>	<b>1,252,219</b>	<b>1,368,260</b>	<b>2,162,075</b>	<b>2,003,945</b>	<b>1,534,563</b>	<b>1,582,325</b>	<b>1,378,279</b>	<b>1,459,287</b>	<b>589,535</b>	<b>16,855,201</b>	

Table A.3. HAPMS records for TSCS - Selected XSPs and left wheelpath only

# Appendix B. Network level analysis - by TSCS type

Area	TSCS Length (m)			TOTAL
	Fibre	Generic	Polymer	
1	472,180	206,120	36,506	714,807
2	5,758	763,291	518,553	1,287,601
3	6,574	901,112	614,620	1,522,306
4	2,727	1,247,954	1,538	1,252,219
6	121,718	1,182,923	63,619	1,368,260
7	7,653	1,957,763	196,659	2,162,075
8	597,610	779,579	626,756	2,003,945
9	35,142	1,470,693	28,728	1,534,563
10	339,716	1,242,609	~	1,582,325
12	18,031	1,360,248	~	1,378,279
13	97,609	580,154	781,524	1,459,287
14	6	589,529	~	589,535
<b>TOTAL</b>	<b>1,704,724</b>	<b>12,281,975</b>	<b>2,868,503</b>	<b>16,855,201</b>

Table B.1. Summary of TSCS types in each HA Area

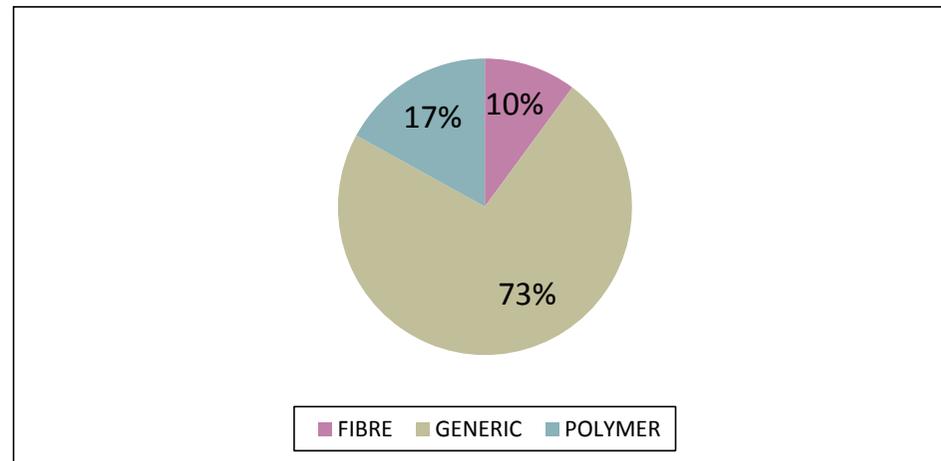


Figure B.1. Summary of TSCS types - % of total length of TSCS across full HA Network

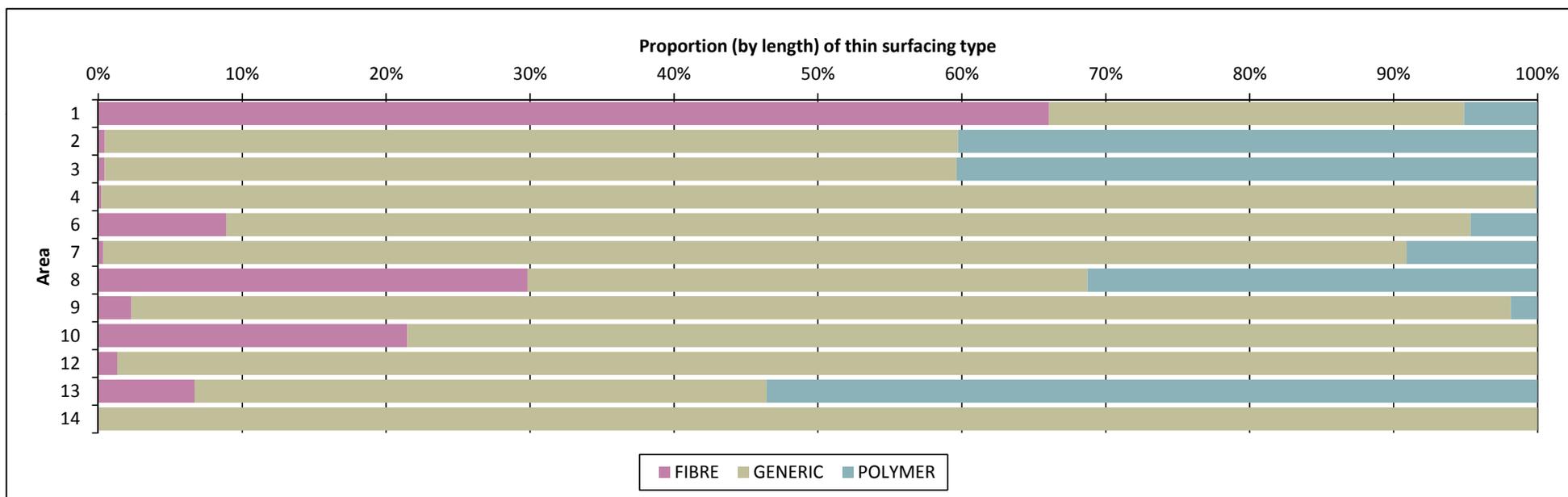


Figure B.2. Summary of TSCS types - % of total length (m) of TSCS in each HA Area

# Appendix C. Network level analysis - by age

Length (m) of TSCS																	
Area	<5.0 yrs	5.0 to 5.9999 yrs	6.0 to 6.9999 yrs	7.0 to 7.9999 yrs	8.0 to 8.9999 yrs	9.0 to 9.9999 yrs	10.0 to 10.9999 yrs	11.0 to 11.9999 yrs	12.0 to 12.9999 yrs	13.0 to 13.9999 yrs	14.0 to 14.9999 yrs	15.0 to 15.9999 yrs	16.0 to 16.9999 yrs	17.0 to 17.9999 yrs	18.0 to 18.9999 yrs	19.0 to 19.9999 yrs	>=20 yrs
1	350,627	108,693	74,791	45,540	34,163	15,794	33,658	3,377	25,576	12,459	2,221	7,867	-	-	-	40	-
2	325,325	87,670	74,956	125,681	82,094	37,213	37,244	88,970	151,205	50,483	146,208	9,140	-	5,010	24	-	66,380
3	726,864	90,090	118,675	62,965	157,881	103,874	8,242	69,492	114,896	49,847	8,532	-	-	3,268	-	-	7,680
4	333,294	45,195	150,458	181,180	51,223	238,145	47,907	57,892	46,191	67,024	15,632	6,982	-	2,215	274	194	8,413
6	298,282	103,859	131,009	96,267	180,262	182,768	125,851	6,294	170,682	40,788	8,957	6,140	2,165	156	-	408	14,372
7	855,988	44,054	278,173	219,940	74,276	351,193	137,083	83,158	94,415	7,475	4,478	-	-	-	4,050	287	7,506
8	910,288	189,499	261,238	22,254	76,158	166,582	42,018	36,643	105,295	182,522	6,215	-	-	124	-	884	4,224
9	581,021	70,057	154,627	59,233	38,017	48,038	-	1,353	13,913	7,975	7,790	23,951	100	17,885	1,836	3,127	505,640
10	618,450	75,475	96,671	106,763	161,235	131,529	49,877	178,793	31,977	42,875	7,831	1,538	-	-	210	-	79,101
12	541,762	67,181	128,411	120,296	85,872	161,316	85,023	85,483	36,951	38,232	3,027	2,067	-	-	129	-	22,528
13	743,556	89,665	77,855	93,322	147,440	80,557	75,027	24,883	90,301	13,877	5,197	6,205	-	10,370	-	1,032	-
14	307,630	14,108	28,960	34,493	5,043	16,240	58,166	37,459	38,135	6,252	26,148	-	13,389	-	19	-	3,495
<b>TOTAL</b>	<b>6,593,087</b>	<b>985,546</b>	<b>1,575,825</b>	<b>1,167,933</b>	<b>1,093,665</b>	<b>1,533,249</b>	<b>700,096</b>	<b>673,797</b>	<b>919,536</b>	<b>519,809</b>	<b>242,236</b>	<b>63,889</b>	<b>15,654</b>	<b>39,028</b>	<b>6,542</b>	<b>5,972</b>	<b>719,338</b>
<b>%</b>	<b>39.12</b>	<b>5.85</b>	<b>9.35</b>	<b>6.93</b>	<b>6.49</b>	<b>9.10</b>	<b>4.15</b>	<b>4.00</b>	<b>5.46</b>	<b>3.08</b>	<b>1.44</b>	<b>0.38</b>	<b>0.09</b>	<b>0.23</b>	<b>0.04</b>	<b>0.04</b>	<b>4.27</b>

Table C.1. Age profile (i) - By length and by HA Area

% of total length of TSCS in each HA Area																	
Area	<5.0 yrs	5.0 to 5.9999 yrs	6.0 to 6.9999 yrs	7.0 to 7.9999 yrs	8.0 to 8.9999 yrs	9.0 to 9.9999 yrs	10.0 to 10.9999 yrs	11.0 to 11.9999 yrs	12.0 to 12.9999 yrs	13.0 to 13.9999 yrs	14.0 to 14.9999 yrs	15.0 to 15.9999 yrs	16.0 to 16.9999 yrs	17.0 to 17.9999 yrs	18.0 to 18.9999 yrs	19.0 to 19.9999 yrs	>=20 yrs
1	49.05	15.21	10.46	6.37	4.78	2.21	4.71	0.47	3.58	1.74	0.31	1.10	-	-	-	0.01	-
2	25.27	6.81	5.82	9.76	6.38	2.89	2.89	6.91	11.74	3.92	11.36	0.71	-	0.39	0.00	-	5.16
3	47.75	5.92	7.80	4.14	10.37	6.82	0.54	4.56	7.55	3.27	0.56	-	-	0.21	-	-	0.50
4	26.62	3.61	12.02	14.47	4.09	19.02	3.83	4.62	3.69	5.35	1.25	0.56	-	0.18	0.02	0.02	0.67
6	21.80	7.59	9.57	7.04	13.17	13.36	9.20	0.46	12.47	2.98	0.65	0.45	0.16	0.01	-	0.03	1.05
7	39.59	2.04	12.87	10.17	3.44	16.24	6.34	3.85	4.37	0.35	0.21	-	-	-	0.19	0.01	0.35
8	45.42	9.46	13.04	1.11	3.80	8.31	2.10	1.83	5.25	9.11	0.31	-	-	0.01	-	0.04	0.21
9	37.86	4.57	10.08	3.86	2.48	3.13	-	0.09	0.91	0.52	0.51	1.56	0.01	1.17	0.12	0.20	32.95
10	39.08	4.77	6.11	6.75	10.19	8.31	3.15	11.30	2.02	2.71	0.49	0.10	-	-	0.01	-	5.00
12	39.31	4.87	9.32	8.73	6.23	11.70	6.17	6.20	2.68	2.77	0.22	0.15	-	-	0.01	-	1.63
13	50.95	6.14	5.34	6.40	10.10	5.52	5.14	1.71	6.19	0.95	0.36	0.43	-	0.71	-	0.07	-
14	52.18	2.39	4.91	5.85	0.86	2.75	9.87	6.35	6.47	1.06	4.44	-	2.27	-	0.00	-	0.59

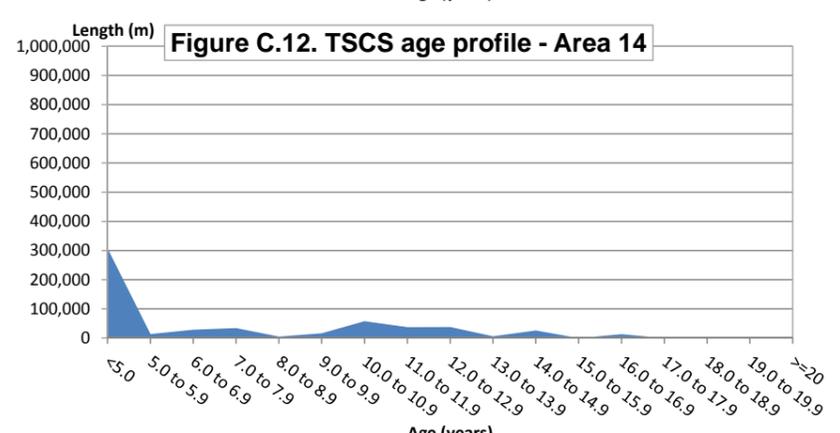
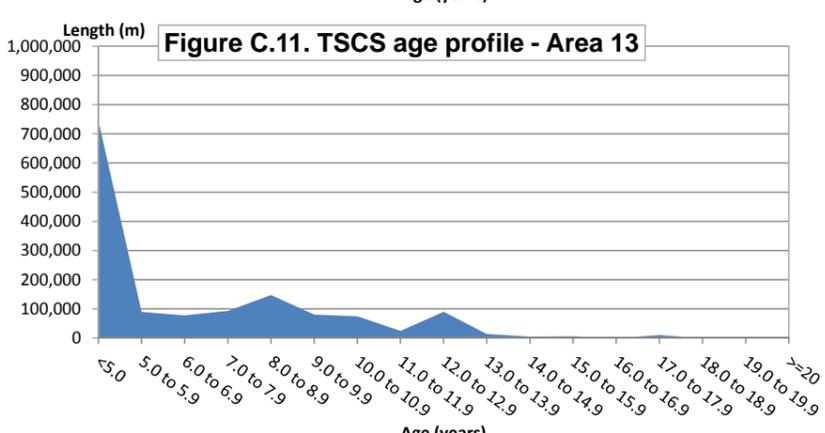
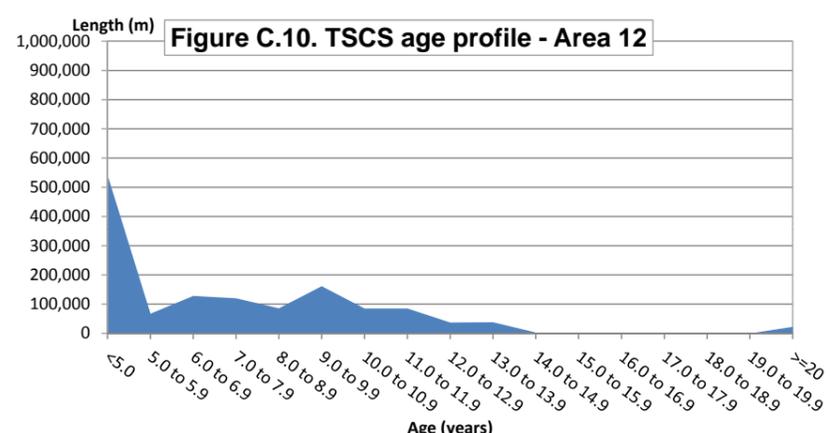
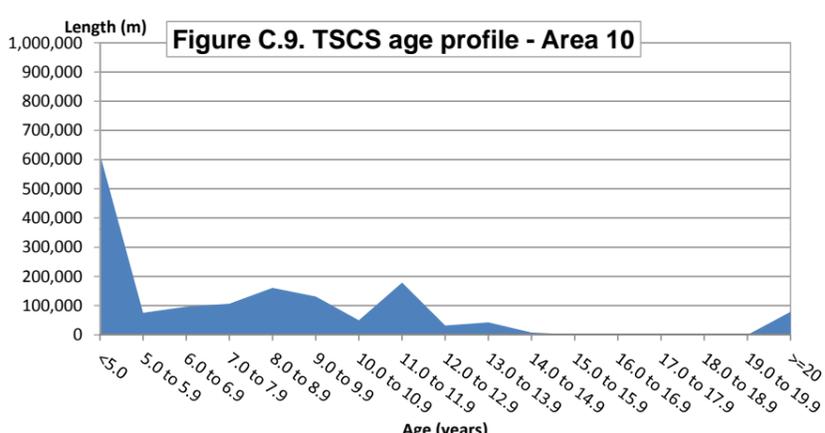
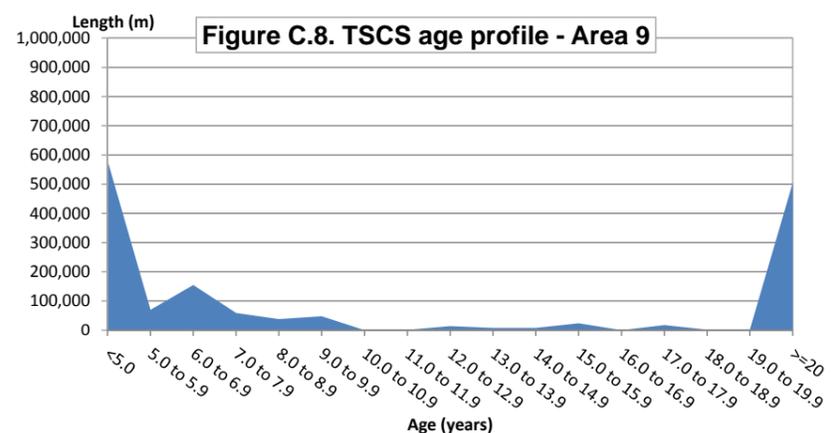
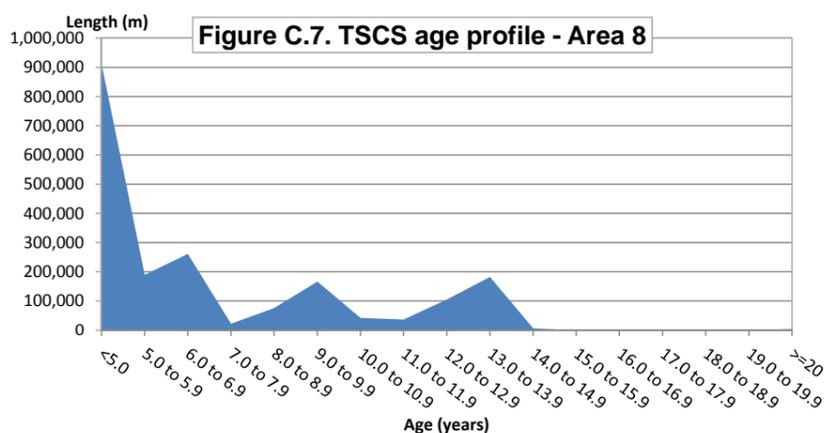
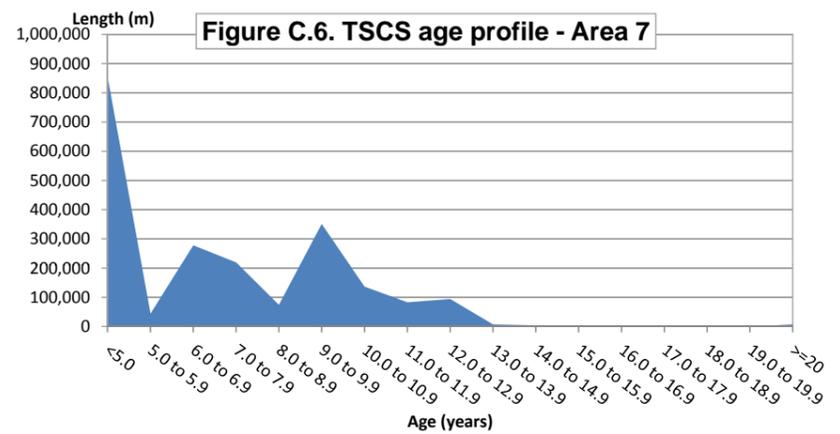
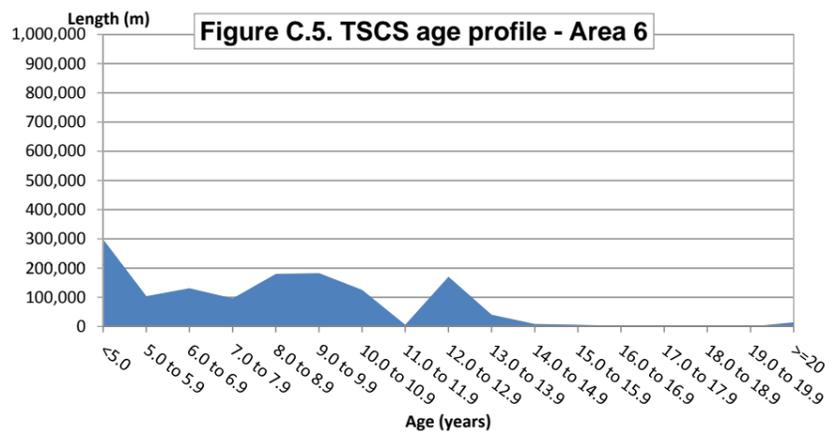
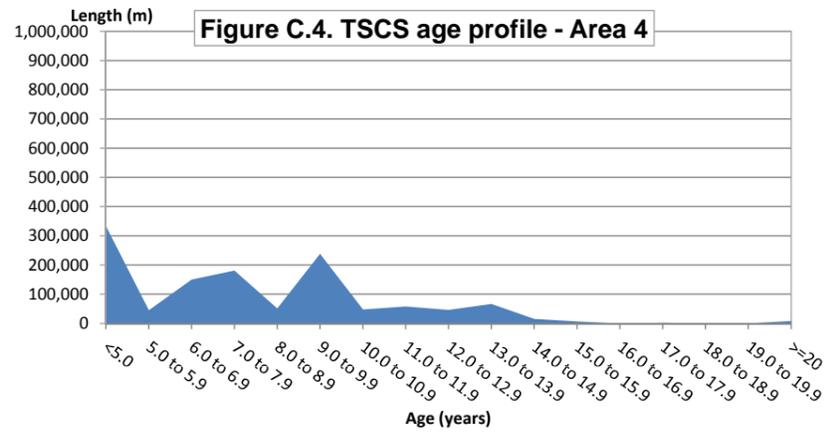
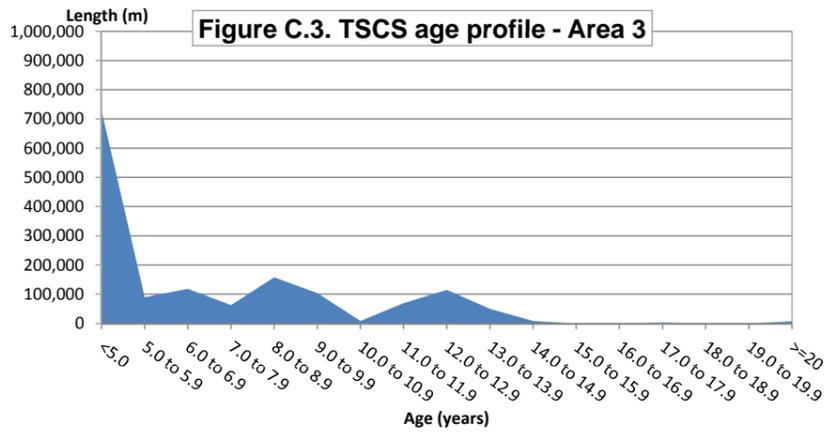
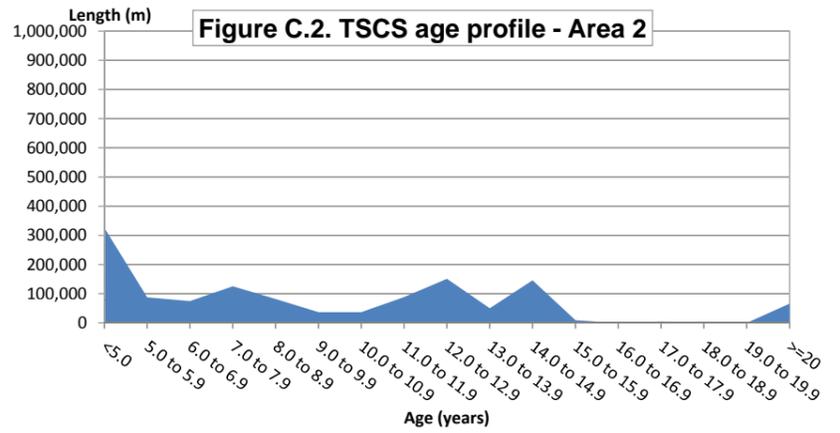
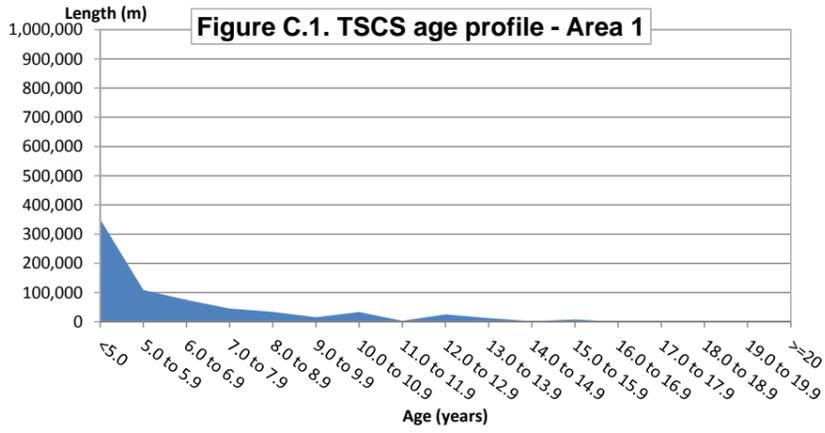
Table C.2. Age profile (ii) - By proportion of total length of TSCS in each HA Area

Length (m) of TSCS																	
XSP	<5.0 yrs	5.0 to 5.9999 yrs	6.0 to 6.9999 yrs	7.0 to 7.9999 yrs	8.0 to 8.9999 yrs	9.0 to 9.9999 yrs	10.0 to 10.9999 yrs	11.0 to 11.9999 yrs	12.0 to 12.9999 yrs	13.0 to 13.9999 yrs	14.0 to 14.9999 yrs	15.0 to 15.9999 yrs	16.0 to 16.9999 yrs	17.0 to 17.9999 yrs	18.0 to 18.9999 yrs	19.0 to 19.9999 yrs	>=20 yrs
CL1L	2,641,723	397,541	574,667	454,065	416,477	490,368	259,760	205,453	248,735	170,173	76,558	14,185	6,093	13,737	2,924	1,959	205,021
CL2L	1,585,619	238,002	427,259	340,036	315,838	467,329	220,907	198,851	235,046	145,545	63,503	13,119	7,068	12,039	930	2,186	173,485
CL3L	507,035	82,057	103,565	95,377	113,249	201,474	54,863	114,137	124,916	54,126	29,962	8,467	-	2,985	-	920	117,165
CL4L	97,244	3,079	1,575	9,821	2,586	23,340	-	11,489	3,149	-	639	-	-	61	-	-	4,391
CR1L	315,808	58,633	63,253	47,544	29,254	35,779	17,934	13,101	36,389	11,250	14,618	297	50	1,729	80	-	18,215
CR2L	8,226	1,090	651	1,639	2,146	3,138	-	293	261	-	-	-	-	-	-	-	1,769
LHL	956,764	137,462	255,320	139,487	151,842	193,644	84,047	104,702	197,483	94,598	43,602	21,158	2,304	4,222	1,468	466	156,748
RHL	480,668	67,682	149,536	79,964	62,273	118,176	62,586	25,772	73,557	44,117	13,353	6,664	139	4,255	1,140	441	42,543
<b>TOTAL</b>	<b>6,593,087</b>	<b>985,546</b>	<b>1,575,825</b>	<b>1,167,933</b>	<b>1,093,665</b>	<b>1,533,249</b>	<b>700,096</b>	<b>673,797</b>	<b>919,536</b>	<b>519,809</b>	<b>242,236</b>	<b>63,889</b>	<b>15,654</b>	<b>39,028</b>	<b>6,542</b>	<b>5,972</b>	<b>719,338</b>
<b>%</b>	<b>39.12</b>	<b>5.85</b>	<b>9.35</b>	<b>6.93</b>	<b>6.49</b>	<b>9.10</b>	<b>4.15</b>	<b>4.00</b>	<b>5.46</b>	<b>3.08</b>	<b>1.44</b>	<b>0.38</b>	<b>0.09</b>	<b>0.23</b>	<b>0.04</b>	<b>0.04</b>	<b>4.27</b>

Table C.3. Age profile (iii) - By length and by XSP

% of total length of TSCS in each XSP																	
XSP	<5.0 yrs	5.0 to 5.9999 yrs	6.0 to 6.9999 yrs	7.0 to 7.9999 yrs	8.0 to 8.9999 yrs	9.0 to 9.9999 yrs	10.0 to 10.9999 yrs	11.0 to 11.9999 yrs	12.0 to 12.9999 yrs	13.0 to 13.9999 yrs	14.0 to 14.9999 yrs	15.0 to 15.9999 yrs	16.0 to 16.9999 yrs	17.0 to 17.9999 yrs	18.0 to 18.9999 yrs	19.0 to 19.9999 yrs	>=20 yrs
CL1L	43	6	9	7	7	8	4	3	4	3	1	0	0	0	0	0	3
CL2L	36	5	10	8	7	11	5	4	5	3	1	0	0	0	0	0	4
CL3L	31	5	6	6	7	13	3	7	8	3	2	1	-	0	-	0	7
CL4L	62	2	1	6	2	15	-	7	2	-	0	-	-	0	-	-	3
CR1L	48	9	10	7	4	5	3	2	5	2	2	0	0	0	0	-	3
CR2L	43	6	3	9	11	16	-	2	1	-	-	-	-	-	-	-	9
LHL	38	5	10	5	6	8	3	4	8	4	2	1	0	0	0	0	6
RHL	39	5	12	6	5	10	5	2	6	4	1	1	0	0	0	0	3

Table C.4. Age profile (iv) - By proportion of total length of TSCS in each XSP



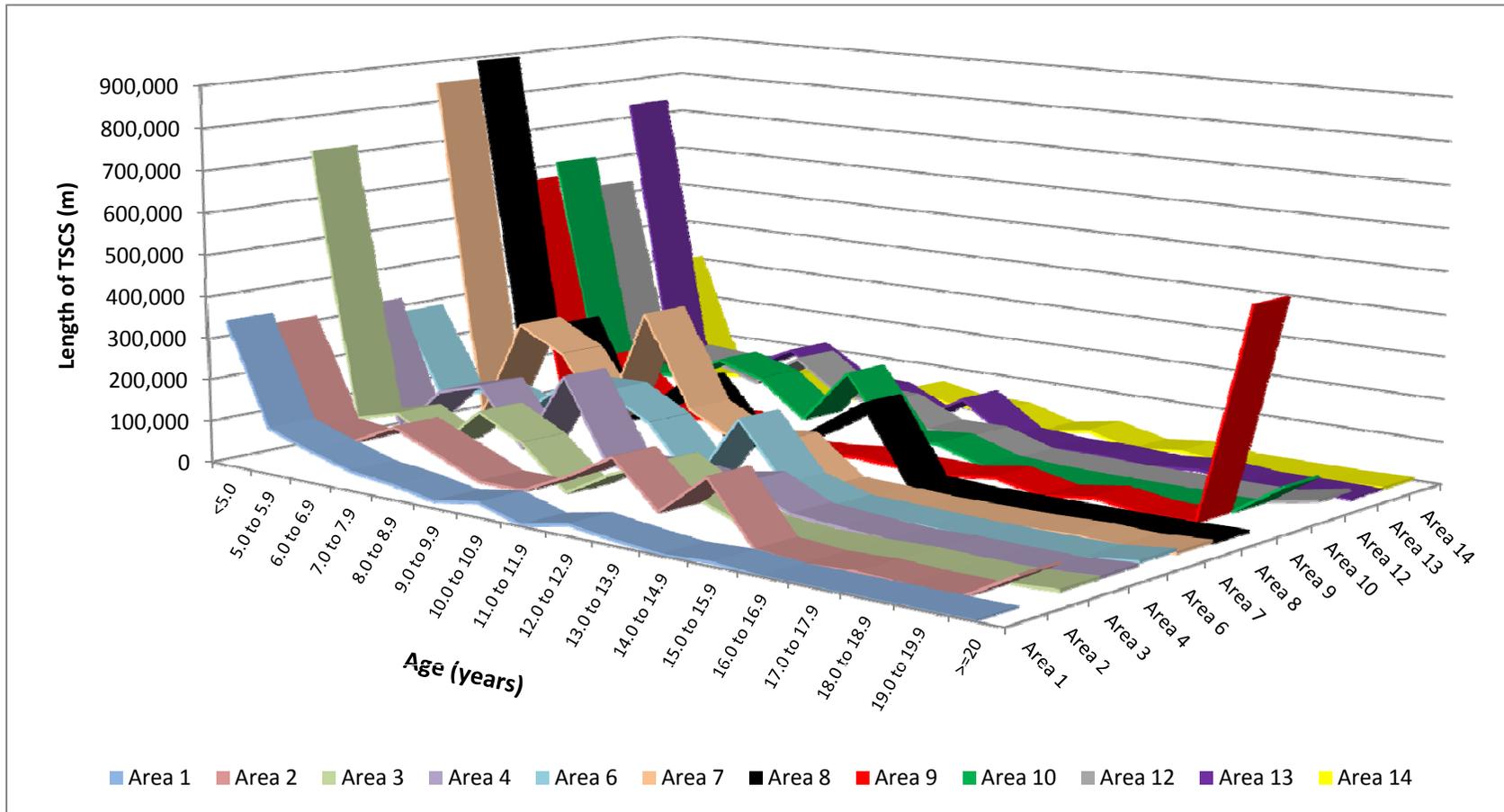


Figure C.13. TSCS age profile - all HA Areas

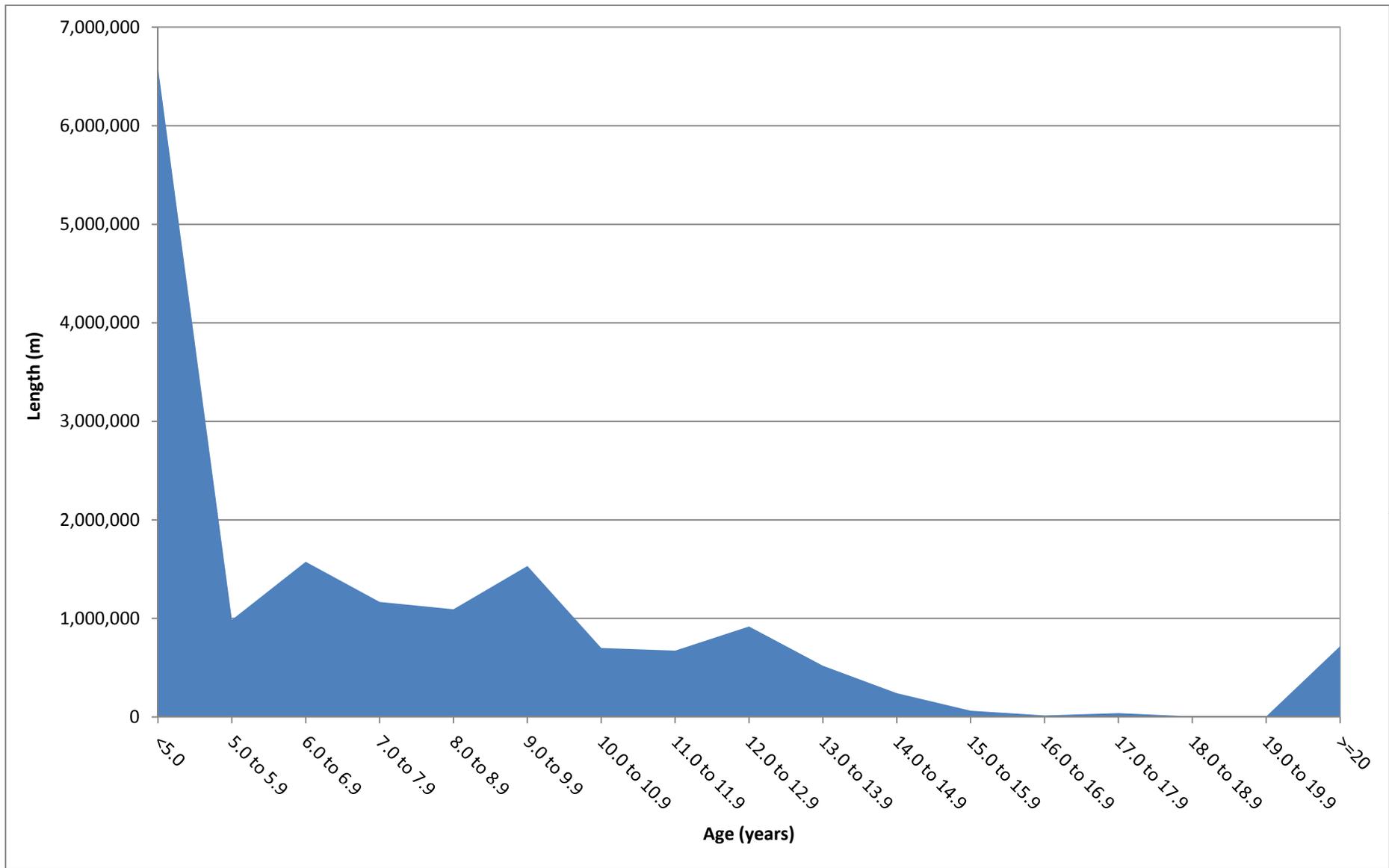


Figure C.14. TSCS age profile - full network

# Appendix D. Network level analysis - by laying season

Area	Length (m) of TSCS		TOTAL
	Laid March to October (incl.)	Laid November to February (incl.)	
1	519,431	195,376	714,807
2	865,478	422,123	1,287,601
3	978,507	543,799	1,522,306
4	915,541	336,678	1,252,219
6	975,242	393,018	1,368,260
7	1,753,423	408,652	2,162,075
8	1,134,748	869,197	2,003,945
9	725,392	809,171	1,534,563
10	1,055,371	526,953	1,582,325
12	935,508	442,771	1,378,279
13	846,214	613,073	1,459,287
14	374,863	214,672	589,535
<b>TOTAL</b>	<b>11,079,718</b>	<b>5,775,484</b>	<b>16,855,201</b>

Table D.1. Length of TSCS laid in 'winter' and 'non-winter' seasons - by HA Area

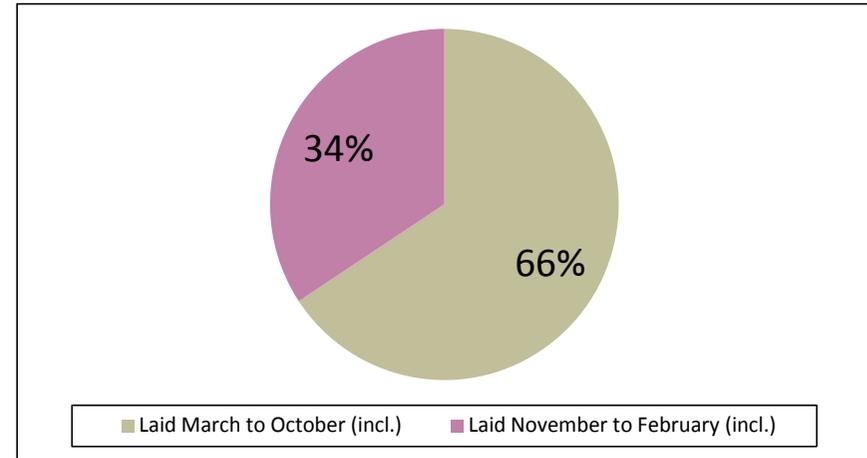


Figure D.1. Proportion (by length) of TSCS laid in 'winter' and 'non-winter' seasons - full HA Network

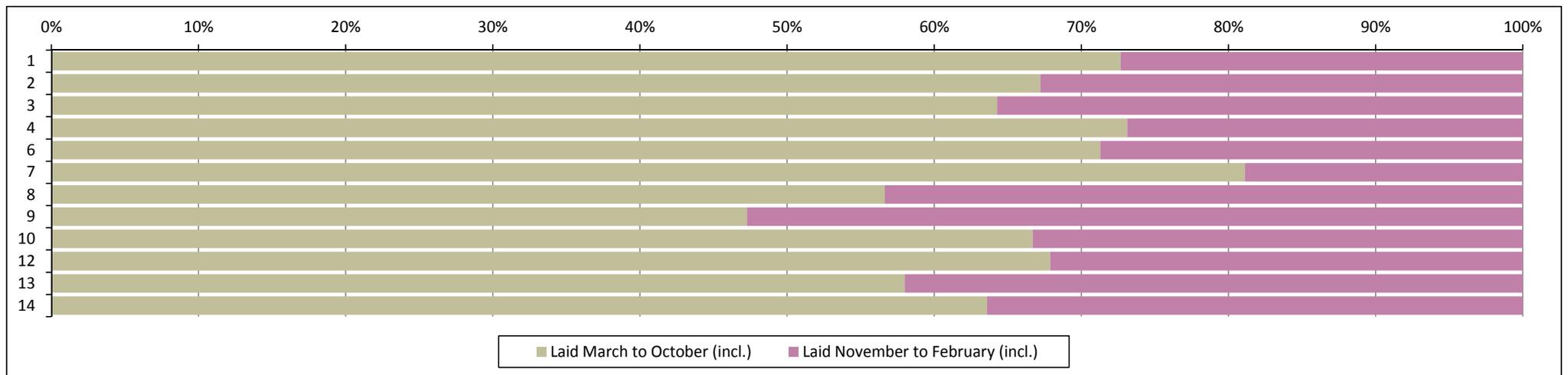


Figure D.2. Proportion (by length) of TSCS laid in 'winter' and 'non-winter' seasons - by HA Area

# Appendix E. Network level analysis - by layer thickness

Area	Nominal thickness	Length (m) of TSCS									TOTAL
		15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	> 50mm	
		Thickness Range	0-15mm	16-20mm	21-25mm	26-30mm	31-35mm	36-40mm	41-45mm	46-50mm	
Area	1	38,309	2,520	81,335	126,095	260,945	33,071	166,347	3,577	2,607	714,807
	2	94,840	21,572	57,131	355,612	82,403	197,630	16,671	451,119	10,624	1,287,601
	3	125	9,373	106,625	409,530	757,784	38,726	34,920	95,151	70,071	1,522,306
	4	3,188	34,288	113,807	508,336	179,573	148,495	35,272	227,946	1,315	1,252,219
	6	4,114	803	791	543,269	386,590	335,628	3,802	90,789	2,475	1,368,260
	7	2,075	79,801	2,302	296,388	492,198	776,234	51,933	451,023	10,121	2,162,075
	8	4,407	38,955	9,994	749,684	668,575	356,544	13,287	147,731	14,769	2,003,945
	9	8,736	11,444	16,576	226,162	238,562	362,668	529,415	118,415	22,586	1,534,563
	10	90,162	17,869	25,423	435,108	236,510	136,301	54,102	559,215	27,635	1,582,325
	12	5,939	53,892	39,212	260,293	298,541	700,139	9,820	8,622	1,821	1,378,279
	13	7,340	1,476	46,802	438,054	76,356	836,730	20,637	18,792	13,100	1,459,287
	14	572	12,656	100,328	371,838	91,842	8,988	450	2,783	78	589,535
	TOTAL	259,807	284,649	600,325	4,720,368	3,769,879	3,931,155	936,656	2,175,163	177,201	16,855,201
	%	1.54	1.69	3.56	28.01	22.37	23.32	5.56	12.90	1.05	

Table E.1. Thickness profile (i) - By length and by HA Area

Area	Nominal thickness	% of total length of TSCS in each HA Area								
		15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	> 50mm
		Thickness Range	0-15mm	16-20mm	21-25mm	26-30mm	31-35mm	36-40mm	41-45mm	46-50mm
Area	1	5.36	0.35	11.38	17.64	36.51	4.63	23.27	0.50	0.36
	2	7.37	1.68	4.44	27.62	6.40	15.35	1.29	35.04	0.83
	3	0.01	0.62	7.00	26.90	49.78	2.54	2.29	6.25	4.60
	4	0.25	2.74	9.09	40.59	14.34	11.86	2.82	18.20	0.11
	6	0.30	0.06	0.06	39.71	28.25	24.53	0.28	6.64	0.18
	7	0.10	3.69	0.11	13.71	22.77	35.90	2.40	20.86	0.47
	8	0.22	1.94	0.50	37.41	33.36	17.79	0.66	7.37	0.74
	9	0.57	0.75	1.08	14.74	15.55	23.63	34.50	7.72	1.47
	10	5.70	1.13	1.61	27.50	14.95	8.61	3.42	35.34	1.75
	12	0.43	3.91	2.84	18.89	21.66	50.80	0.71	0.63	0.13
	13	0.50	0.10	3.21	30.02	5.23	57.34	1.41	1.29	0.90
	14	0.10	2.15	17.02	63.07	15.58	1.52	0.08	0.47	0.01

Table E.2. Thickness profile (ii) - By proportion of total length of TSCS in each HA Area  
[The most prevalent thickness in each HA Area is highlighted].

XSP	Nominal thickness	Length (m) of TSCS									TOTAL
		15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	> 50mm	
		Thickness Range	0-15mm	16-20mm	21-25mm	26-30mm	31-35mm	36-40mm	41-45mm	46-50mm	
XSP	CL1L	73,910	81,414	194,332	1,634,224	1,412,983	1,450,064	321,946	964,382	46,183	6,179,438
	CL2L	65,993	91,890	184,969	1,323,388	971,336	983,321	212,722	580,150	32,994	4,446,762
	CL3L	44,526	22,767	44,195	448,490	366,052	375,642	77,030	215,959	15,637	1,610,298
	CL4L	10,879	205	513	20,431	92,860	11,411	1,252	18,960	621	157,132
	CL5L	0	0	0	0	242	0	0	0	0	242
	CR1L	17,280	7,333	5,561	134,354	114,526	212,675	37,711	130,087	4,406	663,934
	CR2L	0	0	209	4,048	7,188	1,726	3,090	2,952	0	19,213
	LHL	27,716	50,605	101,205	797,829	508,216	584,156	216,438	211,659	47,494	2,545,318
	RHL	19,503	30,434	69,341	357,604	296,477	312,158	66,466	51,013	29,867	1,232,864
	TOTAL	259,807	284,649	600,325	4,720,368	3,769,879	3,931,155	936,656	2,175,163	177,201	16,855,201
	%	1.54	1.69	3.56	28.01	22.37	23.32	5.56	12.90	1.05	

Table E.3. Thickness profile (iii) - By length and by XSP

XSP	Nominal thickness	% of total length of TSCS in each XSP								
		15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	> 50mm
		Thickness Range	0-15mm	16-20mm	21-25mm	26-30mm	31-35mm	36-40mm	41-45mm	46-50mm
XSP	CL1L	1.20	1.32	3.14	26.45	22.87	23.47	5.21	15.61	0.75
	CL2L	1.48	2.07	4.16	29.76	21.84	22.11	4.78	13.05	0.74
	CL3L	2.77	1.41	2.74	27.85	22.73	23.33	4.78	13.41	0.97
	CL4L	6.92	0.13	0.33	13.00	59.10	7.26	0.80	12.07	0.40
	CL5L	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
	CR1L	2.60	1.10	0.84	20.24	17.25	32.03	5.68	19.59	0.66
	CR2L	0.00	0.00	1.09	21.07	37.41	8.98	16.08	15.36	0.00
	LHL	1.09	1.99	3.98	31.34	19.97	22.95	8.50	8.32	1.87
	RHL	1.58	2.47	5.62	29.01	24.05	25.32	5.39	4.14	2.42

Table E.4. Thickness profile (iv) - By proportion (%) of total length of TSCS in each XSP

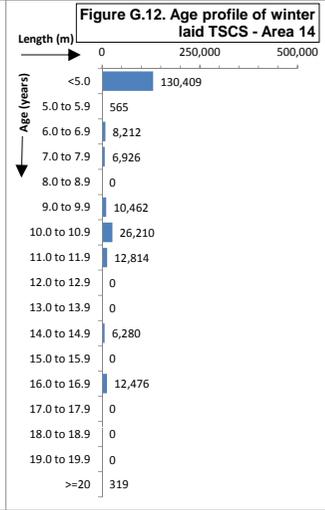
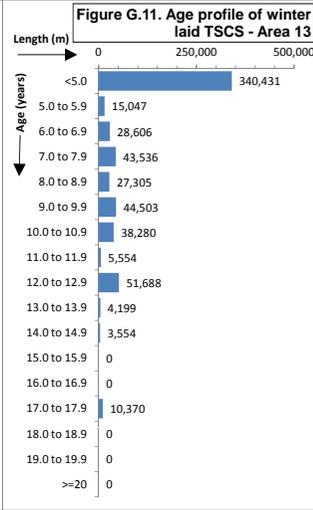
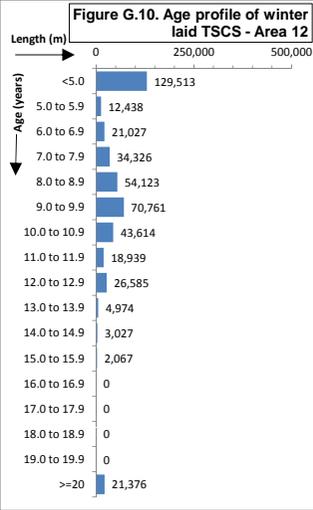
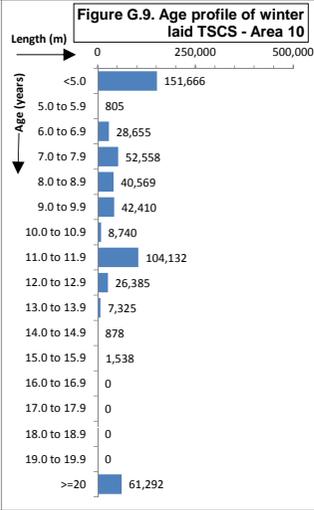
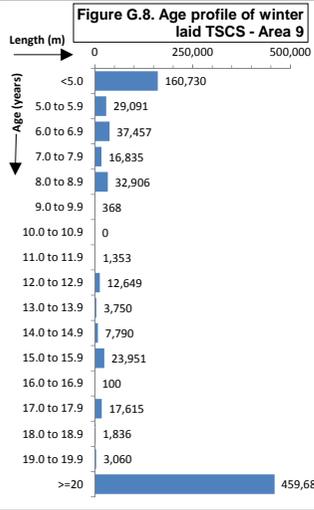
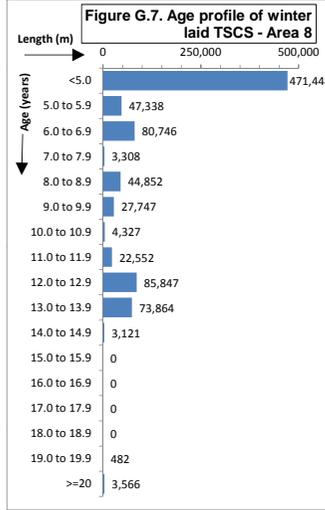
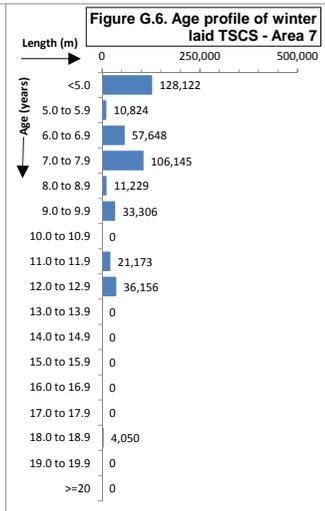
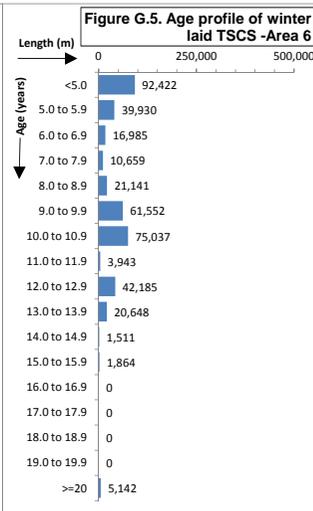
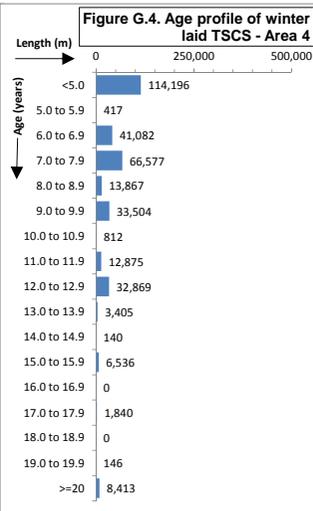
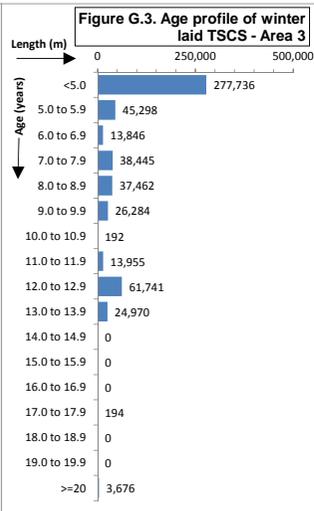
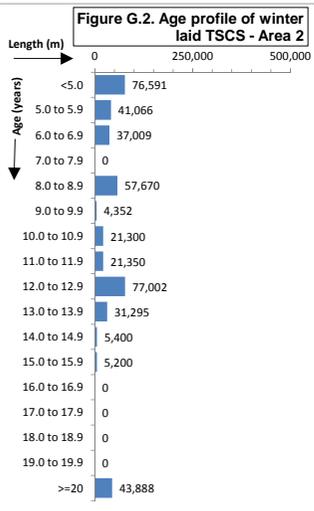
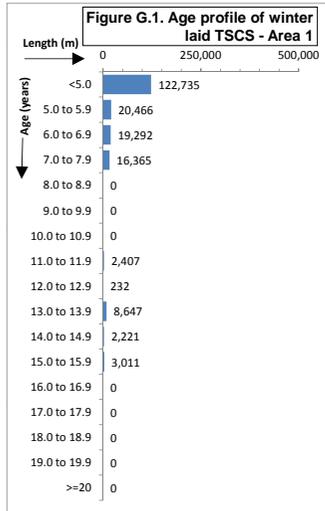
# Appendix F. Network level analysis - by age and by thickness



TSCS lengths (m) by Age and by Thickness

Age (Years)	Nominal thickness Thickness range	Length (m) of TSCS									Grand Total	
		>50mm	50mm	45mm	40mm	35mm	30mm	25mm	20mm	15mm		
		>50mm	46-50mm	41-45mm	36-40mm	31-35mm	26-30mm	21-25mm	16-20mm	0-15mm		
<b>AREA 8</b>												
>=20				94	142			1,284	418	523	1,763	4,224
19.0 to 19.9				482	402							884
18.0 to 18.9												
17.0 to 17.9										124		124
16.0 to 16.9												
15.0 to 15.9												
14.0 to 14.9					2,599	1,222	2,394					6,215
13.0 to 13.9	855	3,660	490	65,356	4,090	100,821	4,257	2,833	161			182,522
12.0 to 12.9		277	981	49,915	32,843	20,153	1,127					105,295
11.0 to 11.9	32	1,316	132	125	1,262	33,260			517			36,643
10.0 to 10.9		4,707	1,104	19,061	9,006	7,091	1,050					42,018
9.0 to 9.9			499	9,096	105,792	49,865	1,330					166,582
8.0 to 8.9		503	461	12,264	5,448	56,991	492					76,158
7.0 to 7.9		1,660	1,778	13,476	4,108	1,212		20				22,254
6.0 to 6.9		5,065	421	13,046	89,802	152,905						261,238
5.0 to 5.9		2,585	6,482	43,595	71,682	63,188				1,967		189,499
<=0	13,881	127,958	364	127,469	343,320	260,521	1,320	35,455				910,288
Grand Total	14,769	147,731	13,267	356,544	668,575	749,684	9,994	38,955	4,407			2,003,945
<b>AREA 9</b>												
>=20	12,736	13,861	131,896	87,377	110,760	115,601	16,161	10,523	6,726			505,640
19.0 to 19.9				115				3,012				3,127
18.0 to 18.9		1,836										1,836
17.0 to 17.9		1,000	1,810	6,758	6,397	1,920						17,885
16.0 to 16.9			100									100
15.0 to 15.9		283		18,545	4,803	320						23,951
14.0 to 14.9				2,609	276	4,905						7,790
13.0 to 13.9			7,975									7,975
12.0 to 12.9		557	2,120	2,077	1,191	7,553	415					13,913
11.0 to 11.9				1,353								1,353
10.0 to 10.9												
9.0 to 9.9			7,315	728	33,630	6,365						48,038
8.0 to 8.9		4,543	7,240	9,763	12,798	3,673						38,017
7.0 to 7.9			4,646	42,676	3,644	7,346		921				59,233
6.0 to 6.9	4,978	7,056	58,926	24,186	5,451	54,031						154,627
5.0 to 5.9	4,242	5,225	17,834	32,744	2,460	5,542			2,010			70,057
<=0	630	84,054	289,553	133,737	57,152	15,895						581,021
Grand Total	22,586	118,415	529,415	362,668	238,562	226,162	16,576	11,444	8,736			1,534,563
<b>AREA 10</b>												
>=20	2,121	15,349	9,823	14,810	9,221	13,409	1,778	2,268	10,323			79,101
19.0 to 19.9												
18.0 to 18.9		210										210
17.0 to 17.9												
16.0 to 16.9												
15.0 to 15.9				1,538								1,538
14.0 to 14.9				878				6,953				7,831
13.0 to 13.9		3,822	500	200	2,888	35,465						42,875
12.0 to 12.9		4,908	1,194	6,648	8,834	8,232	2,161					31,977
11.0 to 11.9	5,751	4,933	8,221	20,248	23,540	43,264	4,857	6,259	61,720			178,793
10.0 to 10.9		4,116	4,500	985	31,018	2,448		1,503	5,307			49,877
9.0 to 9.9		36,340	2,533	6,187	31,216	46,901			8,352			131,529
8.0 to 8.9		56,377	2,639	33,062	11,587	56,841	600		130			161,235
7.0 to 7.9	2,452	36,304	10,675	34,345	22,987							106,763
6.0 to 6.9	150	20,648	1,868	9,941	11,651	40,210	11,317	886				96,671
5.0 to 5.9		2,007	1,515	71,603	350							75,475
<=0	17,161	374,201	12,149	5,945	34,952	165,002	4,710		4,330			618,450
Grand Total	27,635	559,215	54,102	136,301	236,510	435,108	25,423	17,869	90,162			1,582,325
<b>AREA 12</b>												
>=20	1,706	3,841	3,725	3,243	1,999	793	1,132	528	5,561			22,528
19.0 to 19.9												
18.0 to 18.9			28		41	39	7	14				129
17.0 to 17.9												
16.0 to 16.9												
15.0 to 15.9				87					1,980			2,067
14.0 to 14.9		807		831					1,026	363		3,027
13.0 to 13.9				23,699	1,182	523			12,828			38,232
12.0 to 12.9			1,068	4,156		10,831	4,250	16,646				36,951
11.0 to 11.9				85,483								85,483
10.0 to 10.9		1,102		39,232	3,617	22,219			18,853			85,023
9.0 to 9.9			518	109,244	20,349	31,149			56			161,316
8.0 to 8.9		1,258	1,218	30,501	52,777	118						85,872
7.0 to 7.9		1,418		60,176	27,844	30,858						120,296
6.0 to 6.9				28,955	20,732	78,724						128,411
5.0 to 5.9				27,470	29,007	10,704						67,181
<=0	115	196	3,263	287,062	140,992	74,334	33,823	1,961	15			541,762
Grand Total	1,821	8,622	9,820	700,139	298,541	260,293	39,212	53,892	5,939			1,378,279
<b>AREA 13</b>												
>=20				1,032								1,032
19.0 to 19.9												
18.0 to 18.9				8,528								10,370
17.0 to 17.9								318				
16.0 to 16.9												
15.0 to 15.9						2,340	3,865					6,205
14.0 to 14.9			60	3,422	60	1,523		132				5,197
13.0 to 13.9				2,865	7,000	4,012						13,877
12.0 to 12.9			3,235	260	49,378	37,428						90,301
11.0 to 11.9				5,078		16,346	3,259	200				24,883
10.0 to 10.9			2,276	36,418	17,352	17,373	30	700	878			75,027
9.0 to 9.9	854		782	75,621	2,459	841						80,557
8.0 to 8.9		1,360	2,487	58,974		84,619						147,440
7.0 to 7.9	3,239		2,750	86,349		984						93,322
6.0 to 6.9			35	77,364		456						77,855
5.0 to 5.9				89,143		522						89,665
<=0	9,007	17,432	9,012	391,676	107	270,086	39,648	126	6,462			743,556
Grand Total	13,100	18,792	20,637	836,730	76,356	438,054	46,802	1,476	7,340			1,459,287
<b>AREA 14</b>												
>=20						3,495						3,495
19.0 to 19.9												
18.0 to 18.9						19						19
17.0 to 17.9												
16.0 to 16.9								8,491	4,898			13,389
15.0 to 15.9												
14.0 to 14.9						6	26,142					26,148
13.0 to 13.9						2,821		3,431				6,252
12.0 to 12.9			78	21	35,954	1,123	958					38,135
11.0 to 11.9				237	13,853	23,369						37,459
10.0 to 10.9				120	28,481	26,255	3,310					58,166
9.0 to 9.9				2,100	4,293	9,253	45	549				16,240
8.0 to 8.9				1,260	3,783							5,043
7.0 to 7.9			365	16,105	13,347	4,676						34,493
6.0 to 6.9				1,169	26,757	1,020	14					28,960
5.0 to 5.9		1,615		185		12,308						14,108
<=0	78	1,168	450	8,360	70,830	226,721						

# Appendix G. Network level analysis - by age and by laying season



# Appendix H. Scheme level analysis - summary of selected schemes

	Scheme Ref	Scheme Length (m)	VM date	Original Material			Treatment				Age of surfacing when replaced (years)	Main driver(s) behind scheme													
				Date laid	Layer Thickness (mm)	Aggregate Size (mm)	Ratio: Thickness/Aggregate	Date Laid	Layer Thickness (mm)	Aggregate Size (mm)			Ratio: Thickness/Aggregate												
WEST AREA	101	1650	Aug-11	2000	Unknown	Unknown	n/a	Schemes not yet undertaken (or HAPMS records not yet updated)				n/a	Fretting and transverse cracking												
	102	720	Aug-11	Nov-99	10	Unknown	n/a					Schemes not yet undertaken (or HAPMS records not yet updated)				n/a	Heavy fretting and open lane joints								
	103	1550	Aug-11	2000	Unknown	Unknown	n/a									Schemes not yet undertaken (or HAPMS records not yet updated)				n/a	Severe fretting and disintegrated lane joints				
	106	407	Aug-11	Jun-98	50	14	3.57													Schemes not yet undertaken (or HAPMS records not yet updated)				n/a	Heavy fretting, potholes, failed patches and open lane joints
	107	1100	Aug-11	Mar-05	10	Unknown	n/a																	Schemes not yet undertaken (or HAPMS records not yet updated)	
	108	500	Aug-11	Jan-00	50	14	3.57	May-12	50	14	3.57														
	110	585	Aug-11	Mar-05	40	14	2.86	Apr-12	50	14	3.57	7	Severe fretting and open lane joints												
	111	942	Sep-11	Jun-01	33	14	2.36	Mar-12	40	14	2.86	11	Lane 2 and Lane 3 fretting												
	112	1328	Sep-11	2000	Unknown	Unknown	n/a	Mar-12	50	14	3.57	12	Lane1 fretting												
	113	1495	Sep-11	Mar-01	40	14	2.86	Mar-12	40	14	2.86	11	Lane 1 and Lane 2 fretting												
EAST AREA	115	600	Dec-10	Dec-00	50	14	3.57	Nov-11	45	14	3.21	11	Potholing, cracking and fretting												
	119	349	Jul-11	Jun-04	40	14	2.86	Jun-12	40	14	2.86	8	Potholing and surface deterioration												
	120	524	Jun-11	Aug-07	40	14	2.86	Aug-12	50	14	3.57	5	Rapid deterioration and potholing												
	121	316	Sep-11	Jun-04	30	14	2.14	Jun-12	50	14	3.57	8	Severe surface course deterioration												
	122	1995	Oct-10	Nov-99	40	14	2.86	Aug-11	50	14	3.57	12	Potholing and fretting												
	124	2175	Mar-10	May-06	40	14	2.86	Oct-11	50	14	3.57	5	Winter damage - Potholing/Fretting												
	125	280	Oct-10	Jun-05	30	14	2.14	Feb-12	50	14	3.57	7	Poor condition potholed carriageway												
	126	1914	Oct-10	Jun-99	Unknown	Unknown	n/a	Mar-12	50	14	3.57	13	Extensive potholing and surfacing stripping off												
	127	1353	Mar-10	Jul-05	40	14	2.86	Nov-11	50	14	3.57	6	Winter damage - Potholing/Fretting												
	128	2710	Oct-10	May-05	40	14	2.86	Oct-11	50	14	3.57	6	Severe Potholing/Fretting												
NORTH AREA	130 N/B	1065	May-11	Jun-01	25	10	2.50	Sep-12	25	10	2.50	11	Unknown												
	131 S/B	1411																							
	132	956	May-11	1965 (?)	Unknown	Unknown	n/a	May-12	35	10	3.50	n/a		Unknown											
	133 N/B	1204	Sep-11	Nov-05	30	10	3.00	Aug-12	35	10	3.50	7													
	134 S/B	1046																							
	135	2785	May-11	Apr-03	35	Unknown	n/a	Apr-12	35	10	3.50	9													
	136	3821	Jul-10	1970 (?)	Unknown	14	n/a	Nov-11	30	10	3.00	n/a													
	137	2603	Jul-10	Jan-02 & Feb-10	30 & 40	14	2.14 - 2.86	Dec-11	30	10	3.00	9 & 2													
	138 W/B	1823	Jul-10	Sep-00	30	10	3.00	Nov-11	30	10	3.00	11													
	139 E/B	1162																							
	140 N/B	3613	May-11	Jan-02	20	10 (?)	2.00	Aug-12	25	10	2.50	9.5													
	141 S/B	3730																							
	142	5731	May-11	Apr-05 & Sept-07	25 & 30	10	2.5 - 3.0	Jul-12	30	10	3.00	7 & 5													
	143 E/B	2400	Jul-10	Dec-01	30	10	3.00	Oct-11	30	10	3.00	10													
144 W/B	2461																								

Table H.1. Selected schemes - summary data

# Appendix I. Scheme level analysis - visual assessment



# Appendix J. Scheme level analysis - RMMS defects summary

WEST SCHEME	Cat 1 defects per km							WEST SCHEME	Cat 1 defects per km							WEST SCHEME	Cat 1 defects per km							WEST SCHEME	Cat 1 defects per km							WEST SCHEME	Cat 1 defects per km							
	Years pre-VM				VM	Years post-VM			Years pre-VM				VM	Years post-VM			Years pre-VM				VM	Years post-VM			Years pre-VM				VM	Years post-VM										
	4	3	2	1		1	2 (PART)		4	3	2	1		1	2 (PART)		4	3	2	1		1	2 (PART)		4	3	2	1		1	2 (PART)		4	3	2	1	1	2 (PART)		
101	1.2	5.5	2.4	0.0		0.0	0.0	103	7.7	0.0	1.3	0.0		0.0	0.0	107	1.8	0.0	0.0	1.8		0.0	0.0	110	3.4	10.3	0.0	0.0		0.0	CONSTRUCTED	112	0.0	1.5	0.0	0.0		0.0	2.3	CONSTRUCTED
102	8.3	4.2	6.9	1.4		4.2	0.0	106	2.5	9.8	2.5	0.0		0.0	0.0	108	0.0	0.0	26.0	0.0		0.0	CONSTRUCTED	111	7.4	4.2	0.0	1.1		0.0	CONSTRUCTED	113	0.7	2.7	2.0	0.7		0.0	2.7	CONSTRUCTED

FIGURE J.1. Summary of Cat 1 defect histories for West schemes

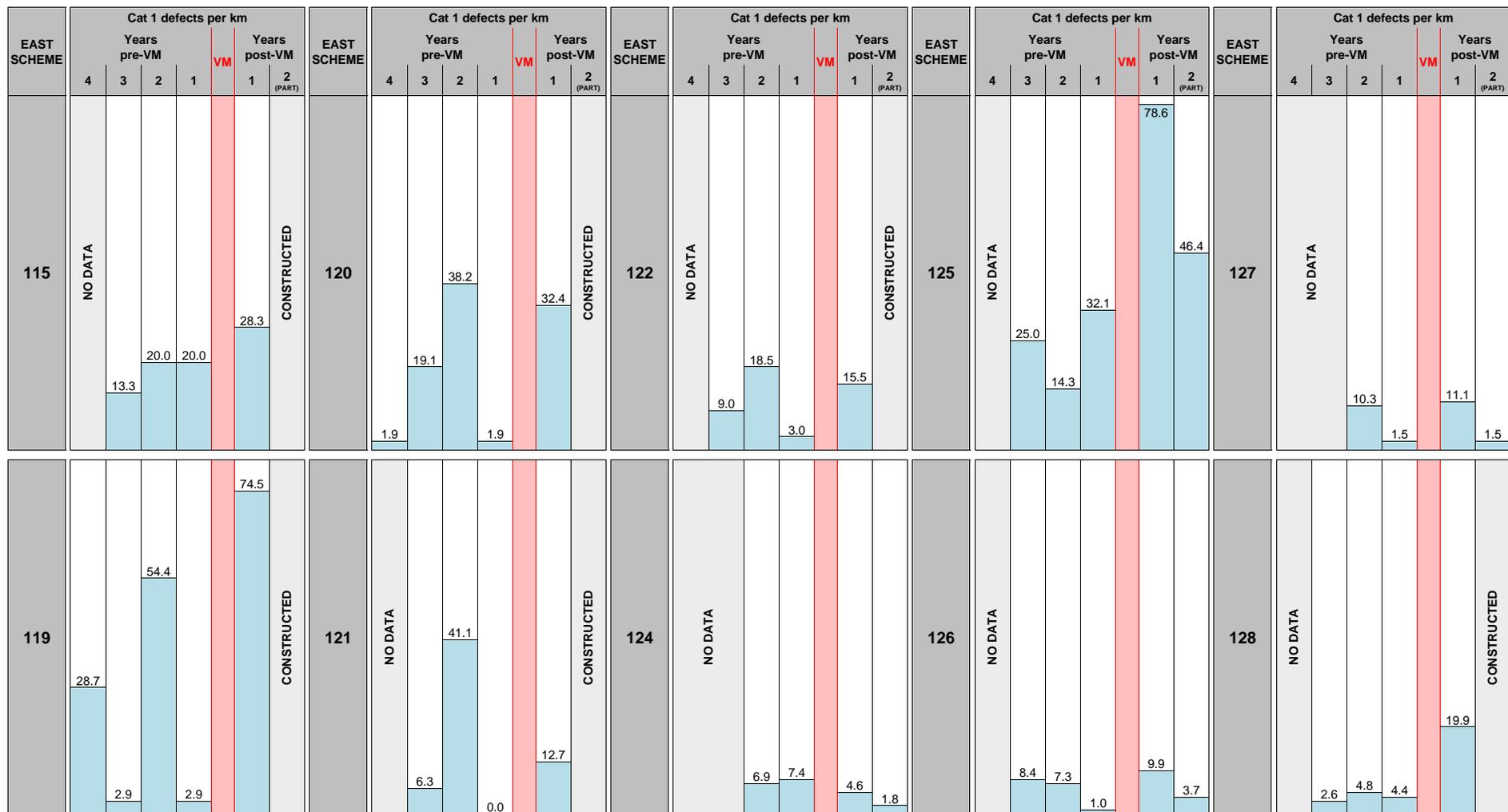


FIGURE J.2. Summary of Cat 1 defect histories for East schemes

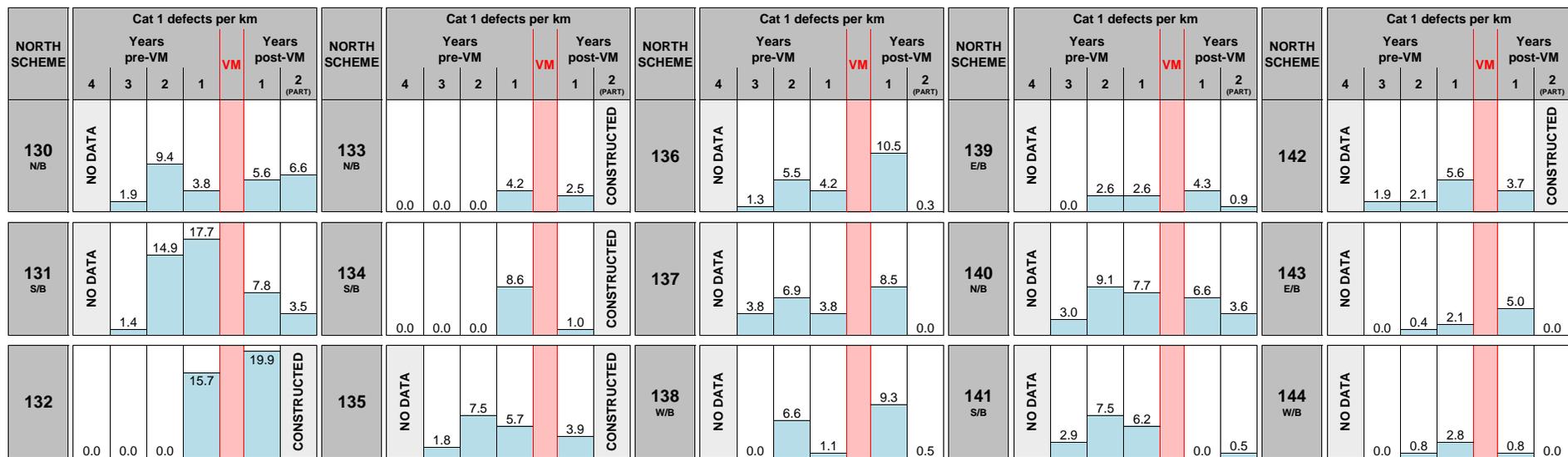
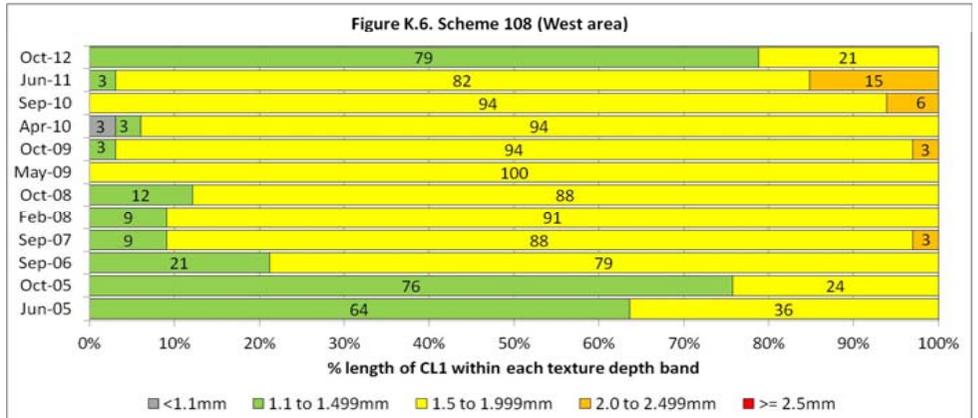
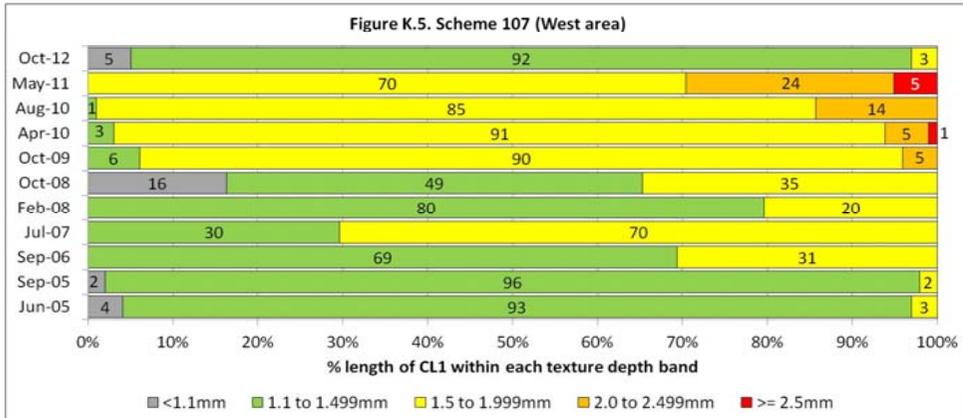
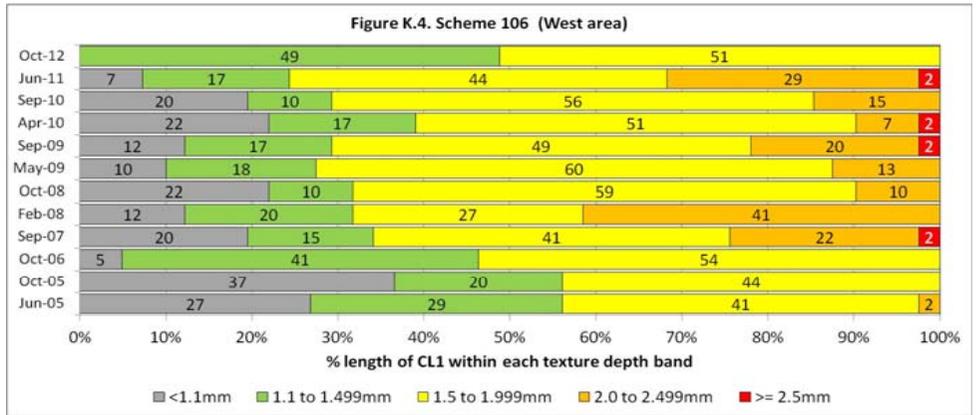
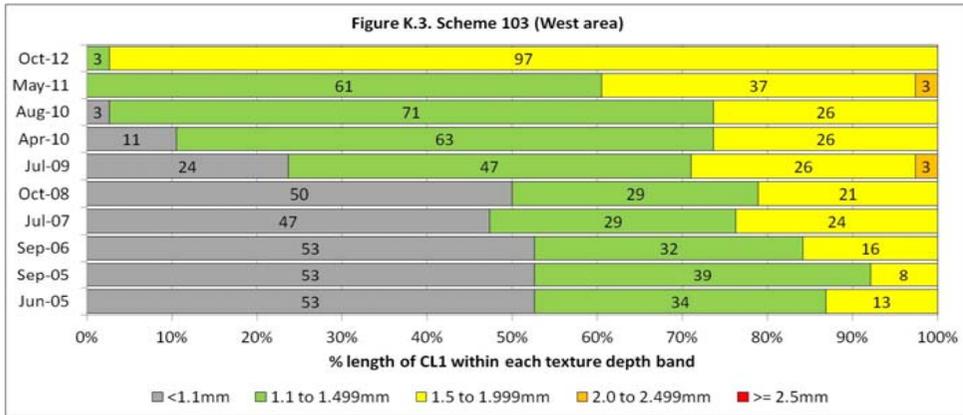
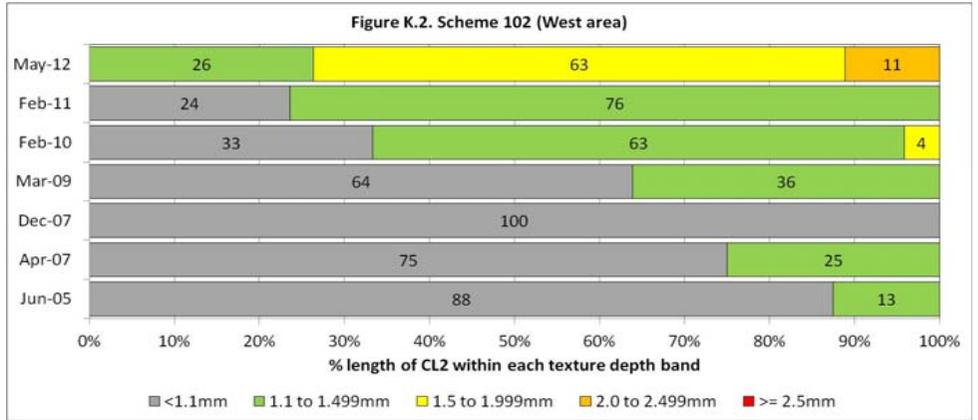
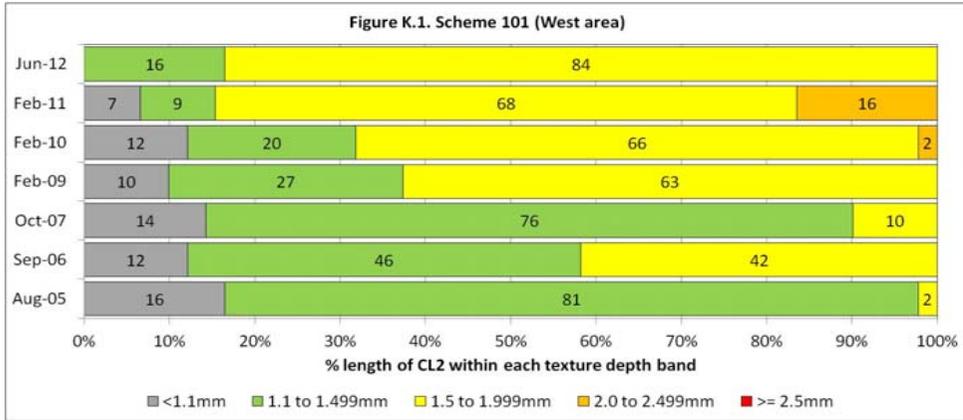
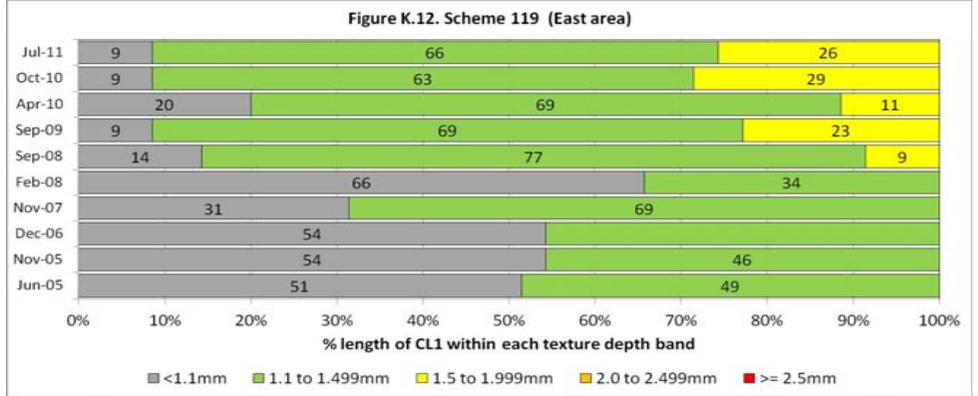
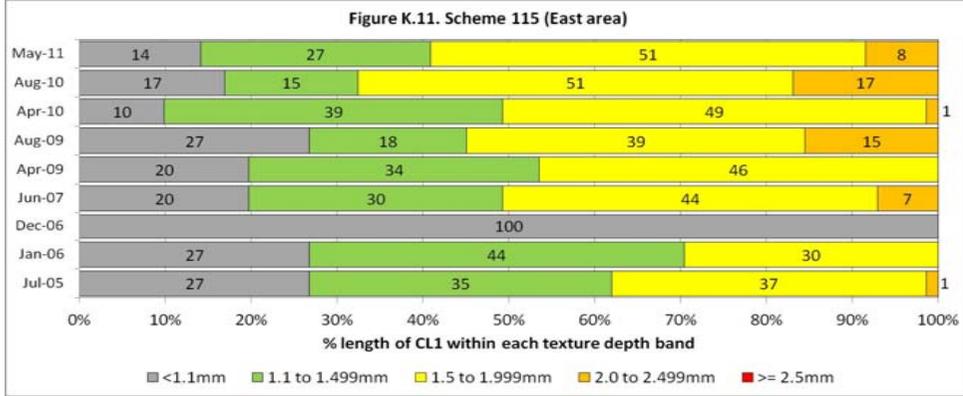
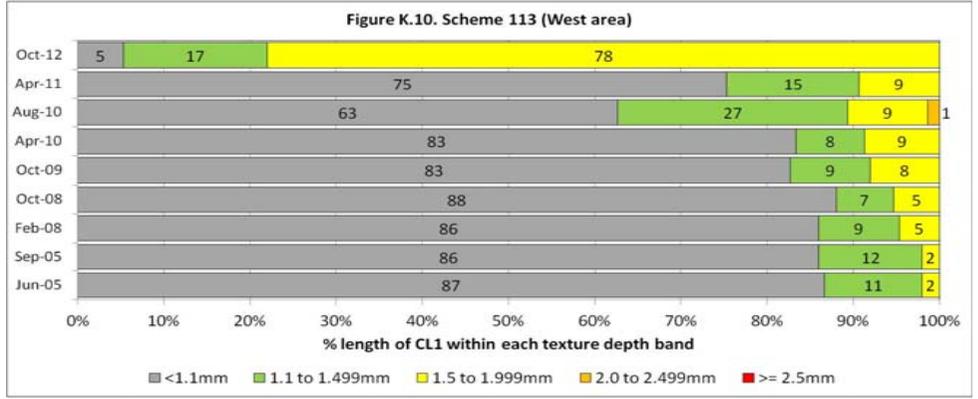
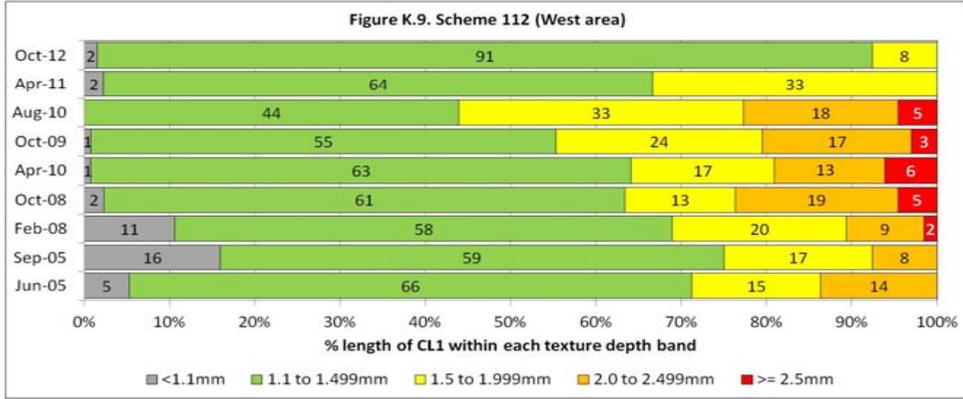
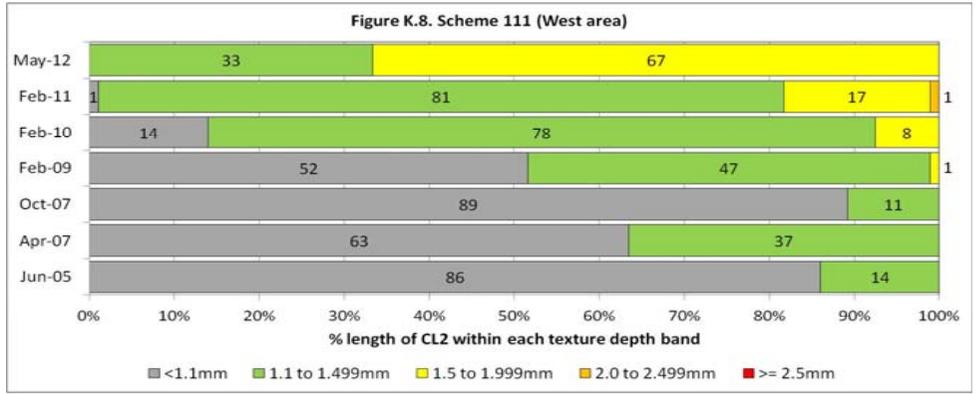
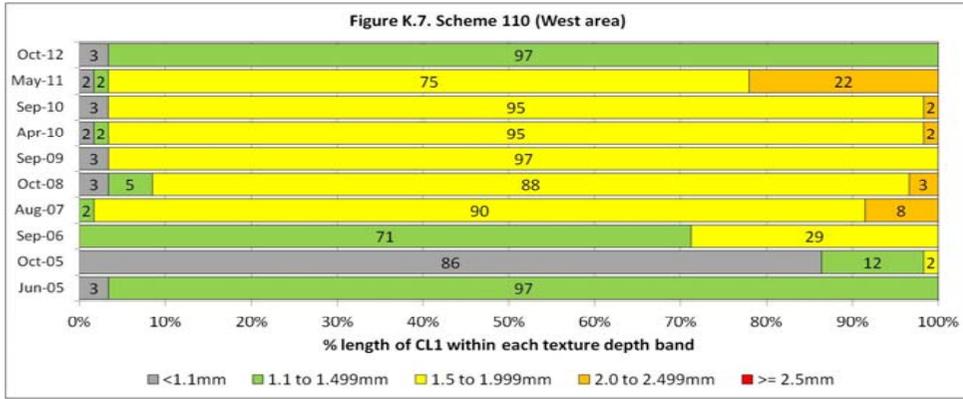
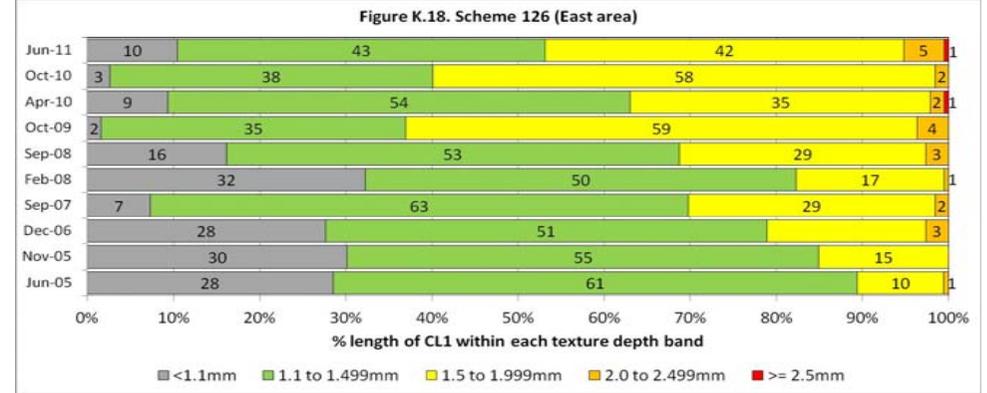
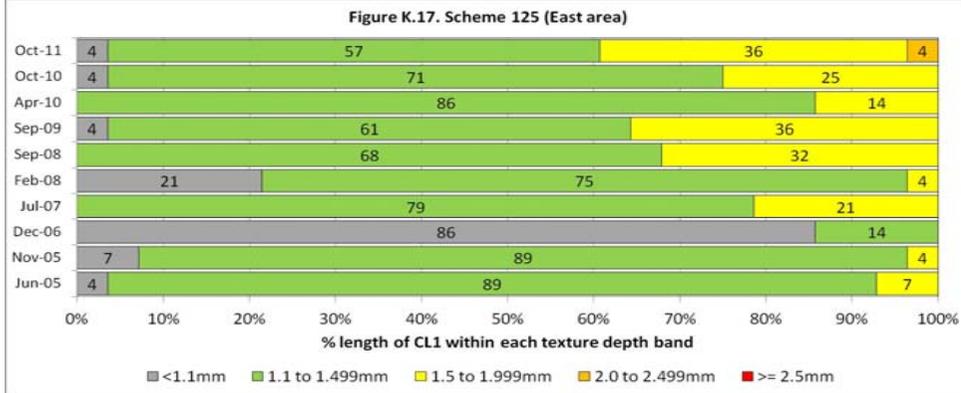
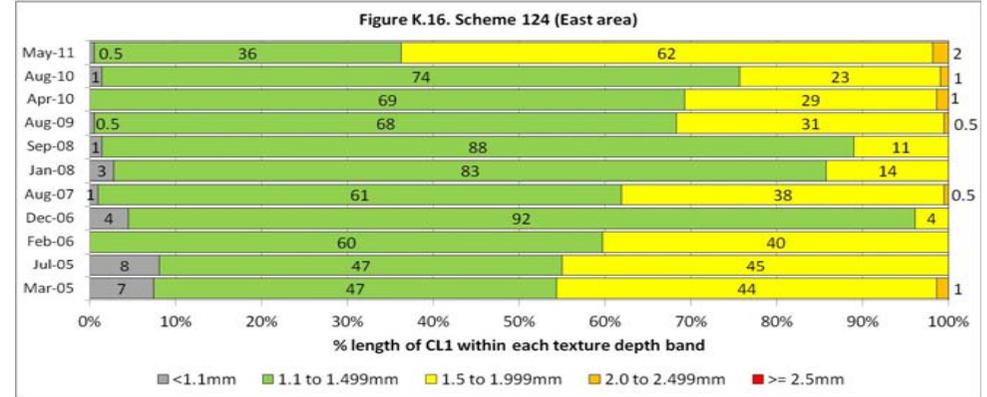
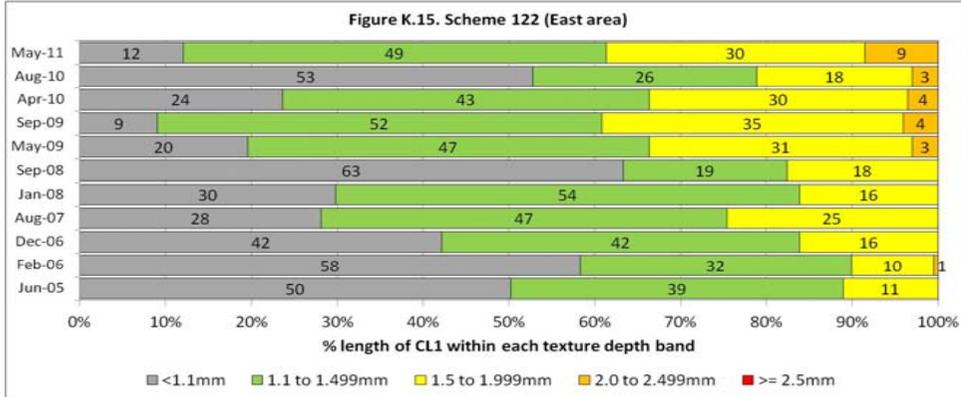
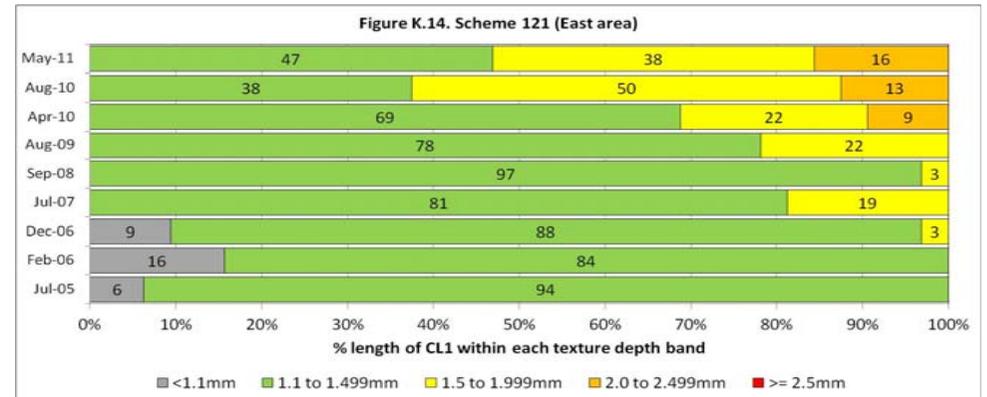
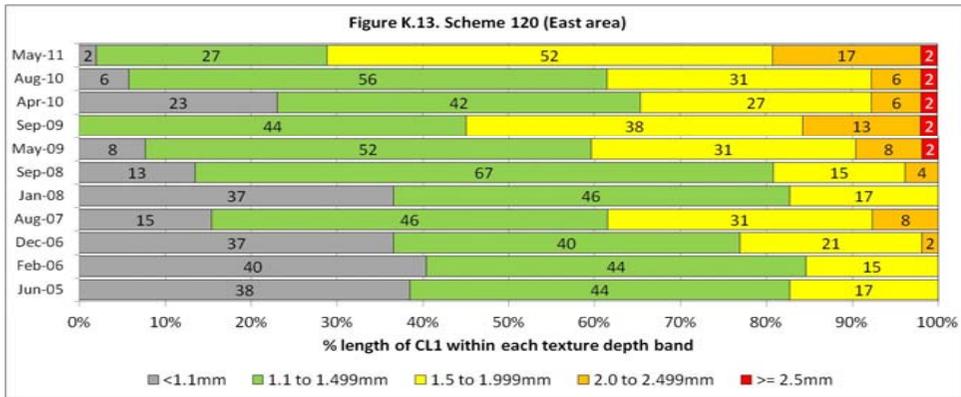


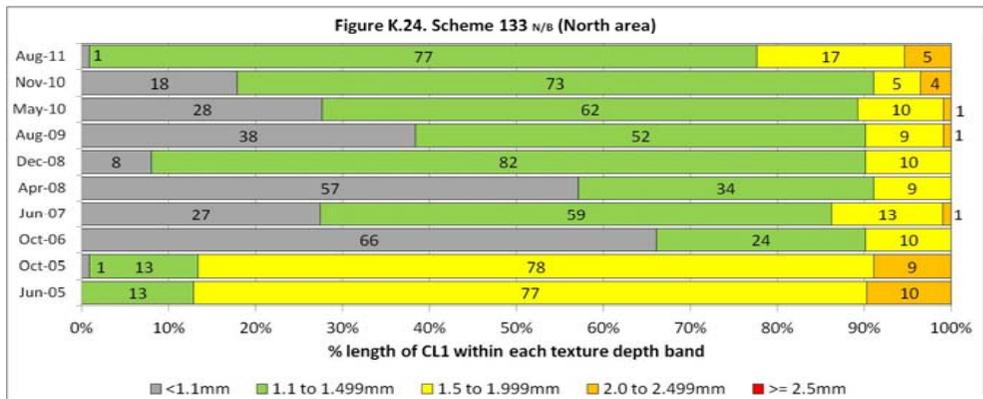
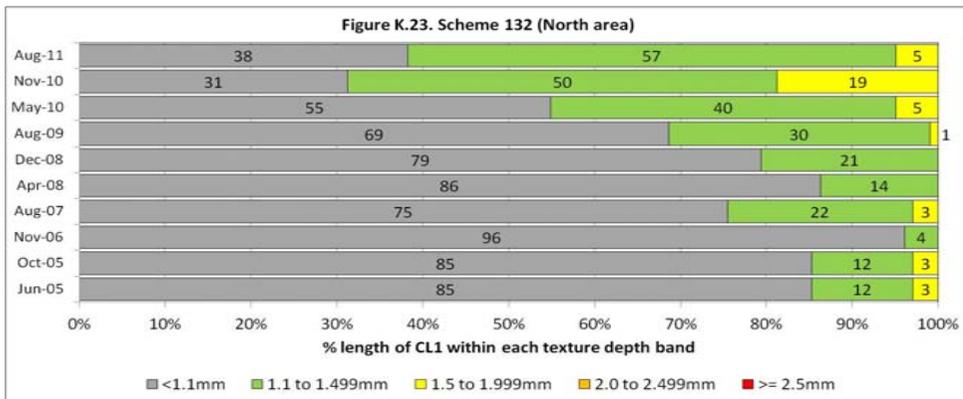
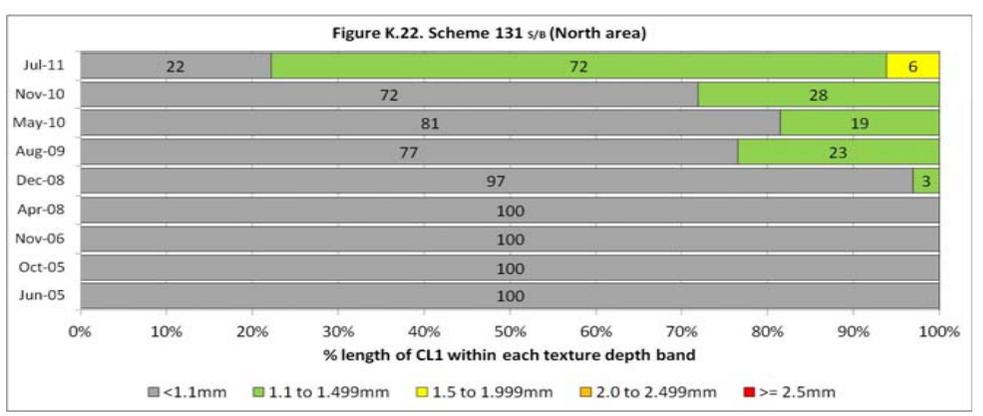
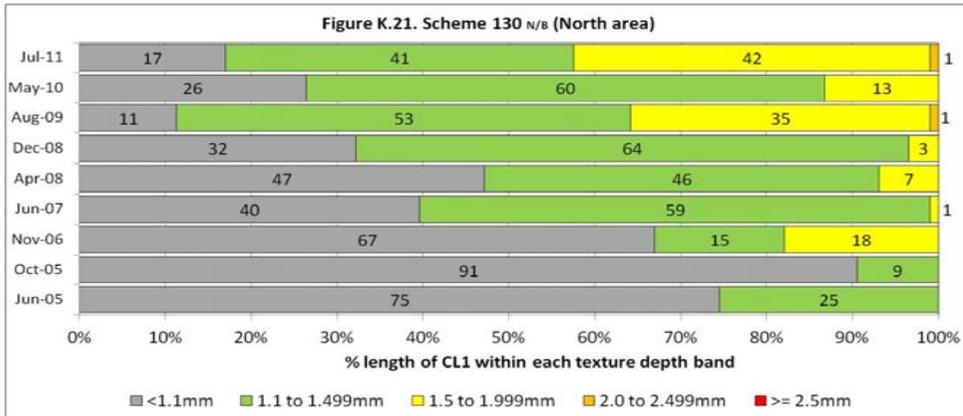
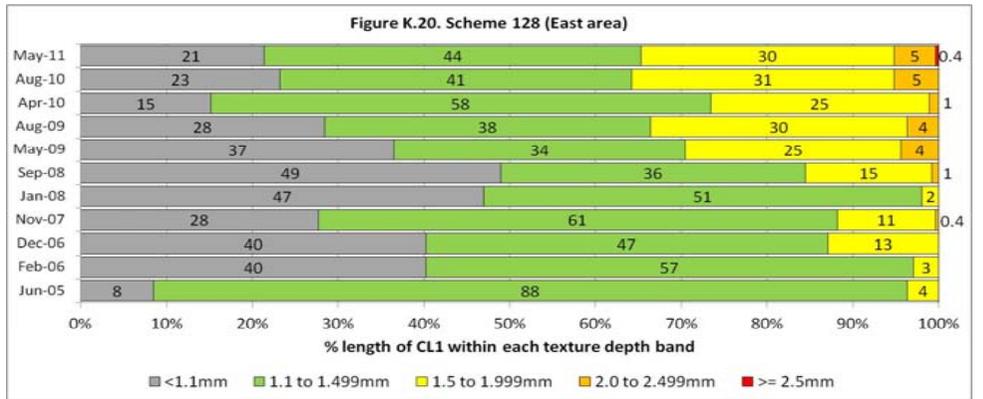
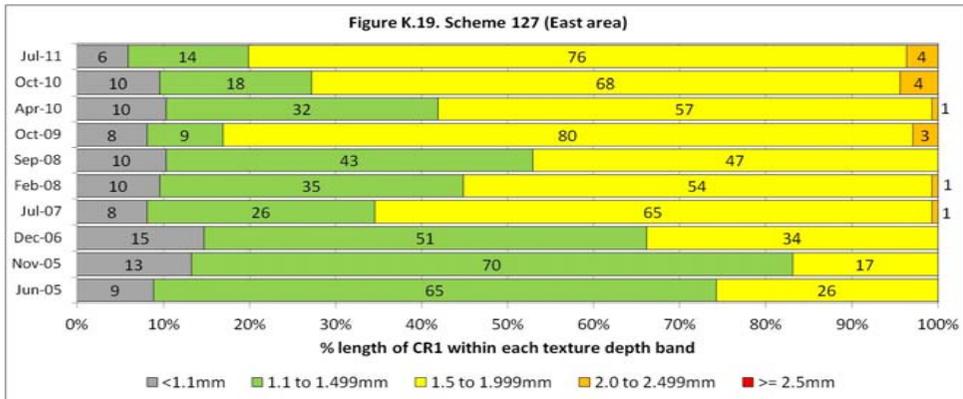
FIGURE J.3. Summary of Cat 1 defect histories for North schemes

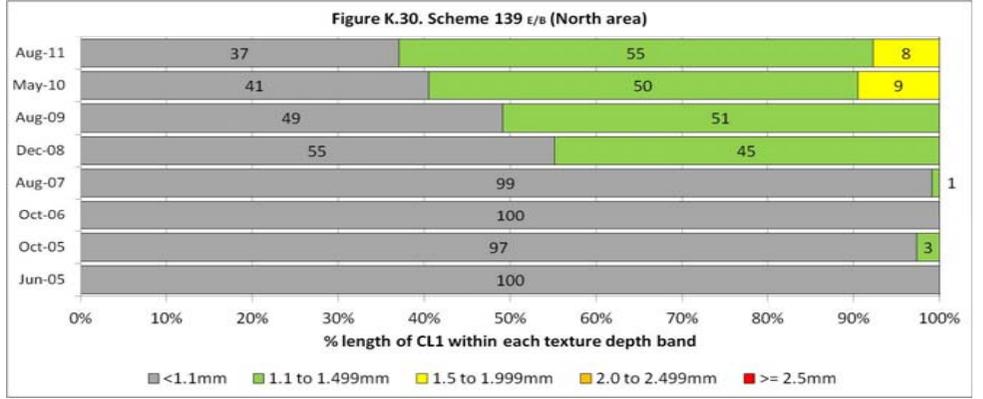
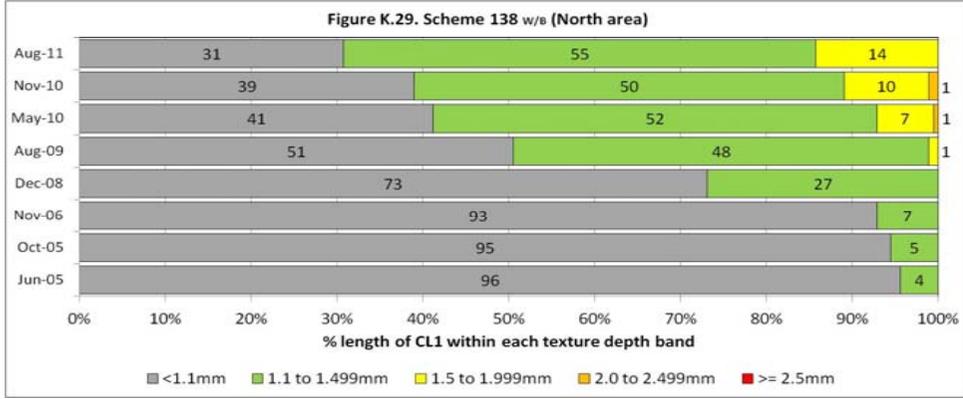
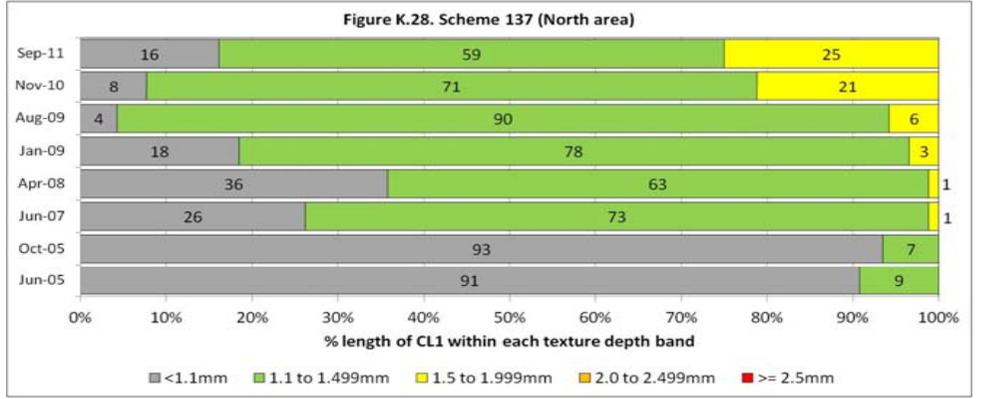
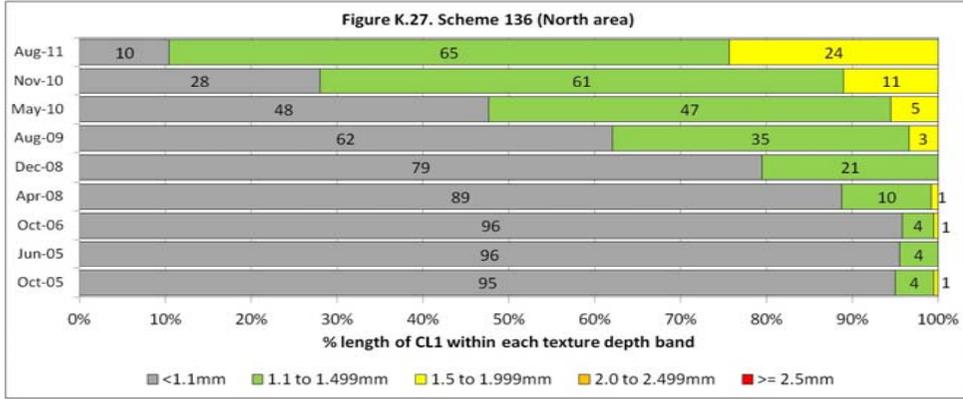
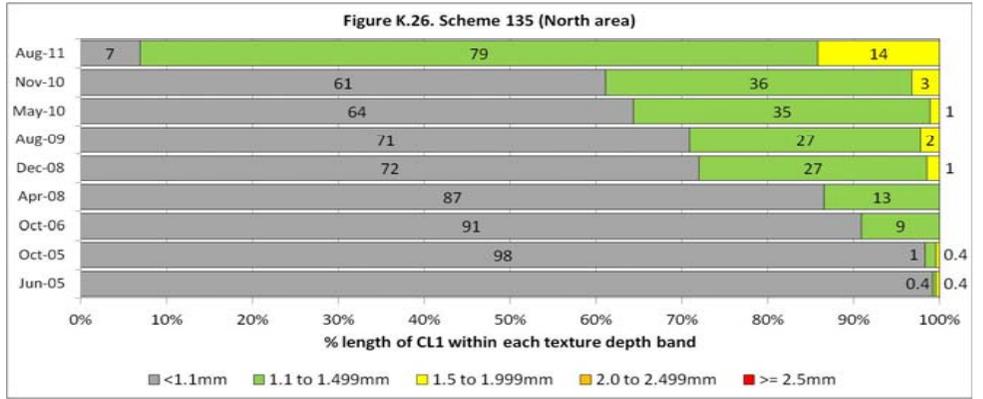
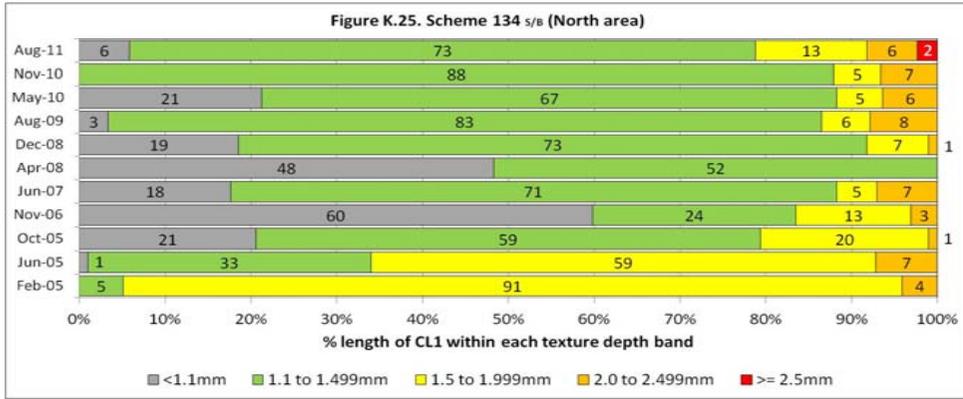
# Appendix K. Scheme level analysis - texture depth summary

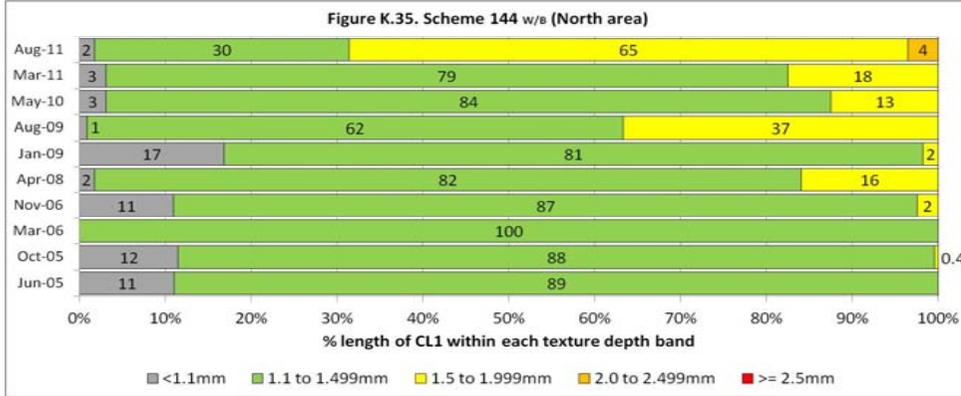
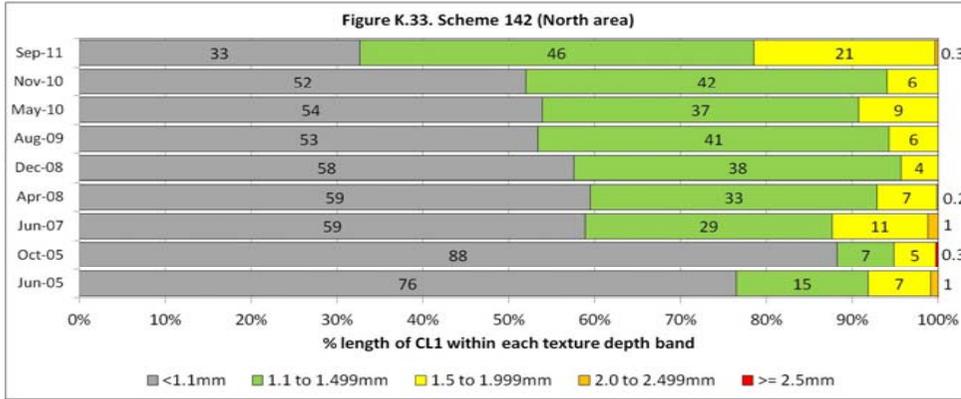
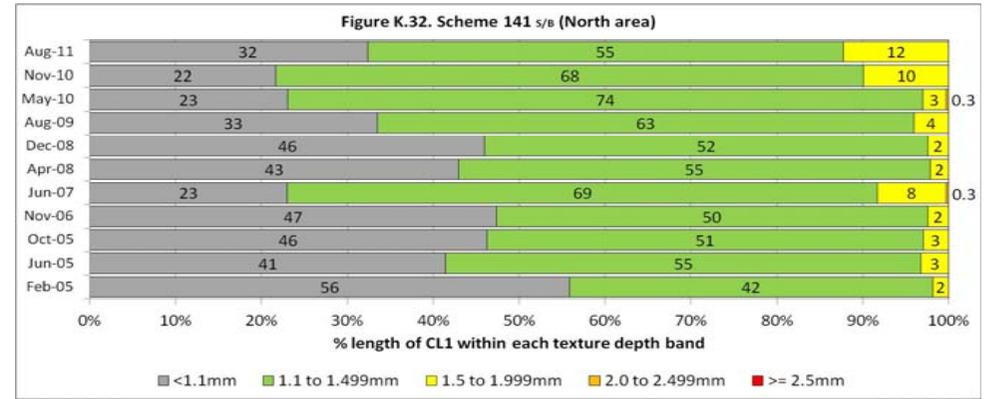
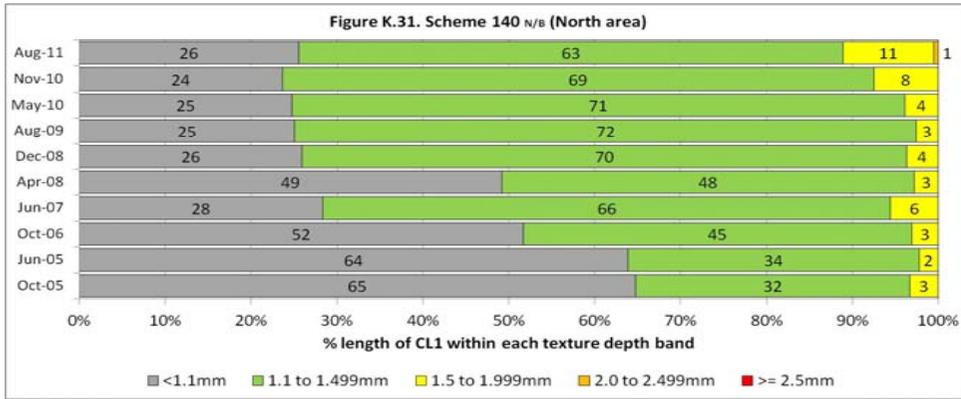












AREA	Scheme Ref	4 years prior to VM					VM year					Change during VM period					
		% of scheme length in each of the following texture bands.....					% of scheme length in each of the following texture bands.....					% of scheme length in each of the following texture bands.....					
		Grey	Green	Yellow	Orange	Red	Grey	Green	Yellow	Orange	Red	Grey	Green	Yellow	Orange	Red	
		<1.1mm	1.1 to 1.499mm	1.5 to 1.999mm	2.0 to 2.499mm	> 2.5mm	<1.1mm	1.1 to 1.499mm	1.5 to 1.999mm	2.0 to 2.499mm	> 2.5mm	<1.1mm	1.1 to 1.499mm	1.5 to 1.999mm	2.0 to 2.499mm	> 2.5mm	
WEST	101	14	76	10			7	9	68	16		-8	-67	58	16		
	102	100					24	76				-76	76				
	103	47	29	24				61	37	3		-47	32	13	3		
	106	20	15	41	22	2	7	17	44	29	2	-12	2	2	7		
	107		30	70					70	24	5		-30		24	5	
	108		9	88	3			3	82	15			-6	-6	12		
	110		2	90	8		2	2	75	22		2		-15	14		
	111	63	37				1	81	17	1		-62	44	17	1		
	112	11	58	20	9	2	2	64	33			-8	6	13	-9	-2	
	113	86	9	5			75	15	9			-11	6	5			
	115	27	18	39	15		27	44	30				25	-10	-15		
	119	31	69				9	63	29			-23	-6	29			
	EAST	120	15	46	31	8		2	27	52	17	2	-13	-19	21	10	2
121			81	19				47	38	16			-34	19	16		
122		42	42	16			53	26	18	3		11	-16	2	3		
124		4	92	4				68	31			-4	-24	27			
125			79	21				86	14				7	-7			
126		7	63	29	2		9	54	35	2	1	2	-9	6		1	
127		8	26	65	1		8	9	80	3			-18	15	2		
128		28	61	11			23	41	31	5		-4	-20	19	5		
NORTH		130	N/B	40	59	1		26	60	13			-13	1	12		
		131	S/B	100				72	28				-28	28			
	132		75	22	3		31	50	19			-44	28	16			
	133	N/B	27	59	13	1	1	77	17	5		-27	18	4	4		
	134	S/B	18	71	5	7	6	73	13	6	2	-12	2	8	-1	2	
	135		91	9			61	36	3			-30	27	3			
	136		96	4	1		28	61	11			-68	57	10			
	137		93	7			4	90	6			-89	83	6			
	138	W/B	93	7			41	52	7	1		-52	45	7	1		
	139	E/B	100				41	50	9			-59	50	9			
	140	N/B	28	66	6		24	69	8			-5	3	2			
	141	S/B	23	69	8		22	68	10			-1		2			
	142		59	29	11	1	52	42	6			-7	13	-5	-1		
	143	E/B	13	81	6		7	50	43			-6	-31	36			
	144	W/B	11	87	2		3	84	13			-8	-2	10			

Table K.1. Summary of change in texture depth during VM period

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