Geotechnical Hazard Knowledge

Task 1-062 Report

31 January 2018

Highways England

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Highways England

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Contents

1 Introduction

This document has been prepared by Mott MacDonald on behalf of the WSP|PB Consortium.

The report covers the objectives of the task, the methodology implemented to achieve the deliverables and the next steps required for future development.

1.1 Background

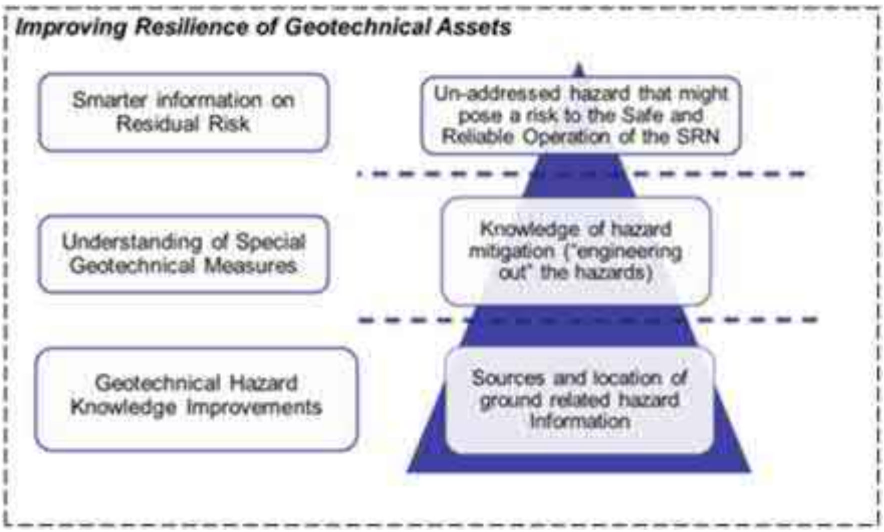
The overriding aim of this task was to contribute to the body of work commissioned by Highways England to improve the resilience of their geotechnical asset portfolio.

Specifically, this task sets out to improve the knowledge of ground-related hazards that may impact on the Strategic Road Network (SRN).

The main objective, as set out in the task specification in Appendix A, was to supplement the geotechnical hazard knowledge already held within Highways England and work to improve the resilience of the SRN. The ground related hazard products of this task will ultimately feed into the understanding of their spatial relationship to Special Geotechnical Measures (SGMs) that have been constructed on (or around) the SRN. The ultimate aim of the entire body of research and development work is to enable the identification of un-addressed hazards on the SRN, as illustrated in Figure 1 below.

Early in the life of the project, an incident on the SRN resulted in a change to the project objectives (in full agreement with Highways England) that is set out in detail in the WPQP in Appendix B.

Figure 1: Hierarchy of ground-related hazard and residual risk knowledge



Source: Mott MacDonald Task 408

1.2 Specification

The specification, as provided by Highways England in the tender information for this task, is included in Appendix A.

It is important to recognise that there has been a significant change to the objectives of this project, and as such the specification is superseded in a number of places. The WPQP included in Appendix B sets out the revised objectives, and the methodology by which the objectives were envisaged to be met.

1.3 Objectives and solutions

Table 1 provides a summary of the objectives of the task and a description of any changes to the solutions that were delivered.

Table 1: Summary of task objectives and work required with comments on any changes since project initiation

Work Required (summarised from the Task Specification in Appendix A)	Work completed and comments
Development of a Project Initiation Document, and agreement with the Highways England Project Sponsor	Fulfilled by the Work Package Quality Plan (Appendix B)
Liaison with existing Highways England task teams, working on resilience assessment and Special Geotechnical Measures	Regular liaison with HE teams, Arup team, Atkins team and wider stakeholder groups. See Section 3
Review of previous tasks related to the development of improved understanding of ground-related hazards and their relationship to the SRN	Completed
Development of a draft framework for ground related hazard assessment. This framework would need to consider both the availability of information and its quality	Removed from task, as agreed in WPQP
Prioritisation of ground related hazards to be assessed, in agreement with Highways England and a stakeholder group	Completed, see Section 2.7
Previous work has been undertaken to determine key-word sets for intelligent searching of records in the HAGDMS technical archive. As part of this task, key-word sets for the remaining identified hazard groups should be derived, and tested, prior to handing over to the HAGDMS Support Team	Completed, see Section 2.4
Previous work has been undertaken to determine a Slope Hazard Rating for earthwork slopes recorded in the HAGDMS Geotechnical Asset Database. As part of this task, this ground-related hazard dataset should be reviewed and updated. Consideration should be given to: • The currency of the data used in the analysis • The geotechnical asset types, and their appropriateness for inclusion in the analysis • The determination of any weightings used in the analysis, and their correlation to other HE tasks (such as the tasks considering cross-asset risk assessment) • The potential to calibrate the revised Slope Hazard Rating against records of geotechnical failures The potential for liaison with other infrastructure asset owners, to potentially collaborate on elements of the analysis to gain mutual benefit	Completed, see Section 2.5
Previous work has been undertaken to investigate and quantify the cross-asset relationships that impact on geotechnical assets, the most important being the relationship to drainage. This task should be cognisant of this work, and should investigate how this improved understanding of cross-asset relationships can be brought into practical usage in improving the understanding of ground-related hazards	Investigated for SHR update, but not completed due to lack of available data. See Section 2.5.3

Work Required (summarised from the Task Specification in Appendix A)	Work completed and comments
Development of a pilot phase, possibly for a single hazard and a constrained geographical area, to be determined by the contractor, and agreed with the Highways England Project Sponsor. This pilot phase should explore all the envisaged elements of the main project phase, and should: • Combine hazard information sources to determine the geographical location of the hazard(s) in relation to the SRN • Make use of available information on the location of Special Geotechnical Measures (SGMs) in the geographical area, and show these in relation to the SRN • Determine a means of relating the effectiveness of the recorded SGMs in addressing the identified hazard(s) Produce information on the location, and type, of potential areas of unaddressed hazard(s) in the pilot area, through completion of the above steps, or similar equivalent steps that are developed by the contractor	Considerably changed as described in agreed WPQP. Initial hazards maps developed nationally, for all hazards (see Section 2.2 and 2.8)
Presentation of the pilot phase to Highways England and the stakeholder group, and determination of the agreed way forward	Changed to various stakeholder discussions on the development and validation of hazard maps
Main phase production of hazard products, in the order of agreed prioritisation. This phase is to be time-boxed, with as much being achieved as possible in the available time. This main phase of the task will: • Be carried out based on the agreed way forward determined from the pilot phase • Be adaptable, such that any required changes to the methodology can be carried out, once agreed with the Highways England Project Sponsor • Consider the likely impact of the outputs of the task on the current (and potential future) Performance Indicators used by Highways England in their Geotechnical Asset Management processes Consider the linkages between ground-related hazards, and wider SRN resilience, through liaison with the related tasks that are addressing resilience issues	Considerably changed as described in agreed WPQP. Initial hazard maps developed nationally, for all hazards (see Section 2.2 and 2.8). Initial development of vulnerability maps commenced (see Section 4) Regular liaison with Arup Resilience team, including input to development of guidance notes (See Appendix G)
Validation of developed products, with the stakeholder group and Highways England. This stage may include liaison with other infrastructure asset owners. Should it be deemed appropriate by the Project Sponsor, this stage may also include feedback to the British Geological Survey (BGS) on any of their products used as part of the task analysis, and their effectiveness in relation to specific issues affecting the SRN	Completed. Liaison with HE and stakeholders throughout development of hazard maps and beyond. Some discussions held with BGS (more in plan).
Preparation of a final report, including recommendations for next steps	Completed – this report

Source: Task 1-062 WPQP and this report

Table 2 summarises the task deliverables stated in the WPQP with comments and signposting to the relevant location of the deliverables in this report.

Table 2 Summary of Deliverables from the Work Package Quality Plan with post completion comments

Sub-task	Key Deliverables from the Work Package Quality Plan (Table 1, Appendix B)	Post completion comments on the deliverables	Report Section
Project Initiation	• Work Package Quality Plan (Project Initiation Document)	Completed – Issued 09/11/16	Appendix B
Preparation and data gathering plus Coal Mining Hazard Map (Revision 1)	• Coal mining hazard map (Rev01)	Completed – Live on HAGDMS on 20/10/16	Section 2.2
	• Guidance documents to accompany coal mining hazard map (Rev01)	Completed – Live on HAGDMS on 20/10/16	Appendix C
	• Determination of method for Slope Hazard Rating refresh and presentation to HE.	Completed – largely based on comments on 2014 iteration from HE	Section 2.5
	• File note on method of location for the task (included in guidance documentation for coal mining map)	Superseded by definition documents and Arup resilience guidance notes	Appendix C,D,E,F and G
Hazard prioritisation	• Agreed prioritisation of hazards for the project	Completed – multiple revisions and finalised on 19/12/16	Section 2.7
Revision 1 version of hazard maps	• Revision 1 hazard maps (offline) for all hazard groups	Completed	Section 2.2, and 2.8
	• Revised 1 hazard maps for upload to HAGDMS/HAGIS following assessment and central validation	Completed – Live on HAGDMS on 20/04/17	Section 2.2, and 2.8
	• Revised Slope Hazard Rating map	Completed – Live on HAGDMS on 20/04/17	Section 2.5
	• Guidance and explanatory documents to accompany Revision 1 hazard maps	Completed – Live on HAGDMS on 20/04/17	Appendix F
	• Launch webinar	Not completed. Publicised by HAGDMS news, and through news story on internal HE intranet	
	ADDITIONAL TASK – RSHI results hazard map	Completed – Live on HAGDMS on 31/08/17	Section 2.6
Revision 2 version of hazard maps	• Hazard topic keyword sets for implementation in HA GDMS.	Completed – Live on HAGDMS on 07/06/17	Section 2.4
	• Suite of revision 2 hazard products for implementation in HAGDMS and HAGIS (number dependent on time-boxing)	Concept changed – completion of a Non-Coal Mining Rev02 map but agreed it should not be implemented in its current development on HAGDMS.	Section 4
	• Explanatory documentation for Revision 2 hazard products.	Concept changed – documentation of the research and development of the revision 2 map forms part of Section 4.	Section 4
	• Envisaged future usage of products in KPIs and resilience assessment (in task report)	Completed – discussion on future user	Section 5
Reporting	• Draft and Final versions of task report and A3 Knowledge Transfer sheet	Completed	Appendix H
	• Presentation for task end webinar.	Replaced by various stakeholder discussions	

2 Methodology and deliverables

2.1 Work Package Quality Plan

The Work Package Quality Plan was the initial project deliverable prepared by Mott MacDonald on behalf of the WSP|PB Consortium. The document set out the plans for the scope of work, project management and project quality. It can be found in Appendix B. It was agreed with Highways England on 09/11/16 (by Project Sponsor David Patterson).

2.2 Coal mining hazard map

2.2.1 Background

The long history of coal mining in England has left a legacy of hazards in the ground with the potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Coal Mining Hazard Rating Map for a 1000m corridor centred around the Strategic Road Network has been prepared. It is intended to be used as an initial high level hazard awareness map, particularly aimed at users that may have little or no geological or geotechnical knowledge.

The production of the Coal Mining Hazard map was prioritised and accelerated due to an event that occurred on the network early in the project. On 25/06/16 a mine shaft cap gave way under the A1 carriageway near Gateshead creating a 5m wide and 3m deep hole, significantly raising the profile of mining hazard within HE (see Figure 2). This change in priority happened early enough in the project for some re-scoping to be successfully achieved, as captured in the WPQP (Appendix B).

Figure 2 Mine shaft capping failure on the A1 carriageway Gateshead

Source: Northumbria Police

2.2.2 Input data sets

The map was constructed using selected Coal Authority data and analysed in a Geographical Information System (GIS). Table 3 summaries the input data, its source and the weightings applied in the generation of the Coal Mining Hazard map.

Table 3 Summary of data Sources and Weightings used in the Coal Mining Hazard Map production

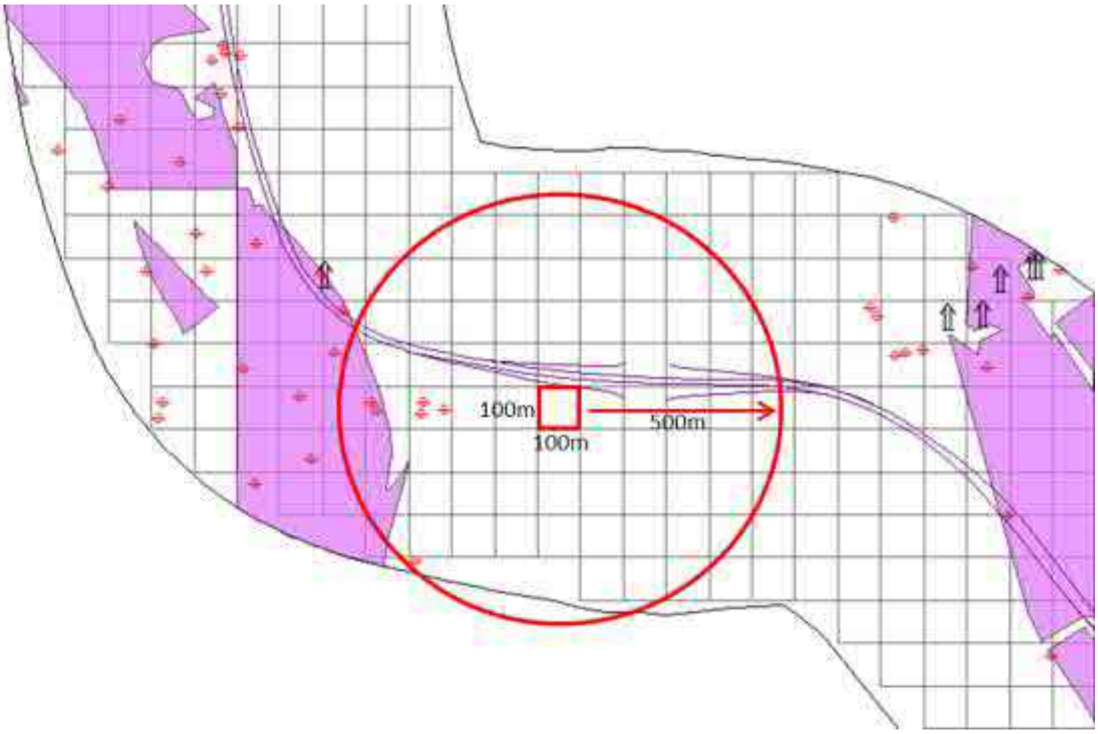
Dataset (HAGDMS Layer Name)	Source	Outline Description	Data type	Date	Expert Judgement Weighting (out of 20)
Mine entries – Adit	Coal Authority	Mine entries comprising of inclined entrances (adits, slants, drifts etc).	Points	2010	18
Mine entries - Shaft	Coal Authority	Mine entries comprising of vertical entrances in the workings (shafts, staples, pits etc).	Points	2010	20
Surface mining	Coal Authority	Surface coal mining, also known as opencast sites, shows the site boundary, which encompasses all extraction areas for a past or present opencast site.	Polygons	2010	8
Probable workings	Coal Authority	Areas where the Coal Authority believe that there is evidence of past coal mine workings but have no formal abandonment plan for those workings e.g. an adjacent mine plan may have the annotation 'Ancient workings', located by development and/or site investigation, the workings may even be shown on an estate/surface plan.	Polygons	2010	12
Underground workings	Coal Authority	Areas known from abandonment plans where underground workings are less than 30m depth. Deemed at risk due to insufficient overlaying strata to dissipate any movement from within the workings before they reach the surface.	Polygons	2010	13
Coalfield extents	Coal Authority	Mining and geographical data held on the Coal Authority Mining Database.	Polygons	2010	5
Workable outcrops	Coal Authority	Identifies where an underground coal seam reaches rockhead. The outcrop seam indicates areas of workable coal that may have been worked at some time in the past. This dataset contains a buffer of 50m on the dip side of the outcrops position as held by the Coal Authority.	Polygons	2010	14

The Coal Authority data used in the creation of the map was as supplied to the HAGDMS team in 2010. When compared to more up-to-date data on the Coal Authority website, the data sets were seen to be very similar in spot-checks, but a full check could not be carried out as the latest data is not available to Highways England. In consultation with the expert stakeholder group convened to generate the hazard map, it was agreed that the 2010 data was sufficient for the generation of the initial map. It should also be noted that the input data used for the map has now been removed from HAGDMS, and users are advised to visit the Coal Authority online map viewer for the latest detailed information.

2.2.3 Methodology

The extent of the datasets used to form the map, were constrained to a 1000m corridor centred on the SRN. This corridor was split into a 100m x 100m grid, and complete grid squares within the corridor were used as the foundation of the GIS methodology. From the centre point of each complete grid square a 500m circular buffer was created, and these buffers were used to spatially query the Coal Authority data, which consists of both polygon and point data, see Figure 3.

Figure 3 Map methodology showing 500m grid buffer intersection polygon and point data within 1000m of the SRN corridor



The percentage intersection of each polygon dataset and the count of each point dataset were calculated for each buffered grid square. The resultant values were then attributed to the original grid square. A weighted average analysis was then used to calculate an overall hazard score per grid square, using a simple additive algorithm to sum all of the individual weighted scores. The weightings (see Table 3) were derived by expert judgement, and based on a 0-20 scale. The weightings were changed over three iterations with expert stakeholders, each time assessing the resulting map outputs

Further details and explanation of the map methodology can be found in the HAGDMS Coal Mining Hazard Rating data description document in Appendix C.

2.2.4 Output

The Output of the analysis is a nationwide coal mining hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into four categories (A to D). A summary of Coal Mining Hazard Rating categories can be seen in Table 4.

Table 4 Summary of Coal Mining Hazard Rating banding

Coal Mining Hazard Rating	Colour	Explanation
A		Outside coalfield area
B		Low hazard (inside coalfield area)
C		Medium hazard (inside coalfield area)
D		High hazard (inside coalfield area)

The categories B, C and D in Table 4 are arbitrary, and are based on expert judgement only.

The map went live on HAGDMS/HADDMS on 20/10/2016 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 4 shows a screenshot of HAGDMS showing the Coal Mining Hazard map with the full range of banding categories for a section of the M58 in the North West of England.

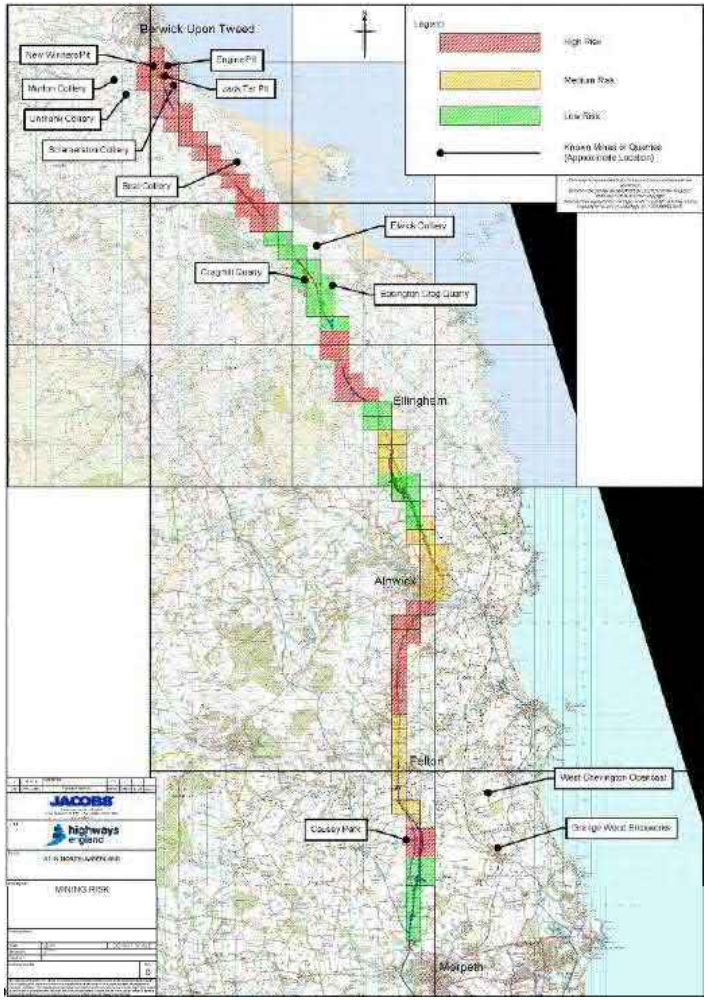
Figure 4 Screenshot from HAGDMS of the Coal Mining Hazard Map

2.2.5 Validation

In 2015 Highways England commissioned Jacobs to identify known or suspected geotechnical risks, including that of coal mining for a section of the A1 between Morpeth and Berwick-upon-Tweed. The resulting Coal Mining Risk map was georeferenced during this task and overlaid on the new Coal Mining Hazard map for comparison. Figure 5 shows the Jacobs Coal Mining Risk map and the final iteration of the Coal Mining Hazard Map. Whilst the hazard map uses one more banding category than the risk map you can clearly see that the spatial distribution of the hazard categories closely resembles that of the risk map.

Figure 5 Comparison of a) Jacobs' Coal Mining Risk map and b) New Coal Mining Hazard map of the A1 between Morpeth and Berwick upon Tweed.

a)



b)

On the 19/09/16 a steering group meeting was held with Highways England project sponsor David Patterson and several Highways England Area Geotechnical Advisors who have knowledge of the ground conditions across the Network in areas of known coal mining. During the meeting the 3rd party data, methodology and map product was presented to the group. Following this, locations of interest across the network were explored and interrogated to assess the results of the methodology. Known problem locations including that of the A1 shaft collapse near Gateshead were also visited to ensure these resided in the highest hazard category. Adjustments to the methodology were made to meet the requirements of the expert group, resulting in the finalised hazard map.

On 09/11/16 there was a demonstration of the hazard map to members of The Coal Authority at their head office in Mansfield. Present at the meeting were coal mining and geospatial experts. In particular the choice of the 3rd party data (from the CA) to include in the assessment and the methodology was discussed. The Coal Authority were content with the methodology used, although several attempts to receive any feedback in writing have been unsuccessful.

2.3 Draft framework for ground related hazard assessment

The development of a framework to link ground related hazards to Special Geotechnical Methods was removed from the task. This was due to a change in the project direction at a very early stage of the project. It was agreed at the time with the Project Sponsor and is documented in the Work Package Quality Plan in Appendix B.

2.4 Completion of topic search keyword lists

As part of the task a previous Mott MacDonald project was revisited. Task 408: As-built geotechnical asset data was completed in 2015 and amongst other tasks defined a list of topic search keywords for a suite of hazards to be used on HAGDMS within a new topic-base search tool. The hazard list was extended to Rock Landslides and Shrink/Swell in this task. Table 5 shows the list of keywords for both hazards that was implemented into the topic search functionality of HAGDMS.

Table 5 List of topic search keywords for Rock Landslide and Shrink/Swell hazards

Rock Landslide Keywords
Dentition
Hazard Index Survey
Ravelling
RHI
RHRS
Rock bolts
Rock fall
Rock falls
Rock slope hazard index system
Rock slope hazard rating system
Rock slope inspection
Scaling
Scree
Talus
Toppling
Toppling failure
Wedge failure

Shrink/Swell Keywords
Desiccation
Expansible
Management Action Plan
Shrink swell
Shrink-swell
Shrink/swell
Swell shrink
Swell-shrink
Swell/Shrink

The topic search for the new hazards went live on HAGDMS on 07/06/2017. Figure 6 shows a screenshot of a topic search result of Rock Landslides for a portion of the M6 at Lune Gorge.

Figure 6 Screenshot of HAGDMS showing a Rock Landslides topic search result

2.5 Slope Hazard Rating (SHR) map

2.5.1 Background

The Slope Hazard Rating (SHR) layer on HAGDMS provides the output of an analysis into the performance of the major Geotechnical Assets of Highways England (HE). An initial iteration of the SHR analysis was carried out in 2014, and the associated layer (along with the note on its derivation) remain on HAGDMS. This is to ensure that reference can still be made to this initial iteration if it has been cited in any reports or other documents produced for HE. A new iteration (2017) was calculated to update the 2014 variant. Alongside an update of the datasets that feed into the analysis, modifications to the methodology were made:

- Consideration of only Major Earthworks (Cuttings, Embankments and Bunds). Minor Earthworks (at grade sections and earthworks less than 2.5m in height) are excluded from the analysis,
- Improved filtering of the observations used to determine the performance of the asset cohorts, to only include those which can be related to relevant slope stability issues

(through use of GAD tick boxes and key word searching in the observation descriptions),

- Update to the observation weightings to take account of changes in the HD41/15 revision,
- Review, and update where required, of the geological code grouping, to take account of improved knowledge, some of which has been gained through liaison with other major UK transportation infrastructure owners.

2.5.2 Input data sets

The 2017 iteration of the Slope Hazard Rating is based on a data cut of the HAGDMS Geotechnical Asset Database (GAD) taken on 28/09/16. Any applicable geotechnical assets added to HAGDMS after this date will not be included in the analysis, and likewise any assets deleted after this date will be included. The SHR represents an analysis of the performance of the geotechnical assets at that date, and any changes to observations, or addition of new observations, after that date, will not be represented in the 2017 SHR output.

2.5.3 Methodology

The geotechnical assets included in the analysis (those which have Preliminary and Approved status) are assigned to a cohort based on geological grouping and the morphology factor (combined slope angle and height) of their highest point.

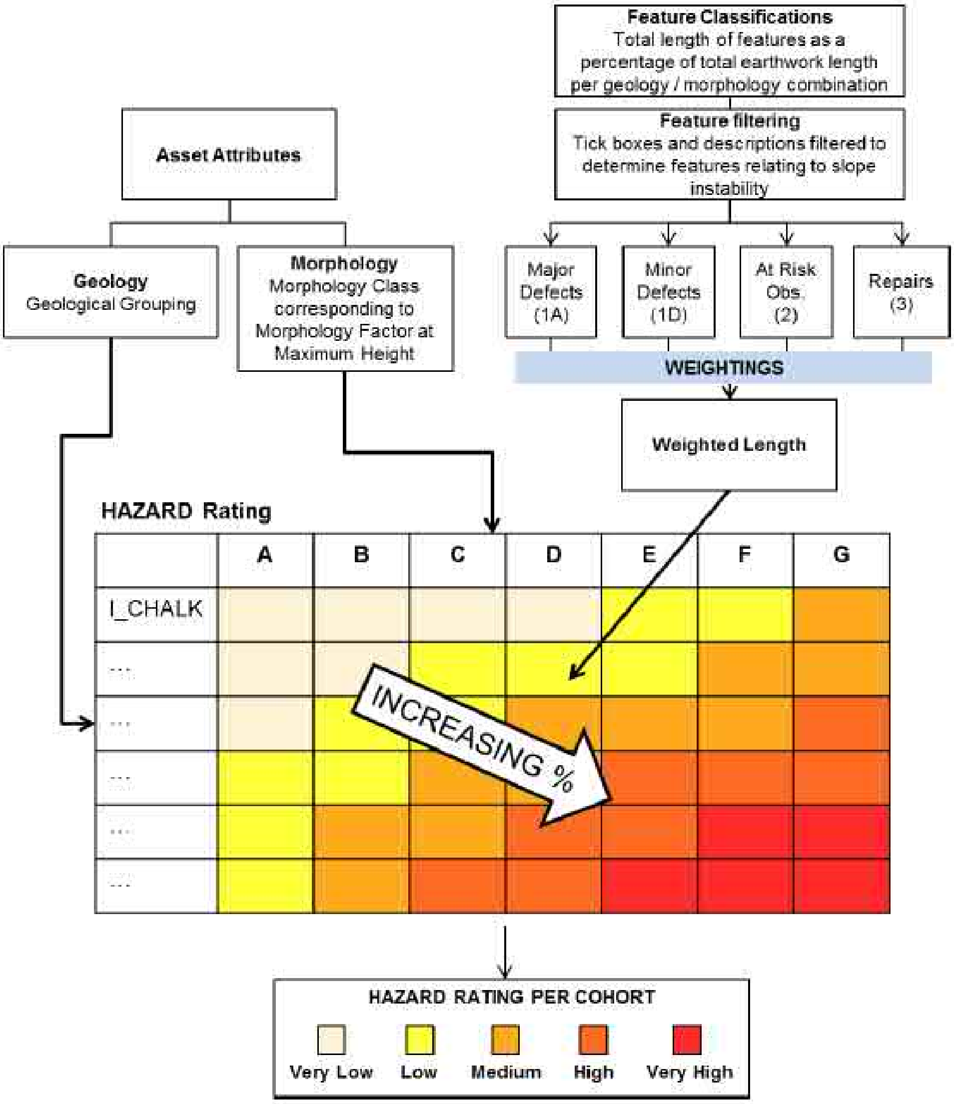
Within each cohort, the total length of defect, at risk and repair observations is then calculated, having first filtered these to include only observations which are related to slope instability. The total lengths are determined for:

- Major defects (Class 1A),
- Minor defects (Class 1D),
- At risk areas (Class 2),
- Repairs (Class 3).

The total lengths are then weighted for importance (in relation to asset performance), and summed for each cohort. The weighted lengths of observations are expressed as a percentage of the total length of earthworks within the cohort. For clarity this percentage is referred to as the Weighted Length.

A summary of the updated analysis methodology is shown in Figure 7 below.

Figure 7 Slope Hazard Rating (2017) analysis methodology



Cross asset relationships were initially investigated to be implemented into the update to the methodology, but were abandoned because drainage data is transitory, and cross-asset behaviour was only calculated for failed assets in tasks 434, thus making it unsuitable for an assessment of the whole asset portfolio.

Further details of the data and map creation can be found in the HAGDMS Slope Hazard Rating data description document in Appendix D.

2.5.4 Output

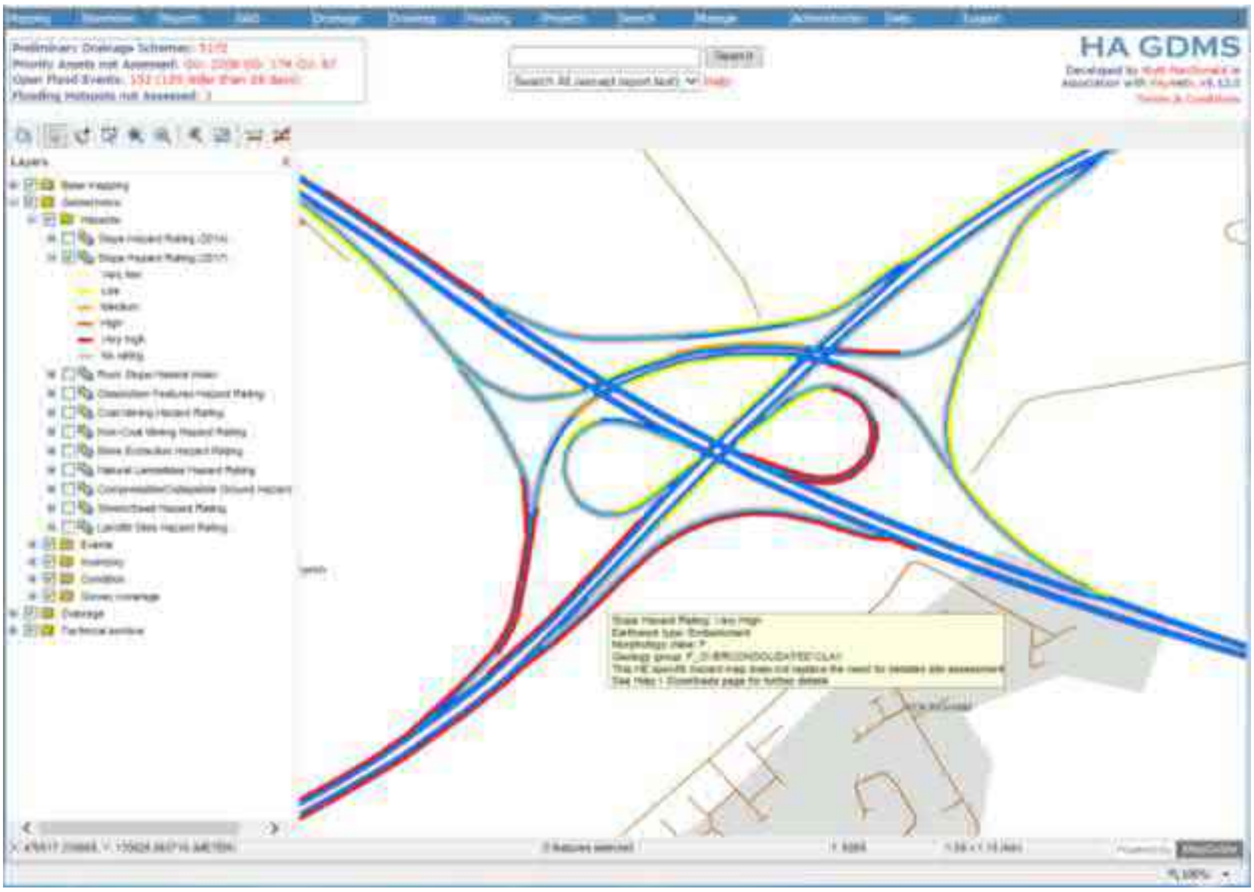
The result of the analysis is a national thematic map layer, based on extents of geotechnical assets, with the SHR banded into six ratings (Very Low to Very High and No rating). This banding is based on achieving a distribution of assets into each rating category that halves through the bands (e.g. 50% of assets in A, 25% in B, 12.5% in C etc.), as used in the 2014 calculation. A summary of the Slope Hazard Rating categories can be seen in Table 6 below.

Table 6 Summary of the Slope Hazard Rating (2017) banding

Slope Hazard Rating	Colour	Explanation
Very Low		Lowest SHR applied in this cohort (approximately 52% of rated assets)
Low		Next lowest SHR applied in this cohort (approximately 26% of rated assets)
Medium		Middle rated SHR applied in this cohort (approximately 13% of rated assets)
High		Second highest rated SHR applied in this cohort (approximately 6% of rated assets)
Very High		Highest rated SHR applied in this cohort (approximately 3% of rated assets)
No Rating		No SHR applied, as asset cannot be represented within one of the cohorts

The map went live on HAGDMS/HADDMS on 20/04/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS (albeit in a slightly different format, as points at the midpoint of each geotechnical asset). Figure 8 shows a screenshot of HAGDMS showing the Slope Hazard Rating (2017) map near Wokingham at J10 of the M4 in the South of England.

Figure 8 Screenshot from HAGDMS of the Slope Hazard Rating (2017) map

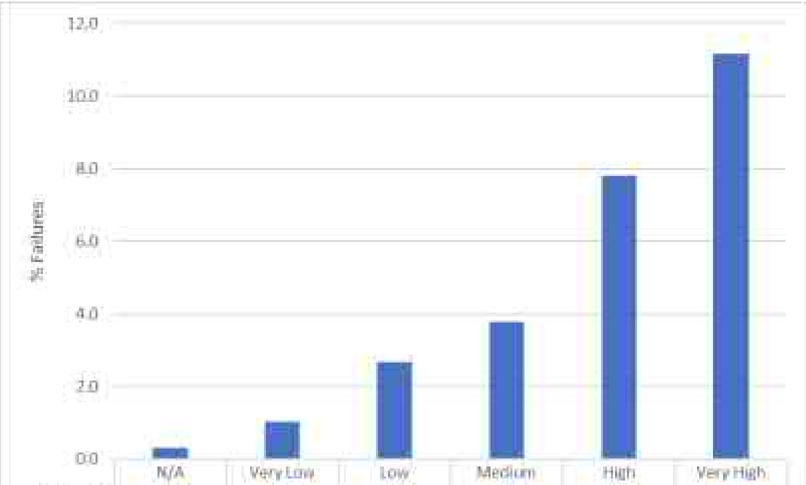


It is important to note that there is no equivalence between the results obtained in the 2014 analysis to those in this 2017 update for a given Geotechnical Asset. Due to the changes in the methodology described above, it is entirely possible that an asset will change its Slope Hazard Ratings between the analyses carried out. This does not infer an improvement or degradation of asset performance. Likewise, there is no equivalence of the colour coding used between the 2014 and 2017 analyses as shown on HAGDMS, the two datasets stand alone and should be considered separately.

2.5.5 Validation

As part of an analysis of the relationship between drainage condition and earthworks performance previously for Highways England (Mott MacDonald, 2016), an assessment of earthwork slope failures on the SRN was carried out. This work, based on reports made through the Geotechnical Maintenance Form (GMF) process on HAGDMS and evidence of slope repairs, determined that 1338 failures could be found. To validate the SHR methodology, these failures were compared to the SHR assigned to the earthworks in which the failures occurred. By then determining the number of failures in each SHR band compared to the total number of earthworks in the band, a percentage of failures can be determined (see Figure 9).

Figure 9 Percentage of failures within each SHR band



	N/A	Very Low	Low	Medium	High	Very High
% Failures	0.3	1.0	2.7	3.8	7.8	11.2
Failures	61	143	220	132	81	219
Assets	20740	13795	8219	3491	1037	1964

A clear relationship can be seen between increasing slope hazard rating and percentage of recorded failures. It is also worthy of note that where the SHR calculation is not applicable (most at-grade sections) the percentage of failure is very low.

It should be recognised that the percentage of failure values in Figure 9 cannot be considered as a 'likelihood of failure' measure, as the failure records used are not time-bound, and the SHR assessment is based on present condition, not the condition prior to the failure occurring. It should also be remembered that evidence of previous failure (Class 3 observations) make up part of the calculation of the SHR and the majority of GMF Part As relate to class 1A defects, so to a significant extent the result shown in Figure 9 is merely a representation of the SHR calculation itself. However, it is of interest to note the percentage of assets in each SHR category that have been subject to failure.

2.6 Rock Slope Hazard Index (RSHI) map

The creation of a Rock Slope Hazard Index (RSHI) map was added to the task as a request of the Project Sponsor, replacing consideration of a 'natural rock slope' hazard, which is deemed to be of negligible concern to Highways England.

2.6.1 Background

The Rock Slope Hazard Index layer on HAGDMS provides a visualisation of the results of a series of specialist rock slope inspections undertaken by Halcrow. These inspections utilised the Rock Slope Hazard Index (RSHI) methodology developed by TRL, and described in the published report PPR554: Rock slope risk assessment (TRL, 1995). The inspections were carried out on rock slopes on the Strategic Road Network whose locations had been determined from a desk study and review of information on HAGDMS.

2.6.2 Input data sets

The data used in the production of the slope hazard index map is summarised in Table 7 below.

Table 7 Summary details of the dataset used in the Rock Slope Hazard Index map

Dataset	Provider	Data Currency
HAGDMS Geotechnical Asset Database (GAD)	HAGDMS	29/03/17
RSHI inspection results (Spreadsheets)	Highways England	12/03/03 to 18/03/11

The rock inspections were undertaken mostly in 2011 (with some previous data from 2003 and 2004 also being used), these data collection spreadsheets were collated by Halcrow and made available through Richard Shires of Highways England. The data from these sheets is reproduced in the definition document for the map, shown in Appendix E.

2.6.3 Methodology

In many cases the presence of a HAGDMS Earthwork ID in the Halcrow spreadsheets allowed the results to be immediately related to the correct Geotechnical Asset. Where an HAGDMS Earthwork ID was not available, a marker post, or HAPMS reference location was provided, typically with an offset distance and direction. These inspection results were manually attributed to the correct Geotechnical Asset through use of available base datasets on HAGDMS. In most cases, the attribution could be confirmed by finding the original RSHI inspection sheets attached as documents to the Geotechnical Asset record in the Geotechnical Asset Database of HAGDMS. Where there were multiple RSHI inspection results for a single asset, the attribution on the Rock Slope Hazard Index layer on HAGDMS relates to the maximum RSHI value and Category for that asset.

Further details of the data and map creation, including all of the RSHI values from the inspections can be found in the HAGDMS Slope Hazard Rating data description document in Appendix E.

2.6.4 Output

Based on the RSHI value obtained from the inspections, rock slopes are placed into four Categories, with recommended actions as shown in Table 8.

Table 8 RSHI Category and recommended actions

RSHI Value	RSHI Category	Recommended Action
> 100	CAT 1	Urgent detailed inspection required
10 to 100	CAT 2	Detailed inspection required
1 to 10	CAT 3	Review in 5 years
< 1	CAT 4	No review required in the next 5 years

Source: Rock Slope Hazard Assessment Completion Report, HA Task 402(1308)HALC, June 2011

These Categories are used to theme the map layer on HAGDMS, as described in Table 9 below. Note that all Geotechnical Assets (including cuttings and embankment made of soil) have been included on the map layer, the vast majority of which fall into the No Data Present category.

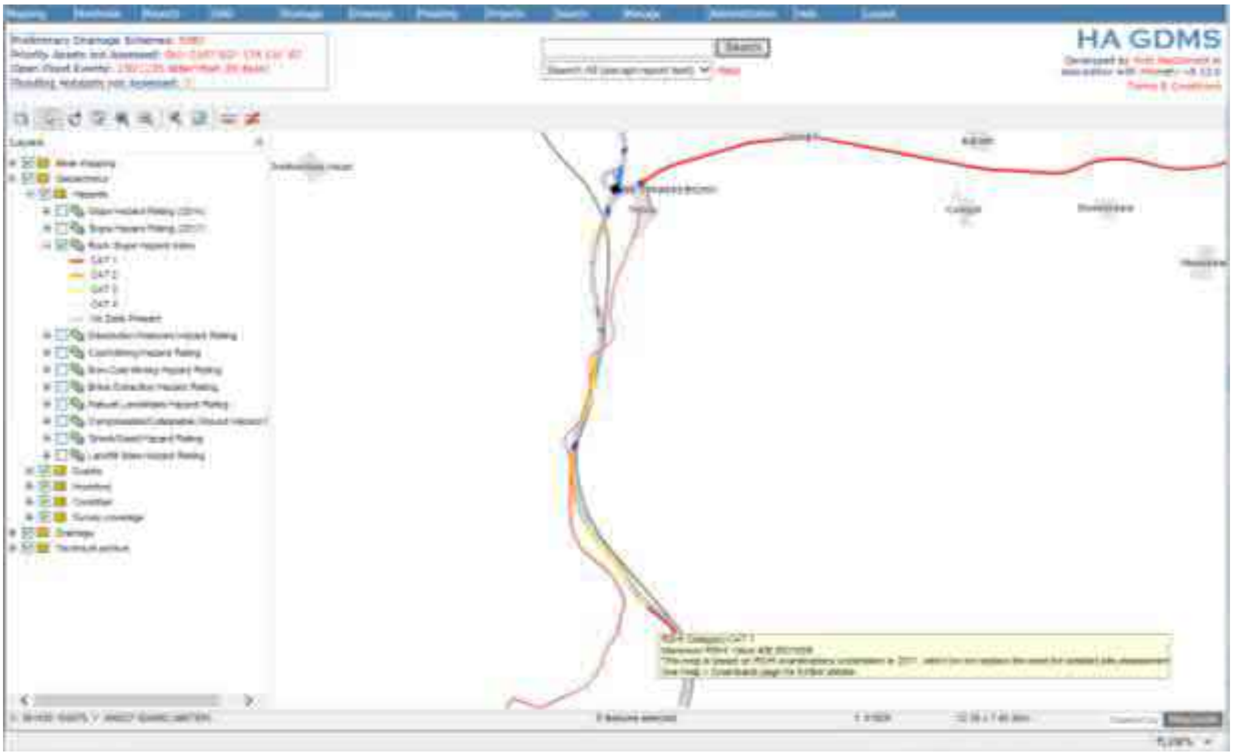
Table 9 Summary of Rock Slope Hazard Index map legend on HAGDMS

RSHI Category	Colour	Explanation
CAT 4		Maximum RSHI value < 1
CAT 3		Maximum RSHI between 1 and 10
CAT 2		Maximum RSHI between 10 and 100
CAT 1		Maximum RSHI value > 100
No Data Present		No RSHI inspection data available for the Geotechnical Asset

It should be noted that the inspections used as the basis for this layer were undertaken in 2011 (or earlier) and hence may not reflect the current hazard posed by the inspected rock slopes.

The map went live on HAGDMS/HADDMS on 01/09/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS (albeit in a slightly different format, as points at the midpoint of each geotechnical asset). Figure 10 shows a screenshot of HAGDMS showing the Rock Slope Hazard Index map near J38 of the M6 in the North West of England.

Figure 10 Screenshot from HAGDMS of the Rock Slope Hazard Index map



2.6.5 Validation

No formal validation was carried of the Rock Slope Hazard Index layer, other than internal QA of the GIS workflow to create the map. As this map is based on a series of specialist inspections, undertaken to a rigorous methodology and banded according to a method determined by others, no further validation was deemed necessary.

2.7 Prioritisation of hazard maps

As part of the key deliverables an agreed prioritisation of the hazards to be addressed in the main phase of the task was carried out. This was initially based on a previous prioritisation exercise carried out with Highways England, and their Research and Development supply chain. Internal prioritisation within the Mott MacDonald team was presented to Highways England stakeholders over several meetings before being finalised. Table 10 summaries the agreed prioritisation process as it changed through the course of the task.

Table 10 Summary of the agreed prioritisation of the Rev01 ground related hazard maps

Hazard Grouping	Task 408[1]	MM Internal[2]	HE Agreed[3]	Final Rev01 prioritisation[4]	Notes on position at end of task
Coal Mining	M	1	1	1	Completed
Dissolution Features	M	2	2	2	Completed
Non-Coal Mining	M	3	x	3	Completed
Brine extraction	N/A	N/A	N/A	N/A	Completed – added during preparation of non-coal mining map
Groundwater Flooding	M	4	x	4	Rev01 map not progressed due to the presence of existing flood mapping on HAGDMS
Landfill Sites	S	6	x	5	Completed
Natural Landslides (Soil)	M	5	x	6	Completed
Soil and Groundwater Chemistry	S	7	x	7	Not progressed due to the lack of available data to construct the map
Compressible/Collapsible Ground	S	8	x	8	Completed
Shrink/swell	C	10	x	9	Completed
Natural Landslides (Rock)	C	9	x	N/A	Not progressed – replaced by RSHI map
Engineered slopes of marginal stability (rock or soil)	Out of Scope	1	x	N/A	Completed – Production of the Rock Slope Hazard Index map and an Update to the Slope Hazard Rating map.
Defective or inappropriate drainage	Out of Scope	1	?	N/A	Previously determined that this is too transitory to allow a hazard map to be created, and condition data is not available for the whole network
Animal burrows	Out of Scope	11	?	N/A	Limited data available
Loss of vegetation	Out of Scope	12	-	N/A	Limited data available

Notes

[1] MoSCoW (Must, Should, Could, Won't) prioritisation undertaken in T-TEAR Task 408. N/A means hazard was not considered in this round of prioritisation.

[2] Internal MM prioritisation suggestion, discussed with HE on 19/10/16. N/A means hazard was not considered in this round of prioritisation.

[3] Agreed initial prioritisation with Highways England stakeholder group on 19/10/16, recognising the need to complete the liaison meeting with the Coal Authority on 9/11/16 prior to completing the prioritisation task. N/A means hazard was not considered in this round of prioritisation.

[4] Final prioritisation of Rev01 hazard maps with Highways England stakeholder group on 19/12/2016. N/A means hazard was not considered in this round of prioritisation.

2.8 Hazard map creation

2.8.1 Outline methodology

The methodology developed during the accelerated production of the Coal Mining Hazard map detailed in section 2.2 became the foundation for the suite of remaining hazard maps. During the development of each map, the analysis and final algorithm was reviewed and developed dependent on an assessment of the hazard's characteristics and influence on the SRN. Section 2.8.2 to Section 2.8.9 presents the hazard maps in turn, detailing the input data sets, any variation in methodology, the final output and validation.

2.8.2 Dissolution features hazard map

2.8.2.1 Input data sets

The map was constructed using available data on HAGDMS related to dissolution features and analysed in a GIS. Table 11 summaries the source and currency of the data used in the Dissolution Features Hazard map.

Table 11 Summary details of the datasets used in the Dissolution Features Hazard Map

Dataset	Provider	Data Currency
BGS Geosure: Soluble Rocks	British Geological Survey	26/07/14
Natural Cavities	Peter Brett Associates	14/12/15

2.8.2.2 Methodology

The datasets that fed into the analysis of the Dissolution Features Hazard Map are different in type and origin so two methods were developed to best utilise the data.

The BGS Geosure: Soluble Rocks is a continuous, polygon based dataset that presents the potential for dissolution via a hazard rating. The full derivation of this hazard map is not stated by BGS, although it is known that it is based largely on geological mapping and BGS records of recorded dissolution features. The spatial analysis of this dataset utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The maximum hazard rating that intersected the 500m buffer was attributed to the relevant 100m grid square. This provided a conservative smoothing of the dataset to feed into the later analysis.

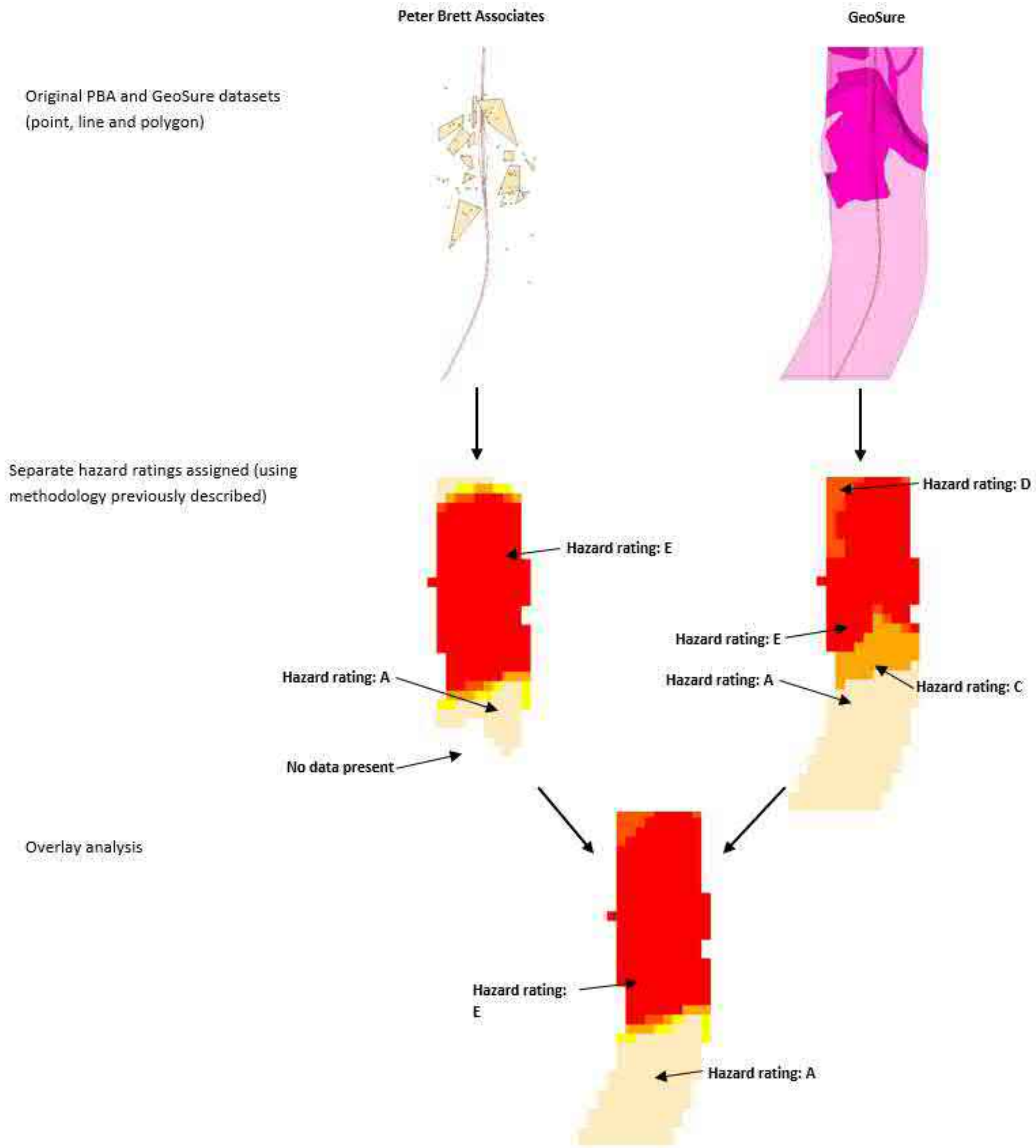
The Natural Cavities data from Peter Brett Associates (PBA) is derived from a database of known physical features that have occurred through the action of erosion and/or dissolution. It is important to note that the dataset does not have full national coverage, being particularly focussed on chalk dissolution features in the Southeast. The dataset contained points, lines and polygons, of which the attributes contained the type and number of dissolution features at each location. The number and type of features was extracted using the 500m buffer methodology and weightings applied that were derived based on expert judgement of the task stakeholder group, see Table 12 below.

Table 12 Summary of the weightings assigned to each of the PBA Natural Cavities type

Natural Cavity Type	Weighting (out of 20)	Notes
Sinkhole	20	
Solution Pipe	15	
Swallow Hole	20	
Bourne Hole	0	Not related to dissolution
Gulls/Fissures due to Cambering	0	Not related to dissolution
Not supplied	16	
Piping in non-cohesive deposits	0	Not related to dissolution
Sea Cave	0	Primarily created by hydraulic action
Solution widened Joint or Fissure	5	
Unknown	16	
Vadose Cave	20	
Scour Hollows	0	Not related to dissolution

The resulting weighted PBA scores were then calibrated to the GeoSure categories to ensure parity in the density of features between the datasets. Where the 500m buffer of a grid square was not a complete circle because it partially falls outside the 1000m corridor then the density of features outside the circle was assumed to be the same as the density inside the corridor and a correction was applied accordingly. Overlay analysis was then used to take the maximum hazard rating of either dataset and assign it to the grid square, see Figure 11 below.

Figure 11 Methodology used to combine the BGS Geosure: Soluble Rocks and PBA Natural Cavities datasets



Further details and explanation of the map methodology can be found in the HAGDMS Dissolution Features Hazard Rating data description document in Appendix F.

2.8.2.3 Output

The result of the analysis is a nationwide dissolution features hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into five categories (A to E). A summary of the Dissolution Features Hazard Rating categories can be seen in Table 13 below.

Table 13 Summary of the Dissolution Features Hazard Rating Map banding

Dissolution Features Hazard Rating	Colour	Explanation
A		Soluble rocks are either not thought to be present, or are not prone to dissolution. Dissolution features are unlikely to be present. *and/or* The density of known dissolution features is very low
B		Soluble rocks are present but unlikely to cause problems except under exceptional conditions *and/or* The density of known dissolution features is low
C		Significant soluble rocks are present. Low possibility of localised subsidence or dissolution related-degradation of bedrock occurring naturally, but may be possible in adverse conditions such as high surface or subsurface water flow. *and/or* The density of known dissolution features is medium
D		Very significant soluble rocks are present with a moderate possibility of localised natural subsidence or dissolution-related degradation of bedrock, especially in adverse conditions such as concentrated surface or subsurface water flow. *and/or* The density of known dissolution features is high
E		Very significant soluble rocks are present with a high possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, especially in adverse conditions such as concentrated surface or subsurface water flow *and/or* The density of known dissolution features is very high

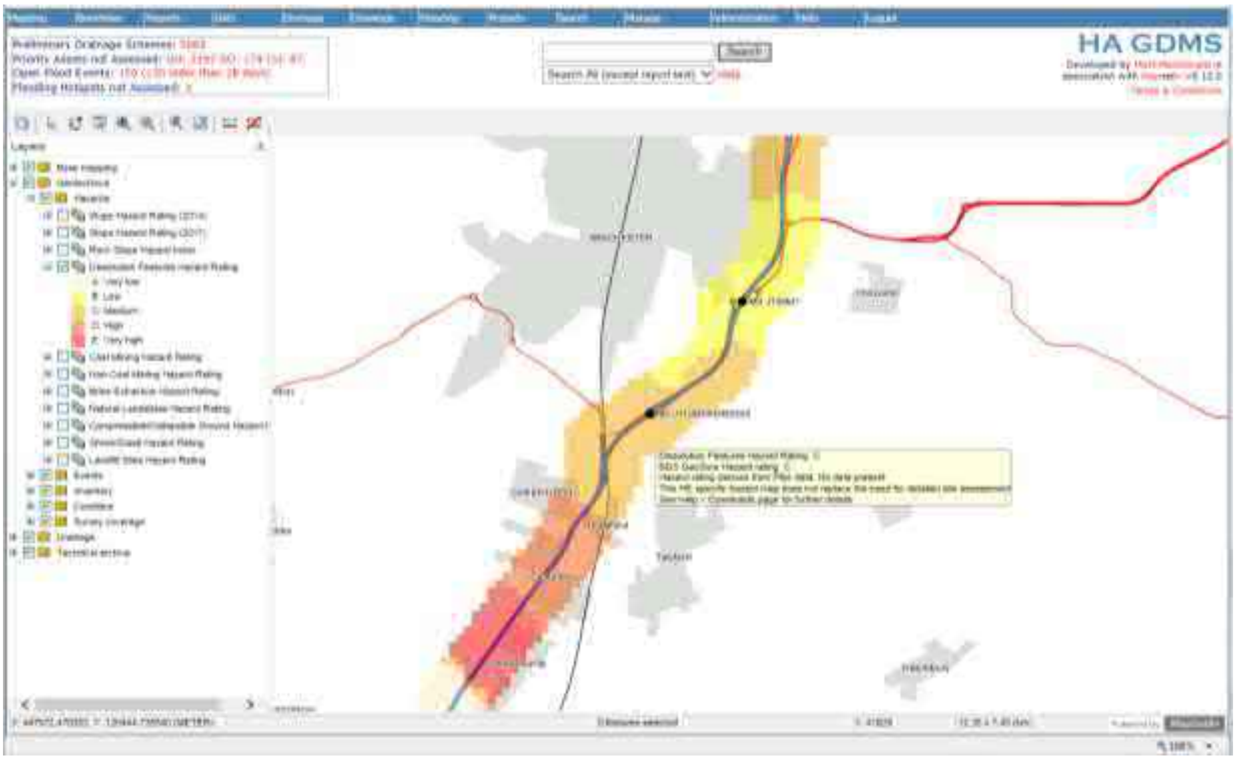
NB: The first part of explanation is taken from the BGS GeoSure: Soluble Rocks dataset.

The second part is a relative density of data from the PBA natural cavities dataset.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a ‘B’ rating for shrink/swell is not the equivalent of a ‘B’ for dissolution features).

The map went live on HAGDMS/HADDMS on 20/04/2017 and was also supplied to HE, to be hosted on Highways England’s internal system HAGIS. Figure 12 shows a screenshot of HAGDMS showing the Dissolution Features Hazard map with the full range of banding categories for a section of the M3 in the South of England.

Figure 12 Screenshot from HAGDMS of the Dissolution Features Hazard map at M3 J11



2.8.2.4 Validation

In order to validate the Dissolution Features Hazard Map part of the challenge lies in the fact all available, large coverage datasets related to dissolution were already considered in the analysis. To address the lack of validating data and confirm the validity of the map output a technical expert was approached. On the 25/04/17 a meeting was held with Professor Rory Mortimore, a specialist Cretaceous and Chalk geologist with over 33 years' experience of research and lecturing. During the meeting the input data sources, the methodology and the map output were presented and discussed. Several areas of interest were interrogated where Professor Mortimore had particular knowledge. During these discussions, Professor Mortimore was content with the approach undertaken.

In addition, site specific validation was carried out by considering particular issues known to have existed at the M4/A34 junction at Chieveley and on the M2 in Kent. In each of these cases, the new hazard map was shown to represent the known hazards well.

2.8.3 Non-coal mining hazard map

2.8.3.1 Input data sets

The map was constructed using available data on HAGDMS related to Non-Coal Mining and analysed in a GIS. summaries the source and currency of the data used in the Non-Coal Mining Hazard map.

Table 14 Summary details of the datasets used in the Non-Coal Mining Hazard Map

Dataset	Provider	Data Currency
BGS Mining Hazard (not including coal)	British Geological Survey	11/03/16
BGS Recorded Mineral Sites	British Geological Survey	15/05/16
Inventory of Closed Mining Waste	Environment Agency	01/11/13
Mining Instability	Ove Arup & Partners	30/06/98
Man Made Mining Cavities	Peter Brett Associates	17/12/15
Potential Mining Areas	Wardell Armstrong LLP	08/05/08

2.8.3.2 Methodology

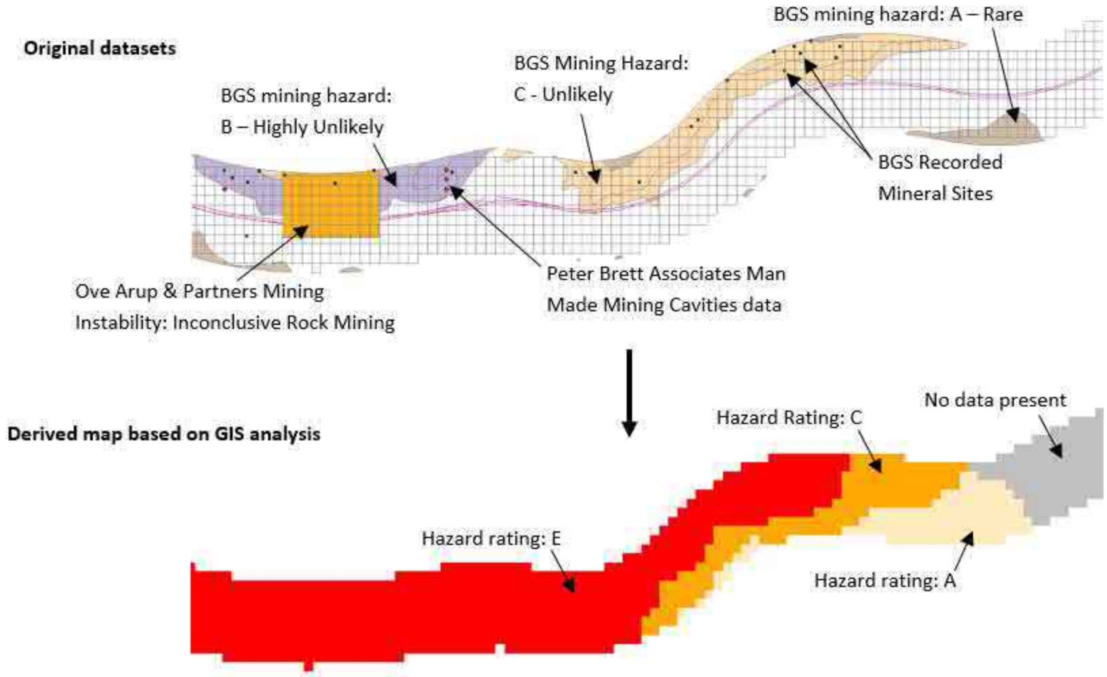
All datasets were aligned to the BGS Mining Hazard (not including coal) bands using engineering judgement, see Table 15.

Table 15 Summary of assigned banding for each Non-Coal Mining dataset

Band	Dataset:	Mining Hazard (not including coal)		Recorded mineral sites		Inventory of Closed mining waste facilities	Mining instability	Man made mining cavities	Potential mining areas
	Data Source:	British Geological Survey		British Geological Survey		Environment Agency	Ove Arup & Partners	Peter Brett Associates	Wardell Armstrong LLP
	Data Type:	Polygon		Point		Point	Polygon	Point	Polygon
Null	No data present	No intersect with 500m circles		No intersect with 500m circles		No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles
A	Very low	Rare							
B	Low	Highly Unlikely							
C	Moderate	Unlikely	Commodity type:						
D	High or inconclusive	Likely	Chalk Firestone/Hearthstone Firestone/Hearthstone/Chalk Flint/Chalk				Evaporites - inconclusive Iron ore - inconclusive Metalliferous - inconclusive Rock - inconclusive		
E	Very high or proven/conclusive	Highly Likely	Fuller's Earth Fuller's Earth/Limestone - Bath Stone Ganister Gypsum Iron Ore Iron Ore (bedded) Iron Ore (bedded)/Limestone - Black Country Iron Ore (non vein) Jet Jet/Vein Mineral Lignite/Chalk Limestone - Bath Stone Limestone - Black Country/Vein Mineral Limestone/Vein Mineral Raddle Sand Sand/Building Stone Sand/Chalk Sandstone Sandstone - Elland Flags Vein Mineral/Ball Clay Vein Mineral/Iron Ore Vein Mineral/Sandstone	Point type: Opencast Tip Underground Underground and opencast	Commodity type: Alabaster Ball Clay Barytes Chalk Chert China Clay China Stone Common Clay and Shale Copper Coprolite Crushed Rock Desulphogypsum Dolomite Fireclay Flint Fuller's Earth Ganister Gypsum Igneous and Metamorphic Rock Iron ore Iron Ore - Hematite Iron Ore - Ironstone Iron Ore - Ochre Iron Pyrite Lead Limestone Marine Sand And Gravel Mineral Not Supplied Oil Sand Sand and Gravel Sandstone Secondary Silica rock Silica Sand Slate Tin Tufa Tungsten Zinc	Mine type: Building minerals Industrial minerals Metalliferous	Evaporites - conclusive Iron ore - conclusive Metalliferous - conclusive Rock - conclusive	Ball Clay Barytes Chalk Clay Copper Coprolite Fireclay Flagstones Flint Fluorspar Fuller's Earth Gypsum Hematite Iron Lead Limestone Mangalese (Should be manganese) Raddle Sandstone Shale Silver Slate Stone Tin Unknown Zinc	Mining of: Clays Copper and associated ores Iron and associations Lead and associations Other metal ores Sedimentary rocks Silver and associated ores Sulphates Tin and associations Tungsten ores Unknown commodities
Not included			Brine	Liquid or gas extraction Power Station Rail Depot Recycled Wharf	Abandoned Mine Methane Coal - Deep Coal - General Coal - Surface Mined Furnace Bottom Ash Lignite Peat Pulverised Fuel Ash Slag (Including Basic Oxygen Slag and Electric Arc Furnace Slags)	Coal	Coal (inconclusive and conclusive)	Lignite (Should be Lignite)	Mining of Carbon Rich Commodities

The spatial analysis of the Non-Coal Mining data utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The band for each dataset within the buffer was then extracted and the maximum band was assigned to the grid square at the centre of the buffer. This assigned value represents the hazard rating score for that grid square. Note that there has been no consideration of the number of point locations within each buffer, or the amount of overlap with polygon data sets. Any intersection with a record within each of the datasets is recorded within the methodology, and as such the method is conservative, and suitable for such a high level hazard map.

Figure 13 Map Methodology showing 500m grid buffer intersecting the Non-Coal Mining datasets and the resulting hazard map



Further details and explanation of the map methodology can be found in the HAGDMS Non-Coal Mining Hazard Rating data description document in Appendix F.

2.8.3.3 Output

The result of the analysis is a nationwide non-coal mining hazard map for a 1000m corridor around the Strategic Road Network with the level of hazard banded into six categories (No data present then A to E). A summary of the Non-Coal Hazard Rating categories is detailed in Table 16.

Table 16 Summary of Non-Coal Mining Hazard rating banding

Non-Coal Mining Hazard Rating	Colour	Explanation
No data present		No data present
A		Very low
B		Low
C		Moderate
D		High or inconclusive
E		Very high or proven/conclusive

NB: The first part of explanation for Ratings D and E is taken from the BGS Non-coal mining areas of Great Britain dataset. The second part is taken from other non-coal mining datasets.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a 'B' rating for non-coal mining is not the equivalent of a 'B' for dissolution features).

The map went live on HAGDMS/HADDMS on 20/04/2017 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 14 shows a screenshot of HAGDMS showing the Non-Coal Mining Hazard map for a section of the M5 J14.

Figure 14 Screenshot from HAGDMS of the Non-Coal Mining Hazard Map at M5 J14

2.8.3.4 Validation

Validation of the Non-Coal Mining map utilised the experience and knowledge of the Highways England Geotechnical Advisors, and other supply chain expertise from within the stakeholder steering group. A request for any existing maps and datasets related to Non-Coal Mining in the proximity of the Network was sent out to the Highways England Area teams. Representatives from Area 1 and Area 13 responded with a series of plans and information. These plans were georeferenced to allow a discussion and critique of the mapping output during a stakeholder meeting on the 26/07/17. During the meeting the good correlation of the Area 13 plans and the Hazard maps was observed. The map was also interrogated across various locations known by the Geotechnical Advisors to be areas with a legacy of Non-Coal mining. The recent Non-Coal Mining related failure that occurred on the 16/01/16 in Area1 on the A30 near Scorrier was located and Very High Hazard at this location was confirmed in the Hazard map.

2.8.4 Brine extraction hazard map

During creation of the non-coal mining hazard map, discussion with the expert stakeholder group determined that brine extraction should be treated separately to other mining techniques. Based on that advice, a separate brine extraction hazard map was created as described below.

2.8.4.1 Input data sets

The map was constructed using available data on HAGDMS related to brine dissolution features and analysed in a GIS. Table 17 summaries the source and currency of the data used in the Brine Extraction Hazard map.

Table 17 Summary details of the datasets used in the Brine Extraction Hazard Map

Dataset	Provider	Data Currency
BGS Mining Hazard (not including coal)	British Geological Survey	11/03/16
Brine Compensation Areas	Cheshire Brine Compensation Board	11/06/12
Brine Pumping Related Features	Wardell Armstrong LLP	03/03/06
Brine Subsidence Solution Areas	Johnson, Poole and Bloomer	26/08/09

2.8.4.2 Methodology

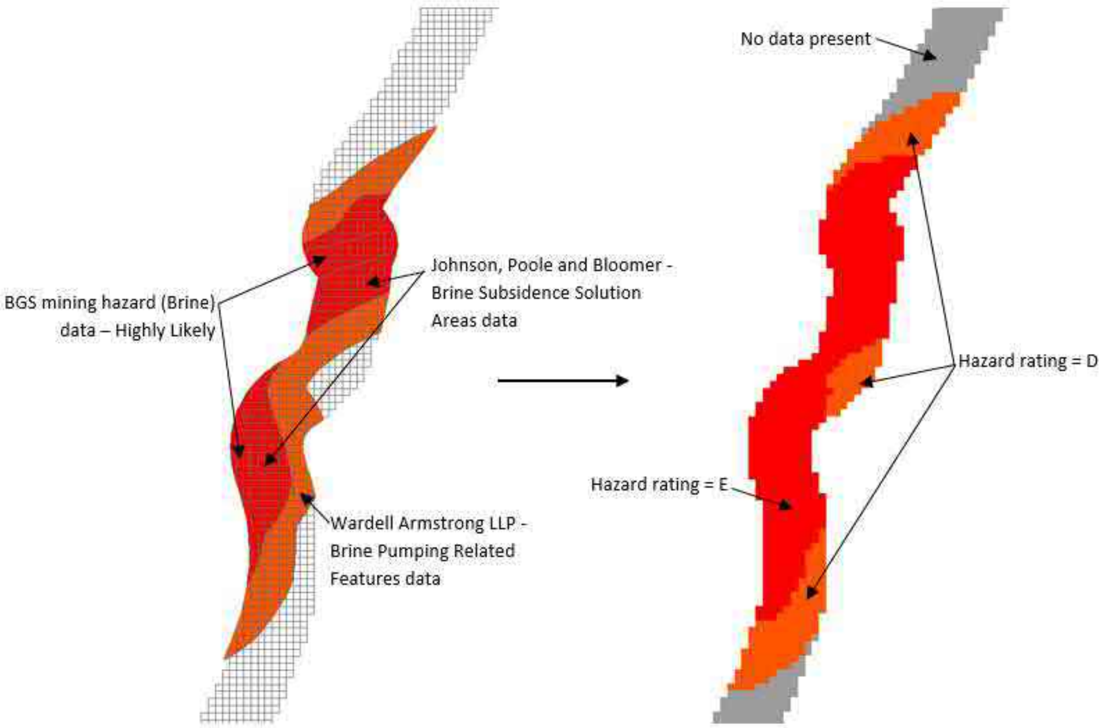
All datasets were assessed relative to the brine layer of the BGS Mining Hazard (not including coal) bands using engineering judgement (see Table 18).

Table 18 Summary of assigned banding of the brine datasets

	Dataset:	Mining Hazard (not including coal)		Brine compensation areas	Brine pumping related features	Brine subsidence solution areas
Band	Data Source:	British Geological Survey		Cheshire Brine Compensation Board	Wardell Armstrong LLP	Johnson, Poole and Bloomer
	Data type	Polygon		Polygon	Polygon	Polygon
Null	No data present	No intersect with 500m circles	Commodity type: Brine	No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles
A	Very low	Rare				
B	Low	Highly Unlikely				
C	Moderate	Unlikely		Brine compensation areas		
D	High or inconclusive	Likely			Areas potentially affected by brine runs	
E	Very high or proven/conclusive	Highly Likely			Brine dissolution areas Brine runs	Brine subsidence solution areas
Not included			Chalk Firestone/Hearthstone Firestone/Hearthstone/Chalk Flint/Chalk Fuller's Earth Fuller's Earth/Limestone - Bath Stone Ganister Gypsum Iron Ore Iron Ore (bedded) Iron Ore (bedded)/Limestone - Black Country Iron Ore (non vein) Jet Jet/Vein Mineral Lignite/Chalk Limestone - Bath Stone Limestone - Black Country/Vein Mineral Limestone/Vein Mineral Raddle Sand Sand/Building Stone Sand/Chalk Sandstone Sandstone - Elland Flags Vein Mineral/Ball Clay Vein Mineral/Iron Ore Vein Mineral/Sandstone			

The spatial analysis of the BGS brine mining data utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The assigned band for each dataset intersected within the buffer was then extracted and the maximum band was assigned to the grid square (refer to Table 18). This assigned value represents the hazard rating score for that grid square (Figure 15).

Figure 15 Map methodology showing 500m grid buffer intersecting the brine datasets and the resulting hazard map



Further details and explanation of the map methodology can be found in the HAGDMS Brine Extraction Hazard Rating data description document in Appendix F.

2.8.4.3 Output

The result of the analysis is a nationwide brine hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into six categories (No data present then A to E). A summary of the Brine Extraction Hazard Rating categories is detailed in Table 19.

Table 19 Summary of Brine Extraction Hazard rating banding

Brine Hazard Rating	Colour	Explanation
No data present		No data present
A		Very low
B		Low
C		Moderate
D		High or inconclusive
E		Very high or proven/conclusive

NB: The first part of explanation for Ratings D and E is taken from the BGS non-coal mining (brine) areas of Great Britain dataset. The second part is taken from other brine hazard datasets.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a 'B' rating for compressible/collapsible ground is not the equivalent of a 'B' for brine extraction features).

The map went live on HAGDMS/HADDMS on 20/04/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 16 shows a screenshot of HAGDMS showing the Brine Extraction Hazard Rating map near Droitwich Spa at J5 of the M5 in the West Midlands.

Figure 16 Screenshot from HAGDMS of the Brine Extraction Hazard Map of the M5 J5

2.8.4.4 Validation

No formal validation was carried on Brine Extraction Hazard layer, other than internal QA of the GIS workflow to create the map. This was deemed acceptable as the datasets that fed into the analysis were so geographically limited.

2.8.5 Natural landslides hazard map

2.8.5.1 Input data sets

The map was constructed using available data on HAGDMS related to natural landslides and analysed in a GIS. Table 20 summaries the source and currency of the data used in the Natural Landslides Hazard map.

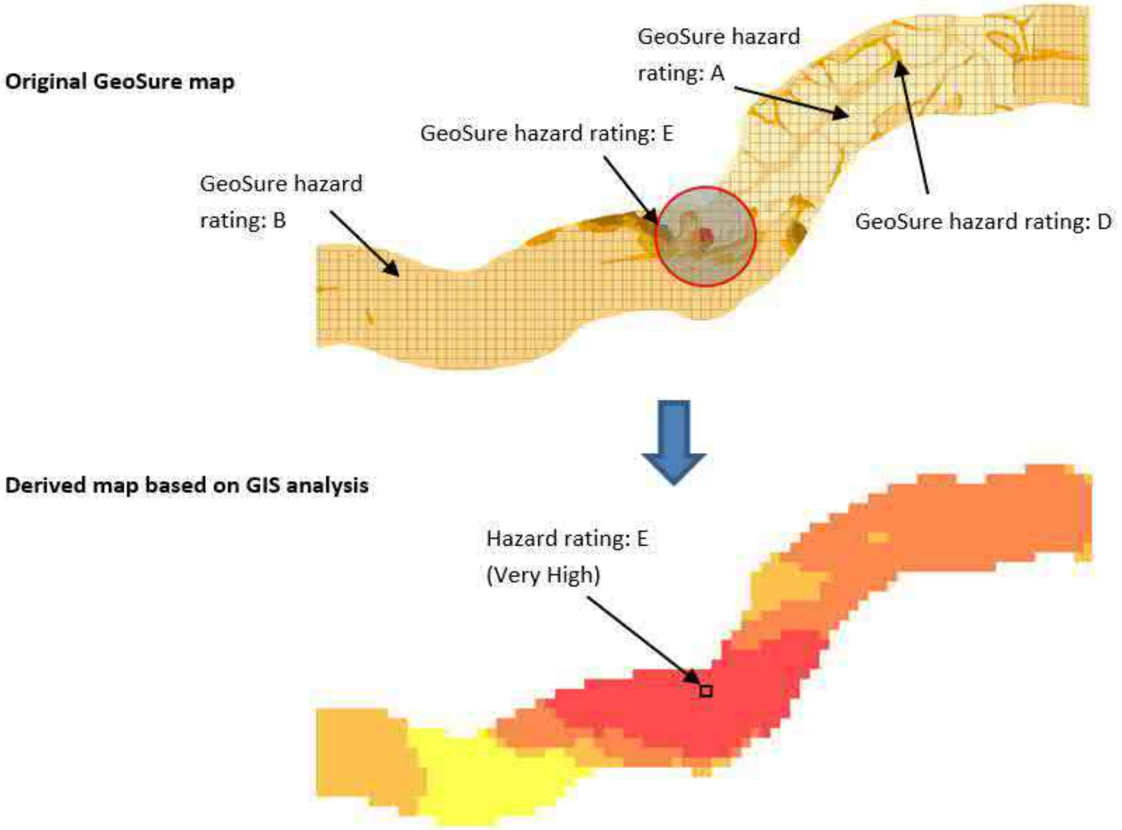
Table 20 Summary details of the datasets used in the Natural Landslides Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Natural Landslides	British Geological Survey	26/07/14

2.8.5.2 Methodology

The spatial analysis of the natural landslides data utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The maximum landslide GeoSure band within each buffered circle was then assigned to the grid square at the centre of the buffer (see Figure 17).

Figure 17 Map methodology showing the 500m grid buffer intersecting the BGS Geosure polygon data within the 1000m SRN corridor



Further details and explanation of the map methodology can be found in the HAGDMS Natural Landslides Hazard Rating data description document in Appendix F.

2.8.5.3 Output

The result of the analysis is a GeoSure derived nationwide natural landslides hazard map for a 1000m corridor of the Strategic Road Network. A summary of the landslide GeoSure categories is detailed in Table 21 below.

Table 21 Geosure: Landslides bands used for the Natural Landslides hazard map

Natural Landslides Hazard Rating	Colour	Explanation
A		No indicators for slope instability identified
B		Slope instability problems are unlikely to be present
C		Possibility of slope instability problems after major changes in ground conditions
D		Significant potential for slope instability with relatively small changes in ground conditions
E		Very significant potential for slope instability. Active or inactive landslides may be present.

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Landslides dataset.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a 'B' rating for landslides is not the equivalent of a 'B' for dissolution features).

The map went live on HAGDMS/HADDMS on 20/04/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 18 shows a screenshot of HAGDMS showing the Natural Landslides Hazard Rating map at J4 of the M25 in the South East of England.

Figure 18 Screenshot from HAGDMS of the Natural Landslides Hazard Map at M25 J4

2.8.5.4 Validation

No formal validation was carried on the Natural Landslides Hazard layer, other than internal QA of the GIS workflow to create the map. Spot checking of known unstable areas was carried out to ensure that the map is plausible.

2.8.6 Compressible/collapsible ground hazard maps

2.8.6.1 Input data sets

The map was constructed using available data on HAGDMS related to compressible and collapsible ground and analysed in a GIS. Table 22 summaries the source and currency of the data used in the Compressible/Collapsible Ground Hazard map.

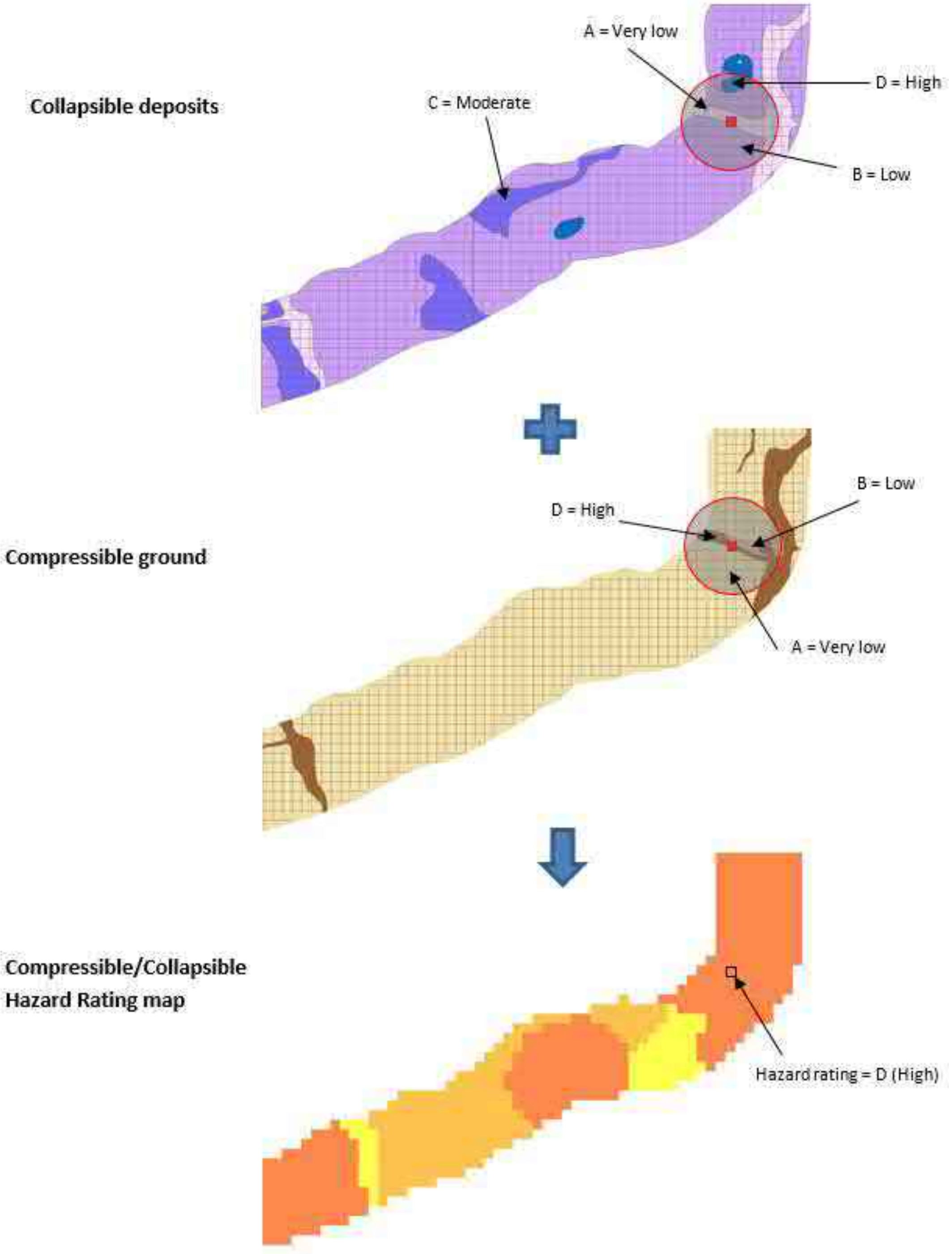
Table 22 Summary details of the datasets used in the Compressible/Collapsible Ground Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Compressible Ground	British Geological Survey	26/07/14
BGS GeoSure: Collapsible Ground	British Geological Survey	26/07/14

2.8.6.2 Methodology

The spatial analysis of the two BGS GeoSure data sets utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The maximum collapsible and compressible ground GeoSure band within each buffered circle was extracted and the maximum of either value was assigned to the associated grid square (Figure 19).

Figure 19 Map methodology showing the attribution of the maximum Geosure band to grid squares and the resulting maximum from both layers



Further details and explanation of the map methodology can be found in the HAGDMS Compressible/Collapsible Ground Hazard Rating data description document in Appendix F.

2.8.6.3 Output

The result of the analysis is a GeoSure derived nationwide compressible/collapsible ground hazard map for a 1000m corridor of the Strategic Road Network. A summary of the compressible and collapsible ground GeoSure categories is detailed in Table 23 below.

Table 23 Summary of compressible/collapsible ground GeoSure bands used for the compressible/collapsible ground hazard map

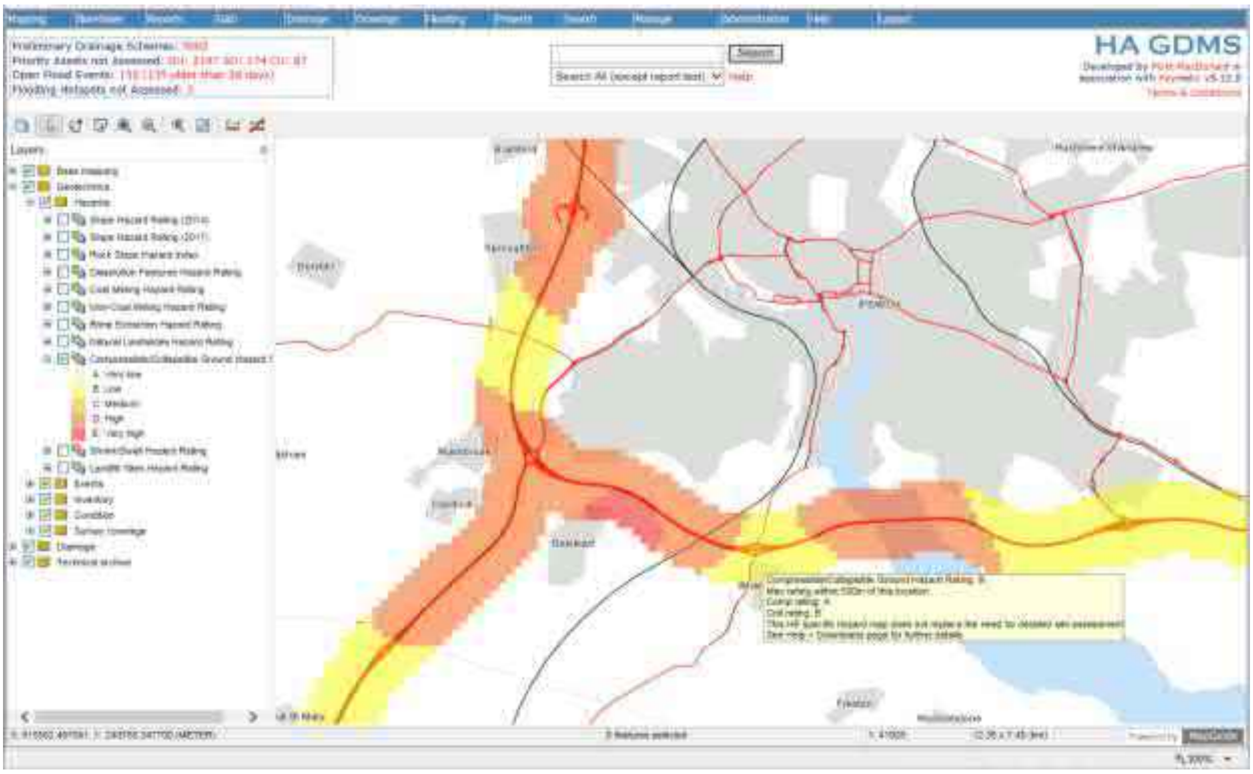
Compressible/Collapsible Ground Hazard Rating	Colour	Explanation
A		No indicators for compressible deposits identified *and/or* Deposits with potential to collapse when loaded and saturated are believed not to be present
B		Very slight potential for compressible deposits to be present *and/or* Deposits with potential to collapse when loaded and saturated are unlikely to be present
C		Slight possibility of compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated are possibly present in places
D		Significant potential for compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated are probably present in places
E		Very significant potential for compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated have been identified

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Compressible Ground and Collapsible Ground datasets.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a 'B' rating for compressible/collapsible ground is not the equivalent of a 'B' for dissolution features). This is also applies to compressible ground vs collapsible deposits.

The map went live on HAGDMS/HADDMS on 20/04/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 20 shows a screenshot of HAGDMS showing the Compressible/Collapsible Ground Hazard Rating map near Ipswich in the South East of England.

Figure 20 Screenshot from HAGDMS of the Compressible/Collapsible Ground Hazard Map near Ipswich



2.8.6.4 Validation

No formal validation was carried out on the Compressible/Collapsible Ground Hazard layer, other than internal QA of the GIS workflow to create the map. This was deemed appropriate as the only available datasets to test the validity were used in the creation of the map itself. Spot checking against a geological map on HAGDMS was carried out to ensure that the map is a plausible representation of the ground related hazard.

2.8.7 Shrink/swell hazard map

2.8.7.1 Input data sets

The map was constructed using available data on HAGDMS related to shrink/swell and analysed in a GIS. Table 24 summaries the source and currency of the data used in the Shrink/Swell Hazard map.

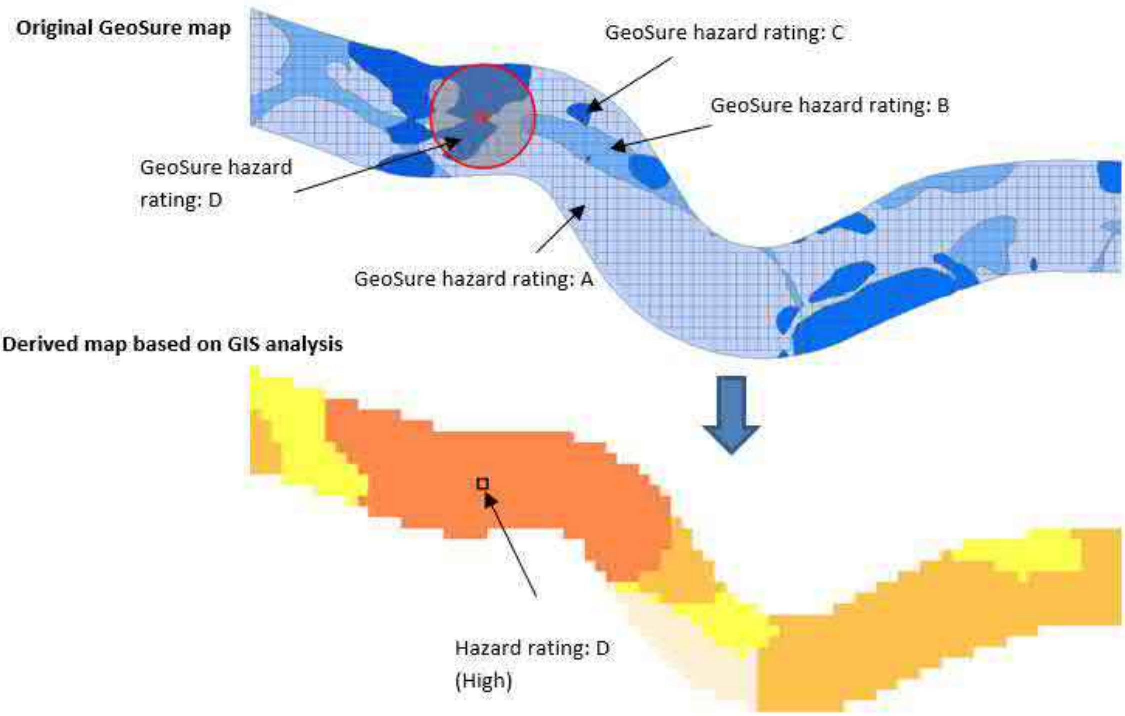
Table 24 Summary details of the datasets used in the Shrink/Swell Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Shrink-Swell	British Geological Survey	26/07/14

2.8.7.2 Methodology

The spatial analysis of the shrink/swell data utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The maximum shrink/swell GeoSure band within each buffered circle was then assigned to the grid square at the centre of the buffer (see Figure 21).

Figure 21 Map methodology showing the 500m grid buffer intersecting the BGS Geosure polygon data within the 1000m SRN corridor



Further details and explanation of the map methodology can be found in the HAGDMS Shrink/Swell Hazard Rating data description document in Appendix F.

2.8.7.3 Output

The result of the analysis is a GeoSure derived nationwide shrink/swell hazard map for a 1000m corridor of the Strategic Road Network. A summary of the shrink/swell GeoSure categories is detailed in Table 25 below.

Table 25 Summary of shrink/swell GeoSure bands used for the shrink/swell hazard map

Shrink/Swell Hazard Rating	Colour	Explanation
A		Ground conditions predominantly non-plastic
B		Ground conditions predominantly low plasticity
C		Ground conditions predominantly medium plasticity
D		Ground conditions predominantly high plasticity
E		Ground conditions predominantly very high plasticity

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Shrink-Swell dataset.

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a 'B' rating for shrink/swell is not the equivalent of a 'B' for dissolution features).

The map went live on HAGDMS/HADDMS on 20/04/17 and was supplied to HE, to be also hosted on Highways England's internal system HAGIS. Figure 22 shows a screenshot of

HAGDMS showing the Shrink/Swell Hazard Rating map at J30 of the M25 in the South East of England.

Figure 22 Screenshot from HAGDMS of the Shrink/Swell Hazard Map at J30 M25

2.8.7.4 Validation

No formal validation was carried on the Shrink/Swell Hazard layer, other than internal QA of the GIS workflow to create the map. This was deemed appropriate as the only available dataset to test the validity was used in the creation of the map itself. Spot checking against a geological map on HAGDMS was carried out to ensure that the map is a plausible representation of the ground related hazard.

2.8.8 Landfill sites hazard map

2.8.8.1 Input data sets

The map was constructed using available data on HAGDMS related to landfill sites and analysed in a GIS. Table 26 summaries the source and currency of the data used in the Landfill Sites Hazard map.

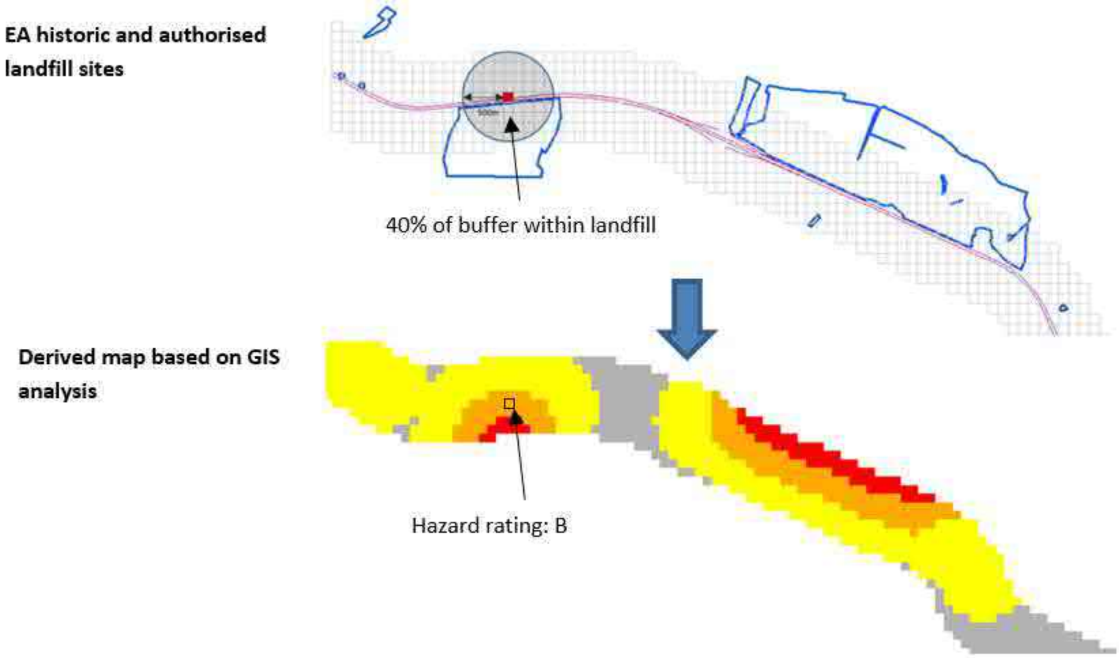
Table 26 Summary details of the datasets used in the Landfill Sites Hazard Map

Dataset	Provider	Data Currency
Historic Landfill Sites	Environment Agency	01/07/16
Authorised Landfill Sites	Environment Agency	01/07/16

2.8.8.2 Methodology

The spatial analysis of the landfill data utilised the 100m grid and 500m buffer methodology as presented in section 2.2.3. The percentage area of landfill sites intersecting the buffer was calculated and assigned to the grid square at the centre of the buffer (see Figure 23). A hazard band was then allocated.

Figure 23 Map methodology of attributing the percentage of landfill sites within 500m to the grid squares



Further details and explanation of the map methodology can be found in the HAGDMS Landfill Sites Hazard Rating data description document in Appendix F.

2.8.8.3 Output

The result of the analysis is a nationwide landfill sites hazard map for a 1000m corridor of the Strategic Road Network with the level of intersection with landfill sites banded into four categories (No data present through to C). A summary of the Landfill Sites Hazard Rating categories is detailed in Table 27.

Table 27 Summary of Landfill Sites Hazard Rating banding

Landfill Sites Hazard Rating	Colour	Explanation
No data present		Outside landfill area
A		Low hazard (landfill sites covers 0.1-33% of area within 500m)
B		Medium hazard (landfill sites covers 33.1-66% of area within 500m)
C		High hazard (landfill sites covers 66.1-100% of area within 500m)

It should be noted that the ratings provided are qualitative and are not equivalent to hazard ratings in other maps (i.e. a ‘B’ rating for landfill sites is not the equivalent of a ‘B’ for dissolution features).

The map went live on HAGDMS/HADDMS on 20/04/17 and was also supplied to HE, to be hosted on Highways England's internal system HAGIS. Figure 24 shows a screenshot of HAGDMS showing the Landfill Sites Hazard Rating map at J15 of the M25 near Heathrow Airport.

Figure 24 Screenshot from HAGDMS of the Landfill Sites Hazard Map at M25 J15

2.8.8.4 Validation

No formal validation was carried out on the Landfill Sites Hazard layer, other than internal QA of the GIS workflow to create the map. This was deemed appropriate as the only available datasets to test the validity were used in the creation of the map itself. Spot checking of known areas of landfill was carried out, making use of the base datasets on HAGDMS, to ensure that the map is a plausible and useful representation of the ground related hazard. During this process it was noted that where a landfill has a long linear boundary along one side of the SRN, the hazard to the SRN may be under-represented. It is recommended that the percentage proximity method adopted for this hazard be reviewed at a subsequent iteration of this map.

2.8.9 Outputs to HAGIS

As mentioned in the Output sections of this report, each hazard map was supplied to HE, to be hosted on Highways England's internal GIS: HAGIS. This was facilitated by Simon Coleman, GIS and Spatial Data Manager at Highways England. The maps went live on the system on 09/10/17 and were advertised as a news item on the Highways England online portal. All maps are depicted on HAGIS as they are in HAGDMS apart from minor variations applied to the Slope Hazard Rating and the Rock Slope Hazard Index, which used a centre point to symbolise the hazard rating score rather than symbolising the extent of the earthwork. All the maps are supported by copies of the definition documents (see Appendices C,D,E and F) held on the HE SHARE system and hyperlinked from HAGIS.

3 Interface with other tasks/organisations

3.1 Arup Resilience task

Throughout this task, there has been regular liaison and discussion with the Arup team working on resilience enhancement tasks for Highways England. Particularly close working was required in the drafting of:

- The hazard map definition documents (see Appendices C,D,E and F) prepared by Mott MacDonald
- The resilience guidance notes, based on the same ground related hazards (see Appendix G) prepared by Arup

In the preparation of these documents, each of the teams reviewed and commented on the work of the other, to ensure complete alignment of the two document sets.

In combination, the hazard maps (on HAGDMS and HAGIS), the definition documents accompanying the maps and the resilience guidance notes for each ground related hazard, comprise the 'Tier 0' information that the HE Geotechnical team are providing to the wider organisation.

3.2 Atkins Special Geotechnical Measures (SGM) task

It was envisaged in the initial specification for this task, that the relationship between ground related hazards and Special Geotechnical Measures (SGMs) would be investigated. However, as outlined in this report, in the initial stages of the task there was a rescoping exercise to prioritise completion of a coal mining hazard map, and to ensure that further high level maps were created for all major hazards. This change in focus meant that less contact was required with the work being undertaken on SGMs by Atkins. That said, members of the task team have been kept informed of the SGM work, and have a good understanding of the work completed by Atkins, and its importance for future geotechnical knowledge development for HE.

3.3 Interfaces outside of Highways England research community

3.3.1 Network Rail

There is a particularly strong link between Highways England and Network Rail for geotechnical research and development tasks, including the consideration of ground related hazards. This is possible because key Mott MacDonald team members carry out work for both organisations, and are keen to facilitate joint learning wherever possible.

Regular discussions between the Project Sponsor and Simon Abbott, the Professional Head of Geotechnics at Network Rail, ensure that alignment of tasks is undertaken where useful and practical. Of particular interest to Highways England is work on hazards from third party land, undertaken by the British Geological Survey for Network Rail.

Continued discussions between HE and NR are encouraged, and Mott MacDonald are very happy to facilitate this.

3.3.2 CIRIA Geotechnical Asset Owners Forum (GAOF)

The Geotechnical Asset Owners Forum (GAOF) is a group of major infrastructure owners, convened by CIRIA, that meet several times a year to discuss issues of mutual benefit to all the organisations represented.

Progress of the Geotechnical Hazard Knowledge task has been reported to GAOF by the Project Sponsor.

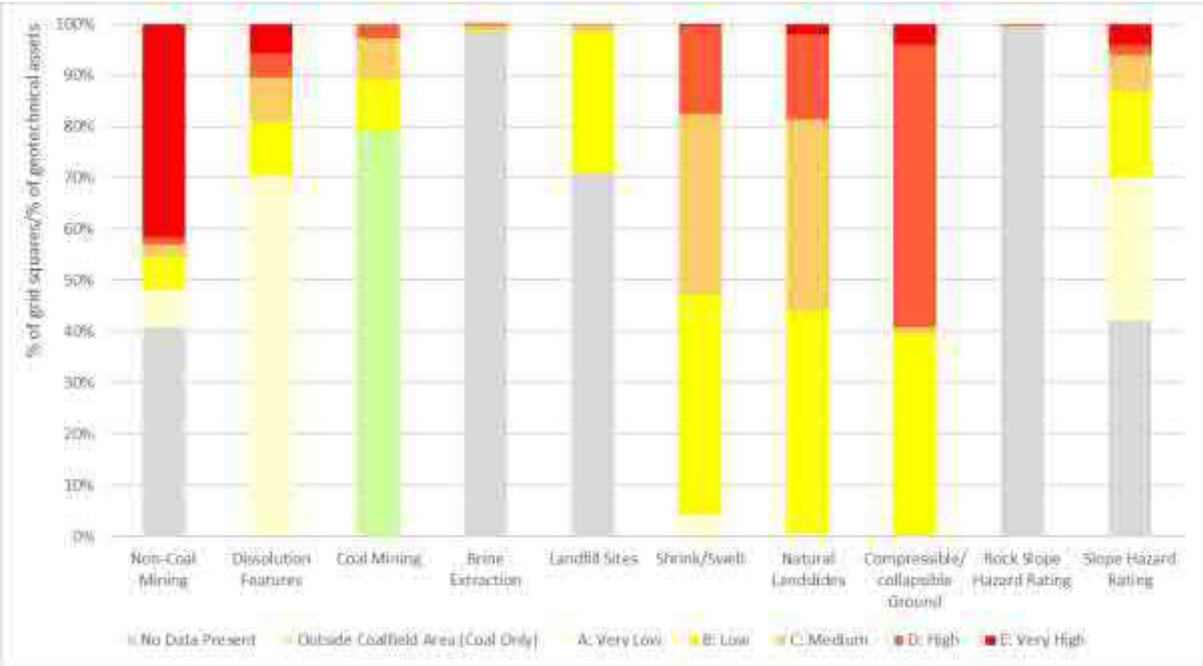
4 Development beyond hazard maps

4.1 Hazard map summary

The hazard maps created during this task are described in detail in the preceding sections of this report, and in the documents in Appendices C,D,E and F. All the maps are now live on HAGDMS and HAGIS.

Ground related hazards are the result of the geological and anthropomorphic history of the landscape, and as such the different hazards are variable in their distribution around the country, and beneath the footprint of the SRN. Figure 25 illustrates this by showing the percentage coverage of the 1km corridor around the SRN of each of the hazard classes, for each of the ground related hazards. Whilst it must be remembered that there is no direct equivalency between the hazard classes, it is apparent that some hazards (such as brine extraction and Rock Slope Hazard Rating) are very limited in extent, and others (such as natural landslides) are more widespread.

Figure 25 Coverage of the SRN by hazard category for each hazard type



Note: All hazard rating coverage is calculated based on the number of 100m grid squares, apart from Rock Slope Hazard Rating and Slope Hazard Rating, that are based on a count of number of geotechnical assets.

4.2 Vulnerability maps

Ground related hazards can potentially impact on the many parts of the SRN, but the degree of impact can be magnified or lessened by the particular characteristics of the SRN at individual locations. For example, a void created by collapse of a dissolution feature is likely to have a lessened impact on the carriageway if the road is supported by an embankment above the natural ground, compared to a similar void occurring on an at-grade section of road. Conversely, where the road is adjacent to a landfill, the pollution hazard may be magnified where the road is in cutting, compared to where it is on embankment.

As part of this task, initial work has been undertaken to develop a methodology for assessment of this change in impact, to attempt to determine the vulnerability of the SRN to a particular ground related hazard. The work was undertaken based on the non-coal mining hazard.

4.2.1 Methodology

Whilst the hazard maps were created for a 1km corridor around the SRN, a map for vulnerability is specifically concerned with the immediate vicinity of the SRN, particularly the carriageway and associated earthworks. To recognise this, the non-coal mining vulnerability map was created based on points on the carriageway at 25m centres along the SRN. The SRN is defined by use of the HAPMS (Pavement Management System) centreline, which has benefits in terms of future relationships to pavement quality data (see Section 5). The 25m spacing of assessment points gives a good balance between display of detail (particularly around complex junctions) and providing a degree of generalisation to assist the user in understanding the information presented (see Figure 26).

Figure 26: Vulnerability assessment points at 25m centres along the SRN

These assessment points were used as the basis for determining the components of vulnerability to the non-coal mining hazard. The components considered for each point were:

- Non-coal mining hazard rating (from the task 62 hazard map): this being the underlying ground related hazard,
- Earthwork type (from the Geotechnical Asset Database of HAGDMS): this being an magnifying or lessening factor should a mining related collapse or settlement occur,
- Flooding hotspot status (from HADDMS, the Drainage Data Management System): this identifies areas of regular flooding that may lead to an increased likelihood of collapse or

settlement, which was believed to be a factor in the mine shaft capping collapse on the A1 near Gateshead,

- Assessed earthwork age of construction (from the Geotechnical Asset Database of HAGDMS): on the assumption that older sections of the SRN may have been constructed with less rigour and consideration of ground related hazards than newer sections,
- Carriageway types (from HAPMS): this factor was subsequently excluded, as the data was of insufficient reliability for use.

A GIS methodology was developed to allow each assessment point to be assigned a value for each of the four utilised components above. These were then combined through a series of trial algorithms, to determine a vulnerability score. Initial attempts at a multiplicative algorithm proved unsuccessful, as it was not possible to differentiate the vulnerability ratings sufficiently. Therefore, a simplified, additive algorithm was created, based on engineering judgement and iterative assessment of results against known areas of non-coal mining hazard and a mix of earthwork types and flooding status. The algorithm was based on primary factors (hazard rating and earthwork type) and secondary factors (asset age and flooding status). These factors are presented in Figure 27.

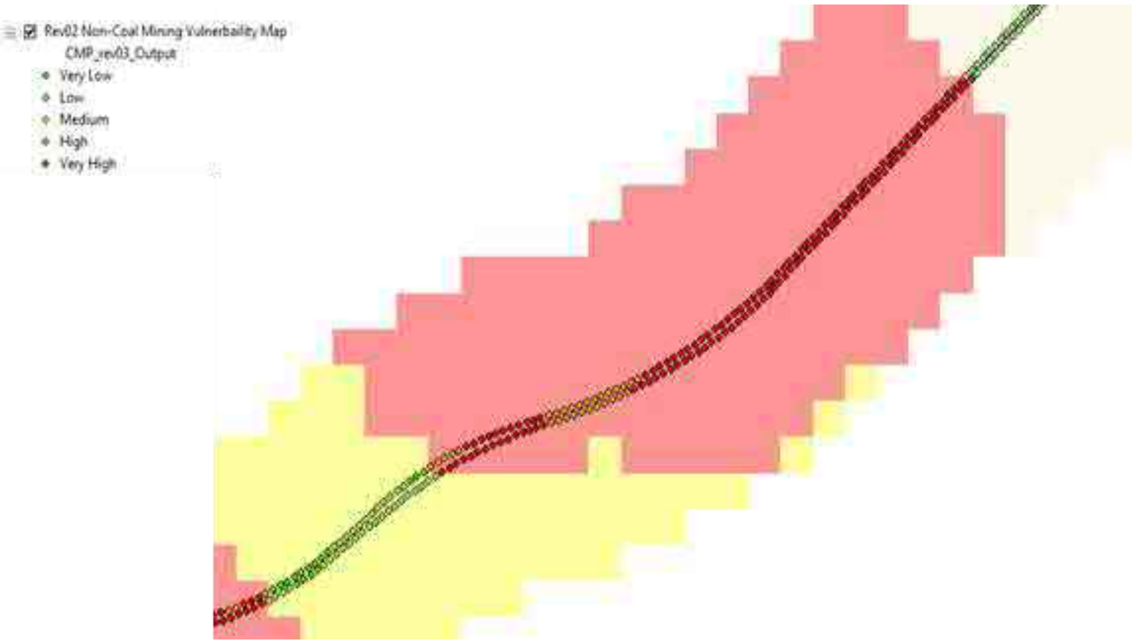
Figure 27: Primary and secondary algorithm factors for example non-coal mining vulnerability map

Primary Factors		Initial Weighting
Non-Coal Mining Hazard Category	Asset Type	
E : Very High	Not Embankment	4
	Embankment	3
D : High	Not Embankment	3
	Embankment	2
C : Medium	Not Embankment	2
	Embankment	1
B : Low	Not Embankment	1
	Embankment	1
A : Very Low	Not Embankment	1
	Embankment	1
No data present	All Assets	0

Secondary Factors	Category	Secondary Weighting
Asset Age	<1958	+0.5
	1958 – 1992	0
	>1992	-0.5
Flooding Overall Status	>High	+0.5
	<High	0
~~Carriageway Type~~	~~Not used~~	~~0~~

It is difficult to present the output of the vulnerability map in a report, as it is best viewed in a GIS, where the output can be compared to the inputs, to allow subjective validation to be carried out. However, an extract of the non-coal mining vulnerability map that was generated is shown in Figure 28, showing the relationship between assessed vulnerability at the 25m points, relative to the non-coal mining hazard map.

Figure 28: Extract of the non-coal mining vulnerability map



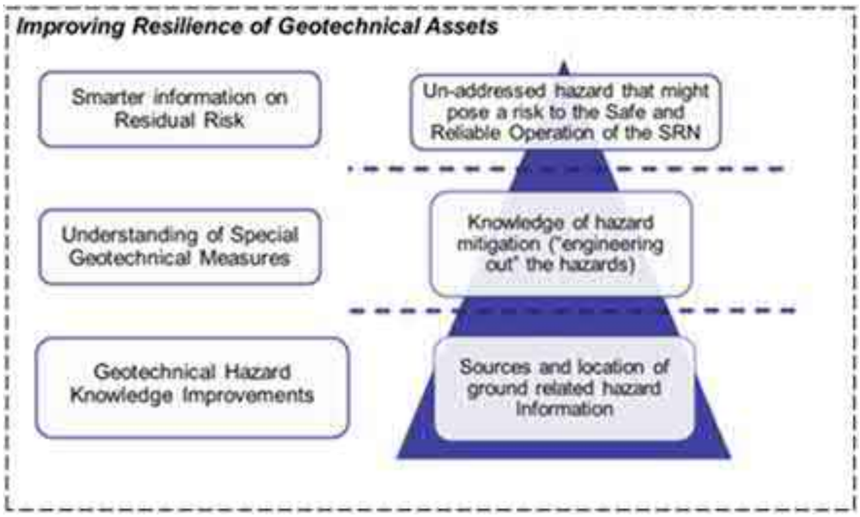
4.2.2 Discussion on usage

Generation of the non-coal mining vulnerability map was extremely useful for developing a methodology, and driving discussion in this area of the research and development of improved geotechnical knowledge for HE. In discussions with the Project Sponsor, and the convened expert stakeholder group, the fundamental question was raised about whether a vulnerability map is something that is of use in operational asset management (and hence should be made available on HAGDMS and HAGIS). There was a concern voiced that it would cause confusion, and that what users actually need is a risk map, for which an understanding of consequence of a realised hazard would need to be considered. As it is not currently possible to build a risk map (as no agreed data for consequence on the SRN is available), it was agreed that the created vulnerability map would remain offline, to feed into later developments (see Section 5).

4.3 Road map of knowledge development

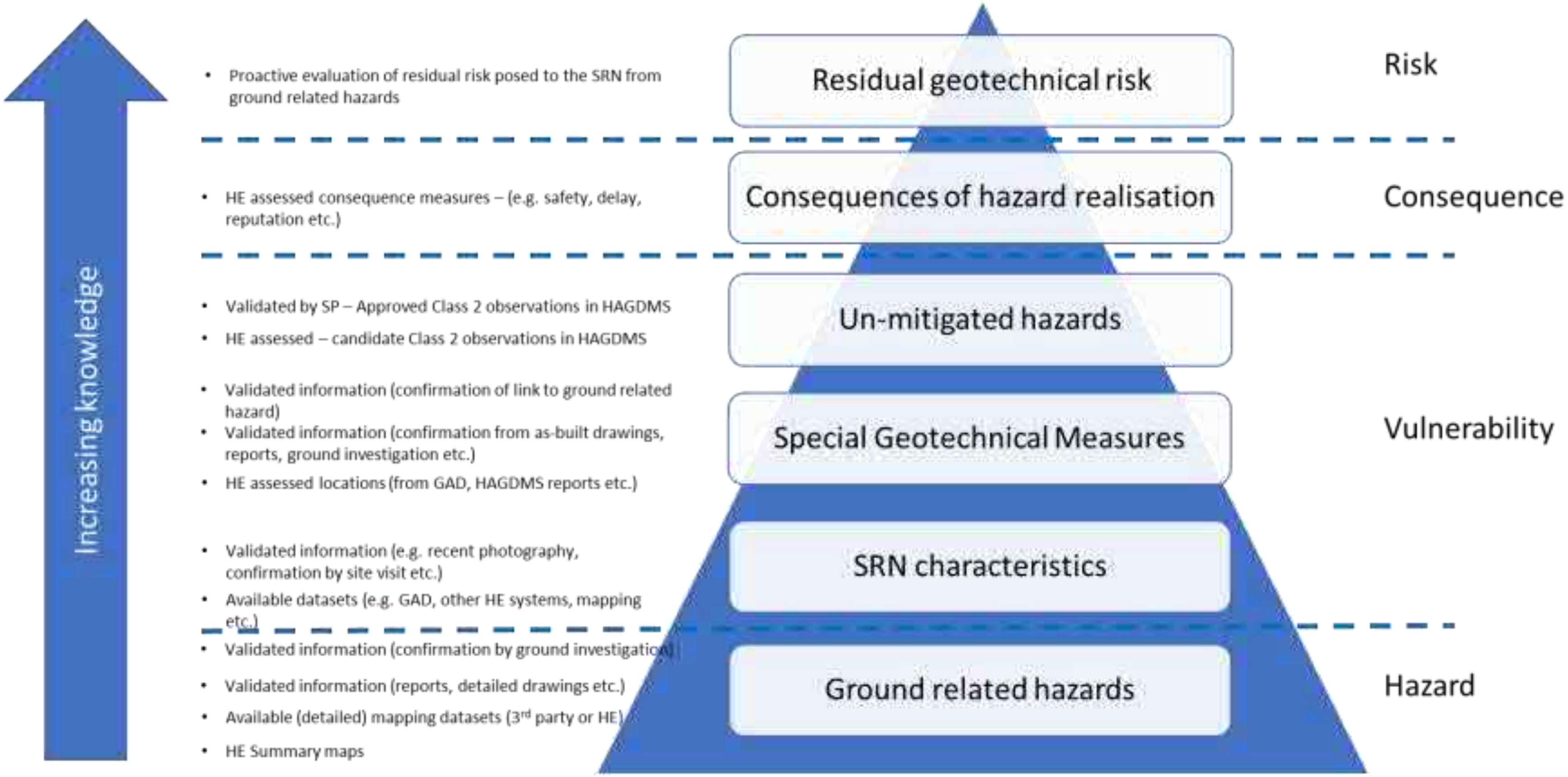
Mott MacDonald Task 408 (Mott MacDonald, 2015) generated a hierarchy of ground-related hazard and residual risk knowledge, represented in Figure 29. Based on advances made through the HE research and development programme, a revision to this often quoted diagram is presented in Figure 30.

Figure 29: Hierarchy of ground-related hazard and residual risk knowledge (2015)



Source: Mott MacDonald Task 408

Figure 30: Hierarchy of ground-related hazard, vulnerability and residual risk knowledge (2017)



Source: Mott MacDonald Task 1-062

Figure 30 has the following components, from the bottom up:

- **Ground related hazards**: an understanding of the spatial distribution of ground-related hazards in and around the SRN corridor. This can be assessed as follows:
  - From HE summary maps, completed as part of this task,
  - From available, more detailed mapping datasets (either from 3rd parties or from an HE source). These are the inputs to the HE summary maps created in this task, and are more applicable at a site level, when assessing the hazards that may impact on individual schemes, or as part of a consideration of key ground-related hazards in a management Area,
  - From a validation exercise, interrogating the reports archive of HAGDMS, looking at detailed mapping and drawings, relating to a particular scheme, site or Area,
  - From a ground investigation carried out to confirm the presence of a hazard, it's size, and location,
- **Strategic Road Network (SRN) characteristics**: the particular characteristics of the SRN at a given location, for example the form of earthworks, the age of construction, propensity to flooding etc. This can be assessed as follows:
  - From available datasets such as the Geotechnical Asset Database of HAGDMS, other HE systems for data on other assets, available HE and third party mapping. A proof of concept use of such data for a non-coal mining vulnerability map has been carried out in this task,
  - From a validation exercise for particular locations, which may include an investigation of aerial or drive-by photography, or by confirmation site visits,
- **Special Geotechnical Measures**: the location and type of SGMs present around the SRN, which may or may not be in place to mitigate a ground related hazard. This can be assessed as follows:
  - Through use of information held in HAGDMS such as records in the GAD and technical reports and drawings. This task has been undertaken by Atkins,
  - Through validation of the presence and type of SGMs from detailed investigation of available as-built reports and drawings, at a scheme or site specific level. Where an SGM is expected, but no records can be found, site inspection and/or ground investigation may be required,
  - Further validation may be required to unambiguously link the presence of an SGM to a ground related hazard, to ensure that the measure(s) installed are actually in place to mitigate a hazard, rather than for some other reason. It may also be necessary to assess the current condition and hence effectiveness of the SGM,
- **Un-mitigated hazards**: following assessment of ground related hazards, the particular characteristics of the SRN, and the location and reason for SGMs, areas of un-mitigated hazard can be determined. This assessment can be carried out as follows:
  - Accepting that full validation to conclusively validate hazards, SRN characteristics and SGMs occurs at all levels, a conservative assessment of areas of un-mitigated hazard can be determined through use of available datasets (based on data from HAGDMS and the various tasks in the HE R&D portfolio). This is envisaged as a centralised HE activity that will produce a 'candidate' set of Class 2 observations (described as 'at risk' observations in HD41, which is a misnomer) that could be presented to the user community in various ways:

    - As offline GIS files, made available to Area Service Providers, for offline assessment
    - As a static layer on HAGDMS, not an inherent part of the GAD, which would allow the Area Service Providers to validate Class 2 observations on a location by location basis,
    - As preliminary Class 2 observations, inserted into geotechnical assets in GAD, which would then require approval, modification or deletion by the Area Service Providers on a location by location basis,
  - The Area Service Provider would be responsible for assessing each candidate un-mitigated hazard to arrive at a validated un-mitigated hazard inventory, held on HAGDMS as Approved Class 2 observations.
- **Consequences of hazard realisation**: the consequences of a ground-related hazard being realised may vary considerably, based on the size of the impact, it's speed of development and severity. The consequences may relate to safety, performance, reputation, environmental damage or cost to recover. Such consequences may arise from any hazard, ground-related or not, but each can be assessed within the same framework (as demonstrated in the Task 434 report on drainage cross-asset risk, Mott MacDonald, 2016). An agreed framework for consequence assessment does not yet exist for Highways England, but is essential for full consideration of risk, across all asset types,
- **Residual geotechnical risk**: true, proactive evaluation of residual risk to the SRN from ground-related hazards can only be assessed once all of the measures above are in place. This is the top of the hierarchy in Figure 30, and is the goal that many of the HE geotechnical R&D tasks are working towards.

In order to understand progress on the building blocks shown in Figure 30, a summary of completed, partially completed and outstanding tasks is presented in Table 28. Progress to date is colour coded as follows:

(green)	Task completed, and/or information available to practitioners through HAGDMS or other HE systems
(amber)	Task partially completed, and/or information partially available to practitioners through HAGDMS or other HE systems. Task is such that it is not appropriate to fully complete it as a centralised activity and will require site specific investigation.
(yellow)	Task partially completed, and/or information partially available to practitioners through HAGDMS or other HE systems. Task is such that it is possible to complete it as a centralised activity as part of the HE geotechnics R&D programme.
(red)	Task not completed, and/or information not currently available to practitioners.

Table 28: Progress to fully understanding residual geotechnical risk on the SRN

Area of Hierarchy	Detailed development Area	Progress to date	Resilience Programme workstream
Ground-related hazards	HE Summary maps	Completed by Mott MacDonald in Task 1-062 (This task)	Ground-related hazards
	Available detailed mapping datasets (3rd party or HE)	Majority of datasets available on HAGDMS, or through 3rd party providers. At a site specific level, further data may need to be reviewed for particular sites from other sources.	N/A
	Validated information (reports, detailed drawings etc.)	Majority of detailed information available on HAGDMS. Hazard specific search tools have been provided on HAGDMS by Mott MacDonald Task 408 (Mott MacDonald, 2015). At a site specific level, further interrogation of data sources not on HAGDMS may be required. These data sources may include previous ground investigations undertaken to investigate ground related hazards.	N/A
	Validated information (confirmation by ground investigation)	In the context of consideration of new schemes or sites, this information will not be available and would be acquired on a site-by-site basis.	N/A
SRN characteristics	Available datasets (e.g. GAD, other HE systems, mapping etc.)	Data available through HAGDMS, other HE systems or freely available 3rd party sources.	N/A
	Validated information (e.g. recent photography, confirmation by site visit etc.)	Aerial photography displayed on HAGDMS, or available through HE imagery archives, should be consulted, as should recent drive by photography and LiDAR imagery held on AVIS, and the aerial and drive by photography held on Google maps. Confirmation by site inspection may also be required.	N/A
Special Geotechnical Measures	HE assessed locations (from GAD, HAGDMS reports etc.)	Completed by Atkins in their SGM task and offline data available for use in future R&D tasks.	Special Geotechnical Measures
	Validated information (confirmation from as-built drawings, reports, ground investigations etc.)	Majority of detailed information available on HAGDMS. At a site specific level, further interrogation of data sources not on HAGDMS may be required. Currently, the search terms for SGMs developed by Atkins are not implemented on HAGDMS.	N/A
	Validated information (confirmation of link to ground related hazard)	Initial steps to address this could be undertaken as a centralised activity by completing a matrix relating SGMs to the hazards that they could typically be used to mitigate. Site specific investigation would be required to fully validate the linkage.	N/A
Un-mitigated hazards	HE assessed – candidate Class 2 observations in HAGDMS	Based on completed ground related hazard maps, HE assessed locations for SGMs (currently not in a GIS format), and a matrix of interactions relating the two, this could be completed as a centralised activity.	Ground-related hazards (with liaison with SGM team)
	Validated by SP – Approved Class 2 observations in HAGDMS	This is a future task that would be the responsibility of the Area Service Providers to assess the data on candidate Class 2 observations on a site-by-site basis.	N/A
Consequences of hazard realisation	HE assessed consequence measures (e.g. safety, delay, reputation etc.)	Work is in progress within various parts of HE to define a consequence measure, but no definitive definition yet exists that is universally accepted across the business.	Resilience (outline methodology) Ground related hazards (pilot implementation)
Residual geotechnical risk	Proactive evaluation of residual risk posed to the SRN from ground related hazards	This is a future task that requires the completion of the steps outlined above.	Ground related hazards (pilot implementation)

Source: Task 1-062

4.3.1 Link to resilience enhancement framework

As described in Section 3.1, this task has maintained a strong relationship with the resilience enhancement framework task undertaken by Arup. As part of the Arup task , a risk management framework is presented (see guidance notes in Appendix G), as shown in Figure 31.

Figure 31: Arup resilience risk management framework

Source: Arup resilience enhancement framework task

The revised hierarchy shown in Figure 30 is consistent with the framework set out in Figure 31, albeit with a different focus, and intended use:

- The hierarchy shown in Figure 30 relates to largely 'static' data, that can be analysed in a proactive manner, in advance of any hazard realisation, and with an aim of preventing any risk to the SRN (either through mitigation of the hazard, reducing the likelihood of an incident or mitigation of the consequences, hence reducing the risk),
- The resilience risk management framework shown in Figure 31 cross-references elements of the hierarchy in Figure 30 (such as the initial assessment of ground-related hazards), but crucially brings in 'dynamic' factors, which provide the triggers to realisation of some of the hazards (such as extreme weather) and response measures put in place to recover from an incident. As such the framework can be considered to be a tool aimed at operational asset management.

5 Next steps

Table 28 sets out progress to date on determination of residual geotechnical risk, including areas where further advances can be made through completion of R&D activities by HE as part of the knowledge enhancement programme. Based on this, and consideration of other opportunities, suggested next steps are set out in Table 29.

Table 29: Suggested next steps

Next step description	Workstream
Completion of a means of demonstrating the concept of key components of vulnerability to users, learning from the methodology developed within this task for non-coal mining. This should be adapted for each hazard type, and may not extend as far as the production of qualitative scoring methodologies,	Ground-related hazards
Furthering the Slope Hazard Rating methodology by consideration of cross-asset drainage interactions building on the quantification of these interactions carried out in Tasks 434,	Ground-related hazards
Furthering the Slope Hazard Rating by consideration of banding of the results based on time-bound likelihood of failure, rather than arbitrary asset distribution. Consideration of requirements for decision support tool modelling should be included in this work,	Ground-related hazards
Continuously reviewing availability of new ground related hazard datasets from third party providers, including the BGS, Landmark, GroundSure and any others, and periodically refreshing the hazard maps accordingly,	HAGDMS/HADDMS informed by Ground-related hazards
As part of the next hazard map refresh, further consideration of the methodology adopted for the preparation of the landfill sites hazard map,	Ground-related hazards
Liaising with, and understanding the recommendations from, the recent HE project investigating remote sensing methods, to determine the part they may play in assessment of ground related hazards,	Ground-related hazards (and remote sensing)
Working with other asset teams in HE, particularly the pavements team, to explore relationships between ground related hazards, associated SRN vulnerability and pavement performance metrics. This has in part been facilitated by basing the vulnerability map methodology the HAPMS network definition,	Ground-related hazards (and HE pavements team)
Considering improvements to geotechnical data requirements that would assist in consideration of ground-related hazards. Examples to consider include geological material codification, where opportunities to work alongside Network Rail should be investigated,	Ground-related hazards
Where geotechnical data improvement opportunities arise, these should be communicated to the team updating the HE standards and guidance documents (or any documents replacing the existing standards and guidance),	Ground-related hazards (and HE DMRB review team)
Preparing a matrix linking ground related hazard to the SGMs that can typically be used to mitigate them,	Ground-related hazards (in liaison with SGM team)
Preparing a map based on the Atkins list of centrally assessed SGM location and type for display on HAGDMS,	Ground-related hazards
Implementation of the Atkins SGM search terms within the HAGDMS search tool to aid user identification of relevant reports in the HAGDMS online archive,	HAGDMS/HADDMS
Through use of the ground related hazard maps, the SGM locations GIS layer and the interaction matrix between the two, preparing an offline dataset of 'candidate' Class 2 observations of un-mitigated ground related hazards,	Ground-related hazards
Determining the means of communicating 'candidate' Class 2 observations to Service Providers, such that they can be validated and entered as approved observations in HAGDMS,	Ground-related hazards (liaison with HAGDMS/HADDMS team)
Providing training and support to the above Service Provider activity,	Ground-related hazards or HAGDMS/HADDMS team
Identifying, and collaborating with, other asset groups within HE, to produce an agreed HE means of measuring the consequences of incidents on the SRN,	Ground-related hazards, Resilience and HAGDMS/HADDMS teams
Whilst the above is undertaken, produce a pilot (offline) map of assessed consequence based on existing work in this area	Ground-related hazards

Next step description	Workstream
Once a pilot map of consequence measurement has been produced, combining this with the 'candidate' Class 2 observations to produce a dataset of residual geotechnical risk on the SRN (as an offline 'proof of concept' task). It must be recognised that this will be a conservative estimate in the initial stages, as validation on a site-by-site basis will be required to fully understand residual risk. This validation will take many years,	Ground-related hazards
In the future, once a means of consequence measure is agreed across HE, it will be possible to prepare a map of the residual geotechnical risk for display on HAGDMS, learning from the pilot, proof of concept map described above,	Ground-related hazards, Resilience and HAGDMS/HADDMS teams
Determine Key Performance Indicators that measure the residual geotechnical risk and progress towards validation of the risk, and implementing them in the HAGDMS monthly report,	Ground-related hazards (for pilot) and HAGDMS/HADDMS teams
Linking the identification and validation of residual geotechnical risk to the resilience enhancement task, to ensure that mitigations are in place for areas of residual risk (either in terms of proactive prevention, or consequence reduction and rapid recovery),	Ground-related hazards and Resilience teams
Setting residual risk validation and mitigation targets for RIS2, and reporting progress against the targets in the HAGDMS monthly report.	Ground-related hazards, Resilience and HAGDMS/HADDMS teams

Source: Task 1-062

6 Highways England Knowledge Transfer Sheet

A completed A3 Knowledge Transfer Sheet for the Geotechnical Hazard Knowledge tasks is presented in Appendix H.

7 References

Halcrow, June 2011. Rock Slope Hazard Assessment Completion Report. HA Task 402(1308)HALC

Mott MacDonald, 2015. Task 408: As-built geotechnical asset data. Task final report. Revision 12.

Mott MacDonald, 2016. Task 434 (PPRO 4/45/12) – Sustainable Drainage Phase 3. Activity 2 – Drainage cross asset risk. Closeout report. Version 2.0.

Transport Research Laboratory, 1995. Published Project Report PPR554. Rock slope risk assessment. P McMillan and I M Nettleton.

Appendices

A. Task specification

Task specification provided in the tender information for Task 1-062.

Specification for
Geotechnical Hazard Knowledge

1. Introduction

Highways England wishes to initiate a contract for the provision of consultancy services to complete a research and development task as part of the 5-year outline plan for geotechnical assets within the Capable Asset Portfolio. This planned task is part of a coherent programme of Geotechnical Knowledge development (part of the PTS Road Based Asset Group Business Plan 2015-2020), which comprises a series of activities to sustain and improve the knowledge of the geotechnical asset portfolio of Highways England.

2. Background

Ground related hazards pose a significant threat to the Strategic Road Network, affecting not only geotechnical assets (significant earthworks and at grade sections), but potentially all the other assets that comprise the network infrastructure. These hazards are exacerbated during periods of severe and extreme weather, and are potentially set to become more significant due to the impact of climate change and increased network use. Management of the risks that these hazards pose to the Strategic Road Network (SRN) begins with understanding their type, location and relationship to any Special Geotechnical Measures (SGMs) that have been put in place to mitigate or remove them. To date, much of the management of these hazards has been undertaken by Service Providers, utilising generalised national data sets made available through the Highways Agency Geotechnical Data Management System (HAGDMS), combined with local knowledge. This information is communicated to Highways England through an established Geotechnical Asset Management Plan (GeoAMP) process. Previous successfully completed tasks for Highways England have laid the foundation for the development of ground related hazard information that is specific to the SRN, making particular use of the large knowledge base of geotechnical data held on HAGDMS. These tasks include:

- Task 197: development of a slope hazard rating for geotechnical assets
- Task 408: geotechnical as-built asset data
- Task 434: particularly the quantification of cross asset risks
- HAGDMS/HADDMS: provision of the key asset management information system for geotechnical and drainage information

3. Requirements

3.1. Objectives

The objectives of this task are as follows:

- To improve the knowledge of **ground-related hazards** that may impact on the SRN, and develop products that will communicate this improved knowledge to stakeholders in Highways England and our supply chain

- To contribute to the suite of Highways England knowledge improvement tasks determining the **resilience** of the geotechnical asset portfolio, and it's **vulnerability** to severe and extreme weather events. This task seeks to determine the **susceptibility** of the asset portfolio to particular ground-related hazards, either natural or man-made, after consideration of any Special Geotechnical Measures put in place to mitigate the impact of such hazards
- To gain **maximum value** from the information held within the technical archives of HAGDMS by making use of improved, topic-based search facilities, and manual assessment of key information sources
- To produce **practical, centrally validated hazard products** that have been developed with input from key stakeholders, including the intended end users of the information. The hazards to be considered should be prioritised, with the degree of validation potentially varying according to the order of prioritisation.
- To produce as many hazard products as possible within the available task programme, and to ensure that requirements for future continued work are well document
- To contribute to improvements in the way that Highways England collates **as-built information**, such that ground-related hazard information from current, and planned schemes (such as the Smart Motorways programme) can feed into corporate knowledge in a more efficient manner

3.2. Work Required

To complete the objectives of this task, the following work will be required:

- Development of a Project Initiation Document, and agreement with the Highways England Project Sponsor
- Liaison with existing Highways England task teams, working on resilience assessment and Special Geotechnical Measures
- Review of previous tasks related to the development of improved understanding of ground-related hazards and their relationship to the SRN (including Task 197, Task 408 and Task 434)
- Development of a draft framework for ground related hazard assessment. This framework would need to consider both the availability of available information and its quality
- Prioritisation of ground related hazards to be assessed, in agreement with Highways England and a stakeholder group
    - Previous work has been undertaken to determine key-word sets for intelligent searching of records in the HAGDMS technical archive. As part of this task, key-word sets for the remaining identified hazard groups should be derived, and tested, prior to handing over the HAGDMS Support Team,
- Previous work has been undertaken to determine a Slope Hazard Rating for earthwork slopes recorded in the HAGDMS Geotechnical Asset Database. As part of this task, this ground-related hazard dataset should be reviewed and updated. Consideration should be given to:
    - The currency of the data used in the analysis

  - The geotechnical asset types, and their appropriateness for inclusion in the analysis
  - The determination of any weightings used in the analysis, and their correlation to other HE tasks (such as the tasks considering cross-asset risk assessment)
  - The potential to calibrate the revised Slope Hazard Rating against records of geotechnical failures
  - The potential for liaison with other infrastructure asset owners, to potentially collaborate on elements of the analysis to gain mutual benefit
- Previous work has been undertaken to investigate and quantify the cross-asset relationships that impact on geotechnical assets, the most important being the relationship to drainage. This task should be cognisant of this work, and should investigate how the this improved understanding of cross-asset relationships can be brought into practical usage in improving the understanding of ground-related hazards
- Development of a pilot phase, possibly for a single hazard and a constrained geographical area, to be determined by the contractor, and agreed with the Highways England Project Sponsor. This pilot phase should explore all the envisaged elements of the main project phase, and should:
  - Combine hazard information sources to determine the geographical location of the hazard(s) in relation to the SRN
  - Make use of available information on the location of Special Geotechnical Measures (SGMs) in the geographical area, and show these in relation to SRN
  - Determine a means of relating the effectiveness of the recorded SGMs in addressing the identified hazard(s)
  - Produce information on the location, and type, of potential areas of unaddressed hazard(s) in the pilot area, through completion of the above steps, or similar equivalent steps that are developed by the contractor
- Presentation of the pilot phase to Highways England and the stakeholder group, and determination of the agreed way forward
- Main phase production of hazard products, in the order or agreed prioritisation. This phase is to be time-boxed, with as much being achieved as possible in the available time. This main phase of the task will:
  - Be carried out based on the agreed way forward determined from the pilot phase
  - Be adaptable, such that any required changes to the methodology can be carried out, once agreed with the Highways England Project Sponsor
  - Consider the likely impact of the outputs of the task on the current (and potential future) Performance Indicators used by Highways England in their Geotechnical Asset Management processes
  - Consider the linkages between ground-related hazards, and wider SRN resilience, through liaison with the related tasks that are addressing resilience issues
- Validation of developed products, with the stakeholder group and Highways England. This stage may include liaison with other

infrastructure asset owners. Should it be deemed appropriate by the Project Sponsor, this stage may also include feedback to the British Geological Survey (BGS) on any of their products used as part of the task analysis, and their effectiveness in relation to specific issues affecting the SRN

- Preparation of a final report, including recommendations for next steps

4. Responsibilities

Project Sponsor: David Patterson

Task to be completed by a consultant engaged under the SPaTS Lot 1 framework with the necessary skills and experience set out below.

5. Skills/Experience

This task requires an experienced consultant, with skills as set out below.

5.1. Essential Skills

- In-depth understanding of ground related hazards, and how they can impact on the SRN
- In-depth understanding of the importance of resilience on the SRN, and how geotechnical assets perform during periods of severe and extreme weather (impacting on SRN resilience)
- In-depth understanding of cross-asset interactions affecting the performance of the SRN, and the particular importance of drainage on geotechnical asset performance
- Understanding the previous work undertaken by Highways England in the development of ground related hazard knowledge
- Understanding of the previous work undertaken by Highways England on Special Geotechnical Measures (SGMs) that have been utilised in the construction, and subsequent asset management of the SRN
- In depth understanding of the key Standards and other documents relating to geotechnical asset management within Highways England, and experience in their application to asset management practice
- A strong working knowledge of the key sources of national ground related hazard information available to Highways England (and its supply chain)
- In-depth understanding of the information available within the HAGDMS and HADDMS
- A proven capability in Geographical Information Systems (GIS) undertaken by a team of specialists with a good understanding of geotechnical asset management and familiarity with Highways England data sources
- Strong communication skills to enable the outputs of the task to be well understood by Highways England and their supply chain
- A proven culture of high levels of Quality Assurance and checking

- Prior experience of working with Highways England.

5.2. Desirable Skills

- Particular experience of working as a Service Provider to Highways England within a Management Area contract
- Experience of working with other transport infrastructure owners facing similar ground related hazards
- Understanding of, and involvement in, national and international research projects relating to the development of ground related hazard knowledge

6. Deliverables

Deliverable Number	Deliverable Description	Completion Date
WP001	Project Initiation Document	Within 1 month of project start
WP00	Stakeholder consultation pilot phase presentation and webinar	Completion of pilot phase
WP00	Developed hazard information products in a format suitable for implementation in the HAGDMS	Project End
WP00	Final project report	Project End
WP00	Stakeholder consultation final presentation and webinar	Project End

7. Location

Consultant to be based within their offices. Where meetings to be undertaken with Highways England, the preferred location is Birmingham.

Where possible, sustainable means of communication (such as online meetings) to be utilised.

8. Timescales

Start date: June 2016

Duration: 16 months

9. Evaluation Criteria

Work Package Evaluation criteria –

Primary Criteria	Sub-criteria	Weighting	Score
`Resources and capabilities	Supplier's prior performance on this type of work	1	
	Suitability of key personnel	1	
	Appropriate allocation of resource	1	
	Overall capability and expertise	1	
Technical solution proposed and competence	Demonstrates understanding of the objectives and deliverables	1	
	Robustness of the proposal and methodology	1	
	Creative and innovative thinking	1	
	Adequate are the proposed project management and quality control systems	1	
Suitability of proposed processes	Identification and management of risks	1	
Subtotal			
Total	Total Mark (Subtotal x 100/90*)		

* This figure should change subject to the number of criteria used (eg 9 criteria = 90, 11 criteria = 110, 12 criteria = 120 etc) – this calculation is required to ensure total mark is calculated as a percentage.

The assessment panel will use the marking system as shown below, to award marks for approach or evidence, as relevant to the sub-criteria in the previous table.

Score	**Reason**	**Mark**
Weak	The proposed approach fails to demonstrate an adequate understanding of the project objectives and fails to address adequately the risk management issues. There is little evidence that the proposed approach has been influenced by experience on other projects.	1-4
Acceptable	The proposed approach demonstrates an adequate understanding of the project objectives; it addresses the success factors and risk management issues to an acceptable standard. There is an adequate level of evidence that the proposed approach has been developed as a result of successful experience on other projects.	5-7
Good	The proposed approach demonstrates a good understanding of the project objectives; it addresses fully the success factors and risk	8-9

	management issues and provides for delivering continuous improvement over the life of the framework. There is substantial evidence that the proposed approach has been developed from other projects using formal continual improvement processes.	
Excellent	The proposed approach has been tailored specifically to deliver the project objectives, and deals comprehensively with the risks to maximising performance against Key Performance Indicators and to delivering continuous improvement. There is substantial evidence that the approach has been developed using continual improvement processes, which are routinely used to develop approaches and deliver the objectives successfully on all projects.	10

The proposal with the highest mark will be given a score of 100. The score of other competing suppliers will be calculated by deducting from 100 one point for each full percentage point by which their mark is below the highest mark. The minimum requirement for this work package is to reach a threshold of 60. A submission that has failed to achieve the minimum quality requirements may not be considered further in the assessment.

The lowest priced tender will be given a score of 100. The score of other competing suppliers will be calculated by deducting from 100 one point for each full percentage point by which their price is above the lowest price. The overall quality score and the finance score will be combined in the ratio 60:40 applied to the quality and financial scores respectively.

Following receipt of your evaluation reports the rejection/acceptance letter will be sent out by the Framework team. Before the contract can be officially awarded, a 10 day “standstill” period needs to elapse.

10. Contact Information

Role	Location	Phone
Project Sponsor/Manager: David Patterson	Temple Quay, Bristol	0117 372 8399
Framework Manager: Hannah Milliner	Temple Quay, Bristol	0117 372 8185
Procurement Officer: Rob Amor	The Cube, Birmingham	0121 678 8486

B. Work Package Quality Plan

MOTT MACDONALD

highways england

WSP | PARSONS BRINCKERHOFF

Geotechnical Hazard Knowledge (SPaTs 1-062)

Work Package Quality Plan

9 November 2016

Highways England

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Geotechnical Hazard Knowledge (SPaTs 1-062)

Work Package Quality Plan

9 November 2016

Highways England

Issue and Revision Record

Revision	Date	Originator	Checker	Approver	Description
A5	08/11/16	Chris Power	David Grant Keith Halstead	Chris Power	Draft for client review
A6	09/11/16	Chris Power	David Grant	Chris Power	Final for issue to client

Information class: Standard

Contents

1 Scope of work plan

This document has been prepared by Mott MacDonald on behalf of the WSP|PB Consortium.

This section of the Work Package Quality Plan sets out the objectives of the task, the methodology to be adopted, and the work breakdown structure and timescales.

1.1 Background and objectives

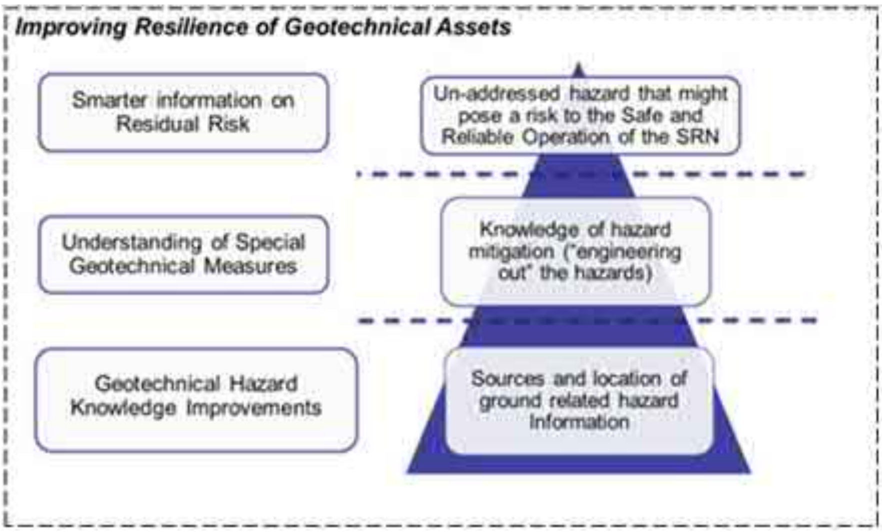
The overriding aim of this task is to contribute to the body of work commissioned by Highways England to improve the resilience of their geotechnical asset portfolio.

Specifically, this task sets out to improve the knowledge of ground-related hazards that may impact on the Strategic Road Network (SRN)

The initial objective, as set out in the task specification, was to supplement this knowledge of hazards with an understanding of their spatial relationship to Special Geotechnical Measures (SGMs) that have been constructed on (or around) the SRN and the relationship between the types of SGMs and their ability to mitigate the potential impacts of the hazards. This had the aims of assisting in the identification of un-addressed hazards on the SRN, as illustrated in Figure 1 below.

However, early in the life of the project, an incident on the SRN resulted in a change to the project objectives (in full agreement with Highways England) that is set out in detail in this WPQP.

Figure 1: Hierarchy of ground-related hazard and residual risk knowledge



Source: Mott MacDonald Task 408

In the execution of this task, the following objectives are set:

- To develop products that will allow the improved knowledge of ground related hazards that may impact on the SRN to be communicated to stakeholders, in Highways England and their wider supply chain. These products will be practical and centrally validated (in conjunction with geotechnical experts within Highways England),
  - It is relevant to note here that since the preparation of the task proposal document, events on the Strategic Road Network (specifically the collapse of a coal mining shaft near Gateshead) have meant that Highways England have requested the acceleration of an early iteration of a mining hazard map. This change, and further changes requested in discussions prior to the preparation of this document, are recorded in this WPQP,
- To gain the best possible value from the large technical archive of information held within the Asset Management Information System of Highways England (HA GDMS), specifically making use of improved functionality for searching introduced by Task 408 (undertaken for Highways England by Mott MacDonald),
  - Again, it is relevant to note here that this requirement has been modified in this WPQP, relative to the wording included in the task proposal document,
- To make use of the well-established time-box approach (employed for over a decade by Mott MacDonald in their management of the HA GDMS and HA DDMS) to maximise the products that can be produced within the task period,
- To contribute to the wider improvements that are being made in the collation of as-built information, such that they contribute efficiently to the corporate knowledge of Highways England. This will build on the considerable expertise that Mott MacDonald have in this area.

1.2 Specification

The specification, as provided by Highways England in the tender information for this task, is included in Appendix A.

As noted above, it is important to recognise that there has been a significant change to the objectives of this project, and as such the specification is superseded in a number of places. This WPQP sets out the revised objectives, and the methodology by which the objectives will be met.

1.3 Standards

No specific technical standards from Highways England or other bodies apply to the completion of this task. However, consideration will be given to the following during the development of this task:

- The geotechnical asset management processes of Highways England, as set out in HD41/15 Maintenance of Highway Geotechnical Assets
- The certification and review processes of geotechnical works undertaken by Highways England, as set out in HD22/08 Managing Geotechnical Risk
- The data management requirements of Highways England set out in IAN 184/16 Highways Agency Data and CAD Standard, and in the Asset Data Management Manual
- The guidance on scheme handover requirements of Highways England set out in IAN 182/14 Major Schemes: Enabling Handover into Operation and Maintenance

The above list is not intended to be an exhaustive list of relevant standards and advice notes that could be consider relevant to this task.

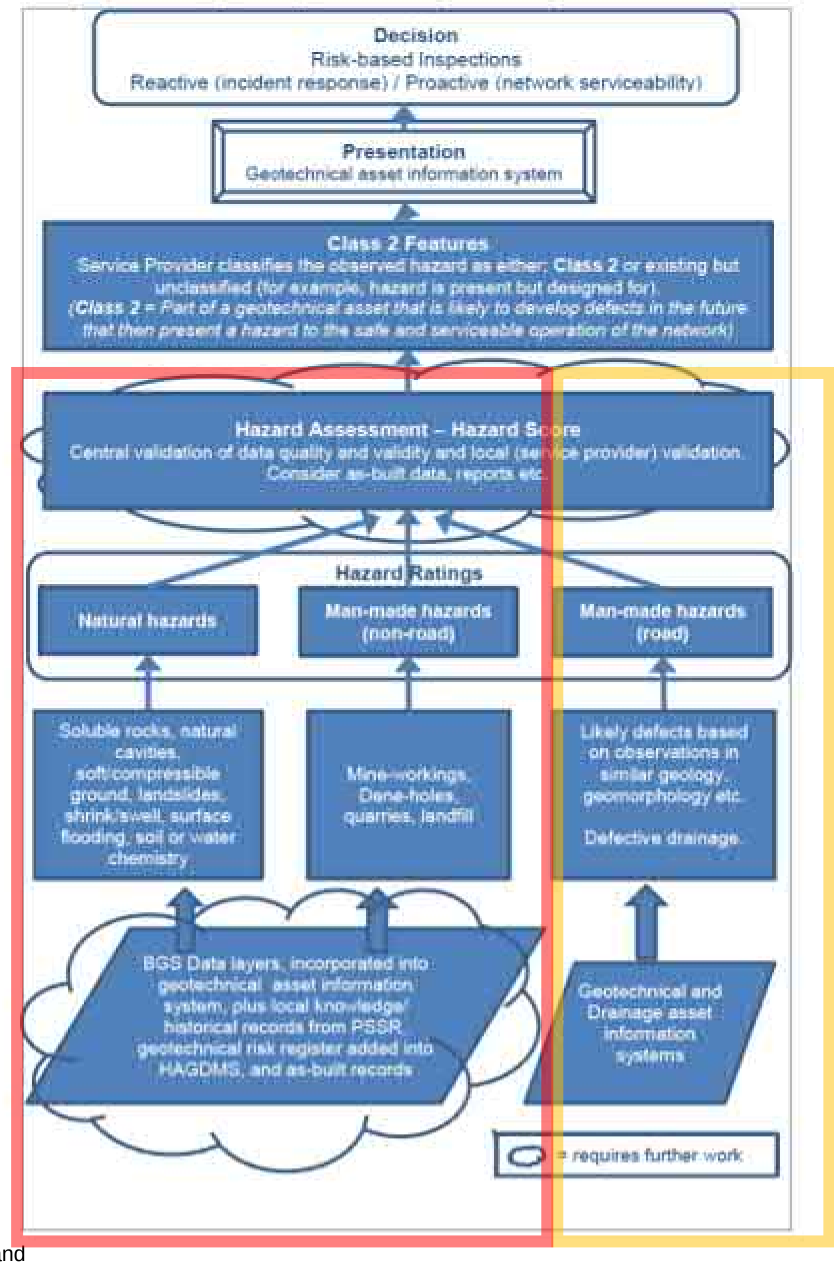
1.4 Methodology and deliverables

The main task activities will be split into separate sub tasks plus the project initiation / start-up. Our proposed approach for each of these tasks is outlined below, and described in detail in Section 1.5.

The figure below outlines the suite of activities that were defined with Highways England (then the Highways Agency) during the development of the predecessor (enabling) tasks for this current task. On Figure 2, boxes have been drawn to show:

- In orange, the part of the wider process to which this task will update and improve existing methodologies and procedures,
- In red, the part of the wider process to which this task will build on tools built in HA GDMS, and on the experience of the task team and the wider network of Highways England geotechnical advisors, to produce new products aimed at contributing to the overall aim of improved geotechnical asset management decision making and risk management.

Figure 2: Development of improved knowledge on ground-related hazards affecting the SRN



Source: Highways England

The accepted proposal for this task outlined the envisaged methodology to be employed to meet the requirements of the specification. Following task award, and prior to preparation of this WPQP, discussions have been held with the Project Sponsor to somewhat adjust the requirements of the task, to meet some developing challenges and opportunities that have arisen. A summary of these stages of task development is provided in Table 1.

Table 1: Summary of work required (as specified), proposed methodology (at proposal stage) and comments on the revised methodology in this WPQP

Work required (from task specification, see Appendix A)	Proposal Section	Comment on methodology outlined in this WPQP (relative to task proposal)
Development of a Project Initiation Document, and agreement with the Highways England Project Sponsor	Section 4.2	Unchanged – this requirement is fulfilled by this Work Package Quality Plan
Liaison with existing Highways England task teams, working on resilience assessment and Special Geotechnical Measures	Section 4.3	Generally unchanged (see Stakeholders section), but liaison with the SGM team now less important
Review of previous tasks related to the development of improved understanding of ground-related hazards and their relationship to the SRN	Section 4.3	Unchanged
Development of a draft framework for ground related hazard assessment. This framework would need to consider both the availability of available information and its quality	Section 4.4	Removed. See Section 1.5.2
Prioritisation of ground related hazards to be assessed, in agreement with Highways England and a stakeholder group Previous work has been undertaken to determine key-word sets for intelligent searching of records in the HAGDMS technical archive. As part of this task, key-word sets for the remaining identified hazard groups should be derived, and tested, prior to handing over to the HAGDMS Support Team	Section 4.4	Generally unchanged, but mining hazard must remain at the top of the prioritisation list
Previous work has been undertaken to determine a Slope Hazard Rating for earthwork slopes recorded in the HAGDMS Geotechnical Asset Database. As part of this task, this ground-related hazard dataset should be reviewed and updated. Consideration should be given to: • The currency of the data used in the analysis • The geotechnical asset types, and their appropriateness for inclusion in the analysis • The determination of any weightings used in the analysis, and their correlation to other HE tasks (such as the tasks considering cross-asset risk assessment) • The potential to calibrate the revised Slope Hazard Rating against records of geotechnical failures • The potential for liaison with other infrastructure asset owners, to potentially collaborate on elements of the analysis to gain mutual benefit	Section 4.3	Unchanged
Previous work has been undertaken to investigate and quantify the cross-asset relationships that impact on geotechnical assets, the most important being the relationship to drainage. This task should be cognisant of this work, and should investigate how this improved understanding of cross-asset relationships can be brought into practical usage in improving the understanding of ground-related hazards	Section 4.3	Unchanged
Development of a pilot phase, possibly for a single hazard and a constrained geographical area, to be determined by the contractor, and agreed with the Highways England Project Sponsor. This pilot phase should explore all the envisaged elements of the main project phase, and should: • Combine hazard information sources to determine the geographical location of the hazard(s) in relation to the SRN • Make use of available information on the location of Special Geotechnical Measures (SGMs) in the geographical area, and show these in relation to the SRN • Determine a means of relating the effectiveness of the recorded SGMs in addressing the identified hazard(s) • Produce information on the location, and type, of potential areas of unaddressed hazard(s) in the pilot area, through completion of the above steps, or similar equivalent steps that are developed by the contractor	Section 4.5	Significantly changed approach. See Section 1.5.4
Presentation of the pilot phase to Highways England and the stakeholder group, and determination of the agreed way forward	Section 4.5	Concept remains unchanged, but detail changed – see Section 1.5.4
Main phase production of hazard products, in the order of agreed prioritisation. This phase is to be time-boxed, with as much being	Section 4.6	Significantly changed approach. See Section 1.5.5

Work required (from task specification, see Appendix A)	Proposal Section	Comment on methodology outlined in this WPQP (relative to task proposal)
achieved as possible in the available time. This main phase of the task will: • Be carried out based on the agreed way forward determined from the pilot phase • Be adaptable, such that any required changes to the methodology can be carried out, once agreed with the Highways England Project Sponsor • Consider the likely impact of the outputs of the task on the current (and potential future) Performance Indicators used by Highways England in their Geotechnical Asset Management processes • Consider the linkages between ground-related hazards, and wider SRN resilience, through liaison with the related tasks that are addressing resilience issues		
Validation of developed products, with the stakeholder group and Highways England. This stage may include liaison with other infrastructure asset owners. Should it be deemed appropriate by the Project Sponsor, this stage may also include feedback to the British Geological Survey (BGS) on any of their products used as part of the task analysis, and their effectiveness in relation to specific issues affecting the SRN	Section 4.6	Concept remains unchanged, but detail changed – see Section 1.5.5
Preparation of a final report, including recommendations for next steps	Section 4.7	Unchanged

Source: Task 1-062 proposal

Note: Green: unchanged, yellow: minor change to details, orange: significant change, red: removed.

1.4.1 Summary of deliverables

A summary of task deliverables and their reference number, as presented in our proposal and agreed at the Project Inception Meeting is shown in Table 2.

Table 2: Summary of deliverables

Sub-task	Key Deliverables
Project Initiation	Work Package Quality Plan (Project Initiation Document)
Preparation and data gathering plus Coal Mining Hazard Map (Revision 1)	Coal mining hazard map (Rev01) Guidance documents to accompany coal mining hazard map (Rev01) Determination of method for Slope Hazard Rating refresh and presentation to HE. File note on method of location for the task (included in guidance documentation for coal mining map)
Hazard prioritisation	Agreed prioritisation of hazards for the project
Revision 1 version of hazard maps	Revision 1 hazard maps (offline) for all hazard groups Revised 1 hazard maps for upload to HAGDMS/HAGIS following assessment and central validation Revised SHR map Guidance and explanatory documents to accompany Revision 1 hazard maps Launch webinar
Revision 2 version of hazard maps	Hazard topic keyword sets for implementation in HA GDMS. Suite of revision 2 hazard products for implementation in HAGDMS and HAGIS (number dependent on time-boxing) Explanatory documentation for Revision 2

Sub-task	Key Deliverables
	hazard products. Envisaged future usage of products in KPIs and resilience assessment (in task report)
Reporting	Draft and Final versions of task report and A3 Knowledge Transfer sheet Presentation for task end webinar.

1.5 Work breakdown structure and timescales

1.5.1 Project initiation

Project initiation will commence on award of the Work Package. The Work Package Manager will have an inception meeting with the Client Work Package Order Manager to discuss and agree the detailed scope of work as presented in this proposal.

The agreed scope of work will be documented in the Work Package Quality Plan (WPQP) (this document). Due to the urgent requirement to modify this project in its very early stage (for the coal mining hazard map), the preparation of this WPQP has been delayed, in agreement with Client Work Package Order Manager.

The WPQP will include review of the Draft Work Package Risk Register.

1.5.2 Preparation and data gathering plus Coal Mining Hazard Map (Revision 1)

This initial stage of the project after initiation includes:

- Liaison with the HA GDMS Support Team (within Mott MacDonald) to obtain an update on the latest round of reviews of third party mapping products that may be of interest to this task,
- Making contact with each of the Highways England Geotechnical Advisors, and each of the GMLEs (Geotechnical Maintenance Liaison Engineers), to determine if any electronic sources of hazard information (particularly maps) are held in their locations that are not held on HA GDMS. This is to address the fact that some such sources are known about (for example the drawing archive in Area 1), and that they may be of value to this task. Note that scanning and uploading of any data sources found to HA GDMS will not be included in this task specification, but if any valuable sources of information are found, discussions will be held with Highways England to determine the best means of getting this information into the technical archive,
- Determining the means of location referencing that will be used by the task. This is a key activity:
  - Information on ground related hazards, and the location of SGMs, will come in a range of spatial formats: point, line and polygon based. A means must be determined to conflate this information into a representation of a common location. Various means of achieving this will be investigated, and the final decision must be cognisant of:
    - Development of common referencing systems within Highways England (which will need to be investigated),
    - The appropriate scale, and lateral extent (away from the SRN) that should be considered,
    - Other developments within the geotechnical knowledge programme that should be aligned to, for example consideration of cross-asset risk management, and SRN resilience,
    - Future requirements for Decision Support Tool (DST) modelling that are being considered by Highways England.

The proposal included several other tasks in this stage of the project. However, on commencement of the project, an incident on the Strategic Road Network (the collapse of a coal mining shaft under the A1 near Gateshead) meant that a re-prioritisation of the project was carried out, with involvement of the Work Package Manager and the Client Work Package Order Manager. In terms of this Work Package, this incident resulted in:

- An agreed delay to the preparation of this WPQP
- The accelerated development of a Coal Mining Hazard map for the SRN, focussed on providing support to the Operational and Resilience parts of the HE business
  - Implemented on the HAGDMS system
  - Provided for implementation on the internal HE HAGIS system
- Development of associated technical documentation to support the Coal Mining Hazard Map
- Liaison with the HE Resilience project team (Arup led) and joint authorship of operations-focussed documentation relating to coal mining hazards in relation to the SRN
- Liaison with the Coal Authority (meeting to be held on 9/11/16)
- Accelerated development of the means of location referencing for the hazard maps (see above)
- A re-appraisal of the priorities of the project as a whole, and the means of phasing of works (now described in this document)

Based on this re-appraisal, the following items were changed in this section of the project (when compared to the proposal):

- The main work relating to the updating of the Slope Hazard Rating layer was moved to the 'Revision 1 version of hazard maps' part of the project (see Section 1.5.4). However, the determination of the methodology to be employed for this task was retained in this stage of the project and presented to the Client Work Package Order Manager on 7/11/16
- The development of a framework to link ground related hazards to Special Geotechnical Measures was removed from this stage of the project

1.5.3 Hazard Prioritisation

This stage of the project includes:

- Agreement on the prioritisation of hazards to be addressed in the main phase of the task. This will be based on previous prioritisation exercises carried out with Highways England, and their Research and Development supply chain. This prioritisation forms the order in which hazards will be addressed in the main phase of the task.

Due to the re-prioritisation of the tasks described in the section above, the preparation of this WPQP has been delayed from the original programme to allow the new project outline to be determined. This has meant that there has been an opportunity to carry out a very initial stage of the hazard prioritisation task, undertaken on a phone call with the Client Work Package Order Manager on 19/10/16. This resulted in agreement to progress next to the Dissolution Features hazard group, to allow this to progress whilst awaiting a liaison meeting with the Coal Authority planned for 9/11/16. Following that meeting, the hazard prioritisation can be finalised. Table 3 details the initial prioritisation carried out on 19/10/16, and also references the previous MoSCoW prioritisation from task 408. There are also a number of notes on the prioritisation exercise that are explained below.

Table 3 Agreed prioritisation of ground related hazards (19/10/16)

	Task 1-062 Prioritisation					
Hazard Grouping	**Task 408[1]**	**MM Internal[2]**	**HE Agreed[3]**	**HE Stakeholder Group[4]**	**Number of datasets[5]**	**Notes**
Coal Mining Rev01	M	1	1		22	Complete
Coal Mining Rev02	M	2?	x		22	To discuss with David Patterson
Non Coal Mining	M	3	x		12	
Groundwater Flooding	M	4	x		4	Need to consider existing flood mapping - check with TWS
Landfill Sites	S	6	x		4	
Natural Landslides (Soil)	M	5	x		5	
Natural Landslide (Rock)	C	9	x		3	
Soil and Groundwater Chemistry	S	7	x		4	
Dissolution Features	M	2	2	Jamie Codd, Jan Marsden, Mark Shaw	5	
Compressible Ground	S	8	x		3	
Shrink/swell	C	10	x		2	
Engineered slopes of marginal stability (rock or soil)	Out of Scope	1	x		2	In progress
Defective or inappropriate drainage	Out of Scope	1	?		1	Can be produced as an output from the engineered slopes hazard map
Animal burrows	Out of Scope	11	?		2	
Loss of vegetation	Out of Scope	12	-		0	

Notes

[1] MoSCoW prioritisation undertaken in T-TEAR Task 408

[2] Internal MM prioritisation suggestion, discussed with HE on 19/10/16 (to be reviewed again after 9/11/16)

[3] Agreed initial prioritisation with HE on 19/10/16, recognising the need to complete the liaison meeting with the Coal Authority on 9/11/16 prior to completing the prioritisation task

[4] Initial thoughts on particular expertise on the hazard group within HE. Will be completed for all hazard groups. The Client Work Package Order Manager will be included in discussions on all hazard groups

[5] An initial assessment of the number of spatial datasets available now for the creation of the hazard maps

The proposal included in this stage of the project a number of activities that are now considered superseded by the new methodology to be employed for this task. In summary, these superseded activities were:

- Determination of a limited geographical area for a pilot phase,
- Determination of a framework to link ground related hazards, asset types and SGMs for coincident locations on, and around, the SRN. The link to SGMs has been removed from this project. The influence of asset types is retained, to be considered on a hazard-by-hazard basis in the main phase of the project.

1.5.4 Revision 1 version of hazard maps

This stage of the project is significantly different to that set out in the proposal. Based on the experience gained in the development of the Coal Mining Hazard Map (Rev 01), we have been able to demonstrate that a first pass hazard map, specific to the SRN, can be produced based on currently available data (held for HAGDMS). Preparation of these 'Revision 1' maps allows the validation exercise (by the project team and the HE experts) to be commenced against a tangible product, rather than discussing the hazard maps in abstract terms. It proved extremely valuable to be able to review the Coal Mining Hazard Map against known locations of mining hazard, and also against scheme specific hazard products found in reports on HAGDMS.

Based on this experience, the envisaged stage of producing a detailed pilot map, for a series of hazards in a constrained geographical area has been abandoned. In its place, this stage of the project will:

- Produce a series of revision 1 hazard maps for all the hazard groups, based on currently available data from within HAGDMS/HADDMS (which will be a mix of HE owned data, and data from 3rd parties)
  - These maps will be true hazard maps only, they will be specific to the location of the SRN, but will not take into account the particular geometry or the SRN at any location, or the particular asset types at each location
- Assess each of the produced maps, and validate them by:
  - Expert judgement of the project team, and the agreed set of HE expert advisors
  - Comparison to externally produced maps for the same hazards, that can be found within the HAGDMS technical archive
- Determine if the produced hazard maps are suitable for dissemination via HAGDMS and HAGIS:
  - It is recognised that the revision 1 Coal Mining Hazard Map produced early in this project had a wealth of available datasets for its creation (see the Number of datasets in Table 3) and that for other hazard groups, the sparsity of available data may render a hazard map unsuitable for use

- Pass the hazards maps deemed suitable for use onto the HAGDMS and HAGIS support teams
- Produce the guidance documentation to support the hazard maps to be placed on HAGDMS and HAGIS
- Included in this stage will be the production of a revised Slope Hazard Rating map, to the previously agreed method, and an update to the supporting documentation for this map
- On completion of the revision 1 hazard maps, and their upload to HAGDMS and HAGIS, undertake a launch webinar.

The proposal included in this stage of the project a number of activities that are now considered superseded by the new methodology to be employed for this task. In summary, these superseded activities were:

- Combination of available hazard maps (note: this part still included in the stage as outlined above) with detailed information extracted from reports in the HAGDMS technical archive for three agreed hazards in an agreed, limited geographical area,
- Determination of the locations and types of SGMs in the pilot area (through use of data from the Atkins SGM team), and consideration of their impact in terms of mitigating the ground related hazards in the area, utilising the previously prepared framework,
- Assessing the results produced by the use of the strawman framework, and making adjustments to the framework to achieve a sensible result (as determined by the task team alone at this stage). Up to three iterations of adjustments to the framework will be made,
- Once a revised framework has been agreed, an assessment of how areas of un-mitigated hazard can be sensibly determined. This assessment will need to consider the quality of information that is available, as well as the spatial relationships and interactions determined by the framework linking the hazards, asset types and SGMs,
- Producing a presentation on the pilot phase, for discussion with Highways England (and any supply chain geotechnical experts that they may wish to include) in a day long workshop. This workshop will review the work completed to date, but also shape the remainder of the task, taking account of any outcomes from the pilot phase of the Research and Development task that cannot be currently envisaged.

1.5.5 Revision 2 version of hazard maps

Following completion of the revision 1 hazard maps, this subsequent stage of the project will build on the initial maps to introduce more detail, and take greater account of the influence of the specific elements of the SRN at each location on the potential vulnerability to ground related hazards. As with the envisaged ‘main phase’ of the project set out in the proposal, this stage will be time-boxed, with maps being refined as far as time and project budgets allow.

This stage of the project will:

- Carry out a review exercise (format to be determined, but likely to be an E-mail survey, followed by a conference call) to gather feedback on the iteration 1 maps from the HAGDMS and HAGIS user communities. This activity will have the following focus:
  - To gather valuable feedback to help improve the hazard maps in revision 2 (see below)
  - To determine the key contacts with specific hazard expertise within the user community, that could bolster the expert review panel for the revision 2 maps
- Improve the revision 1 hazard maps, in a time-boxed manner (i.e. recognising that it may not be possible to complete revision 2 maps for all the hazard groups in the time available), by consideration of:

  - Additional input data sets that may become available
  - The specific details of the SRN at each location (most importantly the geotechnical asset type) and the impact that this has on the potential to ‘buffer’ the vulnerability of the SRN to the particular ground related hazards
  - Whether any general relationships can be drawn to relate the age of the network at a given location to the specific details of the hazards at that location. An example would be whether the assessed quality of historical mining remediation at the location of a modern road (particularly one constructed after the implementation of the HD22 processes) should be treated differently to a location of an older road (where record keeping and HE overview may have been lower key, or not present)
  - Specific information that can be obtained from the technical archive of HAGDMS, where spatial references can be found (such as hazard maps within technical reports)
  - Specific information that can be obtained from information sources found from the round of contact made with Maintenance Agent Geotechnical Liaison Engineers in the second stage of the project
  - User feedback from the HAGDMS and HAGIS user communities
- Validate the newly created revision 2 hazard maps by:
  - Use of expert panels, of both the HE Geotechnical Advisors deemed appropriate for each hazard group, and any identified experts in the HAGDMS and HAGIS user communities
  - Liaison with the HE resilience and operations parts of the business, to ensure the that the revised map products (and guidance information, see below) meet their requirements
- Complete guidance information to accompany each revised hazard map
  - These will be an update to the documentation prepared for the revision 1 maps
- Carry out cross-industry liaison with other infrastructure owners (particularly Network Rail), but potentially other owners (through the GAOF) to present the HE hazards maps and discuss similar approaches within their organisations
- Give consideration to feeding back any comments on available third party datasets to their originators, the most relevant being the British Geological Survey
- Liaise with the HAGDMS/HADDMS and HAGIS Support teams to upload the revision 2 maps to their systems
  - The project will also aid in the preparation of any required publicity documentation (such as HE internal ‘press releases’)
- Complete a series of additional tasks not directly related to the preparation of the revision 2 maps, to include:
  - Completion of the keyword lists for the HAGDMS topic search functionality for those hazard groups not already completed (as part of T-TEAR task 408)
  - Giving consideration to Performance Indicators that can be derived from this task, such that Highways England can gain a measure of the size and severity of the ground related hazards that may impact on the SRN. The task will also consider where the quality of available information does not allow a sensible degree of confidence in the results of the analysis to be made, such that future knowledge improvement activities can be carried out in a targeted manner

The proposal included in this stage of the project a number of activities that are now considered superseded by the new methodology to be employed for this task. In summary, these superseded activities were:

- In-depth review of information on ground-related hazards included within the text of reports held in the HAGDMS technical archive,
- Determination of the location of areas of 'un-mitigated' ground-related hazards, through the combination hazard information and SGM information, and the assessment of the interaction between the two. It is now envisaged that these interactions are likely to be complex and site specific, and would be better addressed on a scheme-by-scheme basis by the HE supply chain, rather than through a centrally completed project such as this.

1.5.6 Reporting

This final stage of the task will:

- Document all the previous stages of the task into a final report, collating any file notes or other deliverables developed,
- Document any lessons learned in the collation of hazard information that can be fed back into improvements to the future capture of hazard information by Highways England (through, for example, the handback of as-built information),
- Provide a listing of hazard products that could not be completed in the time available for the task,
- Provide guidance, suitable for passing on to the HE supply chain, explaining how the hazard maps, in conjunction with the information that is available on SGMs, can be combined with in-depth reviews of the available technical information held in the HAGDMS technical archive with the aim of determining the areas of un-mitigated hazards on the SRN. The level of guidance that can be provided will depend on:
  - How successful this project is in delivering centrally validated hazard maps for the ground related hazards
  - The degree to which the outcomes of the SGM project(s) have delivered their outputs for presentation to users on HAGDMS
- Provide recommendations for next steps,
- Present the final findings of the task to Highways England and their selected stakeholders via a webinar.

2 Project Management Plan

This section of the Work Package Quality Plan sets out the means by which the task will be managed. This includes the detailed schedule of sub-tasks, details of resources, billing and monthly reporting procedures, risk management and the means by which information will be managed.

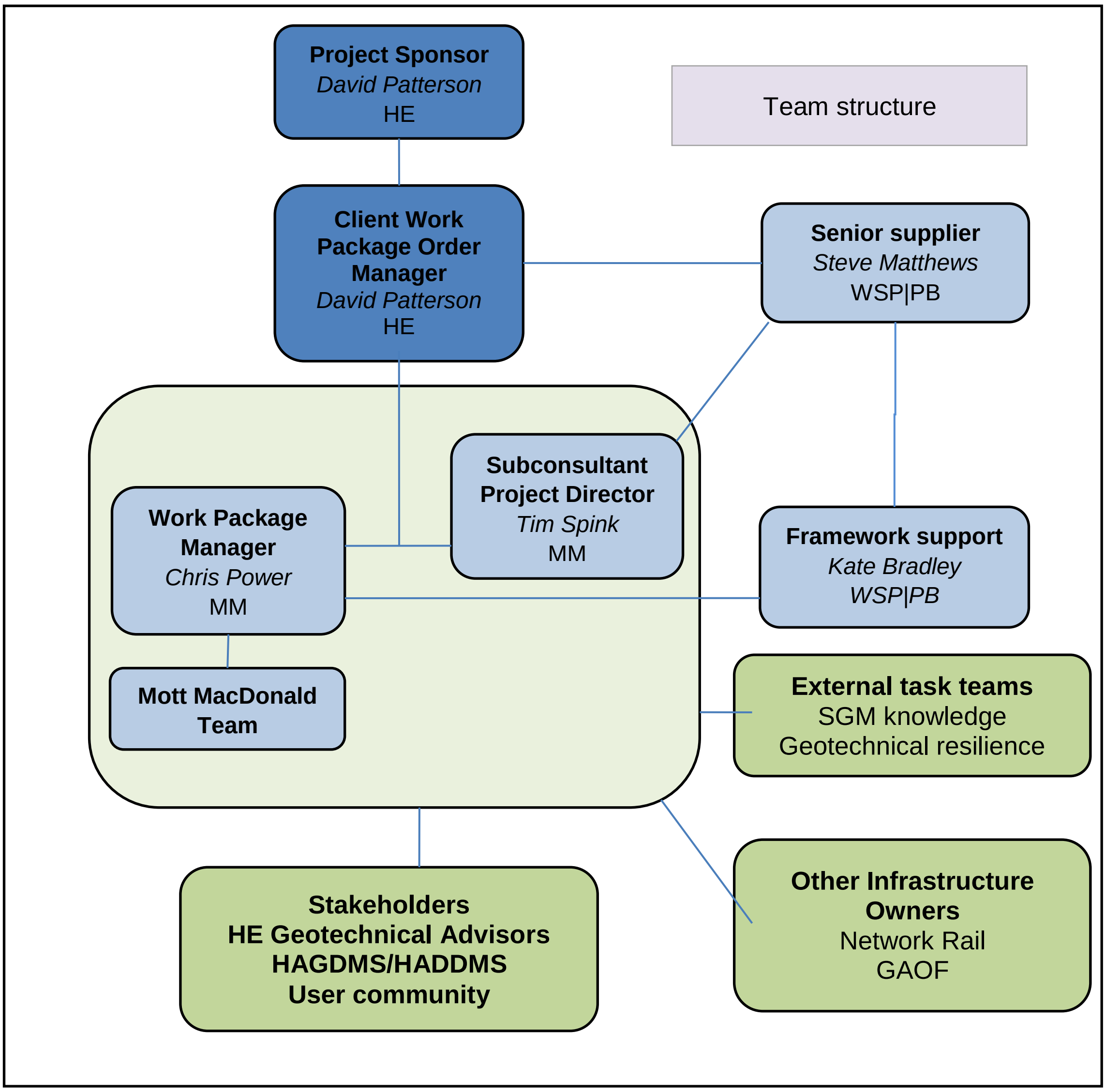
2.1 Schedule

The following high level programme is currently envisaged. This has been modified from the version presented in our proposal, to account for the changed project priorities that have come to light since the proposal was submitted.

	2016								2017							
	PPS Year 1								PPS Year 2							
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Project initiation		■														
Prep and data gather and coal mining hazard map		■	■													
Hazard prioritisation				■												
Rev 1 maps				■	■	■	■									
Rev 2 maps								■	■	■	■	■	■	■		
Reporting															■	■

2.2 Resource management plan

The core team structure is presented below, and is unchanged from our proposal.



2.2.1 Framework support team responsibilities

- Our Framework support team (Steve Matthews, Kate Bradley and Leticia Rojo) will undertake the following activities:
- Liaison with the Work Package Manager, Chris Power and Highways England Work Package Order Manager, David Patterson in respect of reporting, forecasting and invoicing.
- Submission of forecasts and invoices to Highways England
- Review of sub-consultants' performance – to provide early warning of deviations from agreed tolerances.
- Identification and resolution of any arising contractual matters
- Overview of any Change Management that should prove necessary
- Liaison with Highways England Framework Team if required.

2.2.2 Work Package Manager responsibilities

Our Work Package Manager will be Chris Power. Chris will act as the single point of contact for the Client Work Package Order Manager (David Patterson) on all day-to-day operational, performance and project management aspects of the work package. The duties of the Work Package Manager will be as follows:

- Management of the project.
- Development of the Work Package Quality Plan with the Client Work Package Order Manager as required.
- First point of contact for the Client Work Package Order Manager on day to day performance and progress.
- Agreeing activities and priorities for each month with the Client Work Package Order Manager.
- Drive the work package forward ensuring the resource is available to deliver the activities.
- Managing work package risks and escalating these appropriately to the Client's Work Package Order Manager.
- Quality management including checking and quality recording
- Overall progress management and reporting including external costs incurred.
- Performance management, project review, project archiving
- Preparation of forward forecasts and invoices

2.2.3 Mott MacDonald team

We envisage that the staff involved in this project will be selected from those named in our proposal, as summarised in the skills matrix below.

In addition, following the proposal RUG-8 forms were submitted, and approved, for additional staff members Alice Waterhouse and David Grant. Their details are added to the skills matrix below.

Name	Skill				
	Geotechnical Engineering/ Engineering Geology	Geotechnical asset and/or data management	Highways England Experience	HAGDMS / HADDMS system knowledge	Project Management (including PRINCE 2,ITIL)
Steve Matthews			✓		✓ (PRINCE2, LEAN)
Kate Bradley			✓		✓
Leticia Rojo			✓		
Tim Spink	✓	✓	✓	✓	✓
Chris Power	✓	✓	✓	✓	✓
Keith Halstead	✓	✓	✓	✓	✓ (PRINCE2, ITIL)

Name	Skill				
	Geotechnical Engineering/ Engineering Geology	Geotechnical asset and/or data management	Highways England Experience	HAGDMS / HADDMS system knowledge	Project Management (including PRINCE 2,ITIL)
Tim Bird	✓	✓	✓	✓	✓
Matt Lane		✓	✓	✓	✓
Stuart Clarke	✓	✓	✓		
Alice Waterhouse	✓	✓	✓	✓	
David Grant	✓	✓	✓	✓	

2.2.4 Sub-consultants and outside services

No sub-consultants or other outside services to Mott MacDonald or WSP|PB are currently expected to be required to deliver this Work Package. If any change to this is considered necessary, the Work Package Manager will discuss this with the Client Work Package Order Manager at the earliest opportunity.

2.2.5 Stakeholders

The following are considered to be the key stakeholders to the project:

- David Patterson (HE Work Package Order Manager and technical lead)
- Highways England Geotechnical Advisors (not named – expertise will be brought in based on particular experience within each of the hazard groups)
- HAGDMS/HADDMS Support Team (with respect to upload of completed maps and documents to these systems)
- Simon Colman. HAGIS Support Team (with respect to upload of completed maps and documents to this system)
- Juliet Mian, Arup (link to resilience work)
- HE resilience team (particular links to be advised and managed by the HE Work Package Order Manager)
- HE operations teams (particular links to be advised and managed by the HE Work Package Order Manager)
- SGM team (Mark Shaw, HE, David Wright and Verity Smith, Atkins) – though recognising that the level of liaison required is not as significant as originally envisaged
- HE ‘Peer-to-peer’ Geotechnical group (for information about the developing hazard products)

Attendance of stakeholders at particular task meetings will be determined by the Work Package Manager and the Client Work Package Order Manager on a meeting-by-meeting basis, as appropriate.

2.3 Cost, billing and commercial management plan

This task is a timescale contract, to an agreed ceiling (in total, and in each Financial Year), to be billed at monthly intervals.

Our monthly submission will comprise a Contractor's Monthly Report (using the standard Highways England template) summarising the current budget and forecast position, work carried out in the current month, and planned work for the following month, accompanying our draft invoice (with breakdown of hours and expenses) for receipting purposes.

2.4 Communications strategy

The main communication channel between Highways England and Mott MacDonald is between the Client Work Package Order Manager and Work Package Manager respectively. Other direct contact between the parties is permitted as appropriate, provided these two individuals are copied into all communications.

2.5 Risk management plan

Work Package risks will be managed in accordance with our Framework Processes as set out in our Framework Quality Plan, through this PRINCE2 compliant Work Package Quality Plan.

The Work Package Risk Register valid at the date of this report is included below. This risk register is based on the initial version included with our proposal, and as reviewed with the Client Work Package Order Manager at the Work Package Inception Meeting. Any further changes since inception are noted.

This will be subsequently maintained on a continual basis by the Work Package Manager, making the Client Work Package Order Manager aware of any new or increased risks at the earliest opportunity, and reviewed at progress meetings.

Ref	Risk	Potential Impact	Mitigation	Responsible	Mitigated Impact	Change from Proposal
R1	Key 3rd party datasets required for the task are not available or not suitable	**Medium**	Utilising the considerable experience of the task team, and making use of the same resource that handles the data sources for HAGDMS	Sub-consultant	**Low**	**None**
~~R2~~	~~Format, quality and content of data on SGMs unknown, and may not be suitable for use in this task~~	~~**Medium**~~	~~Early liaison with the SGM team, to discuss the data. Use of the data in a pilot phase, prior to implementation in the main phase of data analysis~~	~~Sub-consultant~~	~~**Low**~~	~~**Removed**~~

R3	Means of location referencing not yet known, and wider Highways England requirements and developments not known	**Medium**	Determination of the means of location referencing is key to this task, so this is placed early in the programme. Requirement for network referencing well understood by experienced task team.	Sub-consultant	**Low**	**None**
~~R4~~	~~Framework for analysing the relationships between ground related hazards, asset types and SGMs not determined, and pivotal to this task~~	~~**High**~~	~~Use of an experience task team. Development of a strawman framework that is tested, adjusted and re-tested within a pilot phase. Building in a key workshop to develop and test the framework with Highways England specialists. Building in the ability to be flexible with the framework, even within the main phase of the task~~	~~Sub-consultant~~	~~**Medium**~~	~~**Removed**~~
R5	Unknown data quality on ground related hazards, and the extent of the information not suitable to support a hazard map specific to the SRN that is determined to be useful to the users	**Medium**	Revision 1 hazard maps will be developed offline, and validated by the expert panels, before placing onto HAGDMS or HAGIS	Sub-consultant	**Low**	**Revised**
R6	Client not satisfied that the direction of the task is meeting their requirements	**Medium**	Maintaining strong relationship with the client built up in a period of over a decade. Regular communication on progress. Building in a key workshop at the end of the pilot phase to ensure that client requirements are being met, and if not re-scoping the task at that time	Sub-consultant	Low	**None**
R7	Not known how many hazards can be assessed within the main phase of the task	**Medium**	Hazard analysis to be carried out utilising a time-box methodology that is well established within the experience of the task team and the client	Sub-consultant	Low	**None**

R8	Validation of hazards analysed may yield poor results	**Medium**	Use of a representative pilot phase before the main phase of the task. Ability to adjust the methodology at the end of the pilot phase and within the main phase of the task	Sub-consultant	Low	**None**
R9	Web conferencing system cannot be accessed by HE staff due to IT security policy. This may mean that teleconferences are replaced by face-to-face meetings, potentially restricting date options.	**Medium**	Dates for all progress meetings and other sessions will be planned and diarised as far in advance as possible	Work Package Manager	Low	**Added in WPQP**

2.6 Information management and technology plan

2.6.1 Information storage and access

All documents, data and other materials associated with the Work Package will be held on MM's internal document management system. It is intended that paper documentation is minimised, but where this is necessary and practicable, it will be scanned and filed on this system to eliminate permanent storage of paper records.

Access to this system and the area holding this project's information is only permitted and possible to MM staff members.

It is assumed that the Client has no specific security requirements, over and above the HE's Data Handling Policy. This assumption will be reviewed in discussions on this WPQP before finalisation.

Mott MacDonald procedures are compliant with the HE's Data Handling Policy.

2.6.2 Incoming information register

All received documents, datasets and other information will be recorded on an incoming information register held by MM. This will include:

- unique reference
- title
- description
- sender
- date of receipt
- checker
- date of check/approval
- status of check/approval
- permanent link to item

2.6.3 Checking and approval requirements

Checking and approval requirements are given in section 3.3.

2.6.4 External distribution of information

It is expected that all information will be distributed electronically, rather than on paper. Distribution will therefore be primarily via email to specifically named individuals.

All issued formal deliverables will be recorded on an outgoing information register held by MM, and be accompanied by a transmittal document confirming version information, purpose of issue, and other recipients.

Unless there is appropriate reason to issue a specific item in an editable format, all documents will be issued in PDF format.

Where large documents or datasets are to be issued, these will be via MM's secure web-based file transfer system. This permits access to download the item via a username and password which are valid for 7 days after issue, and which will be emailed to the item's recipients along with the transmittal. In the event that any of the items require additional security, this will be implemented, and the additional password will be sent to the recipients separately from the download information.

3 Project Quality Plan

This section of the Work Package Quality Plan sets out the means of quality management that will be employed during this task. This includes customer specific requirements, change, checking and review requirements and safety and environmental management requirements.

3.1 Customer specific project procedures

Under the SPaTS framework, suppliers are required to provide KPI measurements following Highways England's Collaborative Performance Framework (CPF). As of October 2016, this is currently being rolled out within the SPaTS framework and full requirements are not yet known.

It is expected that KPI scoring will be required on a quarterly basis, and will be done between the Work Package Manager and Client Work Package Order Manager.

3.2 Change control

If changes are required to embrace improvement opportunities, mitigate risks or reflect changes in context, the Work Package Manager will assess the potential impact on the scope, budget or programme. Minor changes that lie within the Work Package Manager's authority, under NEC terms, will be implemented by the work package team. In other cases where the change is material, the team will follow a formal Change Management Process embedded within the Delivery Process.

A Change Register, held and maintained by the Work Package Manager, will record any material changes that occur which require Client approval, with the following information:

- Change ID number
- Title
- Description of change
- Requested by
- Date raised
- Date authorised
- Status of change
- Owner
- Client approval (name / date / status)
- Impact(s) of change (Schedule, resource, cost and billing)
- Target resolution date
- Comments
- Documentation references

3.3 Check and approval requirements

MM standard, ISO9001-compliant check and approval procedures will be carried out during execution of this work package, on all incoming and outgoing documents and data.

3.3.1 Incoming information

All incoming information will be checked by either the MM Project Director, Work Package Manager or another suitable member of the project team, as appropriate to the type of information.

The results of the check will be added to the incoming information register, together with a link to any annotated checking files.

3.3.2 Outgoing information and deliverables

All formal project deliverables will be checked by either the MM Project Director or Work Package Manager. In all cases the checker will not be the same person as the originator. Once checked and suitably revised, the MM Project Director will approve the deliverable prior to issue.

Check copies of documents will be retained internally by MM, taking the form of marked up electronic documents (e.g. tracked changes Word documents), or scanned paper check copies. The outgoing document will contain the names of the checker and approver.

3.4 Project review

There will be internal reviews of the project in accordance with the procedures of MM.

External review by HE will be via progress meetings, monthly reporting, and the interim progress report.

3.5 Safety management

The work undertaken in this work package is currently envisaged to be entirely office based. The following procedures are in place or will be implemented:

- adherence to organisations' own established safety policies, as applicable to employees or visitors
- use of webinars and teleconferences where these can suitably replace the need to travel to meetings, subject to this being appropriate to fulfilling a meeting's objectives and technological limitations
- where travel is required, use of trains wherever practicable in preference to cars or road-based public transport

The project team is experienced with the above approach to safety management.

3.6 Environment management

The work undertaken in this work package is currently envisaged to be entirely office based. The following procedures are in place or will be implemented:

- adherence to organisations' own established environmental policies, as applicable to employees or visitors
- use of webinars and teleconferences where these can suitably replace the need to travel to meetings, subject to this being appropriate to fulfilling a meeting's objectives and technological limitations
- where travel is required, use of trains wherever practicable in preference to cars or road-based public transport
- use of electronic methods of document/data transfer rather than paper as far as practicable

The project team is experienced with the above approach to environment management.

Appendices

A. Task specification

Task specification provided in the tender information for Task 1-062.

Specification for
Geotechnical Hazard Knowledge

1. Introduction

Highways England wishes to initiate a contract for the provision of consultancy services to complete a research and development task as part of the 5-year outline plan for geotechnical assets within the Capable Asset Portfolio. This planned task is part of a coherent programme of Geotechnical Knowledge development (part of the PTS Road Based Asset Group Business Plan 2015-2020), which comprises a series of activities to sustain and improve the knowledge of the geotechnical asset portfolio of Highways England.

2. Background

Ground related hazards pose a significant threat to the Strategic Road Network, affecting not only geotechnical assets (significant earthworks and at grade sections), but potentially all the other assets that comprise the network infrastructure. These hazards are exacerbated during periods of severe and extreme weather, and are potentially set to become more significant due to the impact of climate change and increased network use. Management of the risks that these hazards pose to the Strategic Road Network (SRN) begins with understanding their type, location and relationship to any Special Geotechnical Measures (SGMs) that have been put in place to mitigate or remove them. To date, much of the management of these hazards has been undertaken by Service Providers, utilising generalised national data sets made available through the Highways Agency Geotechnical Data Management System (HAGDMS), combined with local knowledge. This information is communicated to Highways England through an established Geotechnical Asset Management Plan (GeoAMP) process. Previous successfully completed tasks for Highways England have laid the foundation for the development of ground related hazard information that is specific to the SRN, making particular use of the large knowledge base of geotechnical data held on HAGDMS. These tasks include:

- Task 197: development of a slope hazard rating for geotechnical assets
- Task 408: geotechnical as-built asset data
- Task 434: particularly the quantification of cross asset risks
- HAGDMS/HADDMS: provision of the key asset management information system for geotechnical and drainage information

3. Requirements

3.1. Objectives

The objectives of this task are as follows:

- To improve the knowledge of **ground-related hazards** that may impact on the SRN, and develop products that will communicate this improved knowledge to stakeholders in Highways England and our supply chain

- To contribute to the suite of Highways England knowledge improvement tasks determining the **resilience** of the geotechnical asset portfolio, and it's **vulnerability** to severe and extreme weather events. This task seeks to determine the **susceptibility** of the asset portfolio to particular ground-related hazards, either natural or man-made, after consideration of any Special Geotechnical Measures put in place to mitigate the impact of such hazards
- To gain **maximum value** from the information held within the technical archives of HAGDMS by making use of improved, topic-based search facilities, and manual assessment of key information sources
- To produce **practical, centrally validated hazard products** that have been developed with input from key stakeholders, including the intended end users of the information. The hazards to be considered should be prioritised, with the degree of validation potentially varying according to the order of prioritisation.
- To produce as many hazard products as possible within the available task programme, and to ensure that requirements for future continued work are well document
- To contribute to improvements in the way that Highways England collates **as-built information**, such that ground-related hazard information from current, and planned schemes (such as the Smart Motorways programme) can feed into corporate knowledge in a more efficient manner

3.2. Work Required

To complete the objectives of this task, the following work will be required:

- Development of a Project Initiation Document, and agreement with the Highways England Project Sponsor
- Liaison with existing Highways England task teams, working on resilience assessment and Special Geotechnical Measures
- Review of previous tasks related to the development of improved understanding of ground-related hazards and their relationship to the SRN (including Task 197, Task 408 and Task 434)
- Development of a draft framework for ground related hazard assessment. This framework would need to consider both the availability of available information and its quality
- Prioritisation of ground related hazards to be assessed, in agreement with Highways England and a stakeholder group
    - Previous work has been undertaken to determine key-word sets for intelligent searching of records in the HAGDMS technical archive. As part of this task, key-word sets for the remaining identified hazard groups should be derived, and tested, prior to handing over the HAGDMS Support Team,
- Previous work has been undertaken to determine a Slope Hazard Rating for earthwork slopes recorded in the HAGDMS Geotechnical Asset Database. As part of this task, this ground-related hazard dataset should be reviewed and updated. Consideration should be given to:
    - The currency of the data used in the analysis

  - The geotechnical asset types, and their appropriateness for inclusion in the analysis
  - The determination of any weightings used in the analysis, and their correlation to other HE tasks (such as the tasks considering cross-asset risk assessment)
  - The potential to calibrate the revised Slope Hazard Rating against records of geotechnical failures
  - The potential for liaison with other infrastructure asset owners, to potentially collaborate on elements of the analysis to gain mutual benefit
- Previous work has been undertaken to investigate and quantify the cross-asset relationships that impact on geotechnical assets, the most important being the relationship to drainage. This task should be cognisant of this work, and should investigate how the this improved understanding of cross-asset relationships can be brought into practical usage in improving the understanding of ground-related hazards
- Development of a pilot phase, possibly for a single hazard and a constrained geographical area, to be determined by the contractor, and agreed with the Highways England Project Sponsor. This pilot phase should explore all the envisaged elements of the main project phase, and should:
  - Combine hazard information sources to determine the geographical location of the hazard(s) in relation to the SRN
  - Make use of available information on the location of Special Geotechnical Measures (SGMs) in the geographical area, and show these in relation to SRN
  - Determine a means of relating the effectiveness of the recorded SGMs in addressing the identified hazard(s)
  - Produce information on the location, and type, of potential areas of unaddressed hazard(s) in the pilot area, through completion of the above steps, or similar equivalent steps that are developed by the contractor
- Presentation of the pilot phase to Highways England and the stakeholder group, and determination of the agreed way forward
- Main phase production of hazard products, in the order or agreed prioritisation. This phase is to be time-boxed, with as much being achieved as possible in the available time. This main phase of the task will:
  - Be carried out based on the agreed way forward determined from the pilot phase
  - Be adaptable, such that any required changes to the methodology can be carried out, once agreed with the Highways England Project Sponsor
  - Consider the likely impact of the outputs of the task on the current (and potential future) Performance Indicators used by Highways England in their Geotechnical Asset Management processes
  - Consider the linkages between ground-related hazards, and wider SRN resilience, through liaison with the related tasks that are addressing resilience issues
- Validation of developed products, with the stakeholder group and Highways England. This stage may include liaison with other

infrastructure asset owners. Should it be deemed appropriate by the Project Sponsor, this stage may also include feedback to the British Geological Survey (BGS) on any of their products used as part of the task analysis, and their effectiveness in relation to specific issues affecting the SRN
- Preparation of a final report, including recommendations for next steps

4. Responsibilities

Project Sponsor: David Patterson

Task to be completed by a consultant engaged under the SPaTS Lot 1 framework with the necessary skills and experience set out below.

5. Skills/Experience

This task requires an experienced consultant, with skills as set out below.

5.1. Essential Skills

- In-depth understanding of ground related hazards, and how they can impact on the SRN
- In-depth understanding of the importance of resilience on the SRN, and how geotechnical assets perform during periods of severe and extreme weather (impacting on SRN resilience)
- In-depth understanding of cross-asset interactions affecting the performance of the SRN, and the particular importance of drainage on geotechnical asset performance
- Understanding the previous work undertaken by Highways England in the development of ground related hazard knowledge
- Understanding of the previous work undertaken by Highways England on Special Geotechnical Measures (SGMs) that have been utilised in the construction, and subsequent asset management of the SRN
- In depth understanding of the key Standards and other documents relating to geotechnical asset management within Highways England, and experience in their application to asset management practice
- A strong working knowledge of the key sources of national ground related hazard information available to Highways England (and its supply chain)
- In-depth understanding of the information available within the HAGDMS and HADDMS
- A proven capability in Geographical Information Systems (GIS) undertaken by a team of specialists with a good understanding of geotechnical asset management and familiarity with Highways England data sources
- Strong communication skills to enable the outputs of the task to be well understood by Highways England and their supply chain
- A proven culture of high levels of Quality Assurance and checking

- Prior experience of working with Highways England.

5.2. Desirable Skills

- Particular experience of working as a Service Provider to Highways England within a Management Area contract
- Experience of working with other transport infrastructure owners facing similar ground related hazards
- Understanding of, and involvement in, national and international research projects relating to the development of ground related hazard knowledge

6. Deliverables

Deliverable Number	Deliverable Description	Completion Date
WP001	Project Initiation Document	Within 1 month of project start
WP00	Stakeholder consultation pilot phase presentation and webinar	Completion of pilot phase
WP00	Developed hazard information products in a format suitable for implementation in the HAGDMS	Project End
WP00	Final project report	Project End
WP00	Stakeholder consultation final presentation and webinar	Project End

7. Location

Consultant to be based within their offices. Where meetings to be undertaken with Highways England, the preferred location is Birmingham.

Where possible, sustainable means of communication (such as online meetings) to be utilised.

8. Timescales

Start date: June 2016

Duration: 16 months

9. Evaluation Criteria

Work Package Evaluation criteria –

Primary Criteria	Sub-criteria	Weighting	Score
`Resources and capabilities	Supplier's prior performance on this type of work	1	
	Suitability of key personnel	1	
	Appropriate allocation of resource	1	
	Overall capability and expertise	1	
Technical solution proposed and competence	Demonstrates understanding of the objectives and deliverables	1	
	Robustness of the proposal and methodology	1	
	Creative and innovative thinking	1	
	Adequate are the proposed project management and quality control systems	1	
Suitability of proposed processes	Identification and management of risks	1	
Subtotal			
Total	Total Mark (Subtotal x 100/90*)		

* This figure should change subject to the number of criteria used (eg 9 criteria = 90, 11 criteria = 110, 12 criteria = 120 etc) – this calculation is required to ensure total mark is calculated as a percentage.

The assessment panel will use the marking system as shown below, to award marks for approach or evidence, as relevant to the sub-criteria in the previous table.

Score	**Reason**	**Mark**
Weak	The proposed approach fails to demonstrate an adequate understanding of the project objectives and fails to address adequately the risk management issues. There is little evidence that the proposed approach has been influenced by experience on other projects.	1-4
Acceptable	The proposed approach demonstrates an adequate understanding of the project objectives; it addresses the success factors and risk management issues to an acceptable standard. There is an adequate level of evidence that the proposed approach has been developed as a result of successful experience on other projects.	5-7
Good	The proposed approach demonstrates a good understanding of the project objectives; it addresses fully the success factors and risk	8-9

	management issues and provides for delivering continuous improvement over the life of the framework. There is substantial evidence that the proposed approach has been developed from other projects using formal continual improvement processes.	
Excellent	The proposed approach has been tailored specifically to deliver the project objectives, and deals comprehensively with the risks to maximising performance against Key Performance Indicators and to delivering continuous improvement. There is substantial evidence that the approach has been developed using continual improvement processes, which are routinely used to develop approaches and deliver the objectives successfully on all projects.	10

The proposal with the highest mark will be given a score of 100. The score of other competing suppliers will be calculated by deducting from 100 one point for each full percentage point by which their mark is below the highest mark. The minimum requirement for this work package is to reach a threshold of 60. A submission that has failed to achieve the minimum quality requirements may not be considered further in the assessment.

The lowest priced tender will be given a score of 100. The score of other competing suppliers will be calculated by deducting from 100 one point for each full percentage point by which their price is above the lowest price. The overall quality score and the finance score will be combined in the ratio 60:40 applied to the quality and financial scores respectively.

Following receipt of your evaluation reports the rejection/acceptance letter will be sent out by the Framework team. Before the contract can be officially awarded, a 10 day “standstill” period needs to elapse.

10. Contact Information

Role	Location	Phone
Project Sponsor/Manager: David Patterson	Temple Quay, Bristol	0117 372 8399
Framework Manager: Hannah Milliner	Temple Quay, Bristol	0117 372 8185
Procurement Officer: Rob Amor	The Cube, Birmingham	0121 678 8486

C. Coal mining hazard data description document

HAGDMS Coal Mining Hazard Rating data description

Introduction

The long history of coal mining in England has left a legacy of hazards in the ground with the potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Coal Mining Hazard Rating Map for a 1000m corridor centred around the Strategic Road Network has been prepared. The map was constructed using selected Coal Authority data, analysed in a GIS. It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors or the potential need to contact the Coal Authority for the latest data on site specific issues.

The map is the first product of a suite of hazard maps planned to assess hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Coal Mining Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the coal mining hazard map was created. The extent of the datasets used to form the map, were constrained to a 1000m corridor centred on the SRN. This corridor was split into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology. From the centre point of each complete grid square a 500m circular buffer was created, and these buffers were used to spatially query the Coal Authority data, which consists of both polygon and point data (see Figure 1).

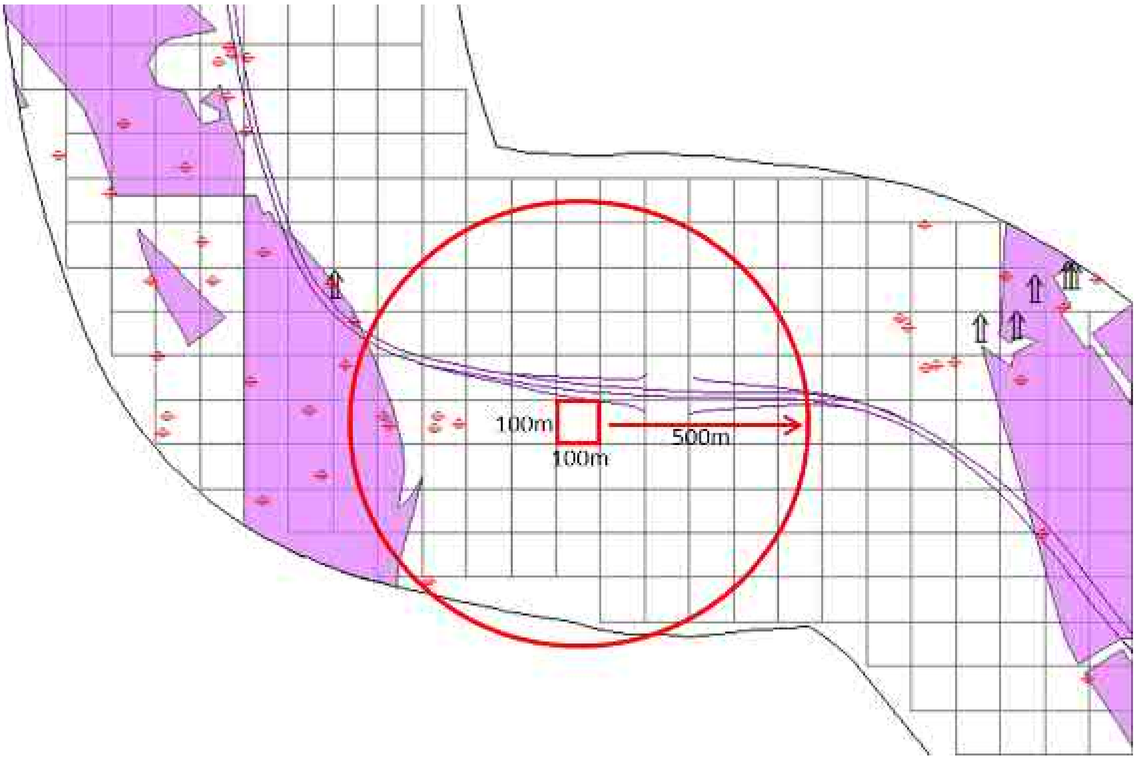


Figure 1 Map methodology showing 500m grid buffer intersecting polygon and point data within the 1000m SRN corridor

The extracted raw numbers of points and areas of the polygon data found within each of the buffers were calculated taking into account the fact that the buffers will be incomplete the nearer they are to the edge of the corridor of available data. The equations below show how the final values were derived for each buffer run within the GIS analysis.

$$\%\ \boldsymbol{of\ polygon\ data} = \frac{\boldsymbol{Area\ of\ the\ polygon\ data\ inside\ 500m\ grid\ buffer}}{\boldsymbol{Area\ of\ 500m\ grid\ buffer\ inside\ the\ 1000m\ SRN\ corridor}}$$

$$\boldsymbol{Weighted\ count\ of\ point\ data} = \frac{\boldsymbol{Count\ of\ point\ data\ inside\ 500m\ grid\ buffer}}{(\%\ \boldsymbol{of\ 500m\ grid\ buffer\ inside\ the\ 1000m\ SRN\ corridor\ /100})}$$

The resultant values from each of the selected coal authority datasets were then joined to each of the corresponding grid squares from whose centre point the grid buffer was initially created. This resulted in a gridded output for each of the coal authority datasets. A weighted overlay analysis was then used to calculate an overall hazard score per grid square, using a simple additive algorithm to sum all of the individual weighted scores. Figure 2 shows this analysis, and Table 1 describes the data sets used in the analysis and the weightings used in the calculation of the overall hazard score for each grid square. The weightings were derived by expert judgement, based on a 0-20 scale.

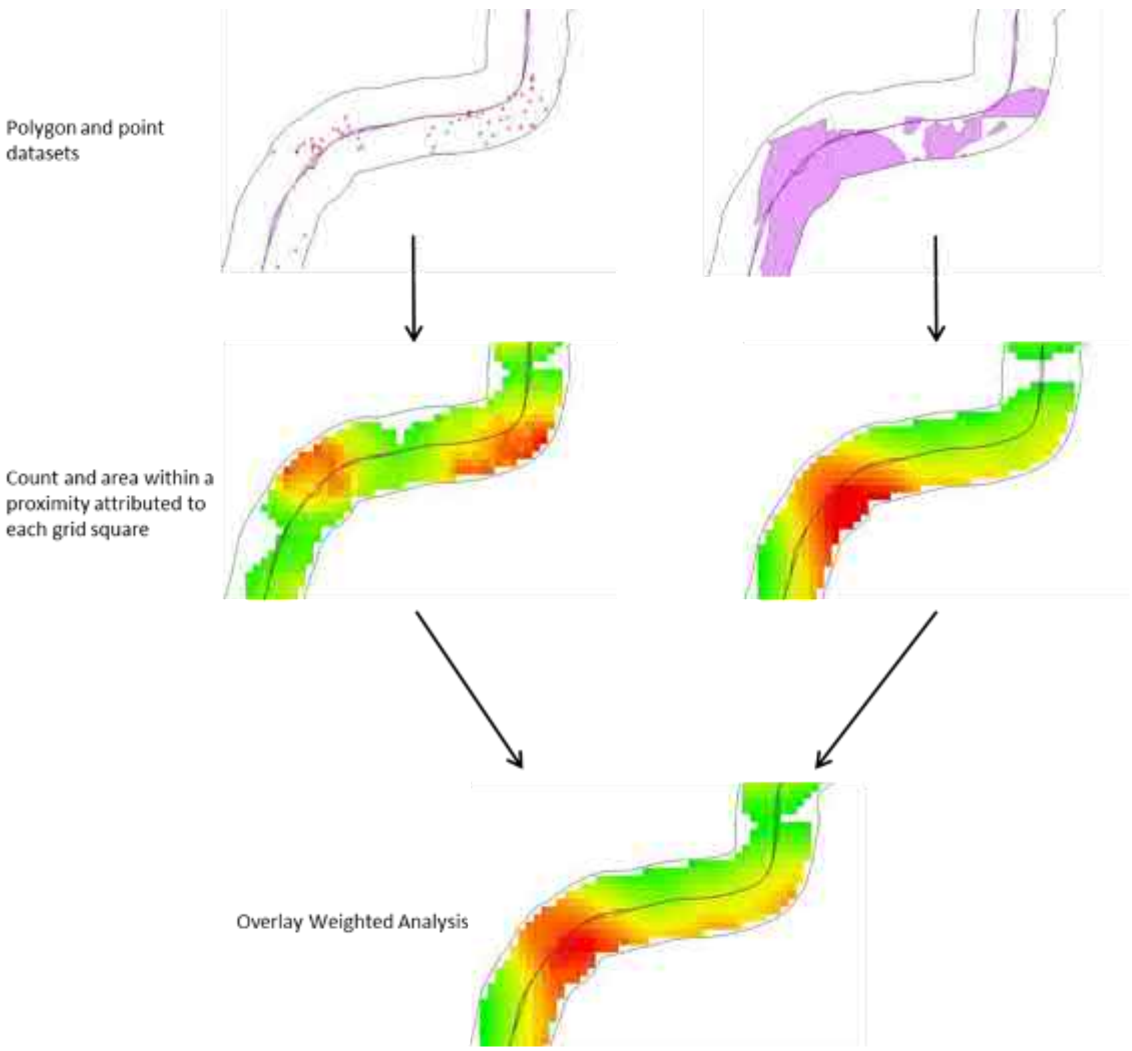


Figure 2 Example workflow of attributing point and polygon datasets to grid squares followed by an overlay analysis.

Data Sources and Weightings

Table 1 Summary of Data Sources and Weightings used in the map production

Dataset (HAGDMS Layer Name)	Source	Outline Description	Data type	Date	Weighting (out of 20)
Mine entries –Adit	Coal Authority	Mine entries comprising of inclined entrances (adits, slants, drifts etc).	Points	2010	18
Mine entries - Shaft	Coal Authority	Mine entries comprising of vertical entrances in the workings (shafts, staples, pits etc).	Points	2010	20
Surface mining	Coal Authority	Surface coal mining, also known as opencast sites, shows the site boundary, which encompasses all extraction areas for a past or present opencast site.	Polygons	2010	8
Probable workings	Coal Authority	Areas where the Coal Authority believe that there is evidence of past coal mine workings but have no formal abandonment plan for those workings e.g. an adjacent mine plan may have the annotation 'Ancient workings', located by development and/or site investigation, the workings may even be shown on an estate/surface plan.	Polygons	2010	12
Underground workings	Coal Authority	Areas known from abandonment plans where underground workings are less than 30m depth. Deemed at risk due to insufficient overlaying strata to dissipate any movement from within the workings before they reach the surface.	Polygons	2010	13
Coalfield extents	Coal Authority	Mining and geographical data held on the Coal Authority Mining Database.	Polygons	2010	5
Workable outcrops	Coal Authority	Identifies where an underground coal seam reaches rockhead. The outcrop seam indicates areas of workable coal that may have been worked at some time in the past. This dataset contains a buffer of 50m on the dip side of the outcrops position as held by the Coal Authority.	Polygons	2010	14

The Result

The result of the analysis is a nationwide coal mining hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into four categories (A to D). A summary of Coal Mining Hazard Rating categories can be seen in Table 2.

Table 2 Summary of Coal Mining Hazard Rating banding

Coal Mining Hazard Rating	Colour	Explanation
A		Outside coalfield area
B		Low hazard (inside coalfield area)
C		Medium hazard (inside coalfield area)
D		High hazard (inside coalfield area)

Highways England Contacts

To obtain further advice on the hazard coal mining poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within PTS below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Coal Authority Contacts

The definitive source of the latest information on coal mining in the UK is the Coal Authority (https://www.gov.uk/government/organisations/the-coal-authority)

The Coal Authority make available an interactive online map (http://mapapps2.bgs.ac.uk/coalauthority/home.html) on which the latest available data on coal mining hazards can be viewed. Detailed information can be obtained by contacting the Coal Authority to discuss your area of interest and/or request a bespoke mining report.

Future Developments

As the Mining Hazard Rating Map is a first issue, it is envisaged further developments will be carried out and new versions produced. The map is the first in a series of maps relating to ground hazards planned to be produced by HE.

Comments or feedback on the coal mining hazard map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

D. Slope Hazard Rating (SHR) map data description document

HAGDMS Slope Hazard Rating data description

Introduction

The Slope Hazard Rating (SHR) layer on HAGDMS provides the output of an analysis into the performance of the major Geotechnical Assets of Highways England (HE). An initial iteration of the SHR analysis was carried out in 2014, and the associated layer (along with the note on its derivation, available on the HAGDMS downloads page) will remain on HAGDMS. This is to ensure that reference can still be made to this initial iteration if it has been cited in any reports or other documents produced for HE. This latest revision of the SHR layer **should be used from this point forward**, as it reflects a revision to the methodology to calculate the SHR, outlined in this document and the latest available data cut at the time of development, detailed in Table 1 below. It is important to note that there is **no equivalence** between the results obtained in the 2014 analysis to those in this 2017 update for a given Geotechnical Asset. Due to the changes in the methodology outlined below, it is entirely possible that an asset will change its Slope Hazard Ratings between the analyses carried out. This **does not** infer an improvement or degradation of asset performance. Likewise, there is no equivalence of the colour coding used between the 2014 and 2017 analyses as shown on HAGDMS, the two datasets stand alone and should be considered separately.

Table 1 Summary details of the dataset used in the Slope Hazard Rating

Dataset	Provider	Data Currency
HAGDMS Geotechnical Asset Database (GAD)	HAGDMS	28-09-2016

The SHR layer is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors or the need to consider the specific performance of individual geotechnical assets (through the use of detailed information held in GAD).

The map is one of a suite being developed to assess hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) where it can be viewed in the map legend at the following location: Geotechnics > Hazards > Slope Hazard Rating (2017). The map is visible at a scale less than 1:200,000.

Methodology

The methodology for the calculation of the SHR has been modified for this (2017) iteration. Whilst fundamentally similar to the initial methodology (from 2014, which is described in detail in the note on its derivation), the modifications seek to improve the analysis by:

- Consideration of only Major Earthworks (Cuttings, Embankments and Bunds). Minor Earthworks are excluded from the analysis,
- Improved filtering of the observations used to determine the performance of the asset cohorts, to only include those which can be related to relevant slope stability issues (through use of GAD tick boxes and key word searching in the observation descriptions),
- Update to the observation weightings to take account of changes in the HD41/15 revision,
- Review, and update where required, of the geological code grouping, to take account of improved knowledge, some of which has been gained through liaison with other major UK transportation infrastructure owners.

The updated analysis methodology is shown in Figure 1 below. The geotechnical assets included in the analysis (those which have Preliminary and Approved status) are assigned to a cohort based on geological grouping (refer to Table 1, Appendix A), and the morphology factor of their highest point (refer to Table 2, Appendix A.).

Within each cohort, the total length of defect, at risk and repair observations is then calculated, having first filtered these to include only observations which are related to slope instability. The total lengths are determined for:

- Major defects (Class 1A),
- Minor defects (Class 1D),
- At risk areas (Class 2),
- Repairs (Class 3).

The total lengths are then weighted for importance (in relation to asset performance), using the values set out in Table 3, Appendix A, and summed for each cohort. The weighted lengths of observations are expressed as a percentage of the total length of earthworks within the cohort. For clarity this percentage is referred to as the Weighted Length.

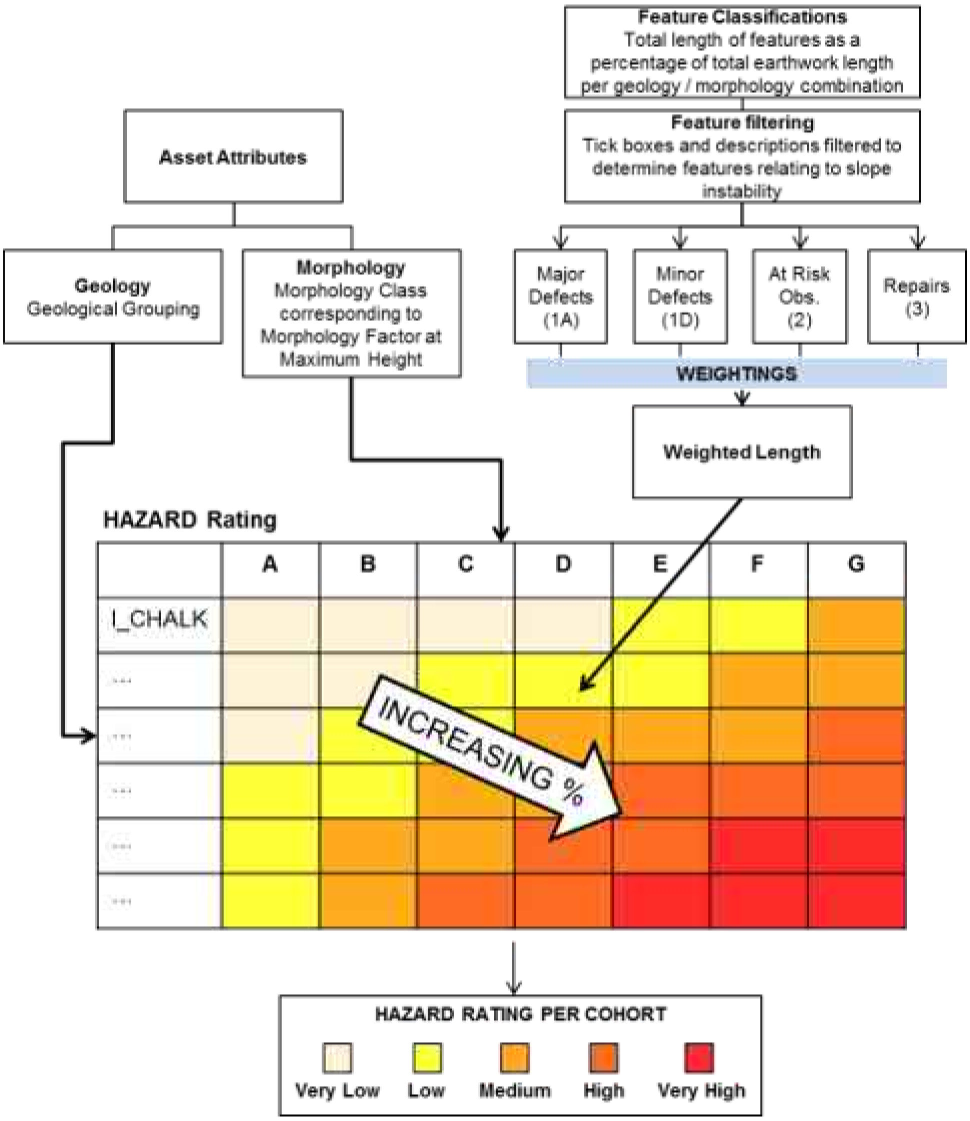


Figure 1 Slope Hazard Rating analysis methodology

In order to rank earthworks in a meaningful way based on their assigned Weighted Length value, a banding of cohorts into five Slope Hazard Ratings was undertaken. The boundaries between Ratings (in the form of a Weighted Length value) have been selected based on achieving a doubling of asset counts between rating bands, with the lowest ratings being assigned to larger numbers of assets than the higher ratings. This banding approach is identical to that used in the 2014 iteration of the SHR calculation. The Weighted Length boundaries used are shown in Table 4 in Appendix A. The Weighted Lengths and assigned Hazard Ratings for each cohort are presented in Table 5 in Appendix A.

Data Source

The 2017 iteration of the Slope Hazard Rating is based on a data cut of the HAGDMS Geotechnical Asset Database taken on 28-09-2016 (as detailed in Table 1). Any applicable geotechnical assets added to HAGDMS after this date will not be included in the analysis, and likewise any assets deleted after this date will be included. The SHR represents an analysis of the performance of the geotechnical assets at that date, and any changes to observations, or addition of new observations, after that date, will not be represented in the SHR output.

The Result

The result of the analysis is a thematic map layer, based on extents of geotechnical assets, with the SHR banded into six ratings (Very Low to Very High and No rating). A summary of the Slope Hazard Rating categories can be seen in Table 2.

Table 2 Summary of Slope Hazard Rating banding

Slope Hazard Rating	Colour	Explanation
Very Low		Lowest SHR applied in this cohort (approximately 52% of rated assets)
Low		Next lowest SHR applied in this cohort (approximately 26% of rated assets)
Medium		Middle rated SHR applied in this cohort (approximately 13% of rated assets)
High		Second highest rated SHR applied in this cohort (approximately 6% of rated assets)
Very High		Highest rated SHR applied in this cohort (approximately 3% of rated assets)
No Rating		No SHR applied, as asset cannot be represented within one of the cohorts

Highways England Contacts

To obtain further advice on the Slope Hazard Rating, or for any other issues associated with ground-related hazards potentially affecting the Strategic Road Network, please contact one of the Geotechnical Advisors available within Table 3 below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

Comments or feedback on the Slope Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

Appendix A

Table 1 Geological Groupings

Geological Grouping	BGS Geology Codes
In situ Groupings	
I_ALLUVIUM AND PEAT	ALF, ALGD, ALRT, ALV, MAAL, MDU, MEA, OMEA, PEAT, PTAL, RBDU
I_CHALK	BDMA2, CK, CKR, CSMA3, HCK, KU, LCK, LECH, LPBLL, LPMB, LSNCK, MCK, MR, MUCK, NCK, NPCH, PCK, RCK, SECK, SPCH, UCK, WMCH, ZZCH
I_CLAY	ACCO, ACVT, ADB, BCLC, BOC, BRB, BRK, BRYD, CLGB, CLSL, COLV, CORF, CWF, DIAM, DVY, DYSM, FOUN, GLLD, GLSC, GST, GSTC, HEAD, HEAD1, HEB, HRR, LAC, LASI, LDE, MARF, MM1, MM3, MM4, PCS, PELC, RIDS, SBC, SLIP, TFD, TILL, TTB, WHI, WIDS, WL, WOC, WPIT
I_LIMESTONE	ABBR, BFLS, BNLS, BO, BRL, BTH, BWL, CARB, CB, CBL, CL, CLR, CR, CU, GL, GNP, GOF, GOG, GOL, GSCL, GSTL, INO, IOGO, LELH, LLKL, LLL, LLST, LMJ, LTLS, MGL, PRMT, TSL, ULL, UNL, WOL
I_MADE GROUND	MGR, WMGR
I_MUDSTONE	ABM, ACM, ACU, ANSH, AS, ATF, AW, AYB, BAN, BCMU, BKF, BNF, BUSS, BVM, CBP, CBRD, CDF, CKF, CLEB, DHLS, DYS, ELM, ETM, FEFR, GRAD, JURA, KRS, KST, LCM, MCM, MFDC, MMG, MOI, PMLS, PNG, RG, SAH, SAL, SKE, SNT, TCF, TPT, TVY, TWM, UCM, ULC, WHG, WIT, YF
I_OTHER ROCK	10FT, 27YD, 2FCC, 2FTC, 2FTV, 4FTC, 5FTC, AB, ABH, ACKW, ACR, ACTO, ALY, BLK, BND, CARA, CMBH, CMV, CWRU, DBLB, DST, EDT, EDW, EN, EYCL, FCF, FLUV, FMCB, GRNT, GUN, HPBR, HVBR, KHS, LDVY, LMC, LO, LTK, LUDL, LUW, MCF, MDT, MDVS, MFSG, MRSL, NMRN, POAN, RMSM, ROX, SFG, SMGP, STAM, TBR, TGM, TLM, TPSF, TR, TRIA, TVF, UC, UDVS, UMAZ, UO, VOLC, WAWK, WBCT, WBY, WEN, WESH
I_OVERCONSOLIDATED CLAY	AC, AMC, AMKC, ASD, BAC, BLCR, BLI, BM, BMN, BNT, BOF, BWC, CHAM, FE, FMB, GAB, GLT, GRBL, GRF, GUGS, KC, KLB, KLOX, LC, LI, LIGO, LIIO, LLIC, LMBE, MHC, NEC, ODTL, OXC, PET, RB, RLD, SAB, SASH, SLSY, SMD, STWE, THT, WC, WDC, WHM, WRB, WTT
I_SAND AND GRAVEL	ALC, BAS, BASG, BDS, BGGR, BGP, BGS, BGSG, BHGR, BHT, BLB, BMSG, BOSA, BSA, BSP, BTFU, CHSG, CMBS, CRAG, CSD, DCSA, DCTS, DMG, EA, FAG, FGD, FGG, FOSA, FPGR, GDH, GDU, GFDU, GFSD, GFSDD, GFSG, GFSU, GFTD, GLGR, GSG, HEG, HETD, HPSG, HWH, KES, KPGR, LESE, LHGR, LOCO, LOFT, LORS, NCRC, NU, ODT, OGFD, OLHD, ORG, PBGR, PENS, PGBD, PGMD, RCG, RGR, RMD, RMDF, SGAO, SGU, SHGR, SSA, STHP, STOB, T2T3, TAB, TALM, TPGR, UTW, WHAT, WOSG, YWS
I_SANDSTONE	ACHS, ALBR, ARS, ASG, BABS, BEAL, BHC, BMS, BNS, BPST, BRI, BRS, BT, CA, CM, CYBR, DAS, DCS, FO, HA, HABR, HAS, HHB, HY, KDM, LAQU, LGS, LNS, LTW, MG, MGLC, MKN, MXR, NS, NSI, NTC, OS, PES, PG, PLG, PS, RESA, SBR, SMG, SSG, STG, THSA, TRSD, UGS, UORS, WBS, WLSF, WPN, WRS
I_TERRACE DEPOSITS	3TMR4, AR3, AR4, CHMS, RTD, RTD1, RTD2, RTD3, RTD5, RTDU, RTSG, TWGR, VLGR
Fill Groupings	
F_CHALK	BDMA2, CK, CKR, CSMA3, HCK, KU, LCK, LECH, LPBLL, LPMB, LSNCK, MCK, MR, MUCK, NCK, NPCH, PCK, RCK, SECK, SPCH, UCK, WMCH, ZZCH
F_COHESIVE	ABM, ABY, ACCO, ACM, ACU, ALF, ALGD, ALRT, ALV, ANSH, AS, ATF, AW, AYB, BABB, BAN, BCLC, BCMU, BDMA1, BKF, BNF, BOC, BRB, BRK, BRYD, BTMA2, BUSS, BVM, CBP, CBRD, CDF, CKF, CLEB, CLGB, CLSL, COLV, CORF, CWF, DHLS, DIAM, DVY, DYS, DYSM, ELM, ETM, FEFR, FOUN, GLLD, GLSC, GRAD, GST, GSTC, HEAD, HEAD1, HEB, HRR, JURA, KRS, KST, LAC, LASI, LCLM, LCM, LDE, LESE, MAAL, MARF, MCM, MDU, MEA, MFDC, MM1, MM3, MM4, MMG, MOI, OMEA, PCS, PEAT, PELC, PMLS, PNG, PTAL, RBDU, RG, RIDS, RTMA2, SAH, SAL, SBC, SKE, SLIP, SNT, TCF, TFD, TILL, TPT, TTB, TVY, TWM, UCM, ULC, WHG, WHI, WIDS, WIT, WL, WOC, WPIT, YF

Geological Grouping	BGS Geology Codes
F_GRANULAR	10FT, 27YD, 2FCC, 2FTC, 2FTV, 4FTC, 5FTC, AB, ABBR, ABDN, ABH, ABN, ABSG, ACHS, ACKW, ACR, ACTO, ALBR, ALC, ALY, ARS, ASG, BABS, BAS, BASG, BDS, BEAL, BFLS, BGGR, BGP, BGS, BGSG, BHC, BHGR, BHT, BLB, BLK, BMS, BMSG, BND, BNLS, BNS, BO, BOSA, BPST, BRI, BRL, BRS, BSA, BSP, BT, BTFU, BTH, BWL, CA, CARA, CARB, CB, CBL, CHSG, CL, CLR, CM, CMBH, CMBS, CMV, CR, CRAG, CSD, CU, CWRU, CYBR, DAS, DBLB, DCS, DCSA, DCTS, DMG, DST, EA, EDT, EDW, EN, EYCL, FAG, FCF, FGD, FGG, FLUV, FMCB, FO, FOSA, FPGR, GDH, GDU, GFDU, GFSD, GFSDD, GFSG, GFSU, GFTD, GL, GLGR, GNP, GOF, GOG, GOL, GRNT, GSCL, GSG, GSTL, GUN, HA, HABR, HAS, HEG, HETD, HHB, HPBR, HPSG, HVBR, HWH, HY, INO, IOGO, KDM, KES, KHS, KPGR, LAQU, LDVY, LELH, LGS, LHGR, LLKL, LLL, LLST, LMC, LMJ, LNS, LO, LOCO, LOFT, LORS, LTK, LTLS, LTW, LUDL, LUW, MCF, MDT, MDVS, MFSG, MG, MGL, MGLC, MKN, MRSL, MXR, NCRC, NMRN, NS, NSI, NTC, NU, ODT, OGFD, OLHD, ORG, OS, PBGR, PENS, PES, PG, PGBD, PGMD, PLG, POAN, PRMT, PS, RCG, RESA, RGR, RMD, RMDF, RMSM, ROX, SBR, SFG, SGAO, SGU, SHGR, SMG, SMGP, SSA, SSG, STAM, STG, STHP, STOB, T2T3, TAB, TALM, TBR, TGM, THSA, TLM, TPGR, TPSF, TR, TRIA, TRSD, TSL, TVF, UC, UCS, UDVS, UGS, ULL, UMAZ, UNL, UO, UORS, UTW, VOLC, WAWK, WBCT, WBS, WBY, WEN, WESH, WHAT, WLSF, WOL, WOSG, WPN, WRS, YWS
F_MADE GROUND	MGR, WMGR
F_OVERCONSOLIDATED CLAY	AC, AMC, AMKC, ASD, BAC, BLCR, BLI, BM, BMN, BNT, BOF, BWC, CHAM, FE, FMB, GAB, GLT, GRBL, GRF, GUGS, KC, KLB, KLC, KLOX, LC, LI, LIGO, LIIO, LLIC, LMBE, MHC, MPMU, NEC, ODTL, OXC, PET, RB, RBLC, RLD, SAB, SASH, SLSY, SMD, STWE, THT, WBL, WC, WDC, WHM, WRB, WTT
F_TERRACE DEPOSITS	3TMR4, AR3, AR4, CHMS, RTD, RTD1, RTD2, RTD3, RTD5, RTDU, RTSG, TWGR, VLGR

Table 2 Morphology Class Definition

Morphology Class	Morphology Factor Range
A	0 – 0.25
B	0.25 – 0.50
C	0.50 – 0.75
D	0.75 – 1.50
E	1.50 – 3.00
F	3.00 – 6.00
G	> 6.00

Table 3 Weightings for each Observation Category

Observation Category	Weighting
Major Defects	1.0
Minor Defects	0.5
At Risk observations	0.1
Repairs	1.0

Table 4 Weighted Lengths per Slope Hazard Rating

Slope Hazard Rating	Weighted Length
Very High	≥ 6.88%
High	≥ 4.5 < 6.88%
Medium	≥ 2.57 < 4.5%
Low	≥ 1.52 < 2.57%
Very low	≥ 0 < 1.52%

Table 5 Weighted Lengths and Slope Hazard Ratings assigned to each cohort (colour coded by SHR)

Geological Grouping	Morphology Class						
	A	B	C	D	E	F	G
I_TERRACE DEPOSITS	0.00	0.03	0.06	0.13	0.28	0.30	0.80
F_CHALK	0.00	0.16	0.33	0.66	0.86	1.49	3.21
F_MADE GROUND	0.06	0.12	0.25	0.45	1.33	2.16	2.96
I_CHALK	0.01	0.01	0.02	0.07	0.37	1.64	3.07
I_SAND AND GRAVEL	0.04	0.09	0.18	0.37	0.82	1.69	3.00
F_COHESIVE	0.00	0.32	0.64	0.79	1.58	2.40	3.46
I_SANDSTONE	0.00	0.20	0.40	0.82	0.86	0.92	5.20
I_MUDSTONE	0.05	0.10	0.20	0.73	1.56	2.34	6.58
F_GRANULAR	0.11	0.21	0.42	0.83	1.05	2.68	5.00
I_CLAY	0.03	0.06	0.12	0.26	1.03	2.97	4.50
F_TERRACE DEPOSITS	0.00	0.11	0.22	0.33	1.99	3.25	4.50
I_OVERCONSOLIDATED CLAY	0.02	0.04	0.07	1.85	2.53	3.76	5.37
I_OTHER ROCK	0.03	0.06	0.12	0.25	0.95	1.35	7.66
I_MADE GROUND	0.02	0.03	0.04	0.05	0.06	3.82	28.92
I_LIMESTONE	0.00	0.62	1.25	1.70	2.00	2.97	14.07
I_ALLUVIUM AND PEAT	0.00	1.30	2.60	3.85	5.94	6.81	26.76
F_OVERCONSOLIDATED CLAY	0.00	0.33	0.73	1.92	6.96	10.12	17.39

E. Rock Slope Hazard Index (RSHI) map data description document

HAGDMS Rock Slope Hazard Index data description

Introduction

The Rock Slope Hazard Index layer on HAGDMS provides a visualisation of the results of a series of specialist rock slope inspections undertaken mostly in 2011 (with some previous data from 2003 and 2004 also being used). These inspections utilised the Rock Slope Hazard Index (RSHI) methodology developed by TRL, and described in the published report PPR554: Rock slope risk assessment (P McMillan and I M Nettleton, TRL, 1995). The inspections were carried out on rock slopes on the Strategic Road Network whose locations had been determined from a desk study and review of information on HAGDMS. The locations of the slopes were not directly linked to HAGDMS Geotechnical Assets in all cases, so some locating (generally making use of marker post, or HAPMS references) was required. In most cases, the original 2011 RSHI inspection sheets have been attached to the relevant Geotechnical Assets in HAGDMS as attached documents (this activity was carried out at the time of the surveys).

The information used to produce the Rock Slope Hazard Index map is described in Table 1.

Table 1 Summary details of the dataset used in the Rock Slope Hazard Index map

Dataset	Provider	Data Currency
HAGDMS Geotechnical Asset Database (GAD)	HAGDMS	29-03-2017
RSHI inspection results (Spreadsheets)	Highways England	12-03-2003 to 18-03-2011

The Rock Slope Hazard Index layer is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors or the need to consider the specific performance of individual geotechnical assets (through the use of detailed information held in GAD). It should also be noted that the inspections used as the basis for this layer were undertaken in 2011 (or earlier) and hence may not reflect the current hazard posed by the inspected rock slopes.

The map is one of a suite being developed to assess hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) where it can be viewed in the map legend at the following location: Geotechnics > Hazards > Rock Slope Hazard Index. The map is visible at a scale less than 1:200,000.

Methodology

The RSHI inspection results were provided in a series of spreadsheets. In many cases these spreadsheets provided an HAGDMS Earthwork ID that allowed the results to be immediately related to the correct Geotechnical Asset. Where an HAGDMS Earthwork ID was not available, a marker post, or HAPMS reference location was provided, typically with an offset distance and direction. These inspection results were manually attributed to the correct Geotechnical Asset through use of available base datasets on HAGDMS. In most cases, the attribution could be confirmed by finding the original RSHI inspection sheets attached as documents to the Geotechnical Asset record. In a few cases, the attribution was carried out by use of other available data held in HAGDMS, and use of Google Streetview to confirm the presence of an exposed rock slope at a location. Every effort has been made to ensure that accurate attribution has been carried out, but in a few cases it is not guaranteed. In a very few cases, an attribution could not be made with any confidence.

In many cases, particularly for large rock slopes in Area 13, there are many RSHI inspection results relating to a single Geotechnical Asset as recorded on HAGDMS. Where this is the case, the attribution on the Rock Slope Hazard Index layer on HAGDMS relates to the **maximum** RSHI value and Category for that asset. **All** of the RSHI values from the inspections can be seen in Table 5 in Appendix A. This table includes the location information recorded during the inspections, which may assist in determining the sections of the Geotechnical Assets to which the individual RSHI scores belong. Additionally, if the RSHI inspection sheets are uploaded to HAGDMS, many of these include the start and end coordinates of each of the individual slope sections.

The Result

Based on the RSHI value obtained from the inspections, rock slopes are placed into four Categories, with recommended actions as shown in Table 2:

Table 2 RSHI Category and recommended actions

RSHI Value	RSHI Category	Recommended Action
> 100	CAT 1	Urgent detailed inspection required
10 to 100	CAT 2	Detailed inspection required
1 to 10	CAT 3	Review in 5 years
< 1	CAT 4	No review required in the next 5 years

Source: Rock Slope Hazard Assessment Completion Report, HA Task 402(1308)HALC, June 2011

These Categories are used to theme the map layer on HAGDMS, as described in Table 3 below. Note that all Geotechnical Assets have been included on the map layer, the vast majority of which fall into the No Data Present category

Table 3 Summary of Rock Slope Hazard Index map legend on HAGDMS

RSHI Category	Colour	Explanation
CAT 4		Maximum RSHI value < 1
CAT 3		Maximum RSHI between 1 and 10
CAT 2		Maximum RSHI between 10 and 100
CAT 1		Maximum RSHI value > 100
No Data Present		No RSHI inspection data available for the Geotechnical Asset

Highways England Contacts

To obtain further advice on the Rock Slope Hazard Index, or for any other issues associated with ground-related hazards potentially affecting the Strategic Road Network, please contact one of the Geotechnical Advisors available within Table 4 below.

Table 4 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

Comments or feedback on the Rock Slope Hazard Index map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

Appendix A

Table 5 Individual RSHI scores

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
1284	M6 Southbound 244/8+50m to 244/3	Conglomerate/Sandstone	04-Mar-11	2.850596087	CAT 3
1786	M56 Eastbound 58/3 At overbridge	Sandstone	15-Feb-11	0	CAT 4
1788	M56 Westbound 58/3 At overbridge	Sandstone	15-Feb-11	0	CAT 4
1789	M56 Westbound 58/3 At overbridge	Sandstone	15-Feb-11	0	CAT 4
1878	Exeter: A38 Westbound MP111/0 to MP111/0-30m	Breccia	08-Mar-11	0	CAT 4
1935	M56 Eastbound 38/5 at Junction 11	Sandstone/siltstone (Vegetated)	15-Feb-11	0	CAT 4
1947	M56 Westbound 38/5 at Junction 11	Sandstone/siltstone (Vegetated)	15-Feb-11	0	CAT 4
2025	M56 Eastbound 58/4	Sandstone	15-Feb-11	0	CAT 4
2025	M56 Eastbound 58/3 At overbridge	Sandstone	15-Feb-11	0	CAT 4
4301	Dunheved: A30 Eastbound MP130/8	Shale	14-Mar-11	4.5920952	CAT 3
5062	M4 Jct 17 Westbound MP152/7 to 152/9	Limestone	01-Mar-11	6.55901229	CAT 3
5063	M4 Jct 17 Westbound MP152/9 to 153/1	Limestone	01-Mar-11	53.20045404	CAT 2
5066	M4 Jct 17 Eastbound MP152/9 to MP153/1	Limestone	01-Mar-11	8.479620601	CAT 3
6918	A56 Southbound 12/1 to 11/8	Sandstone	17-Feb-11	0.05	CAT 4
6919	A56 Northbound 11/9 to 12/1	Sandstone	17-Feb-11	0	CAT 4
7051	Petersfield: A3 S/B MP15/8 to MP14/9	Chalk	17-Mar-11	0.097214304	CAT 4
8210	Jamaica Inn: A30 Eastbound MP110/8	Granite	14-Mar-11	0.038430393	CAT 4
8217	Temple: A30 Eastbound after O/B	Granite (heavily weathered)	14-Mar-11	1.753289307	CAT 3
8218	Temple: A30 Eastbound MP108/2	Granite (heavily weathered)	14-Mar-11	18.90645788	CAT 2
8224	Temple: A30 Westbound after O/B	Granite (heavily weathered)	14-Mar-11	0.007765228	CAT 4
8225	Temple: A30 Westbound verge MP108/2	Granite (heavily weathered)	14-Mar-11	0.04375896	CAT 4
9052	Ide: A30 Westbound	Crackington Formation	11-Mar-11	3.488504227	CAT 3
9139	Rattery: A38 Eastbound Overbridge to on slip	UDVS (no visible outcrop)	11-Mar-11	0	CAT 4
9141	Buckfastleigh: A38 Westbound	UDVS/Mudstone	08-Mar-11	9.52098249	CAT 3
9151	Pridhamsleigh: A38 Westbound offslip	UDVS	08-Mar-11	0	CAT 4
9165	Buckfastleigh: A38 Eastbound MP81/0	UDVS Limestone	11-Mar-11	0.003745214	CAT 4
9165	Buckfastleigh: A38 Eastbound MP80/8	UDVS	11-Mar-11	6.581123486	CAT 3
9167	Pridhamsleigh: A38 Westbound MP83/0 to MP83/6	UDVS	08-Mar-11	8.599639069	CAT 3
9170	Ashburton: A38 Westbound MP84/6 to MP84/4	Shale (No visible outcrop)	08-Mar-11	0	CAT 4
9175	Ashburton: A38 Westbound MP83/8 to MP84/4	Shale	08-Mar-11	0.086567195	CAT 4
9175	Ashburton: A38 Westbound MP84/0 to MP83/8	UDVS	08-Mar-11	0.242751178	CAT 4
9410	Rattery: A38 Westbound	UDVS/Shale	09-Mar-11	11.3860228	CAT 2
9412	Dry Bridge: A38 Westbound	UDVS/Mudstone (heavily vegetated)	08-Mar-11	0	CAT 4
9413	Rattery: A38 Eastbound MP76/6 to Overbridge	UDVS (no visble outcrop)	11-Mar-11	0	CAT 4
10422	M5 Jct 31 Northbound on slip	Breccia	28-Feb-11	12.36252608	CAT 2
10422	M5 Jct 31 Northbound O/B	Breccia	28-Feb-11	76.73456584	CAT 2

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
10425	M5 Southbound MP260/0 to MP260/1	Sandstone	28-Feb-11	0	CAT 4
10599	Brdige: A2 Eastbound MP101/1	Chalk (completely vegetated)	18-Mar-11	0	CAT 4
10658	Canterbury: A2 Eastbound MP97/3	Chalk	18-Mar-11	0.010462575	CAT 4
11677	M66 Southbound 0/7 to 1/0	Sandstone	17-Feb-11	0	CAT 4
11724	A1 (M) - West Cornforth	Magnesian Limestone	27-Jan-11	22.21256364	CAT 2
11735	A1 (M) - West Cornforth	Permian Triassic Limestone/Anhydrite	27-Jan-11	9.032642841	CAT 3
11743	A1 (M) - West Cornforth	Permian Triassic Limestone/Anhydrite	27-Jan-11	1.116562859	CAT 3
11942	A1 (M) - High House Farm	Lower Magnesian Limestone	26-Jan-11	0	CAT 4
12087	M66 Northbound 1/0 to 0/8	Sandstone	17-Feb-11	0.17	CAT 4
12095	M66 Northbound 1/0 to 0/8	Sandstone	17-Feb-11	0.17	CAT 4
12095	M66 Northbound 0/8	Sandstone	17-Feb-11	0.47	CAT 4
12258	M66 Southbound 0/7 to 1/0	Sandstone	17-Feb-11	0	CAT 4
13468	M5 Jct 31 Southbound off slip	Breccia	28-Feb-11	25.89596544	CAT 2
13486	M5 Jct 31 Southbound	Breccia	28-Feb-11	27.50920348	CAT 2
13752	Dover: A20 Westbound MP120/3	Chalk	18-Mar-11	0.038707766	CAT 4
14210	Dover: A20 Westbound MP113/5	Chalk (heavily vegetated)	18-Mar-11	0.934095193	CAT 4
14213	Dover: A20 Eastbound MP113/5	Chalk	18-Mar-11	6.268126032	CAT 3
14870	Exeter: A38 /A30 Westbound onslip MP195/8	Breccia (limited outcrop)	11-Mar-11	0	CAT 4
15477	Exeter: A30 Eastbound MP195/0	Breccia	11-Mar-11	5.006002176	CAT 3
15620	M4 Eastbound onslip Jct 19 MP181/6-80m to MP181/6	Sandstone	01-Mar-11	5.25372354	CAT 3
15986	M5 Southbound MP122/6 to MP122/7+50m	Limestone	28-Feb-11	1.394990623	CAT 3
15987	M5 Southbound MP 122/7+70 to MP123/1+50m	Limestone	28-Feb-11	0.37105408	CAT 4
16078	M5 Northbound MP153/3+70m to MP153/2	Limestone	02-Mar-11	0	CAT 4
16083	M5 Northbound MP152/0+50 to MP151/8+50m	Limestone	02-Mar-11	0	CAT 4
16097	M5 Northbound - Gordano MP149/0 to MP148/4+50m	No outcrop	02-Mar-11	0	CAT 4
16320	M5 Southbound - Gordano MP147/3 to 148/4	Pennant Sandstone	02-Mar-11	0	CAT 4
16321	M5 Southbound - Gordano MP147/3 to 148/4	Pennant Sandstone	02-Mar-11	0	CAT 4
16322	M5 Southbound - Gordano MP148/5 to MP148/7	Pennant Sandstone	02-Mar-11	1.260692415	CAT 3
16322	M5 Southbound - Gordano MP148/7+20 to MP149/1-20	Sandstone	02-Mar-11	6.708646494	CAT 3
16327	M5 Southbound - Gordano MP149/3 to MP149/6	Sandstone	02-Mar-11	0	CAT 4
16329	M5 Southbound - Wyhnol MP149/7+50 to MP150/1+80	Black Rock Limestone	02-Mar-11	0	CAT 4
16332	M5 Southbound - Wyhnol MP 150/2+50 to MP150/6	Limestone	02-Mar-11	0	CAT 4
16333	M5 Southbound - Wyhnol MP150/6 to MP151/0	Limestone (very limited outcrop)	02-Mar-11	1.70835038	CAT 3
16347	M56 Westbound Junction 11 On-Slip	Sandstone/siltstone (Vegetated)	15-Feb-11	0	CAT 4
16361	Ashburton: A38 Westbound MP85/1 to MP85/3	Limestone	08-Mar-11	1.612744233	CAT 3
16361	Ashburton: A38 Westbound MP85/6 to MP85/4	Limestone	08-Mar-11	37.08602037	CAT 2

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
16392	A36 Northbound Limpley Stoke	Oolitic limestone	01-Mar-11	1.772848709	CAT 3
16480	Exeter: A30 Eastbound offslip MP261/5	Breccia	11-Mar-11	8.984137229	CAT 3
16553	Exeter: A38 Westbound MP107/6 to MP107/1+20m	UGS/Breccia (No outcrop)	08-Mar-11	0	CAT 4
16561	Exeter: A38 Westbound MP107/8 to MP107/6	Breccia (severe ravelling and reprofiling of face)	08-Mar-11	7.483291515	CAT 3
16577	Exeter: A38 Westbound MP107/8 to MP108/0	Breccia	08-Mar-11	0	CAT 4
16585	Holdon: A38 Eastbound MP108/0	Breccia (face obscured by spalling)	11-Mar-11	0.01217664	CAT 4
16586	Holdon: A38 Eastbound MP107/6 to MP107/8	Breccia (face obscured by spalling)	11-Mar-11	0.108219888	CAT 4
16589	M5 Southbound MP168/8 to MP169/0	Limestone	28-Feb-11	1.114161599	CAT 3
16846	A1 (M) - West Cornforth	Magnesian Limestone	27-Jan-11	19.7635242	CAT 2
16853	A1 (M) - West Cornforth	Magnesian Limestone	27-Jan-11	0.008524004	CAT 4
16942	A1 (M) - High House Farm	Lower Magnesian Limestone	26-Jan-11	0.004546761	CAT 4
17684	A1 Southbound 45/4	Oolitic Limestone	11-Feb-11	23.54525068	CAT 2
17958	A1 Northbound 45/4	Oolitic Limestone	11-Feb-11	25.40409292	CAT 2
18001	A194 (M) - Springwell	Middle Coal Measures, Grinstone Post	26-Jan-11	4.018571163	CAT 3
18017	A194 (M) - Springwell	Middle Coal Measures, Grinstone Post	26-Jan-11	4.792285079	CAT 3
24410	M6 Sb 429/4+90 - 429/6+12	Siltstone/Sandstone	10-Mar-11	0.010422907	CAT 4
25121	A66 Wb 0900A66/152 Ch 460 for 60m	Slate	09-Mar-11	1.337172369	CAT 3
25465	Exeter: A38 Westbound MP112/1 to MP112/0 -50m	Breccia	08-Mar-11	0.336123126	CAT 4
27964	M5 Southbound 27/4 to 27/7+50m	Sandstone	03-Mar-11	9.016600666	CAT 3
27974	M65 Eastbound 24/5 to 24/6	Sandstone	16-Feb-11	16.61	CAT 2
27980	M65 Eastbound 24/7	Sandstone	16-Feb-11	2.9	CAT 3
27981	M65 Westbound 24/8 to 24/7	Sandstone	16-Feb-11	3.62	CAT 3
28759	Ashburton: A38 Westbound offslip	Limestone	08-Mar-11	11.14209168	CAT 2
28759	Ashburton: A38 Westbound offslip	Limestone (vegetation cover)	08-Mar-11	12.82121899	CAT 2
28816	Goodstone: A38 Eastbound MP89/2 to MP89/8	UDVS massively bedded limestone	11-Mar-11	14.145516	CAT 2
28817	Goodstone: A38 Westbound MP89/6 to MP89/2	Limestone	08-Mar-11	5.955006736	CAT 3
28859	Pear Tree: A38 Eastbound MP 84/8	UDVS shale over Limestone	11-Mar-11	2.981306205	CAT 3
28861	Ashburton: A38 Westbound	Shale	08-Mar-11	0	CAT 4
28916	Doublebois: A38 Westbound	U/MDVS Mudstone	10-Mar-11	0.057114417	CAT 4
28916	Doublebois: A38 Westbound	U/MDVS Mudstone	10-Mar-11	4.1783175	CAT 3
28916	Doublebois: A38 Westbound	U/MDVS Mudstone	10-Mar-11	161.381709	CAT 1
28926	Lewarne Wood: A38 Eastbound		10-Mar-11	0	CAT 4
28932	Doublebois/ Twowatersfoot: A38 Eastbound MP13/4	U/MDVS Slate/Mudstone	10-Mar-11	151.1542301	CAT 1
29023	M6 Sb 392/4+60 - 392/8+20	Limestone	09-Mar-11	4.093466991	CAT 3
29175	419/8	Sandstone/Metamorphic	21-Mar-03	0	CAT 4
29192	424/6+67 - 424/6+90	Metamorphic	12-Mar-03	0.01	CAT 4
29198	M6 Nb 426/1	Siltstone/Sandstone/Shale/Metamorphic	12-Mar-03	406.8831609	CAT 1
29214	426/5+60 - 426/5+20	Sandstone	21-Mar-03	0.03	CAT 4

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
29214	M6 Nb 426/5+40 - 426/5+95	Metamorphic	10-Mar-11	8.685668618	CAT 3
29215	M5 Southbound MP168/4 to MP168/7	Limestone	28-Feb-11	1.370914691	CAT 3
29217	M6 Nb 427/0	Metamorphic	10-Mar-11	1.572112025	CAT 3
29226	M6 Nb 428/3	Siltstone	10-Mar-11	15.70288215	CAT 2
29228	M6 Nb 429/3	Siltstone/Sandstone	14-Mar-03	69.27523469	CAT 2
29236	M6 Nb 431/6+64 - 431/7+20	Sandstone	10-Mar-11	14.54307216	CAT 2
29468	A66 Wb 0900A66/161 Ch 935 for 35m	Slate	09-Mar-11	5.748900233	CAT 3
30053	Exeter: A38 Eastbound MP111/0	Breccia (limited outcrop)	11-Mar-11	17.6904	CAT 2
30519	Saltash Portal: A38 Eastbound	U/MDVS slate	10-Mar-11	5.753347051	CAT 3
31273	A66 - Greta Bridge	Great Limestone	25-Jan-11	1.304881294	CAT 3
31274	A66 - Greta Bridge	Great Limestone	25-Jan-11	2.108742252	CAT 3
31276	A66 - Greta Bridge	Great Limestone	25-Jan-11	5.636950596	CAT 3
31278	A66 - Westbound	Great Limestone	25-Jan-11	0.0061382	CAT 4
31282	A66 - Bowes	Great Limestone	25-Jan-11	0.382237733	CAT 4
31283	A66 - Bowes	Great Limestone	25-Jan-11	0.005265931	CAT 4
31286	A66 - Kilmond westbound	Great Limestone	25-Jan-11	3.989338062	CAT 3
31292	A66 - Kilmond westbound	Great Limestone	25-Jan-11	0.443703284	CAT 4
31295	A66 - Kilmond westbound	Great Limestone	25-Jan-11	0.005115931	CAT 4
31299	A66 - Eastbound	Limestone	25-Jan-11	0	CAT 4
32105	M62 Westbound 83/0 to 82/7	Sandstone	09-Feb-11	0.402638582	CAT 4
32108	M62 Westbound 82/0 to 81/7+50m	Sandstone	02-Feb-11	0	CAT 4
32109	M62 Westbound 81/6+50m to 81/1	Sandstone	02-Feb-11	0	CAT 4
32111	M62 Westbound 85/1 to 84/2	Sandstone	02-Feb-11	0.368876962	CAT 4
32112	M62 Westbound 84/2 to 84/0+50m	Sandstone	09-Feb-11	0.009620454	CAT 4
32126	M62 Eastbound 75/1 to 74/9+60m	Sandstone	17-Mar-11	1.65	CAT 3
32569	A40 Westbound (Lea Line)	HHF	28-Feb-11	0.915462596	CAT 4
32703	A628 Eastbound 401081, 396567 to 401085, 396574	Sandstone	03-Feb-11	0.027625209	CAT 4
32838	Pyecombe: A23 Southbound onslip	Chalk (heavily vegetated)	18-Mar-11	75.159	CAT 2
33163	M62 Eastbound 70/8 to 70/9	Sandstone	16-Feb-11	2.21	CAT 3
33184	M62 Eastbound 71/4	Sandstone	16-Feb-11	1.34	CAT 3
33282	A616 Eastbound 430069, 398902 to 429886, 398894 (Circa MP6/0)	Sandstone	03-Feb-11	105.6957297	CAT 1
33301	M18 Southbound 259/6 to 259/5-20m	Dolomitic Limestone	08-Feb-11	0.003764689	CAT 4
33302	M18 Southbound 259/3 to 259/1-70m	Dolomitic Limestone	08-Feb-11	0.433096052	CAT 4
33318	M18 Northbound start of EW to 259/3+70m	Dolomitic Limestone	08-Feb-11	0.606224558	CAT 4
33319	M18 Northbound 259/6 to 259/5+50m	Dolomitic Limestone	08-Feb-11	0.007419518	CAT 4
33326	M18 Southbound 262/0 to 261/2	Dolomitic Limestone	08-Feb-11	0.017202862	CAT 4
33341	M18 Southbound 253/1-30m to 252/8-30m	Sandstone	08-Feb-11	0.008381546	CAT 4
33349	M18 Northbound	Dolomitic Limestone	08-Feb-11	1.027317873	CAT 3
33594	M65 Eastbound 9/0 (First 80m) to 9/0 (Last 100m)	Intrerbedded Sandstone and Siltstone	16-Feb-11	5.35	CAT 3
33875	Tideford: A38 Eastbound	UDVS	10-Mar-11	15.68956853	CAT 2

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
34039	M62 Westbound 70/9 to 70/6	Sandstone	16-Feb-11	0	CAT 4
34139	M1 Southbound 286/2 to 286/1-50m	Sandstone	02-Feb-11	0.003588537	CAT 4
34140	M1 Southbound 286/2 to 286/1-50m	Sandstone	02-Feb-11	0.003588537	CAT 4
34148	M1 Southbound 282/0 to Overbirdge	Sandstone	03-Feb-11	0.675463139	CAT 4
34149	M1 Southbound 281/8 to Overbridge	Sandstone	03-Feb-11	0	CAT 4
34246	M62 Eastbound 105/9+50m to 406/3	Coal Measures	09-Feb-11	3.750785013	CAT 3
34380	M1 Southbound 272/0+30	Sandstone	03-Feb-11	0.187269937	CAT 4
34550	M65 Westbound 16/2 to 16/1 At Junction 5	Sandstone	16-Feb-11	0	CAT 4
34837	Notterbridge: A38 Eastbound MP35/7	UDVS	10-Mar-11	32.61862739	CAT 2
35115	M54 Westbound 24/3 to 24/5	Conglomerate	08-Mar-11	0.007280266	CAT 4
35163	M54 Eastbound 33/7 to 33/6	Basalt	08-Mar-11	0	CAT 4
35287	A40 Eastbound	HHF	28-Feb-11	13.12544048	CAT 2
35408	M1 Southbound 272/0+30	Sandstone	03-Feb-11	0.187269937	CAT 4
35638	Sourton Cross: A30 Eastbound MP151/0	Upper Carboniferous	14-Mar-11	0	CAT 4
35707	M54 Eastbound 24/5+50m to 24/3	Conglomerate	08-Mar-11	0.004646364	CAT 4
36088	M50 Westbound 33/6 to 33/9	Sandstone	01-Mar-11	3.888607575	CAT 3
36191	M50 Eastbound 34/6 to 34/5	Sandstone	03-Mar-11	9.25101618	CAT 3
36193	M50 Eastbound 33/9+60m to 33/9	Sandstone	03-Mar-11	0.45643629	CAT 4
36196	M50 Eastbound 33/1	Sandstone	03-Mar-11	0	CAT 4
36199	M50 Eastbound 32/4 to 32/7	Sandstone	03-Mar-11	0.696026574	CAT 4
36202	M50 Eastbound 31/8+20m to 31/7	Sandstone	03-Mar-11	15.72485653	CAT 2
36205	M50 Eastbound 31/0 to 30/8	Sandstone	03-Mar-11	3.945153901	CAT 3
36206	M50 Eastbound 30/8 to 30/3+50m	Sandstone	03-Mar-11	16.41600463	CAT 2
36207	M50 Eastbound 30/3+50m to 30/3	Sandstone	03-Mar-11	23.69717425	CAT 2
36210	M50 Eastbound 29/6+30 to 29/5	Sandstone	03-Mar-11	0	CAT 4
36383	M65 Westbound Junction 5 Off-Slip/18/6 to 18/9	Sandstone	16-Feb-11	0.2	CAT 4
36384	M65 Westbound Junction 5 Off-Slip/18/6 to 18/9	Sandstone	16-Feb-11	0.2	CAT 4
36388	M50 Westbound 29/6 to 29/7	Sandstone	01-Mar-11	18.5268913	CAT 2
36390	M65 Eastbound Junction 5 On-Slip	Sandstone	16-Feb-11	0	CAT 4
36393	M50 Westbound 30/3 to Overbridge	Sandstone	01-Mar-11	0.523728118	CAT 4
36394	M50 Westbound 30/4 to 30/5	Sandstone	01-Mar-11	0	CAT 4
36402	M65 Northbound 18/9 to 16/6	Sandstone	16-Feb-11	0.04	CAT 4
36406	M65 Northbound 18/9 to 16/6	Sandstone	16-Feb-11	0.04	CAT 4
36417	437/8+20 - 437/8+90	Limestone	18-Mar-03	0.06	CAT 4
36419	M50 Westbound 32/4 to 32/6	Sandstone	01-Mar-11	7.228647661	CAT 3
36422	M6 Nb 440/4	Limestone	10-Mar-11	0.378972982	CAT 4
36432	M6 Sb 439/9+10 - 439/7+80	Sandstone	09-Mar-11	1.176503315	CAT 3
36495	M50 Eastbound 33/9 to 33/5+70m	Sandstone	03-Mar-11	8.734877404	CAT 3
36883	M18 Southbound 251/5+40m to 251/3	Sandstone	08-Feb-11	2.259633592	CAT 3
37369	A49 Northbound SO 5080 5094 South of Leominster	Sandstone	08-Mar-11	15.55729053	CAT 2

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
37462	A40 Westbound 37/1 to 37/0 (oposite services)	Sandstone	02-Mar-11	0	CAT 4
37510	A49 Northbound (Horizons Farm)	Sandstone	02-Mar-11	4.546787328	CAT 3
37646	A40 Eastbound 34/9+50m to 35/4+50m	Sandstone	01-Mar-11	1.09907875	CAT 3
37647	A40 Eastbound 35/6+50m (at Ganarew Junction)	Sandstone	01-Mar-11	0	CAT 4
37739	A40 Eastbound 37/2+60m to 37/3+20m	Sandstone	02-Mar-11	1.742552956	CAT 3
38029	South Brent: A38 Westbound	MDVS (very limited visible outcrop)	09-Mar-11	7.905434876	CAT 3
38045	South Brent: A38 Eastbound MP72/0	MDVS Slate	11-Mar-11	19.49728962	CAT 2
38049	South Brent: A38 Eastbound	MDVS Slate	11-Mar-11	20.08655277	CAT 2
38059	South Brent: A38 Eastbound MP72/0	MDVS Slate	11-Mar-11	18.87453435	CAT 2
38102	Zelah: A30 Westbound MP61/2	Slate	14-Mar-11	0.244537983	CAT 4
38155	434/4	Sandstone	17-Mar-03	0.02	CAT 4
38205	Lewannick: A30 Westbound MP121/2	UDVS	14-Mar-11	1.491342048	CAT 3
38212	Tolpetherwin: A30 Eastbound MP121/2	Slate	14-Mar-11	24.86823566	CAT 2
38356	A49 Southbound SO 4433 8036 Near Whettleton	Sandstone	08-Mar-11	1.498211146	CAT 3
40030	Lee Mill: A38 Eastbound MP59/7 to MP59/8	UDVS	09-Mar-11	0.377763475	CAT 4
40030	Lee Mill: A38 Eastbound MP56/6-30m to MP59/7	UDVS Slate	09-Mar-11	5.074652784	CAT 3
40030	Lee Mill: A38 Eastbound MP59/1 to MP59/8	UDVS Slate	09-Mar-11	5.24871183	CAT 3
40030	Lee Mill: A38 Eastbound MP59/5 to MP59/6-30m	UDVS	09-Mar-11	28.20714039	CAT 2
40030	Lee Mill: A38 Eastbound MP59/0	MDVS Slate	09-Mar-11	40.84094604	CAT 2
40350	Dunheved: A30 Westbound	Meldon shale	14-Mar-11	0.080067374	CAT 4
40434	Dunheved: A30 Westbound MP130/8 to overbridge	Meldon shale	14-Mar-11	0	CAT 4
40444	Dunheved: A30 Westbound MP131/8	Meldon Shale (limited outcrop)	14-Mar-11	4.328550192	CAT 3
40445	Dunheved: A30 Eastbound MP131/0 to MP131/5	slate	14-Mar-11	3.905991746	CAT 3
40446	Dunheved: A30 Westbound before overbridge	Meldon Shale (no visible outcrop)	14-Mar-11	0	CAT 4
41198	A1 Southbound Middleton	Dolerite	26-Jan-11	0.026284569	CAT 4
41199	A1 Northbound Middleton	Dolerite	26-Jan-11	3.579432638	CAT 3
41215	A1 Southbound Belford	Dolerite	26-Jan-11	0.032522774	CAT 4
41216	A1 Northbound Belford	Dolerite	26-Jan-11	0.008411062	CAT 4
41725	M6 Southbound 249/5 to 249/4	Sandstone	04-Mar-11	0	CAT 4
41826	M6 Northbound 249/4 to 249/5+40m	Sandstone	04-Mar-11	6.337503671	CAT 3
41993	M62 Eastbound 84/0 to 84/2	Sandstone	02-Feb-11	0	CAT 4
41994	M62 Eastbound 84/2 to 84/9	Sandstone	02-Feb-11	0.245181039	CAT 4
42016	M62 Eastbound 81/2 to 81/7+50m	Sandstone	02-Feb-11	0	CAT 4
42017	M62 Eastbound 81/7+50m to 82/0	Sandstone	02-Feb-11	0	CAT 4
42022	M62 Eastbound 83/5 to 83/9	Sandstone	02-Feb-11	2.122158987	CAT 3
42117	442/8+35 - 442/6+5	Sandstone	18-Mar-03	0.04	CAT 4
42119	443/2+70 - 443/3+95	Sandstone	17-Mar-03	0.1	CAT 4
42120	444/1+55 - 444/2+80	Limestone	17-Mar-03	0.04	CAT 4
42121	M6 Nb 444/2	Limestone	10-Mar-11	14.98384812	CAT 2

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
42202	M1 Southbound 174/2 to 174/1	Tuff	10-Feb-11	2.666754018	CAT 3
42399	M1 Northbound 281/8 to Overbridge	Sandstone	03-Feb-11	0	CAT 4
42400	M1 Northbound Overbridge to 282/0	Sandstone	03-Feb-11	1.382698127	CAT 3
42402	M1 Northbound 283/1+50 to 283/3-30m	Sandstone	03-Feb-11	0	CAT 4
42436	M1 Northbound 286/1 to 286/2	Sandstone	03-Feb-11	0.00355678	CAT 4
42437	M1 Northbound 286/1 to 286/2	Sandstone	03-Feb-11	0.00355678	CAT 4
42439	M1 Northbound J39 Off-Slip (Wooley Edge Services)	Sandstone	03-Feb-11	0.003176157	CAT 4
42451	M1 Northbound J23 On-slip 168/6 to 168/7+80	Tuff	10-Feb-11	1.676948438	CAT 3
42458	M1 Northbound 170/4 to 170/5	Tuff	10-Feb-11	0.005089152	CAT 4
42469	M1 Northbound 174/2	Tuff	10-Feb-11	3.059685477	CAT 3
42470	M1 Northbound Layby at 174/4+20	Tuff	10-Feb-11	0.001339251	CAT 4
42548	M6 Nb 449/1	Limestone	10-Mar-11	1.273840348	CAT 3
42667	A1 Southbound 23/0 Behind bridge pier	Dolomitic Limestone	04-Feb-11	12.22452	CAT 2
42668	A1 Southbound 23/0 Behind bridge pier	Dolomitic Limestone	04-Feb-11	12.22452	CAT 2
42702	A1 Southbound 20/7	Limestone	04-Feb-11	3.528	CAT 3
42761	M62 Westbound 84/0 to 83/4+50m	Sandstone	09-Feb-11	0	CAT 4
42781	M1 Southbound J9 On-Slip (Wooley Edge Services)	Sandstone	03-Feb-11	0.003381	CAT 4
42798	A1 Northbound Cramlington	Sandstone	26-Jan-11	2.04326303	CAT 3
42826	A1 Southbound Cramlington	Sandstone	26-Jan-11	0.294853135	CAT 4
42868	A38 Northbound 457/6 to 457/7+30	Coal Measures	10-Feb-11	0	CAT 4
43024	A5 Eastbound 37/6 to 37/4	Rhyolite	08-Mar-11	0.125107997	CAT 4
43074	A5 Westbound 37/4 to 37/6	Rhyolite	08-Mar-11	0.321818938	CAT 4
43228	Handcross: A23 Southbound MP21/9	Sandstone (heavily vegetated)	18-Mar-11	108.6511104	CAT 1
43309	A64 Northbound 51/5+50m to 52/3	Dolomitic Limestone	09-Feb-11	0.869781931	CAT 4
43310	A64 Northbound 53/1 to 53/7	Dolomitic Limestone	09-Feb-11	1.88235949	CAT 3
43311	A64 Northbound 52/3 to 53/1	Dolomitic Limestone	09-Feb-11	7.0072695	CAT 3
43407	445/2+70 - 445/4+60	Limestone	18-Mar-03	0.01	CAT 4
43421	445/6	Limestone	13-Mar-03	0.82	CAT 4
43426	446/7+30 - 446/8+05	Limestone	18-Mar-03	0.01	CAT 4
43440	M6 Sb 421/7+70 - 421/7+00	Siltstone	09-Mar-11	0.163626077	CAT 4
43614	A64 Southbound Lay-by +50m to 53/1	Dolomitic Limestone	09-Feb-11	0.903598416	CAT 4
43615	A64 Southbound 53/1 to 51/6	Dolomitic Limestone	09-Feb-11	5.853615579	CAT 3
43616	A64 Southbound Lay-by +50m to 53/1	Dolomitic Limestone	09-Feb-11	0.903598416	CAT 4
44199	A1 Southbound J36 Off Slip 15/2+20m to Overbridge	Limestone	04-Feb-11	42.293664	CAT 2
44200	A1 Southbound Inner Junction 15/0 to 14/7	Limestone	04-Feb-11	44.76945302	CAT 2
44201	A1 Southbound Inner Junction 15/0 to 14/7	Limestone	04-Feb-11	44.76945302	CAT 2
44202	A1 Southbound Inner Junction 15/0 to 14/7	Limestone	04-Feb-11	44.76945302	CAT 2
45031	A1 Northbound J36 Inner Junction 14/7 to 15/0	Limestone	04-Feb-11	117.355392	CAT 1
45032	A1 Northbound J36 Inner Junction 14/7 to 15/0	Limestone	04-Feb-11	117.355392	CAT 1

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
45033	A1 Northbound J36 Inner Junction 14/7 to 15/0	Limestone	04-Feb-11	117.355392	CAT 1
45146	394/1+82 - 394/0+68	Limestone	26-Jan-04	0.3	CAT 4
45243	A66 Eb 0900A66/216 Ch 615 for 40m	Siltstone	09-Mar-11	0.002048063	CAT 4
45266	A66 Eb 0900A66/216 Ch 600 for 15m	Slate	09-Mar-11	0.688496799	CAT 4
45340	Notterbridge: A38 Westbound MP36/1	UDVS	10-Mar-11	0	CAT 4
45477	A66 Wb 0900A66/157	Slate	09-Mar-11	36.2197836	CAT 2
45517	A66 Eb 0900A660/270 Ch 610 for 150m	Limestone	09-Mar-11	3.76959744	CAT 3
45677	A1 Northbound 15/2 North of J36	Limestone	04-Feb-11	0	CAT 4
45680	A1 Northbound 16/6 to 16/8	Limestone	04-Feb-11	0	CAT 4
45681	A1 Northbound 16/6 to 16/8	Limestone	04-Feb-11	0	CAT 4
45684	A1 Southbound 17/9	Limestone	04-Feb-11	3.525795	CAT 3
45696	A1 Northbound 20/7	Limestone	04-Feb-11	12.863088	CAT 2
45697	A1 Northbound 23/0 Behind bridge pier	Dolomitic Limestone	04-Feb-11	5.93946675	CAT 3
45698	A1 Northbound 23/0 Behind bridge pier	Dolomitic Limestone	04-Feb-11	5.93946675	CAT 3
46367	M4 Jct 17 Eastbound MP152/7	Limestone	01-Mar-11	0.003223431	CAT 4
46705	Rochester: M2 Jct 2 to A228 Link (southbound)	Chalk	18-Mar-11	1.666086663	CAT 3
46706	Rochester: Ms Jct 2 northbound roundabout	Chalk	18-Mar-11	5.923014342	CAT 3
46706	Rochester: M2 Jct 2 to A228 Link (northbound)	Chalk	18-Mar-11	6.748061685	CAT 3
46772	Winchester (Twyford Down): M3 Southbound MP105/5 to MP106/9	Chalk	17-Mar-11	1.286765626	CAT 3
47329	Clicker Garage: A38 Eastbound MP29/2	U/MDVS Slate	10-Mar-11	3.140711761	CAT 3
47348	Clicker Garage: A38 Eastbound	U/MDVS Slate	10-Mar-11	0.178736649	CAT 4
47348	Clicker Garage: A38 Eastbound MP27/2	U/MDVS Slate	10-Mar-11	28.92448439	CAT 2
47546	A38 Eastbound	U/MDVS Shale	09-Mar-11	17.75417049	CAT 2
47547	Plymouth: A38 Eastbound MP46/4	U/MDVS Shale	09-Mar-11	22.02354533	CAT 2
47586	Honicknowle: A38 Westbound MP46/6	U/MDVS Slate	09-Mar-11	59.30247266	CAT 2
47587	Honicknowle: A38 Westbound	U/MDVS Slate	09-Mar-11	89.63285096	CAT 2
47592	Honicknowle: A38 Westbound	U/MDVS Slate (no safe place to stop)	09-Mar-11	0	CAT 4
47596	Plymouth: A38 Eastbound MP44/0 to 44/0+80m	U/MDVS Sandstone	09-Mar-11	0.37930149	CAT 4
47596	Plymouth: A38 Eastbound	U/MDVS Shale	09-Mar-11	1.173179065	CAT 3
47893	A1(M) Northbound A184 Offslip	Coal Measures	26-Jan-11	17.34793598	CAT 2
48006	A628 Eastbound 13/1	Sandstone	03-Feb-11	0	CAT 4
48030	M65 Westbound 9/1 to 9/0	Sandstone and Siltstone	16-Feb-11	0.03	CAT 4
50241	A1 Northbound J36 On-Slip	Limestone	04-Feb-11	19.26288	CAT 2
50243	A1 Southbound J36 Off Slip Overbridge to Roundabout	Limestone	04-Feb-11	6.197184	CAT 3
50244	A1 Southbound J36 On-Slip (At Footbridge)	Limestone	04-Feb-11	11.87444736	CAT 2
50672	A40 Westbound 35/8 to 35/6	Sandstone	01-Mar-11	0	CAT 4
50673	A40 Westbound 35/6 to 35/5	Sandstone	01-Mar-11	0	CAT 4
50730	A40 Eastbound 44/0+60m to 44/4+50m	Sandstone	02-Mar-11	7.293639276	CAT 3
50733	A40 Eastbound 43/6 to 43/9	Sandstone	02-Mar-11	1.394668852	CAT 3

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
50749	A40 Westbound 48/4 to 48/2	Sandstone	01-Mar-11	3.600134904	CAT 3
50749	A40 Westbound 48/0 to 48/2+60m	Sandstone	01-Mar-11	3.869836009	CAT 3
50752	A40 Westbound 48/4 to 48/2	Sandstone	01-Mar-11	3.600134904	CAT 3
50814	A40 Eastbound 48/4 to 48/5	Sandstone	02-Mar-11	0.633685723	CAT 4
50814	A40 Eastbound 48/2 to 48/3+70m	Sandstone	02-Mar-11	2.055164023	CAT 3
50816	A40 Eastbound 48/0+30m to 48/2	Sandstone	02-Mar-11	1.957976813	CAT 3
50816	A40 Eastbound 48/2 to 48/3+70m	Sandstone	02-Mar-11	2.055164023	CAT 3
50964	A40 Eastbound 39/6+20m to 39/8 (at lay-by)	Sandstone	02-Mar-11	1.486770681	CAT 3
51585	A1 Northbound 289/8 to 289/9	Limestone	04-Feb-11	10.61424	CAT 2
51916	Lee Mill: A38 Eastbound	MDVS	11-Mar-11	10.08098438	CAT 2
51922	Deep Lane: A38 Eastbound MP58/6	MDVS	11-Mar-11	56.80306643	CAT 2
51943	Merafield: A38 Eastbound MP53/8	UDVS/ Pink Mudstone (v limited visble outcrop)	09-Mar-11	0	CAT 4
51943	Merafield: A38 Eastbound	UDVS / Mudstone	09-Mar-11	0.175160397	CAT 4
51944	Saltram: A38 Eastbound MP53/0 to MP53/8+20	UDVS (no visible outcrop)	09-Mar-11	0	CAT 4
51947	Plymouth: A38 Eastbound MP52/6	UDVS Shale	09-Mar-11	0	CAT 4
52017	422/9+0 - 422/9+85	Metamorphic	16-Jan-04	0.01	CAT 4
52057	A628 Eastbound MP8/5 (South of Quarry) to MP8/3 (beside lay-by)	Sandstone	03-Feb-11	14.35004086	CAT 2
53412	A616 Westbound	Sandstone	03-Feb-11	61.90940903	CAT 2
53614	444/1+30 - 444/2+50	Limestone	17-Mar-03	0.03	CAT 4
54042	M5 Northbound 25/7 to 25/4+20m	Sandstone	03-Mar-11	0.020593896	CAT 4
55716	A590 Eb 0900A590/144	Slate	11-Mar-11	28.4748428	CAT 2
55729	A590 Wb 0900A590/365 Ch 680 for 65m	Limestone	11-Mar-11	3.304589904	CAT 3
55745	A590 Wb 0900A590/365 Ch 90 for 75m	Limestone	11-Mar-11	7.297347981	CAT 3
55751	A590 Eb 0900A590/365 Ch 660 for 100m	Limestone	11-Mar-11	0.573553493	CAT 4
55752	A590 Eb 0900A590/365 Ch 100 for 75m	Limestone	11-Mar-11	3.45645241	CAT 3
55816	A590 Eb 0900A590/156 Ch 690 for 120m	Slate	11-Mar-11	2.209193175	CAT 3
55819	A590 Wb 0900A590/161	Slate	11-Mar-11	19.54213563	CAT 2
55922	A590 Wb 0900A590/163	Sandstone and Siltstone	11-Mar-11	19.33156368	CAT 2
56068	A590 Wb 0900A590/194 Ch 610 for 295m	Slate	11-Mar-11	1.050305244	CAT 3
56083	A590 Eb 0900A590/187 Ch 530 for 120m	Slate	11-Mar-11	0.250988418	CAT 4
56366	M56 Eastbound Junction 11 Off-Slip	Sandstone/siltstone (Vegetated)	15-Feb-11	0	CAT 4
57385	M1 Southbound 202/1 to 201/9	Sandstone	10-Feb-11	0.33411969	CAT 4
57462	M1 Northbound 210/9 to 211/0	Sandstone	10-Feb-11	0.008924073	CAT 4
57488	M1 Northbound 205/9	Sandstone	10-Feb-11	0	CAT 4
57499	M1 Northbound 211/1 to 211/3	Sandstone	10-Feb-11	0.021169135	CAT 4
57761	M1 Northbound 202/1	Sandstone	10-Feb-11	0.217493905	CAT 4
57766	M1 Northbound J26 On-slip	Sandstone	10-Feb-11	0	CAT 4
57847	M61 Northbound 30/3	Sandstone	16-Feb-11	0.67	CAT 4
57848	M61 Northbound 30/4	Sandstone	16-Feb-11	0.31	CAT 4
58045	Petersfield: A3 S/B MP15/8 to MP14/9	Chalk	17-Mar-11	0.097214304	CAT 4

HAGDMS Earthwork ID	Location (From inspection forms)	Rock Description (From inspection forms)	Date Inspected	RSHI Value	RSHI Category
59378	M62 Westbound 74/9+50m to 74/8	Sandstone	17-Mar-11	0.03	CAT 4
59378	M62 Westbound 74/8 to 74/5+70m	Sandstone	17-Mar-11	2.41	CAT 3
59378	M62 Westbound 74/5+70m to 74/3	Sandstone	17-Mar-11	2.48	CAT 3
59379	M60 Clockwise 55/6	Sandstone	17-Feb-11	4.02	CAT 3
59380	M60 Anticlockwise 55/8-40 to 55/7	Sandstone	17-Feb-11	0.42	CAT 4
59380	M60 Anticlockwise 55/7 to 55/6	Sandstone	17-Feb-11	5.56	CAT 3
59381	M60 Anticlockwise 56/1 to 55/8	Sandstone	17-Feb-11	12.96	CAT 2
59383	M60 Anticlockwise 56/2 to 56/1	Sandstone	17-Feb-11	10.13	CAT 2
59525	Winchester (Twyford Down): M3 Southbound MP105/5 to MP106/9	Chalk	17-Mar-11	1.286765626	CAT 3
59526	Winchester (Twyford Down): M3 Southbound MP105/5 to MP106/9	Chalk	17-Mar-11	1.286765626	CAT 3
59527	Winchester (Twyford Down): M3 Southbound MP105/5 to MP106/9	Chalk	17-Mar-11	1.286765626	CAT 3
60207	M5 Southbound - Wynhol MP152/2 to MP151/9	Limestone	02-Mar-11	0	CAT 4
60207	M5 Southbound - Wynhol MP152/3-20 to MP152/2	Limestone	02-Mar-11	2.127418451	CAT 3
60207	M5 Southbound - Wynhol MP152/7+50 to 152/3-20	Sandy Limestone	02-Mar-11	3.655649322	CAT 3
60207	M5 Southbound - Wynhol	Sandstone	02-Mar-11	10.36530273	CAT 2
60207	M5 Southbound - Wynhol MP152/7+50 to 152/9	Sandy Limestone	02-Mar-11	20.70258854	CAT 2
60207	M5 Southbound - Wynhol	Sandy Limestone/Limestone	02-Mar-11	20.70258854	CAT 2
60266	A1 Southbound 65/5	Oolitic Limestone	11-Feb-11	0.055954819	CAT 4
64100	Temple: A30 Eastbound central reservation MP108/2	Granite (heavily weathered)	14-Mar-11	0.858298412	CAT 4
64101	Temple: A30 Eastbound central reservation MP108/3	Granite (heavily weathered)	14-Mar-11	0.279373122	CAT 4
64103	Temple: A30 Westbound central reservation MP108/2	Granite (heavily weathered)	14-Mar-11	1.972026835	CAT 3

F. Hazard map definition documents

HAGDMS Brine Extraction Hazard Rating data description

Introduction

The history of brine extraction across England (particularly Cheshire) has left a legacy of hazards in the ground with the potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Brine Extraction Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared.

The map was constructed using the datasets listed in Table 1 below.

Table 1 Summary details of the datasets used in the Brine Extraction Hazard Map

Dataset	Provider	Data Currency
BGS Mining Hazard (not including coal)	British Geological Survey	11-03-2016
Brine Compensation Areas	Cheshire Brine Compensation Board	11-06-2012
Brine Pumping Related Features	Wardell Armstrong LLP	03-03-2006
Brine Subsidence Solution Areas	Johnson, Poole and Bloomer	26-08-2009

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors.

The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Brine Extraction Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the brine extraction hazard map was created. The extent of the datasets used to form the map, were constrained to a 1000m corridor centred on the SRN. This corridor was split into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology.

All datasets were assessed relative to the BGS Mining Hazard (not including coal) bands using engineering judgement (Table 2).

	Dataset:	Mining Hazard (not including coal)		Brine compensation areas	Brine pumping related features	Brine subsidence solution areas
Band	**Data Source:**	British Geological Survey		Cheshire Brine Compensation Board	Wardell Armstrong LLP	Johnson, Poole and Bloomer
	Data type	Polygon		Polygon	Polygon	Polygon
Null	No data present	No intersect with 500m circles	Commodity type: Brine	No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles
A	Very low	Rare				
B	Low	Highly Unlikely				
C	Moderate	Unlikely		Brine compensation areas		
D	High or inconclusive	Likely			Areas potentially affected by brine runs	
E	Very high or proven/conclusive	Highly Likely			Brine dissolution areas Brine runs	Brine subsidence solution areas

Not included			Chalk Firestone/Hearthstone Firestone/Hearthstone/Chalk Flint/Chalk Fuller's Earth Fuller's Earth/Limestone - Bath Stone Ganister Gypsum Iron Ore Iron Ore (bedded) Iron Ore (bedded)/Limestone - Black Country Iron Ore (non vein) Jet Jet/Vein Mineral Lignite/Chalk Limestone - Bath Stone Limestone - Black Country/Vein Mineral Limestone/Vein Mineral Raddle Sand Sand/Building Stone Sand/Chalk Sandstone Sandstone - Elland Flags Vein Mineral/Ball Clay Vein Mineral/Iron Ore Vein Mineral/Sandstone			

Table 2 Summary of assigned banding for each brine dataset

From the centre point of each complete grid square a 500m circular buffer was created. The assigned band for each dataset intersected within the buffer was then extracted and the maximum band was assigned to the grid square (refer to Table). This assigned value represents the hazard rating score for that grid square (Figure 1).

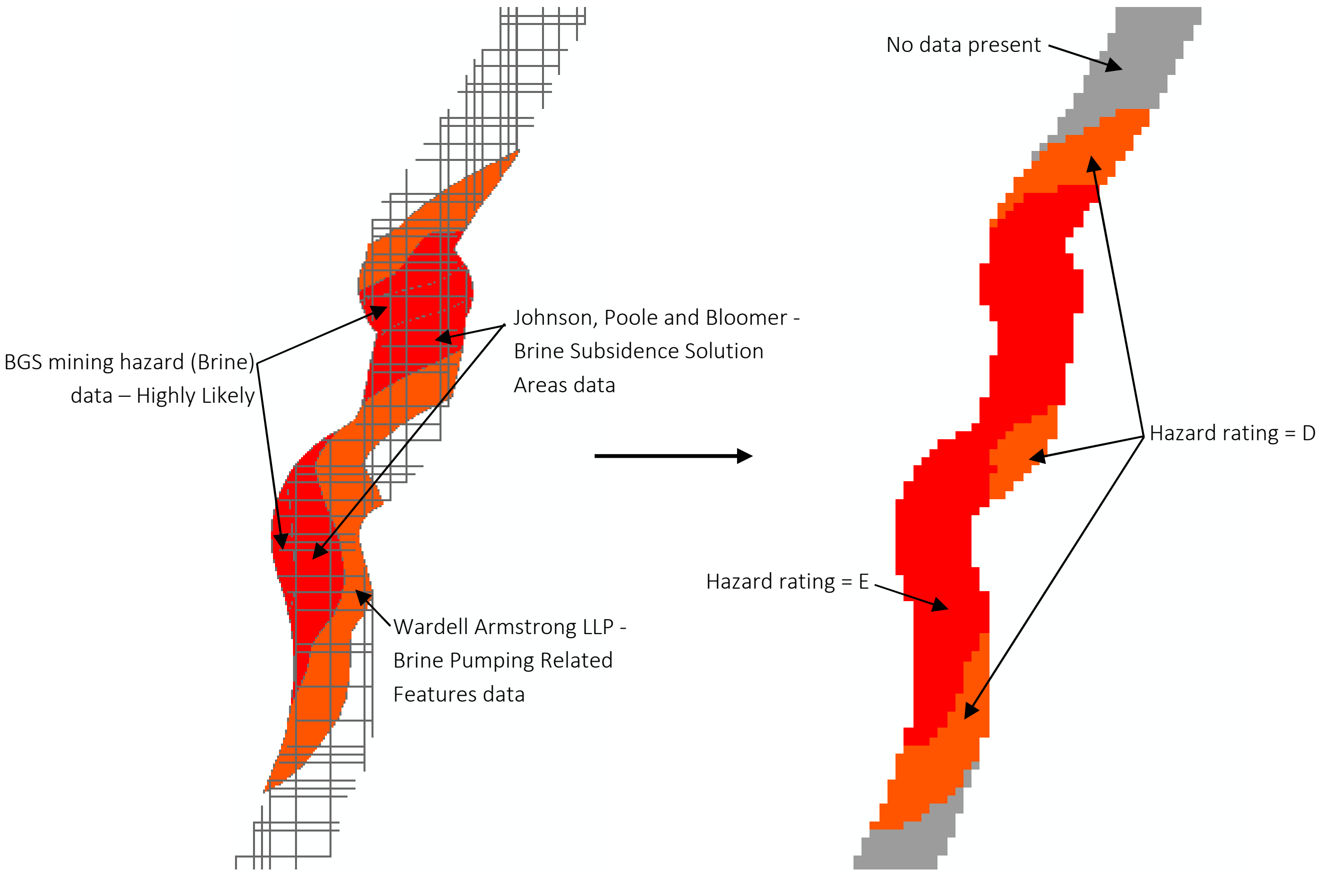


Figure 1 Map methodology showing 500m grid buffer intersecting the brine datasets and the resulting hazard map

The Result

The result of the analysis is a nationwide brine hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into six categories (No data present then A to E). A summary of the Brine Extraction Hazard Rating categories is detailed in Table 3.

Table 3 Summary of Brine Extraction Hazard Rating banding

Brine Hazard Rating	Colour	Explanation
No data present		No data present
A		Very low
B		Low
C		Moderate
D		High or inconclusive
E		Very high or proven/conclusive

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for compressible/collapsible ground is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard brine extraction poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 4 below.

Table 4 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first revision, and it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Brine Extraction Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Compressible/Collapsible Ground Hazard Rating data description

Introduction

Areas of compressible/collapsible ground across England have the potential to cause subsidence of the ground surface and hence possibly impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Compressible/Collapsible Ground Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared.

The map was constructed using the datasets listed in Table 1 below.

Table 1 Summary details of the datasets used in the Compressible/Collapsible Ground Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Compressible Ground	British Geological Survey	26-07-2014
BGS GeoSure: Collapsible Ground	British Geological Survey	26-07-2014

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors.

The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Compressible/Collapsible Ground Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the compressible/collapsible ground hazard map was created. The extent of the datasets used to form the map, were constrained to a 1000m corridor centred on the SRN. This corridor was split into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology.

From the centre point of each complete grid square a 500m circular buffer was created. The maximum collapsible and compressible ground GeoSure band within each buffered circle was extracted and the maximum of either value was assigned to the associated grid square (Figure 1).

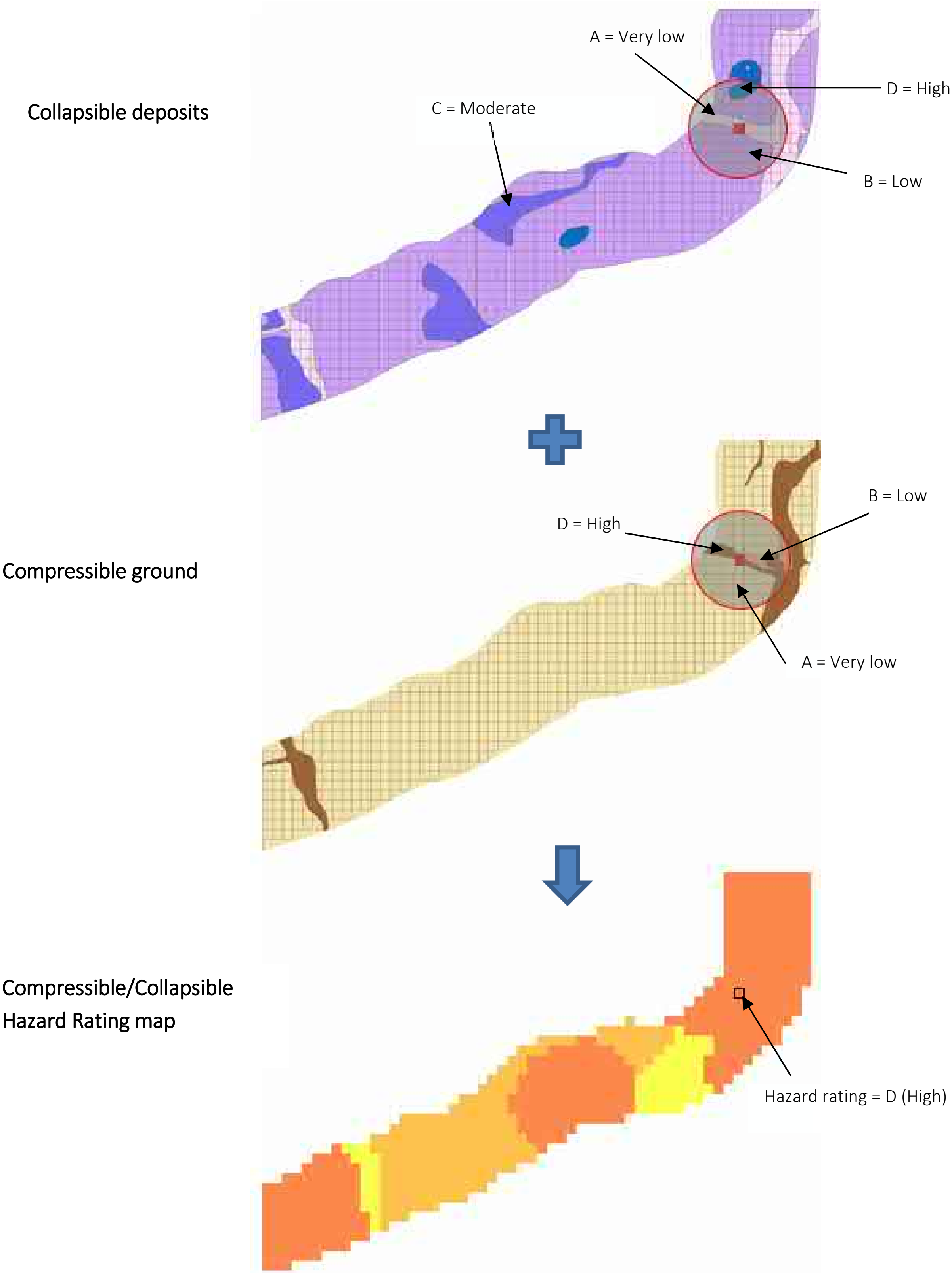


Figure 1 Example of attributing the maximum GeoSure band to grid squares and taking the resulting maximum from both layers

The Result

The result of the analysis is a GeoSure derived nationwide compressible/collapsible ground hazard map for a 1000m corridor of the Strategic Road Network. A summary of the compressible and collapsible ground GeoSure categories are detailed in Table 2 below.

Table 2 Summary of compressible/collapsible ground GeoSure bands used for the compressible/collapsible ground hazard map

Compressible/ Collapsible Ground Hazard Rating	Colour	Explanation
A		No indicators for compressible deposits identified *and/or* Deposits with potential to collapse when loaded and saturated are believed not to be present
B		Very slight potential for compressible deposits to be present *and/or* Deposits with potential to collapse when loaded and saturated are unlikely to be present
C		Slight possibility of compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated are possibly present in places
D		Significant potential for compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated are probably present in places
E		Very significant potential for compressibility problems *and/or* Deposits with potential to collapse when loaded and saturated have been identified

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Compressible Ground and Collapsible Ground datasets.
Compressible ground: https://www.bgs.ac.uk/products/geosure/compressiblePHI.html **Collapsible deposits**: https://www.bgs.ac.uk/products/geosure/collapsiblePHI.html

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for compressible ground is not the equivalent of a 'B' for dissolution features). This is also applies to compressible ground vs collapsible deposits.

Highways England Contacts

To obtain further advice on the hazard compressible/collapsible ground poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 3 below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first revision, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Compressible/Collapsible Ground Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Dissolution Features Hazard Rating data description

Introduction

Dissolution features, particularly in chalk, can have an impact on the operation of the Strategic Road Network managed by Highways England, and can also be a significant issue to be addressed when engineering schemes in affected areas of the country. To respond to this hazard, a high level Dissolution Features Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared.
The map was constructed using the datasets listed in Table 1 below.

Table 1 Summary details of the datasets used in the Dissolution Features Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Soluble Rocks	British Geological Survey	26-07-2014
Natural Cavities	Peter Brett Associates	17-12-2015

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors or the potential need to contact Peter Brett Associates for the latest data on site-specific issues. The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Dissolution Features Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the dissolution features hazard map was created. The extent of the datasets used to form the map was constrained to a 1000m corridor centred on the SRN. This corridor was then partitioned into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology.

BGS GeoSure: Soluble rocks

From the centre point of each complete grid square a 500m circular buffer was created. The maximum GeoSure band within each buffered circle was then assigned to the grid square at the centre of the buffer (see Figure 1).

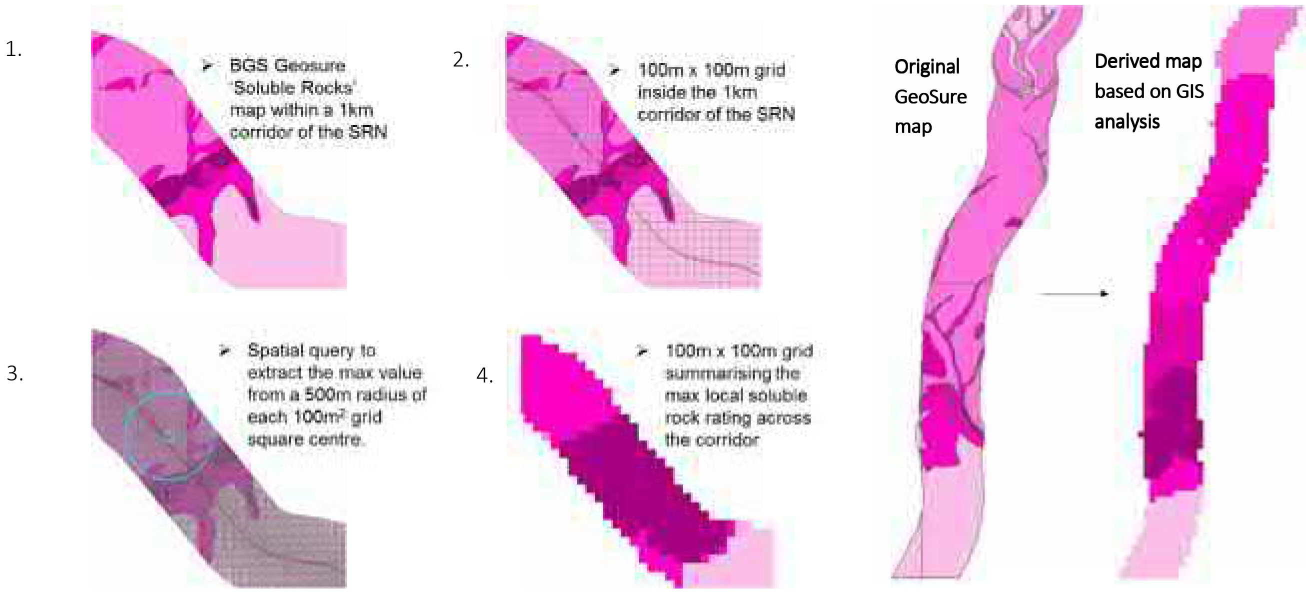


Figure 1 Map methodology showing 500m grid buffer intersecting the BGS GeoSure polygon data within the 1000m SRN corridor

Peter Brett Associates Natural Cavities

The same 500m circular buffers were used to spatially query the PBA Natural Cavity data, which consists of polygon, line, and point data (Figure 2). Where polygons and lines partially intersect a buffer, an even distribution of features across the polygons/lines was assumed and a proportion of the features present were assigned, based on the percentage of the polygon/line that intersects the buffer. The PBA data contains attributes of the number of particular features seen at a given location, for example a single point make record the presence of 5 solution pipes at that location. This information was extracted as part of the GIS analysis in the derivation of the map.

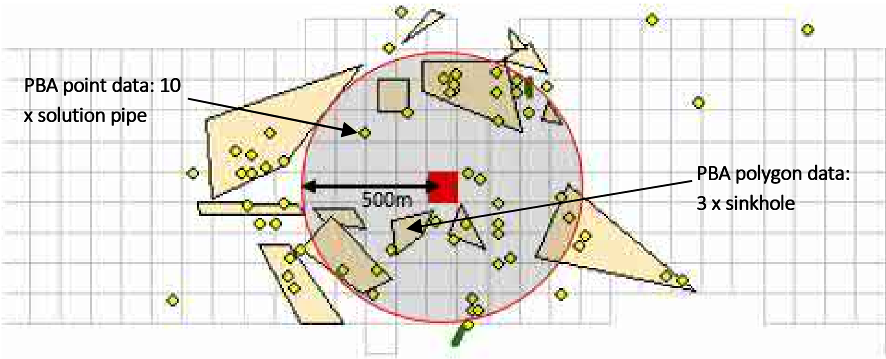


Figure 2 Map methodology showing 500m grid buffer intersecting polygon, line, and point PBA data within the 1000m SRN corridor

The extracted number of features was then weighted based on the natural cavity type that had been intersected. The weightings were derived based on expert judgement of the task stakeholder group (see Table 2).

Table 2 Summary of the weightings assigned to each PBA natural cavity type

Natural Cavity Type	Weighting (out of 20)	Notes
Sinkhole	20	
Solution Pipe	15	
Swallow Hole	20	
Bourne Hole	0	Not related to dissolution
Gulls/Fissures due to Cambering	0	Not related to dissolution
Not supplied	16	Statistics used to derive weightings
Piping in non-cohesive deposits	0	Not related to dissolution
Sea Cave	0	Primarily created by hydraulic action
Solution widened Joint or Fissure	5	
Unknown	16	Statistics used to derive weightings
Vadose Cave	20	
Scour Hollows	0	Not related to dissolution

The resulting weighted PBA scores were then calibrated to the GeoSure categories to ensure parity in the density of features between the datasets. Where the buffer of a grid square was not a complete circle because it partially falls outside the 1000m corridor then the density of features outside the circle was assumed to be the same as the density inside the corridor.

Combining the GeoSure and PBA data sets to produce the HE hazard map

Overlay analysis was used to take the maximum hazard rating of the BGS GeoSure or PBA data for each grid square (see Figure 3).

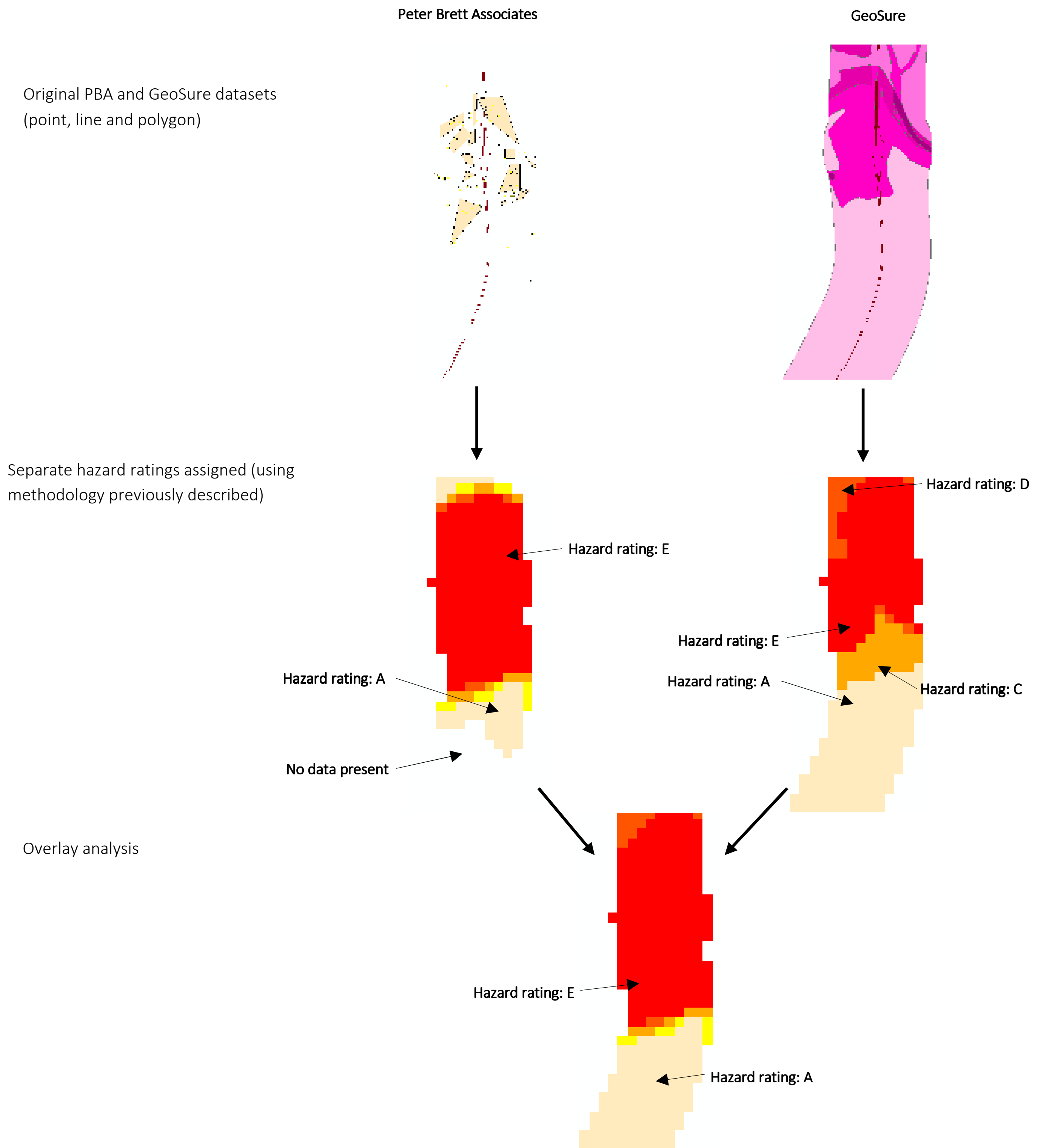


Figure 3 Methodology used to combine the BGS GeoSure and PBA natural cavity datasets

The Result

The result of the analysis is a nationwide dissolution features hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into five categories (A to E). A summary of the Dissolution Features Hazard Rating categories can be seen in Table 3.

Table 3 Summary of Dissolution Features Hazard Rating banding

Dissolution Features Hazard Rating	Colour	Explanation
A		Soluble rocks are either not thought to be present, or are not prone to dissolution. Dissolution features are unlikely to be present. *and/or* The density of known dissolution features is very low
B		Soluble rocks are present but unlikely to cause problems except under exceptional conditions *and/or* The density of known dissolution features is low
C		Significant soluble rocks are present. Low possibility of localised subsidence or dissolution related-degradation of bedrock occurring naturally, but may be possible in adverse conditions such as high surface or subsurface water flow. *and/or* The density of known dissolution features is medium
D		Very significant soluble rocks are present with a moderate possibility of localised natural subsidence or dissolution-related degradation of bedrock, especially in adverse conditions such as concentrated surface or subsurface water flow. *and/or* The density of known dissolution features is high
E		Very significant soluble rocks are present with a high possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, especially in adverse conditions such as concentrated surface or subsurface water flow *and/or* The density of known dissolution features is very high

NB: The first part of explanation is taken from the BGS GeoSure: Soluble Rocks dataset.
The second part is a relative density of data from the PBA natural cavities dataset.

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for shrink/swell is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard dissolution features poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 4 below.

Table 4 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Dissolution Features Contacts

Detailed site-specific dissolution features information can be obtained by contacting Peter Brett Associates to discuss your area of interest and/or request a bespoke dissolution features report (http://www.peterbrett.com/services/services-directory/land-instability/).

Future Developments

This hazard rating map is a first issue, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Dissolution Features Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Landfill Sites Hazard Rating data description

Introduction

The history of landfill sites across England has left a legacy of hazards in the ground with the potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Landfill Sites Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared.

The map was constructed using the datasets listed in Table 1 below.

Table 1 Summary details of the datasets used in the Landfill Sites Hazard Map

Dataset	Provider	Data Currency
Historic Landfill Sites	Environment Agency	01-07-2016
Authorised Landfill Sites	Environment Agency	01-07-2016

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors.

The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Landfill Sites Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the landfill sites hazard map was created. The extent of the datasets used to form the map was constrained to any polygons that intersected the 1000m corridor centred on the SRN. This corridor was then partitioned into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology. From the centre point of each complete grid square a 500m circular buffer was created. The percentage area of landfill sites intersecting the buffer was calculated and assigned to the grid square at the centre of the buffer (see Figure 1). A hazard band was then allocated.

EA historic and authorised landfill sites

Derived map based on GIS analysis

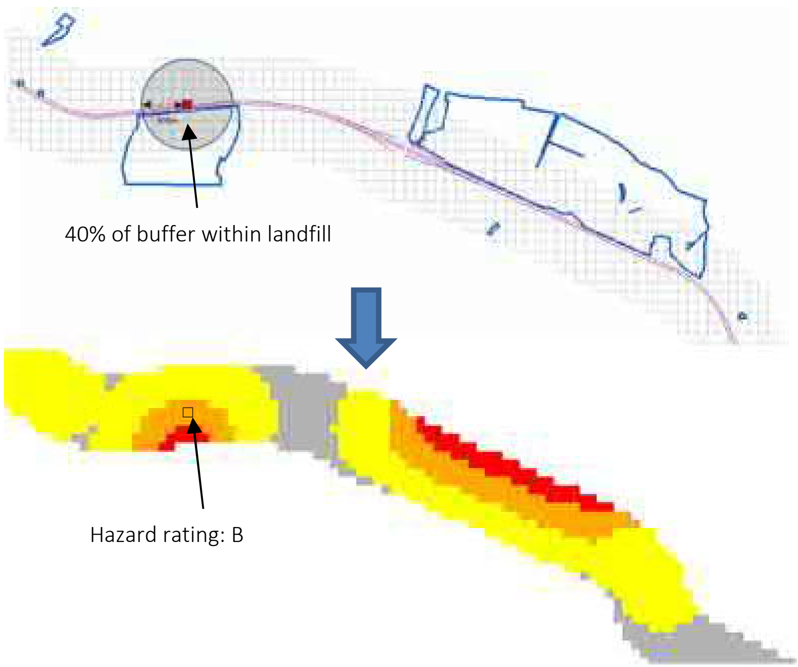


Figure 1 Example of attributing the percentage of landfill sites within 500m to grid squares

The Result

The result of the analysis is a nationwide landfill sites hazard map for a 1000m corridor of the Strategic Road Network with the level of intersection with landfill sites banded into four categories (No data present to C). A summary of the Landfill Sites Hazard Rating categories is detailed in Table 2.

Table 2 Summary of Landfill Sites Hazard Rating banding

Landfill Sites Hazard Rating	Colour	Explanation
No data present	Grey	Outside landfill area
A	Yellow	Low hazard (landfill sites covers 0.1-33% of area within 500m)
B	Orange	Medium hazard (landfill sites covers 33.1-66% of area within 500m)
C	Red	High hazard (landfill sites covers 66.1-100% of area within 500m)

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for landfill sites is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard landfill sites poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 3 below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first issue, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Landfill Sites Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Natural Landslides Hazard Rating data description

Introduction

Natural landslides (particularly soil) across areas of England have significant potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Natural Landslides Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared. The map was constructed using the dataset listed in Table 1 below.

Table 1 Summary details of the dataset used in the Natural Landslides Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Natural Landslides	British Geological Survey	26-07-2014

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors. The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Natural Landslides Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the natural landslides hazard map was created. The extent of the dataset used to form the map was constrained to a 1000m corridor centred on the SRN. This corridor was then partitioned into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology. From the centre point of each complete grid square a 500m circular buffer was created. The maximum landslide GeoSure band within each buffered circle was then assigned to the grid square at the centre of the buffer (see Figure 1).

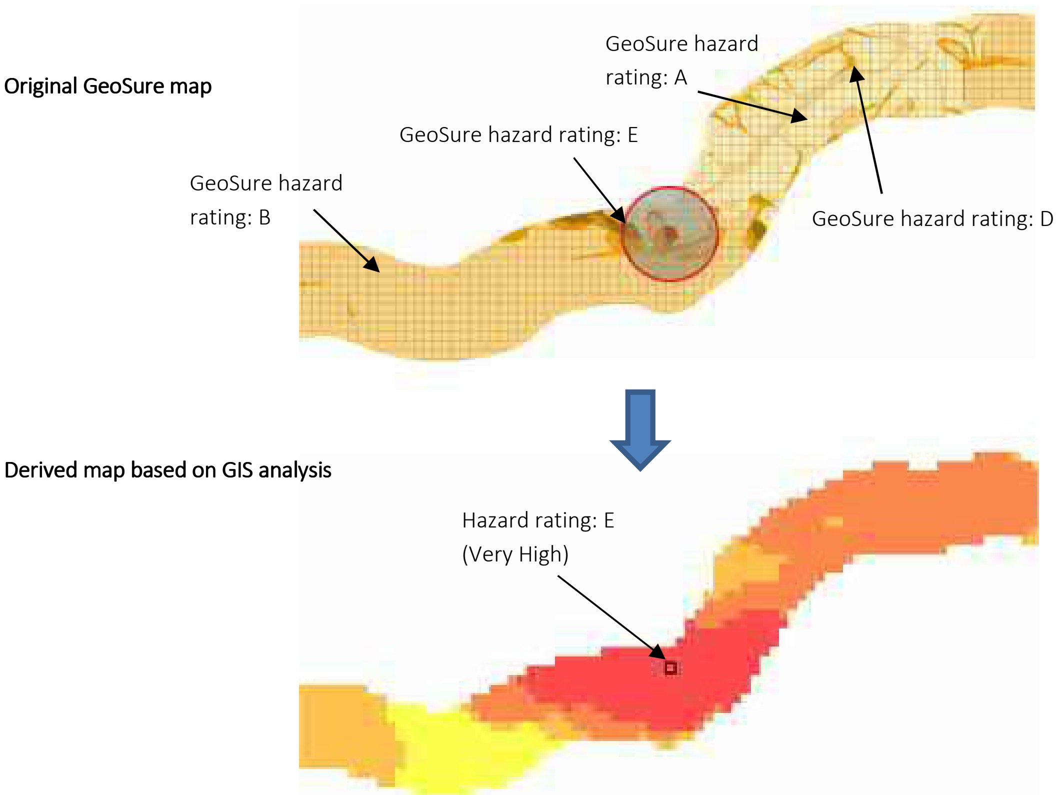


Figure 1 Map methodology shown 500m grid buffer intersecting the BGS GeoSure polygon data within the 1000m SRN corridor

The Result

The result of the analysis is a GeoSure derived nationwide natural landslides hazard map for a 1000m corridor of the Strategic Road Network. A summary of the landslide GeoSure categories is detailed in Table 2 below.

Table 2 Landslide GeoSure bands used for the natural landslides hazard map

Natural Landslides Hazard Rating	Colour	Explanation
A		No indicators for slope instability identified
B		Slope instability problems are unlikely to be present
C		Possibility of slope instability problems after major changes in ground conditions
D		Significant potential for slope instability with relatively small changes in ground conditions
E		Very significant potential for slope instability. Active or inactive landslides may be present.

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Landslides dataset.

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for landslides is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard natural landslides poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 3 below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
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Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first issue, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Natural Landslides Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Non-Coal Mining Hazard Rating data description

Introduction

Mining of natural commodities (excluding coal and other carbon-rich materials) in England has left a legacy of hazards in the ground with the potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Non-Coal Mining Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared.

The map was constructed using the datasets listed in Table 1 below.

Table 1 Summary details of the datasets used in the Non-Coal Mining Hazard Map

Dataset	Provider	Data Currency
BGS Mining Hazard (not including coal)	British Geological Survey	11-03-2016
BGS Recorded Mineral Sites	British Geological Survey	15-05-2016
Inventory of Closed Mining Waste	Environment Agency	01-11-2013
Mining Instability	Ove Arup & Partners	30-06-1998
Man Made Mining Cavities	Peter Brett Associates	17-12-2015
Potential Mining Areas	Wardell Armstrong LLP	08-05-2008

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors.

The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Non-Coal Mining Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the non-coal hazard map was created. The extent of the datasets used to form the map was constrained to a 1000m corridor centred on the SRN. This corridor was then partitioned into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology.

All datasets were aligned to the BGS Mining Hazard (not including coal) bands using engineering judgement (see Table 2).

	Dataset:	Mining Hazard (not including coal)		Recorded mineral sites		Inventory of Closed mining waste facilities	Mining instability	Man made mining cavities	Potential mining areas
Band	Data Source:	British Geological Survey		British Geological Survey		Environment Agency	Ove Arup & Partners	Peter Brett Associates	Wardell Armstrong LLP
	Data Type:	Polygon		Point		Point	Polygon	Point	Polygon
Null	No data present	No intersect with 500m circles		No intersect with 500m circles		No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles	No intersect with 500m circles
A	Very low	Rare							
B	Low	Highly Unlikely							
C	Moderate	Unlikely	Commodity type:						
D	High or inconclusive	Likely	Chalk Firestone/Hearthstone Firestone/Hearthstone/Chalk Flint/Chalk				Evaporites - inconclusive Iron ore - inconclusive Metalliferous - inconclusive Rock - inconclusive		
E	Very high or proven/conclusive	Highly Likely	Fuller's Earth Fuller's Earth/Limestone - Bath Stone Ganister Gypsum Iron Ore Iron Ore (bedded) Iron Ore (bedded)/Limestone - Black Country Iron Ore (non vein) Jet Jet/Vein Mineral Lignite/Chalk Limestone - Bath Stone Limestone - Black Country/Vein Mineral Limestone/Vein Mineral Raddle Sand Sand/Building Stone Sand/Chalk Sandstone Sandstone - Elland Flags Vein Mineral/Ball Clay Vein Mineral/Iron Ore Vein Mineral/Sandstone	Point type: Opencast Tip Underground Underground and opencast	Commodity type: Alabaster Ball Clay Barytes Chalk Chert China Clay China Stone Common Clay and Shale Copper Coprolite Crushed Rock Desulphogypsum Dolomite Fireclay Flint Fuller's Earth Ganister Gypsum Igneous and Metamorphic Rock Iron ore Iron Ore - Hematite Iron Ore - Ironstone Iron Ore - Ochre Iron Pyrite Lead Limestone Marine Sand And Gravel Mineral Not Supplied Oil Sand Sand and Gravel Sandstone Secondary Silica rock Silica Sand Slate Tin Tufa Tungsten Zinc	Mine type: Building minerals Industrial minerals Metalliferous	Evaporites - conclusive Iron ore - conclusive Metalliferous - conclusive Rock - conclusive	Ball Clay Barytes Chalk Clay Copper Coprolite Fireclay Flagstones Flint Fluorspar Fuller's Earth Gypsum Hematite Iron Lead Limestone Mangalese (Should be manganese) Raddle Sandstone Shale Silver Slate Stone Tin Unknown Zinc	Mining of: Clays Copper and associated ores Iron and associations Lead and associations Other metal ores Sedimentary rocks Silver and associated ores Sulphates Tin and associations Tungsten ores Unknown commodities
Not included			Brine	Liquid or gas extraction Power Station Rail Depot Recycled Wharf	Abandoned Mine Methane Coal - Deep Coal - General Coal - Surface Mined Furnace Bottom Ash Lignite Peat Pulverised Fuel Ash Slag (Including Basic Oxygen Slag and Electric Arc Furnace Slags)	Coal	Coal (inconclusive and conclusive)	Liginite (Should be Lignite)	Mining of Carbon Rich Commodities

Table 2 Summary of assigned banding for each non-coal mining dataset

From the centre point of each complete grid square a 500m circular buffer was created. The band for each dataset within the buffer (as per Table 1) was then extracted and the maximum band was assigned to the grid square at the centre of the buffer. This assigned value represents the hazard rating score for that grid square (Figure 1). Note that there has been no consideration of the number of point locations within each buffer, or the amount of overlap with polygon data sets. Any intersection with a record within each of the datasets is recorded within the methodology.

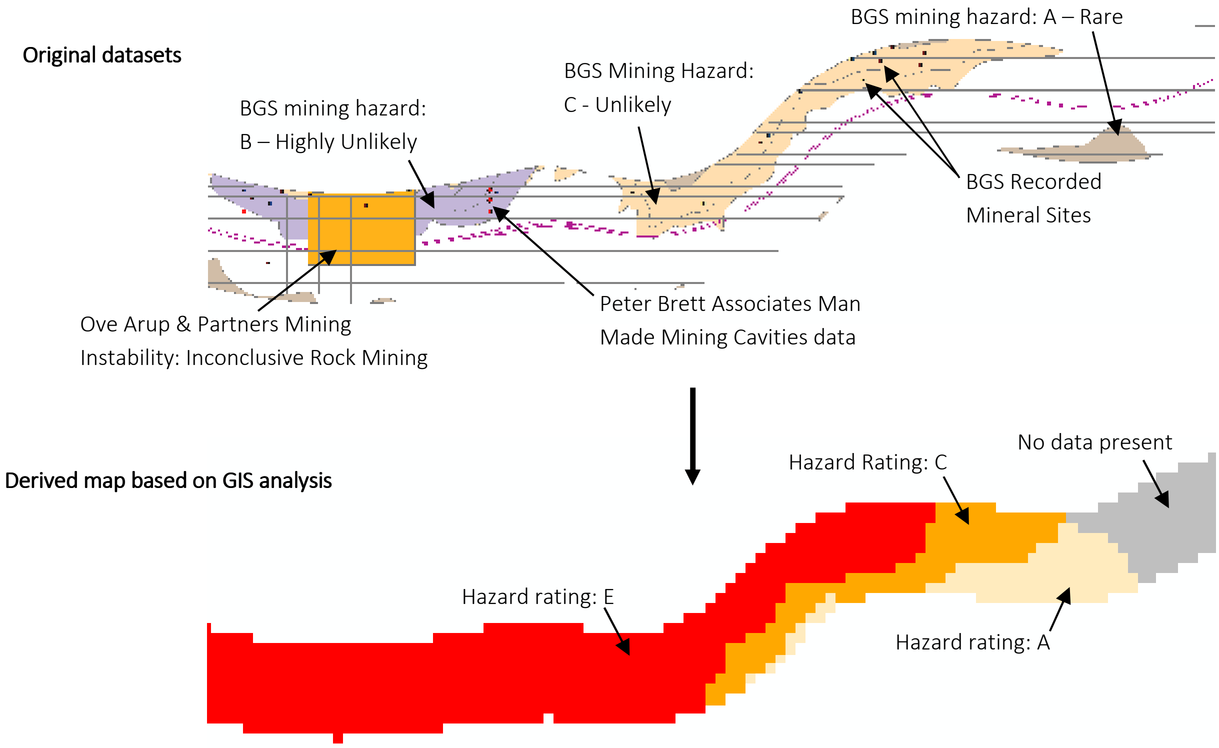


Figure 1 Map methodology showing 500m grid buffer intersecting the non-coal mining datasets and the resulting hazard map

The Result

The result of the analysis is a nationwide non-coal mining hazard map for a 1000m corridor of the Strategic Road Network with the level of hazard banded into six categories (No data present then A to E). A summary of the Non-Coal Hazard Rating categories is detailed in Table 3.

Table 3 Summary of Non-Coal Mining Hazard Rating banding

Non-Coal Mining Hazard Rating	Colour	Explanation
No data present	Grey	No data present
A	Pale cream	Very low
B	Yellow	Low
C	Orange	Moderate
D	Dark orange	High or inconclusive
E	Red	Very high or proven/conclusive

NB: The first part of explanation for Ratings D and E is taken from the BGS Non-coal mining areas of Great Britain dataset. The second part is taken from other non-coal mining datasets (See Table 1).

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for non-coal mining is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard non-coal mining poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 4 below.

Table 4 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first issue, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Non-Coal Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

HAGDMS Shrink/Swell Hazard Rating data description

Introduction

Soils with high shrink/swell potential occur across England which may have some potential to impact on the operation of the Strategic Road Network managed by Highways England. To respond to this hazard, a high level Shrink/Swell Hazard Rating map for a 1000m corridor centred around the Strategic Road Network has been prepared. The map was constructed using the dataset listed in Table 1 below.

Table 1 Summary details of the dataset used in the Natural Landslides Hazard Map

Dataset	Provider	Data Currency
BGS GeoSure: Shrink-Swell	British Geological Survey	26-07-2014

It is intended to be used as an initial high level hazard awareness map. It **does not** replace the need for consideration of hazards through the existing HD22/08 and HD41/15 processes of HE, the need to discuss issues with HE geotechnical advisors. The map is part of a suite of hazard maps to assess ground-related hazards to the Strategic Road Network. It can be accessed on the HAGDMS (HE Geotechnical Data Management System) and on HAGIS (HE Geographical Information System). On HAGDMS it can be viewed in the map legend at the following location: Geotechnics > Hazards > Shrink/Swell Hazard Rating. The map is visible at a scale less than 1:500,000.

Methodology

This section covers the GIS methodology by which the shrink/swell hazard map was created. The extent of the datasets used to form the map, were constrained to a 1000m corridor centred on the SRN. This corridor was split into a 100m x 100m grid and complete grid squares within the corridor were used as the foundation of the GIS methodology. From the centre point of each complete grid square a 500m circular buffer was created. The maximum shrink/swell GeoSure band within each buffered circle was then assigned to the grid square at the centre of the buffer (see Figure 1).

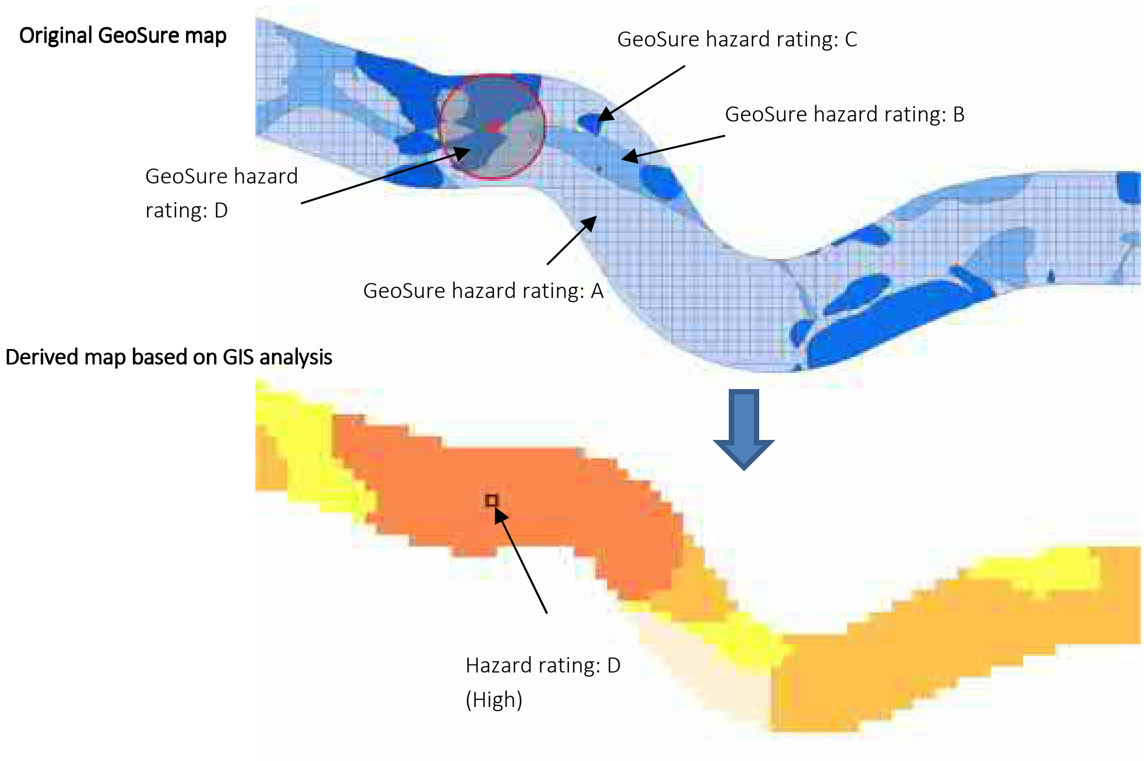


Figure 1 Map methodology showing 500m grid buffer intersecting the BGS GeoSure polygon data within the 1000m SRN corridor

The Result

The result of the analysis is a GeoSure derived nationwide shrink/swell hazard map for a 1000m corridor of the Strategic Road Network. A summary of the shrink/swell GeoSure categories is detailed in Table 2 below.

Table 2 Summary of shrink/swell GeoSure bands used for the shrink/swell hazard map

Shrink/Swell Hazard Rating	Colour	Explanation
A		Ground conditions predominantly non-plastic
B		Ground conditions predominantly low plasticity
C		Ground conditions predominantly medium plasticity
D		Ground conditions predominantly high plasticity
E		Ground conditions predominantly very high plasticity

NB: Hazard ratings and explanations are taken from the BGS GeoSure: Shrink-Swell dataset.

It should be noted that the ratings provided are qualitative and **are not** equivalent to hazard ratings in other maps (i.e. a 'B' rating for shrink/swell is not the equivalent of a 'B' for dissolution features).

Highways England Contacts

To obtain further advice on the hazard shrink/swell poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Table 3 below.

Table 3 Contact details of HE Area Geotechnical Advisors

Highways England Geotechnical Advisor	Area of responsibility	E-mail
Mark Shaw	Areas 1,2,6,8	mark.shaw@highwaysengland.co.uk
Jan Marsden	Areas 3,4	jan.marsden@highwaysengland.co.uk
Raphael Lung	DBFO Area 5	raphael.lung@highwaysengland.co.uk
Dennis Sakufiwa	Areas 7,9	dennis.sakufiwa@highwaysengland.co.uk
Richard Shires	Areas 10,13	richard.shires@highwaysengland.co.uk
Lesley Benton	Area 12	lesley.benton@highwaysengland.co.uk
Shaun Clarke	Area 14	shaun.clarke@highwaysengland.co.uk

Future Developments

This hazard rating map is a first issue, it is envisaged further developments will be carried out and new revisions produced.

Comments or feedback on the Shrink/Swell Hazard Rating map would be welcomed, and should be addressed to the Project Sponsor within Highways England:

David Patterson

david.patterson@highwaysengland.co.uk

G. Resilience guidance notes

Aggressive / Corrosive Soil and Groundwater Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Aggressive / Corrosive Soil and Groundwater to impact the safety and performance of the Strategic Road Network (SRN). At this time there is no Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS) hazard rating map to accompany this note. This note should support effective management of the Aggressive / Corrosive Soil and Groundwater risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Aggressive / Corrosive Soil and Groundwater hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Aggressive / Corrosive Soil and Groundwater
Part III: provides further background information specific to Aggressive / Corrosive Soil and Groundwater, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Aggressive / Corrosive Soil and Groundwater risks

The potential presence of naturally occurring aggressive soil and/or groundwater introduces a chemical hazard to the SRN as materials, structural elements and assets can become corroded or damaged. The background of Aggressive / Corrosive Soil and Groundwater and its impact on the SRN is summarised in Part III.

Concrete that has been affected by sulfate attack

The risk presented by the distribution of Aggressive / Corrosive Soil and Groundwater is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Aggressive / Corrosive Soil and Groundwater and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Aggressive / Corrosive Soil and Groundwater related risk. Consideration of the hazard posed by Aggressive / Corrosive Soil and Groundwater to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 Aggressive / Corrosive Soil and Groundwater mapping

At this time there is no HE specific Aggressive / Corrosive Soil and Groundwater Hazard Rating map available on the Strategic Road Network. However, available to purchase from the BGS are maps of:

- 'Sulfate and sulfide potential'
- 'Corrosivity (ferrous)'

as part of the suite of the 'BGSCivils' engineering properties datasets product. (See Part III).

3.0 Further advice

To obtain further advice on the hazard Aggressive / Corrosive Soil and Groundwater poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Dealing with Aggressive / Corrosive Soil and Groundwater to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Aggressive / Corrosive Soil and Groundwater beneath the SRN, and these present different risks to the network:

- Deterioration and corrosion of the materials of SRN assets or structural components (e.g. foundations, earthwork materials, pavement, steelwork, pipes and utilities) – also see other hazard guidance where there is reliance on the effectiveness of intervention works (measures such as soil nailing) that are potentially affected by corrosion.
- Ground heave – caused by the growth of pyrite/thaumasite crystals

2. Consider potential external triggers of the hazard event

There may be little or no warning of an Aggressive / Corrosive Soil and Groundwater-related event, particularly with buried features, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of an Aggressive / Corrosive Soil and Groundwater hazard event:

- Development of a corrosive or aggressive environment and the proximity of vulnerable materials – such as sulfides combined with anaerobic conditions adjacent to buried concrete containing dolomitic limestone aggregate
- Development of an oxidation environment of pyrite/thaumasite

In general, the development of environments needed for the above chemical environments relates to the mobility of the naturally occurring minerals and the presence of water. The following events may therefore be considered exacerbating triggers:

- A surface flooding event
- Leakage from nearby water mains, sewerage or drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

To undertake a qualitative assessment of the likelihood of deterioration and corrosion of the SRN, the following factors are relevant:

(A) The likely presence of Aggressive / Corrosive Soil and Groundwater

- Maps of naturally occurring sulfates/sulfides or thaumasite, corrosive ground (currently not available on HAGDMS)
- Local evidence of corrosion / chemical-related attack
- History of corrosion / chemical-related repair maintenance
- Winter maintenance policy and use of salting or de-icing technologies
- Proximity to mine workings (and mine water), landfill or a coastal environment

(B) Presence of any mitigating / exacerbating features

- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness (including age degradation) and completeness of any investigations and measures undertaken to identify and treat adverse chemical environments, and selection of appropriate materials for resistance to chemical attack
- Use of pyritic material as fill – thereby introducing the risk of potential sulfate crystal growth

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

As most chemical attack on construction materials requires a degree of moisture, these are predominantly considerations of transport mechanisms of potentially aggressive groundwater to the site / level of vulnerable SRN assets or components:

- Recent / forecast heavy or prolonged rainfall
- A history of flooding (including groundwater flooding)
- Blocked / insufficient / absent drainage
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding

An understanding of the likelihood of an Aggressive / Corrosive Soil and Groundwater hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. At this time there is no HAGDMS information package for this hazard, but there are British Geological Survey (BGS) databases available for purchase (see Part III for further details). Regional strategies are available in some areas.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate and extent of corrosion or deterioration and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The type of SRN element affected – the safety impact of a corrosion-induced element failure will depend on the role of that element and the consequences of its failure. Corrosion of a soil nail may lead to a sudden slope failure, whereas corrosion of barrier fencing would have minimal to no safety impact.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Aggressive / Corrosive Soil and Groundwater presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event. Note that evidence may be from inspections undertaken for other assets e.g. Structures and Pavement Surveys.
- **Response and recovery:** To respond to a potentially unexpected hazard event, development of response plans is recommended for areas of known Aggressive / Corrosive Soil and Groundwater risk. Response plans should include:
    1. (i.) Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    2. (ii.) Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    3. (iii.) Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    4. (iv.) Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Aggressive / Corrosive Soil and Groundwater in England

1.0 Soil and groundwater chemistry

Particular soil / groundwater chemistries can be 'aggressive' to materials used within the SRN environment, causing corrosion or deterioration. In recognition of this, the BGS has available for purchase within its suite of geological engineering properties maps (the 'BGSCivils bundle') the following:

- The 'Corrosivity (ferrous)' map
- 'The Sulfate / Sulfide potential' map

Concrete corrosion – subjected to sulfate (thaumasite) attack

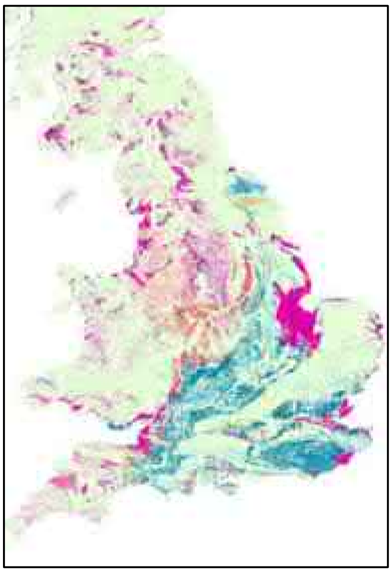
For iron / steel, the Corrosivity (ferrous) map (see below, left) presents the results of a national assessment to categorise which geographical areas would be more prone to corrosion. The assessment is based on a scoring methodology of the following combination of factors: water content, redox status, pH, sulfates/sulfides and electrical resistivity.

For concrete / cement, the presence of Sulfate/Sulfide formations map (see below, middle) indicates the likely presence of sulfur in soil and rocks which can give rise to aggressive ground conditions and associated concrete expansion and softening. It has been standard in the UK for over sixty years to design concrete to be resistant to these conventional attacks, however in the late 1980s deterioration of concrete due to thaumasite sulfate attack was also identified. This can occur in cases where anaerobic conditions are combined with concrete that contains carbonates e.g. calcium carbonate aggregates or bicarbonate dissolved in groundwater.

A further hazard linked to sulfur-rich minerals such as pyrite (iron sulfide) is crystal growth. In aerobic conditions, sulfides can oxidise to form sulfates and the associated volume expansion can become significant – sulfate crystals can push up and through concrete as they grow.

The maps shown are potentially useful to indicate where there is a particular soil / groundwater chemistry hazard along the SRN. However, these maps are not currently available on HAGDMS, but can be purchased from the BGS either nationally or for specified local areas

Corrosivity: Blue shows a higher likelihood of corrosive conditions. Source: BGS Civils Database: Corrosivity (Ferrous)



Sulfate/Sulfide potential. Source: BGS Civils Database: Presence of Sulfate/Sulfide formations

2.0 Aggressive / Corrosive Soil and Groundwater and the Strategic Road Network

The hazard posed by Aggressive / Corrosive Soil and Groundwater arises from the potential for:

- corrosion, degradation or damage to SRN assets and structural elements by potentially aggressive soil / groundwater (corrosion of iron and steel, or sulfate/sulfide attack on concrete or earthwork materials). The subsequent impact upon the SRN depends on what components are affected.

- Ground heave, caused by sulfate crystal growth, that can damage pavement and ground slabs of structures

These hazards could be present due to:

- unidentified, and hence untreated chemical exposure
- inadequate treatment methods (compared to current practice/guidance), which may correlate to the approximate date of treatment
- the treatment measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. surface flooding) or have reached the end of their serviceable life

Whether or not the presence of aggressive soil and groundwater constitutes a hazard to the SRN depends on a variety of factors including the chemical types present, their concentration, availability and scope for replenishment and the extent of exposure.

As with all geotechnical assets, it is reasonable to assume that design and construction after the introduction of HD22 in 1992 would have been subject to a greater level of assurance and rigour, including measures to minimise chemical degradation. In particular, in 1998 the first Interim Advice Note (IAN 15/98) was published to address the issue of thaumasite attack. As of 2014, this is addressed within Series 1700 (Structural Concrete) of the MCHW. These dates may indicate approximate likelihoods of how well mitigated that particular risk would have been at time of construction.

3.0 Key references and further information

British Geological Survey, User Guide for the BGS Soil Chemistry Data for Environmental Assessments - Open Report OR/14/031, 2014

British Geological Survey, Environmental chemistry, www.bgs.ac.uk, 2017

British Geological Survey, Corrosivity (ferrous), www.bgs.ac.uk, 2017

Building Research Establishment, Special Digest 1:2005 Concrete in Aggressive Ground, 2005

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Brine Extraction Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Brine Extraction to impact the safety and performance of the Strategic Road Network (SRN). Together with the Brine Extraction Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Brine Extraction risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Brine Extraction hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Brine Extraction
Part III: provides further background information specific to Brine Extraction, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Brine Extraction risks

Areas where rock-salt (halite) is present and Brine Extraction has been undertaken are susceptible to potentially wide-reaching ground instabilities such as the formation of crown holes or subsidence. The legacy of Brine Extraction and its impact on the SRN is summarised in Part III.

Witton Flashes, Northwich – subsidence lakes formed after brine extraction caused the collapse of a salt mine. Source: Cheshire Brine Subsidence Compensation Board

For hazards associated with natural salt dissolution refer to the Dissolutions Features hazard guidance note. For hazard events associated with dry salt mining – for example 'pillar and stall' salt mines – see the Non-Coal Mining hazard guidance note

The risk presented by the legacy of Brine Extraction is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Brine Extraction and related risks should have been investigated and mitigated appropriate to the Standards or Advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

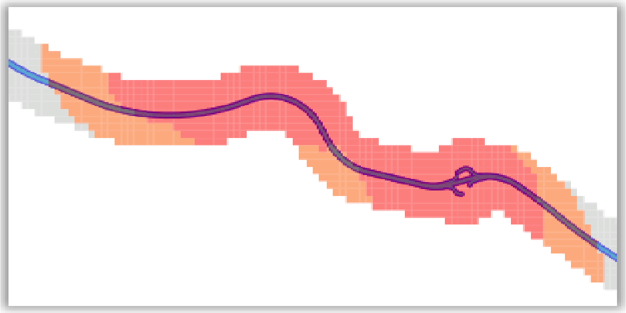
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' (Class 2 features) including those a potential Brine Extraction related risk. Consideration of the hazard posed by Brine Extraction to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Brine Extraction Hazard Rating Map



Section of the Brine Extraction Hazard Rating map

An HE specific Brine Extraction Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Brine Extraction obtained over several years from organisations including British Geological Survey, Cheshire Brine Compensation Board, Wardell Armstrong LLP and Johnson Poole & Bloomer. The derivation of this map is explained in detail in a technical note available on the HA GDMS download page: *HAGDMS Brine Extraction Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Brine Extraction along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Brine Extraction poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Using the Brine Extraction Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Brine Extraction along the SRN, and these present different risks to the network:

- Collapse of the ground (sudden) – forming for example crown holes*
- Settlement / Subsidence associated with deep / near surface cavities (could be either sudden or progressive)

2. Consider potential external triggers of the hazard event

There may be little or no warning of a Brine Extraction-related event, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Brine Extraction hazard event:

- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Change in surface water flow and changes in drainage
- A surface flooding event
- Leakage from improperly sealed boreholes penetrating, or in proximity to, an extraction cavity
- Leakage from nearby water mains, sewerage or drainage

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

* A crown hole is a subsidence depression feature resulting from human activity, unlike sinkholes that form by natural processes and mechanisms.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Brine Extraction Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Brine Extraction features, compared to the rest of the network. The Brine Extraction hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a collapse or related subsidence, the following factors are relevant:

(A) The likely presence of Brine Extraction

- Refer to the Brine Extraction Hazard Rating map

(B) Inherent properties, characteristics, and legacy issues

- Type of Brine Extraction – whether controlled or uncontrolled wild brining
- Age, location and date of cessation – provides an indication of the methods used to control the extraction flows and formation of cavities, and their stabilisation upon decommissioning
- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness and completeness of any investigations and measures undertaken to stabilise cavities (e.g. flooding with brine)

(C) Presence of any mitigating / exacerbating features

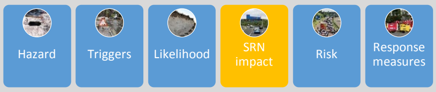
- A hydrogeological regime allowing fresh water flow through extraction cavities – enabling further salt dissolution
- Brine springs – indication of further natural salt dissolution

(D) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- A history of flooding (refer also to the Groundwater Flooding hazard guidance note)
- Recent prolonged rainfall
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding
- Blocked / insufficient / absent drainage
- Recent / planned excavation or deep drilling – such as ground investigation boreholes
- Groundwater extraction / dewatering, soakaways, irrigation

An understanding of the likelihood of a Brine Extraction hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records† demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.

† The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- The size of the potential failure – a large feature presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of feature size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Brine Extraction presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive investigation and mitigation. There should be early engagement with Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring and mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.

- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Brine Extraction risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III The legacy of Brine Extraction in England

1.0 History, legacy and distribution

The following is taken from Cooper (1999) summarising the history, legacy and distribution of brine extraction in Britain:

Rock salt exists, mainly within Permian and Triassic strata from which it has a long history of exploitation. The main salt fields lie within Cheshire, Staffordshire, coastal Yorkshire, Worcestershire, Teesside and parts of Northern Ireland.

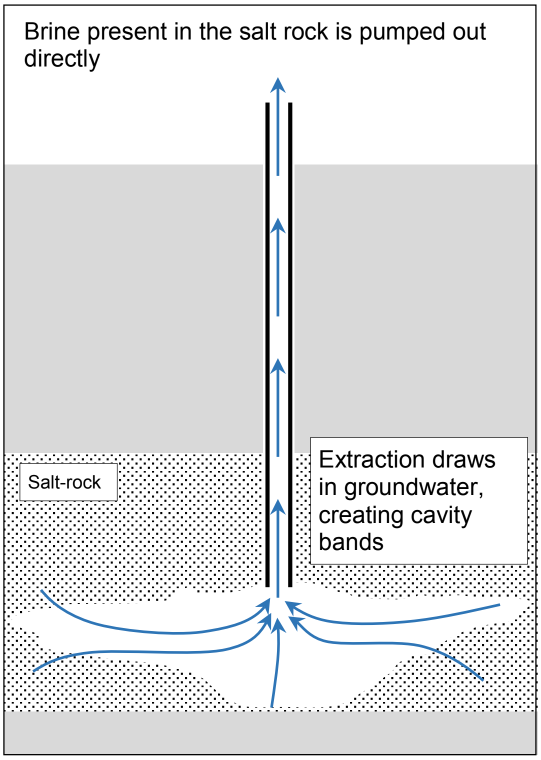
British salt extraction dates back to Roman times, and possibly before. Place names ending in 'wich' or 'wych' indicate natural brine springs, and it is around such springs that the towns of Droitwich, Nantwich, Northwich and Middlewich developed in Cheshire and West Midlands.

Salt and brine have been extracted using various methods since Roman times. In the late 19th and early 20th centuries the salt deposits were worked by two main methods: traditional mining and wild brine solution mining. Most of the conventional [dry] *mining was in 'pillar and stall' mines with networks of tunnels commonly separated by insubstantial salt pillars. Such mines were often flooded on abandonment.*

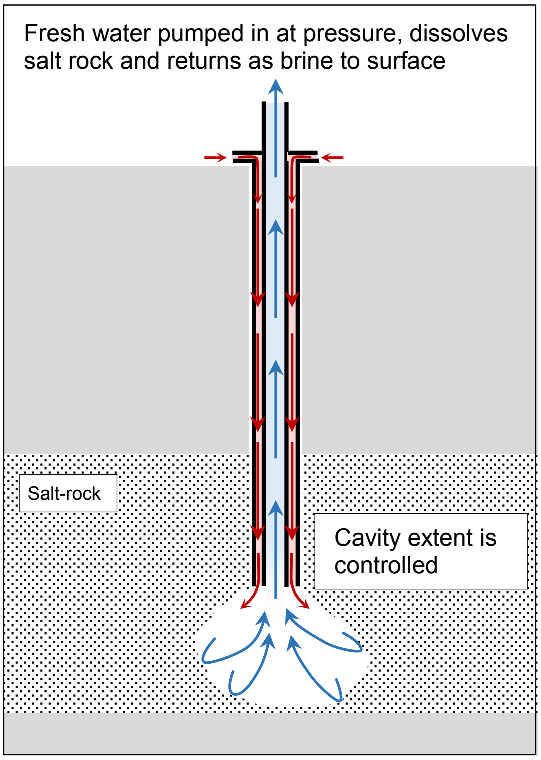
Wild, or uncontrolled, brine solution mining involved sinking boreholes and shafts down to the wet rock-salt surface and pumping the brine out [see figure: top]*. This wild brine method induced the flow of brine towards the extraction boreholes and linear subsidence belts spread out from the boreholes. In some situations, mine owners even pumped the brine from flooded pillar and stall mines* [leading to further subsidence and a weakening of the mines as the pillars dissolved]*.*

Around Northwich and Middlewich, the resulting subsidence was catastrophic. Subsidence caused new lakes to appear on daily basis, and 'meres' or 'flashes' many hundreds of meters across were formed by collapse after salt extraction. The subsidence in Cheshire was so severe that an Act of Parliament [the 1891 Brine Pumping Act, and subsequent 1952 and 1964 acts]*, was passed placing a levy on all local salt extraction. This levy, which funded building reconstruction and compensation schemes, is still made, but collected at a lower rate to reflect the reduced risk from modern extraction.*

Modern salt extraction now takes place mainly in deep dry pillar and stall mines, or by controlled brine extraction [see figure: bottom] *leaving large deep underground chambers that are left flooded and filled with saturated brine* [to prevent further dissolution]*.* ***Current planning procedures ensure that the modern exploitation lies largely outside of urban areas so that risks are considerably reduced.*** *However, there is still a legacy of problems related to the salt deposits. These include old salt mines that have not yet*



Uncontrolled brine extraction



Controlled brine extraction

collapsed, and compressible or unstable collapsed ground over former salt mines. In addition, natural salt dissolution at the rockhead interface, between the salt deposits and the overlying superficial deposits, can cause ground engineering problems and aggressive saline groundwater.

In addition to the legacy as described above, with the cessation of natural brine pumping, brine springs are becoming re-established which would lead to further creation and expansion of cavities, and potentially instability and subsidence. Dissolution caused by fresh water passing through the salt-rock is addressed by the Dissolution Features hazard guidance note.

The Brine Compensation Board is a body that was established to compensate owners for damage to land and buildings as a result of salt mining / brine extraction subsidence. The body is purely financial and is not responsible for undertaking any mitigation works, and does not provide consulting services. It is also of note that the Coal Authority, whose powers were extended in 2011 to enable support to non-coal mine related issues, has no statutory obligations with respect to Brine Extraction, but may offer commercial consulting and response services.

2.0 Brine Extraction and the Strategic Road Network

The hazard posed by Brine Extraction can be considered to arise from the potential for voids and beneath the Highways England estate to either collapse suddenly and catastrophically, or to cause subsidence. The risk of collapse / subsidence could be present due to:

- unidentified, and hence unmanaged, former Brine Extraction sites
- inadequate stabilisation methods (compared to current practice/guidance), which may correlate to the approximate date of implementation
- the stabilisation measures employed have deteriorated subsequently due to changes unforeseen since the time of treatment (e.g. age degradation, chemical, groundwater or surface flooding) or have reached the end of their serviceable life

Salt-rock (halite) is itself a very strong rock with little jointing (cracks within the rock mass that could form planes of weakness). Consequently it is relatively insensitive to changes in loading, and the key hazard is based on the stability of the void and overlying deposits.

This note focuses on the potential for voids and subsidence directly as a result of Brine Extraction, but the potential for other hazards relating to soluble rocks and non-coal mining should not be ignored (refer to the corresponding hazard guidance notes).

3.0 Key references and further information

Brine Extraction Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Brine Extraction Hazard Rating data description, 2017

Cooper, A., (1999) ‘Salt Subsidence: Geohazard legacy and future problem?’, Ground Stability, Issue 14, P14.

Cheshire Brine Subsidence Compensation Board website: www.cheshirebrine.com

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Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE’s Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Coal Mining Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Coal Mining to impact the safety and performance of the Strategic Road Network (SRN). Together with the Coal Mining Hazard Rating map and corresponding hazard assessment note on HE Geotechnical Data Management System / HE Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Coal Mining risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Coal Mining hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Coal Mining
Part III: provides further background information specific to Coal Mining, its relevance to the SRN, and key sources of reference

In addition, a detailed commentary on the history, geography and hazards presented by Coal Mining in the UK can be found in in the CIRIA publication SP32 (1984) which is currently being updated (see www.ciria.org for further details).

Part I Highways England's approach to managing Coal Mining risks

Coal has been mined in the United Kingdom since Roman times (or even earlier), and has left a legacy of past activity across a large proportion of Highways England's network. The history of coal mining and its impact on the SRN is summarised in Part III.

An old coal pit near Bradford. Source: www.geograph.org.uk

The risk presented by the legacy of Coal Mining is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Coal Mining and related risks should have been investigated and mitigated appropriate to the Standards or Advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

1.0 Current ground risk management requirements:

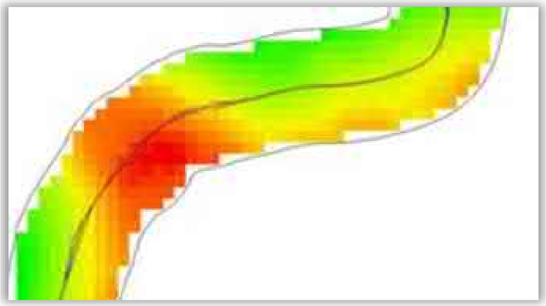
HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' (Class 2 features) including those a potential Coal Mining related risk. Consideration of the hazard posed by Coal Mining to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The

GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Coal Mining Hazard Rating Map



Section of the Coal Mining Hazard Rating map

An HE specific Coal Mining Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Coal Mining obtained over several years from the Coal Authority. The derivation of this map is explained in detail in a technical note available on the HA GDMS download page: *HAGDMS Coal Mining Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Coal Mining along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Coal Mining poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Your geotechnical advisor may also wish to contact the Coal Authority who have a statutory responsibility for managing the effects of past coal mining. They can be contacted on 0345 7626848 (Mon-Thurs: 0845-1700, Fri: 0845-1630) or at thecoalauthority@coal.gov.uk. The organisation also has a 24 hour number for reporting public safety hazards and incidents associated with coal mining and it can be reached at 01623 646 333.

Part II Using the Coal Mining Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Coal Mining beneath the SRN, and these present different risks to the network:

- Collapse of a *very* shallow mine working (may be either sudden or progressive)
- Collapse of a shallow (approx. 0m to 30m depth) mine working (may be either sudden or progressive)
- Subsidence/subsidence related to presence of deep mines (typically progressive)
- The collapse of a mine shaft or mine adit (typically sudden)
- The appearance of mine water on or adjacent to the SRN

2. Consider potential external triggers of the hazard event

There may be little or no warning of a mine-related failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Coal Mining hazard event:

- A surface flooding event
- Change in surface water flow and changes in drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Erosion
- Change in surcharging or loading

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Coal Mining Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Coal Mining, compared to the rest of the network. The Coal Mining hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a mining collapse or related subsidence, the following factors are relevant:

(A) The likely presence of Coal Mining

- Refer to the Coal Mining Hazard Rating map
- Refer to area-specific report records held on HAGDMS
- Indicators that mines would not be captured by records and therefore not included within the Coal Mining Hazard Rating map:
  - Areas of mining pre-1872 – i.e. prior to regulatory registration of mines
  - Areas where mining records are incomplete – such that low confidence that all mines are captured

(B) Inherent properties, characteristics, and legacy issues

- Age of mining / method of extraction / date of abandonment – indicative of inherent stability and original measures to make the mine safe
- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness (including age degradation) and completeness of any investigations and measures undertaken to manage the mine

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

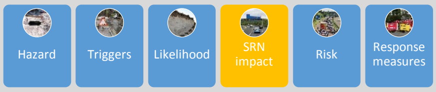
These may be considered by the type of triggering mechanism:

- Weakening of the mine structure, as may be indicated by:
  - A history of flooding (refer also to the Groundwater Flooding hazard guidance note)
  - Recent / forecast heavy or prolonged rainfall
  - Blocked / insufficient / absent drainage
  - Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding
  - Groundwater extraction / dewatering, soakaways, irrigation
- Destabilisation through additional loading, as may be indicated by:
  - Traffic loading (volume) increases
  - Construction / demolition activities, excavations, and temporary plant
  - New structures and permanent loads

An understanding of the likelihood of a Coal Mining hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – a large failure presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of failure size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Coal Mining presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England, service providers and the Coal Authority.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

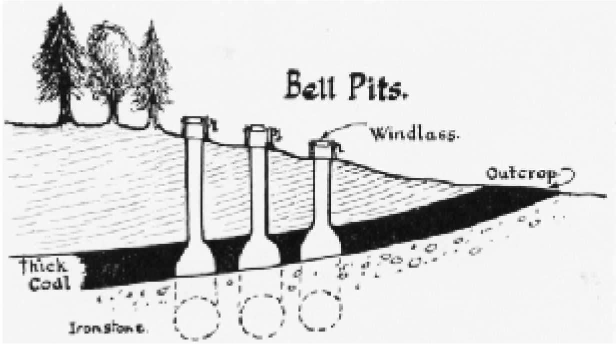
- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.

- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Coal Mining risk. Response plans should include:
  i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
  ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
  iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
  iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III The legacy of Coal Mining in England

1.0 History

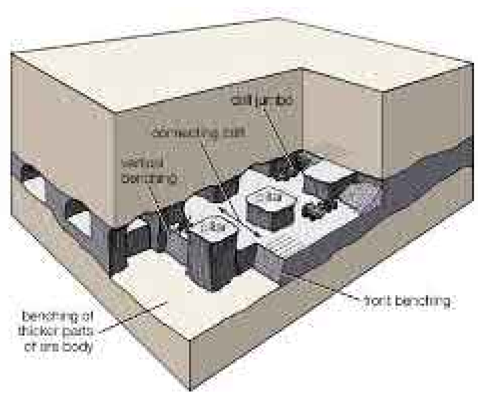
Coal mining has been carried out throughout England. Arup (1990) reports that mining was particularly extensive and covered over 20% of the county area in: the West Midlands (Staffordshire, Warwickshire and West Midlands); East Midlands (Derbyshire, Nottinghamshire); North West England (Greater Manchester, Lancashire, Merseyside); Yorkshire (South and West Yorkshire); and North England (Durham, Northumberland, Tyne & Wear).



Coal mining with Bell Pits.
Source: HD Poole, The Blackcountryman Magazine

Early mining was opportunistic, extracting coal from surface outcrops. As these sources were exhausted mining began to move underground, following seams in simple drift mines (adit mines) and shallow excavations known as 'bell pits'. Coal mining increased significantly during the industrial revolution, and rose to a peak of production in 1913, before declining slowly to the 1960s and rapidly declining thereafter as North Sea oil and gas began to replace coal as the main energy source for the UK.

With increasing production, the means of excavation became more mechanised and took place at greater scales, and to ever increasing depths. Excavation by pillar and stall techniques (where some coal is left in place as pillars to support the roof above) allowed large volumes of coal to be removed. This was largely replaced by longwall mining, where full extraction of the available coal is carried out, and the ground behind the mining is allowed to collapse. In addition, advances in plant and extraction techniques allowed large scale opencast mining to be undertaken for coal near to the surface. Following a long decline, the last deep coal mines in England closed in 2015. Opencast mining continues, but at much smaller scales than previously.



Pillar and stall mining.
Source: © Encyclopaedia Britannica

In 1872 the Coal Mines Regulation Act of Parliament was passed that included the requirement of mine owners to deposit plans with the state after mine closure. The Coal Authority is the current government body that maintains the historical records. Mines that were closed prior to 1872 may well be absent from the records, or incomplete.

The Coal Authority also has the wider responsibility of managing the effects of past coal mining, including safety and mine water pollution. It is within the Coal Authority's remit to respond to any emerging coal hazard and is financially responsible for making mines safe and compensating for any damage caused. **The Coal Authority must be informed immediately should a hazard be identified.**

2.0 Coal Mining and the Strategic Road Network

The hazard posed can be considered to arise from the potential for:

- voids beneath the Highways England estate to either collapse suddenly and catastrophically or to cause subsidence. These voids could be present due to:
  - unidentified, and hence unmanaged, mines or mine shafts (often older mines or mine entries are more difficult to locate)
  - inadequate stabilisation methods (compared to current practice/guidance), which may correlate to the approximate date of works

  - the measures employed have deteriorated subsequently due to changes since the time of works (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life
  - undetected fissuring in certain surface rocks resulting from ground strains caused by longwall mining at depth
- abandoned coal mine workings to produce dangerous emissions, such as mine gas or polluting mine waters. For further details see the Aggressive / Corrosive Soil and Groundwater Guidance Note.

This note focuses on the potential for voids and subsidence, but the potential for release of hazardous gas or polluted waters or other contaminants should not be ignored – also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note.

The type of hazard that the presence of these mines presents to the SRN is further significantly influenced by the age and depth of the mines. Broadly speaking, the hazard type can be grouped as follows:

- **Outcrop and very shallow mine workings:** (typically within 50m of the seam outcrop, although the location of the outcrop and exact distance to mine workings are both uncertain), exploited via open excavations, bell pits and perhaps local underground workings. These can date back to Roman times or earlier. Workings may be unconsolidated, and there is a greater likelihood of unrecorded workings and mine entries. There is also a risk of spontaneous combustion from some seams if exposed to air.
- **Shallow (typically less than 30m deep) mines:** These will be a mix of recorded and unrecorded mine workings, mined using a variety of support solutions. These typically date from the early 1800s to the early 1900s. The hazard to the SRN is again due to the likelihood of unconsolidated mine workings or entries that could allow voids to migrate to the surface and affect highway infrastructure. The risk increases if the mine workings or entries are unrecorded and therefore have not been assessed and mitigated in the past. Previously identified workings may have had mitigation works undertaken (to mine workings and entries). However, these may become compromised where measures were incomplete, have deteriorated and/or are influenced by external factors (e.g. water infiltration) representing a further hazard to the SRN.
- **Deep mining:** Largely undertaken during the 20th century using longwall techniques. In deeper workings the likelihood of a hazard of void migration from mine workings is significantly lower due to higher overburden pressures and the method of mining used. Ground settlement also generally occurs contemporaneously with the workings and is therefore less likely once mining has ceased. This may change should underground coal mining resume in the future. The hazard is therefore primarily from mine entries. The available information on deep mining is typically of better quality (hence reduced uncertainty), but hazards exist where the shaft de-commissioning did not adequately mitigate risks appropriate to a location beneath or close to SRN. Moreover, shaft de-commissioning methods are susceptible to similar compromises as identified for mitigation measures on shallow workings.

At the time of mine abandonment, works such as capping of shafts and backfilling of workings may have been carried out, depending on when the mine was closed. Equally, these activities may have been undertaken at a later stage, for example at the time of construction of the SRN. Historical reports on HAGDMS may provide further information on this and any changes since construction. It is reasonable to assume that if during SRN works a mine was known to be present, there will have been investigation and stabilisation measures undertaken, with the following broad observations:

- Mine stabilisation undertaken before the publication of the CIRIA SP32 (1984) may have been less effective and more ad hoc.
- Mine stabilisation measures implemented before 1984 have now been in place for over 30 years and therefore carry uncertainties about the deterioration due to ageing or other external factors.
- Between 1984 and the first publication of the DMRB in 1992, there should have been an improvement in the investigation and stabilisation of mines based on the level of guidance available.
- Since the publication of the DMRB in 1992, (particularly HD22, management of geotechnical risks) there has been less uncertainty, better records on HAGDMS, and more effective and consistent investigation and stabilisation.

- Where stabilisation has been undertaken in the last 10 years, and has experienced less age-related deterioration the above-mentioned issues of deterioration of stabilisation are less significant, and records should be easily accessible to confirm adequate investigation and stabilisation.

3.0 Key references and further information

Coal Mining Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Coal Mining Hazard Rating data description, 2017

Arup, Review of Mining Instability in Great Britain, 1990

CIRIA SP32 Construction over abandoned mine workings, 1984

CIRIA C758 Abandoned mine workings – publication pending

The Coal Authority, www.gov.uk/government/organisations/the-coal-authority

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Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Compressible / Collapsible Ground Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Compressible / Collapsible Ground to impact the safety and performance of the Strategic Road Network (SRN). Together with the Compressible / Collapsible Ground Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Compressible / Collapsible Ground risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Compressible / Collapsible Ground hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Compressible / Collapsible Ground
Part III: provides further background information specific to Compressible / Collapsible Ground, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Compressible / Collapsible Ground risks

Compressible ground refers to very soft materials (e.g. peat, alluvium, laminated clays, wind-blown deposits, lightly compacted backfills) that are susceptible to large and progressive settlement when loaded or when the groundwater changes.

Collapsible ground refers to deposits that when weakened through saturation and loaded can undergo rapid volume reduction (its micro-structure crushes).

The background of Compressible / Collapsible Ground and its impact on the SRN is summarised in Part III.

Compressible soil (peat)

The risk presented by Compressible / Collapsible Ground is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Compressible / Collapsible Ground and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

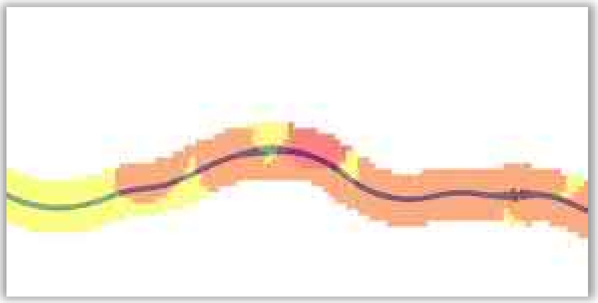
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Compressible / Collapsible Ground related risk. Consideration of the hazard posed by Compressible / Collapsible Ground to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Compressible / Collapsible Ground Hazard Rating Map



Section of the Compressible / Collapsible Ground Hazard Rating map

An HE specific Compressible / Collapsible Ground Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Compressible / Collapsible Ground obtained from the British Geological Survey (BGS). The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Compressible / Collapsible Ground Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Compressible / Collapsible Ground along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Compressible / Collapsible Ground poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

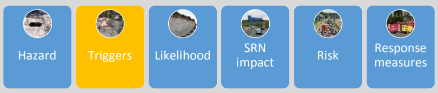
Part II Using the Compressible / Collapsible Ground Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Compressible / Collapsible Ground along the SRN, and these present different risks to the network:

- Collapse of the ground (sudden)
- Subsidence (due to loss of support) or settlement (in response to loading) which can be progressive: they may occur relatively rapidly and also continue long-term



2. Consider potential external triggers of the hazard event

Whilst subsidence of compressible ground is normally progressive with signs of onset, there may be little or no warning when collapsible ground fails. If specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Compressible / Collapsible Ground hazard event:

- Change in surcharging or loading
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Leakage from nearby water mains, sewerage or drainage
- Water ingress from service duct backfill which may act as a water reservoir
- Vibration, e.g. due to traffic, construction activities
- A surface flooding event

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Compressible / Collapsible Ground Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Compressible / Collapsible Ground, compared to the rest of the network. The Compressible / Collapsible Ground hazard rating is not directly comparable to hazard ratings derived for other hazard types. The map gives a separate hazard rating for Compressible and Collapsible, with the colour scale indicating the highest hazard rating of the two.

To undertake a qualitative assessment of the likelihood of either a collapse or subsidence, the following factors are relevant:

(A) The likely presence of Compressible / Collapsible Ground

- Refer to the Compressible / Collapsible Ground Hazard Rating map
- Geotechnical records or reports (see HAGDMS) of continuing long term settlement and repeat settlement mitigation on the SRN – usually caused by an inadequate understanding / mitigation at time of construction of initial and / or long-term settlement mechanisms

(B) Presence of any mitigating / exacerbating features

- Age of the SRN / loading asset – rate of compression decreases over time, unless an additional load is applied.
- Presence and effectiveness (condition) of any ground improvement measures implemented to mitigate Compressible / Collapsible Ground. Such measures may include but are not limited to: ground removal and replacement, pre-construction load surcharging, vertical drainage, compensation grouting or ground modification
- Presence of any mitigating / exacerbating features

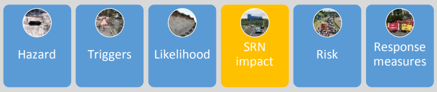
(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur
These may be considered by the type of triggering mechanism:

- Ground loading potentially beyond a stable limit
  - Construction, new structures, or temporary plant (primarily an issue with improvement schemes)
  - Traffic loading (volume) increases
- Water-related destabilisation (saturation):
  - Recent / forecast heavy or prolonged rainfall
  - Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements and may leak
  - Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)
  - Blocked / insufficient / absent drainage

An understanding of the likelihood of a Compressible / Collapsible Ground hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



4. Consider the potential impact on the safety and/or performance of the SRN

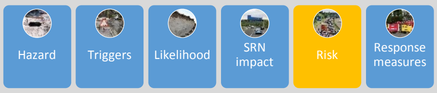
A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- The variable distribution and thickness of Compressible / Collapsible Ground – differential movements and settlement lead to greater damage to pavement, assets and structure compared to uniform settlement. Also see factor relating to SRN foundation level below.
- The size of the potential failure – a large failure presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of failure size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement shows early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- The foundation level of SRN pavement / asset / feature – where support is provided from beneath any Compressible / Collapsible Ground through the using of piling, there is limited sensitivity to this hazard.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.



5. What is the risk (considering likelihood and impact) that Compressible / Collapsible Ground presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Compressible / Collapsible Ground risk. Response plans should include:
    - i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    - ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    - iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    - iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

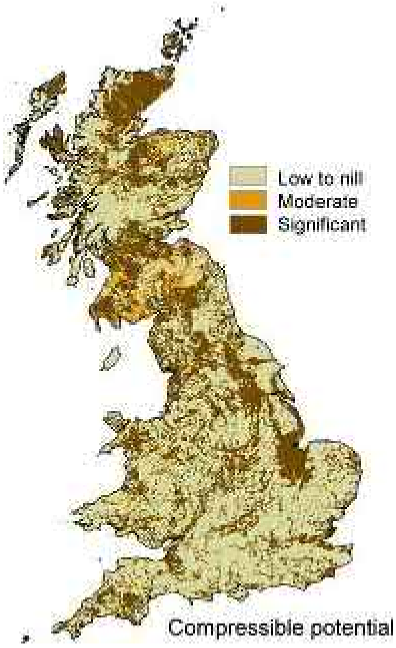
Part III An overview of Compressible / Collapsible Ground in England

1.0 What is Compressible / Collapsible Ground

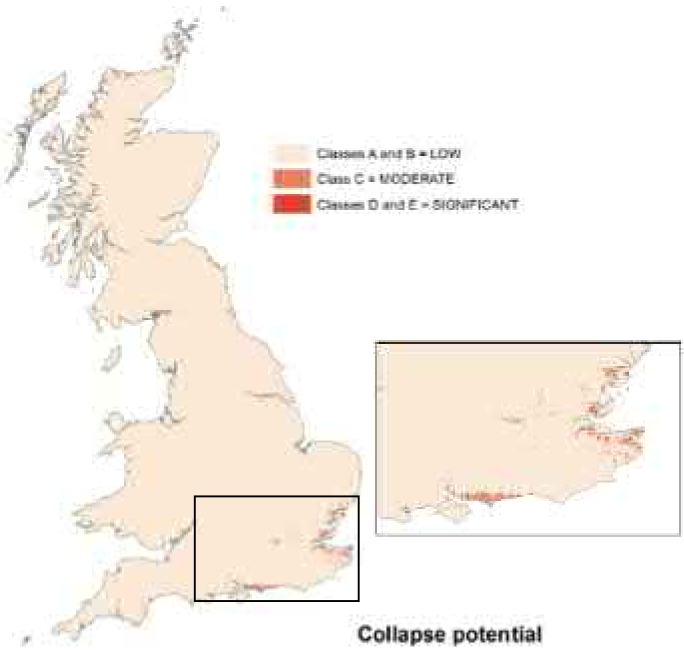
'Compressible ground' refers to mainly superficial deposits that are extremely soft (such as peat, alluvium and laminated clays) and susceptible to large progressive settlement when loaded or when the groundwater level changes. In these materials, they undergo initial rapid settlement (e.g. during or shortly after construction) followed by a slower rate of continued settlement that may extended for years after construction. Compressible deposits are found across the UK – see figure below (left).

Subsidence on a road over compressible soil in Lincolnshire
© http://www.geograph.org.uk/photo/5322777

'Collapsible ground', on the other hand, refers to metastable material that has a micro-structure of solid particles arranged at a relatively large spacing and which are bonded together by clay minerals (comparable to a dried sponge). Upon saturation it loses its strength as the water breaks the clay mineral bonds, and an applied load can then crush the internal structure, resulting in a sudden mass collapse. In the UK, collapsible ground is not widespread and the only susceptible rock type that has been identified is loessic silt (also described as brickearth), a wind-blown deposit. Being a transported sediment, brickearth may be present as an infill material within naturally occurring cavities – also see guidance note for Dissolution Features. Collapsible deposits are most likely to be encountered in parts of southern England (there might be other un-identified deposits) – see figure below (right).



Distribution and classification of compressible ground (Source: BGS)



Distribution and classification of collapsible ground (Source: BGS)

2.0 Compressible / Collapsible Ground and the Strategic Road Network

The hazard posed by Compressible / Collapsible Ground arises from the potential for the presence of compressible or collapsible grounds beneath the Highways England estate to either collapse suddenly and catastrophically or to cause subsidence/settlement. These hazards could be present due to:

- unidentified, and hence unmanaged, compressible / collapsible ground
- inadequate treatment methods (compared to current practice/guidance), which may correlate to the approximate date of treatment. In particular, secondary settlement (long-term settlement under constant load) may not have been understood / addressed at time of construction.
- the treatment measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life
- changes made to the operation of the SRN or on land adjacent to the SRN causing changes in the magnitude and the distribution of the loads.

The hazard that the presence of these types of ground represents to the SRN is further significantly influenced by the groundwater level and the geology of the area.

Compressible ground is often readily identifiable on site, and, where present beneath the existing road network the risk, would most likely already be known following construction or subsequent maintenance work.

For collapsible deposits, as with all geotechnical assets, design and construction after the introduction of HD22 in 1992 would have been subject to a greater level of assurance and rigour, and collapsible deposits should have been identified and considered prior to construction.

3.0 Key references and further information

Compressible / Collapsible Ground Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Compressible / Collapsible Ground Hazard Rating data description, 2017

British Geological Survey, Collapsible Deposits, www.bgs.ac.uk, 2017

British Geological Survey, Compressible Ground, www.bgs.ac.uk, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE’s Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Dissolution Features Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Dissolution Features to impact the safety and performance of the Strategic Road Network (SRN). Together with the Dissolution Features Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Dissolution Features risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Dissolution Features hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Dissolution Features
Part III: provides further background information specific to Dissolution Features, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Dissolution Features risks

Dissolution Features occur when water passes through soluble rocks such as limestone, chalk, dolomite, gypsum or halite and creates voids or cavities. An overview of Dissolution Features and its impact on the SRN is summarised in Part III.

Subsidence sinkhole due to a dissolution feature in chalk, located on the M2

For hazards associated with mining of rock-salt, refer to the Brine Extraction and Non-Coal Mining hazard guidance notes.

The risk presented by Dissolution Features is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Dissolution Features and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

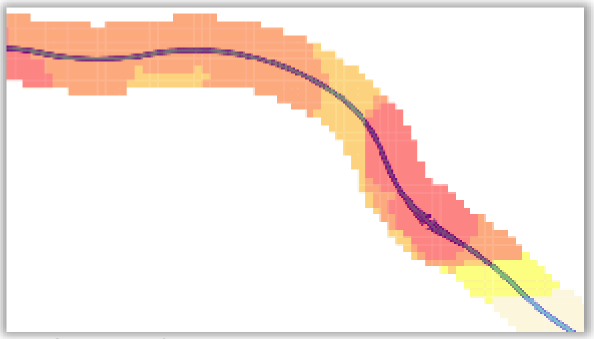
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Dissolution Features related risk. Consideration of the hazard posed by Dissolution Features to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Dissolution Features Hazard Rating Map



Section of the Dissolution Features Hazard Rating map

An HE specific Dissolution Features Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Dissolution Features obtained over several years from organisations including British Geological Survey, and Peter Brett Associates. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Dissolution Features Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Dissolution Features along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Dissolution Features poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Using the Dissolution Features Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Dissolution Features beneath the SRN, and these present different risks to the network:

- Collapse of dissolution feature void (sudden)
- Subsidence associated with near surface cavities or washout of the infill within a dissolution feature (could be either sudden or progressive)

2. Consider potential external triggers of the hazard event

There may be little or no warning of a dissolution-related failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Dissolution Features hazard event:

- A surface flooding event
- Change in surface water flow and changes in drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Heavy or sustained rainfall
- Change in surcharging or loading
- Vibration, e.g. due to traffic, construction activities
- Leakage from nearby water mains, sewerage or drainage

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Dissolution Features Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Dissolution Features, compared to the rest of the network. The Dissolution Features hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a cavity collapse or related subsidence, the following factors are relevant:

(A) The likely presence of Dissolution Features

- Refer to the Dissolution Features Hazard Rating map
- Locations of high water flow (groundwater or surface water) – more mobile water has a higher dissolution action on susceptible rock types.
- Groundwater aggressivity – where groundwater is acidic it has a greater dissolution action on susceptible rock types.

(B) Inherent properties and characteristics

- Geology of the underlying ground – is a key factor in understanding susceptibility to dissolution features. Geology gives an indication of rock solubility.

(C) Presence of any mitigating / exacerbating features

- Depth to any potential Dissolution Feature – shallow cavities are generally more sensitive to loads applied at the surface compared to deeper cavities. Deeper cavities are less likely to have been mitigated during construction of the SRN.
- Type and compressibility of any fill material within dissolution pipes – affects the potential formation of sinkholes / differential movement at the surface.
- Presence and effectiveness (condition) of any ground improvement measures implemented to mitigate cavities or inhibit the flow of water through potential Dissolution Features
- Presence, condition and effectiveness of drainage systems – also soakaways could inadvertently direct water towards soluble rock

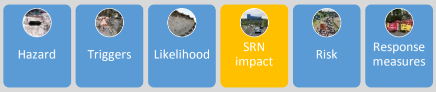
(D) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

These may be considered by the type of triggering mechanism:

- Destabilisation through cavity growth, as may be indicated by:
  - Ongoing dissolution action from existing groundwater flows (i.e. requiring no separate triggering event)
  - Recent prolonged rainfall
  - A history of flooding (also refer to the Groundwater Flooding hazard guidance note)
  - Blocked / insufficient / absent / inappropriate drainage. Also, water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding
  - Groundwater extraction / dewatering, soakaways, irrigation
- Destabilisation through additional loading, as may be indicated by:
  - Traffic loading (volume) increases – causes an increase in stress cycling and vibration
  - Construction / demolition activities, excavations, and temporary plant
  - New structures and permanent loads

An understanding of the likelihood of a cavity collapse or related subsidence occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where

HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – a large feature presents a much higher safety risk to potentially many more users of the network than a small collapse would. Estimation of feature size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Dissolution Features presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

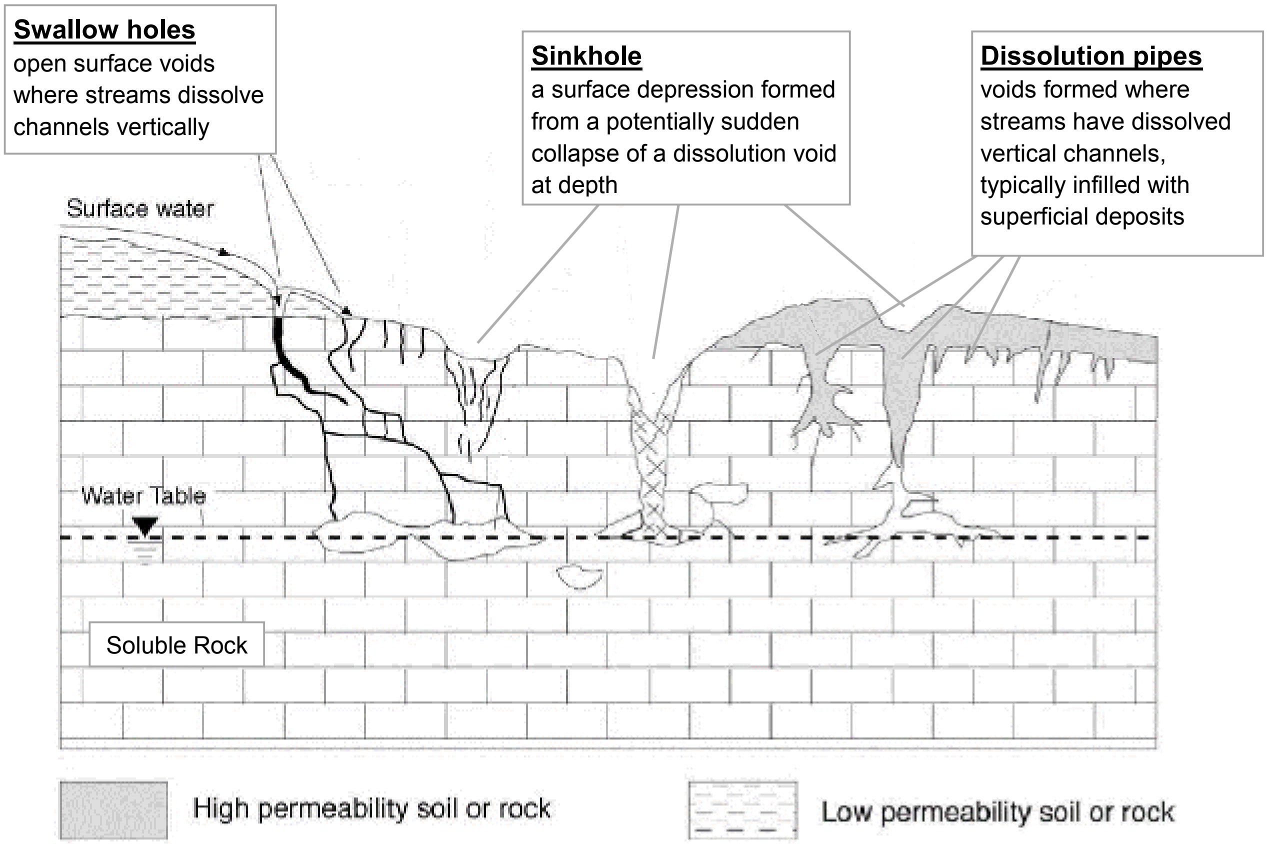
High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Dissolution Features risk. Response plans should include:
    - i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    - ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England’s suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    - iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    - iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Dissolution Features in England

1.0 Formation of Dissolution Features

There are three key types of dissolution features: sinkholes, dissolution pipes, and swallow holes as illustrated in the figure below.



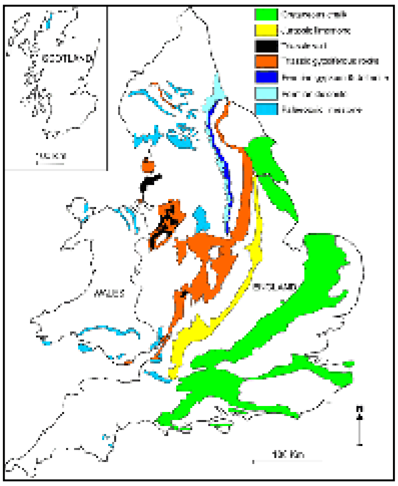
Schematic of common dissolution features in chalk (adapted from CIRIA C574)

- **Sinkholes** are closed depressions that are typically cone, bowl or pipe shaped in cross section, and circular or elliptical in plan. They can appear suddenly or progressively.
- **Dissolution pipes** are cone or pipe shaped in cross section and are typically partially or completely infilled with overlying deposits. It is not usually possible to see them from the ground surface. The hazard associated with dissolution pipes is a localised area of lower strength with greater potential for subsidence. These can become voids again if the groundwater flow in the area changes e.g. due to changes in drainage.
- **Swallow holes** are a surface feature where a void 'swallows' a surface stream. These are likely to have been remediated on the SRN but if in the locality of an asset it could indicate potential future dissolution feature issues.

2.0 Distribution across England

The distribution and type of soluble rock geology varies across the country, with mainly chalk in the south east and east, limestone and gypsiferous rocks in the midlands, rock-salt in the east and limestone in the north, as shown by geological mapping. To confirm the presence of soluble rocks at a particular site a geotechnical investigation using trial pits or boreholes and subsequent testing of samples can be carried out. It may also be possible to identify this hazard using geophysical methods. Some structures in a known high risk area may have monitoring equipment installed. Often the exact location of features may only become apparent when construction is underway but plans are usually in place to deal with features when found.

A cavity due to dissolution on A2 (Highways England)



Distribution of soluble rocks in England and Wales (BGS)

3.0 Dissolution Features and the Strategic Road Network

The hazard posed by Dissolution Features arises from the potential for voids beneath the Highways England estate to either collapse suddenly and catastrophically, or to cause subsidence. These voids could be present due to:

- unidentified, and hence mitigated, dissolution features
- new solution features formed since the construction of SRN
- inadequate mitigation methods (compared to current practice/guidance), which may correlate to the approximate date of works
- the mitigation measures employed have deteriorated subsequently due to changes since the time of treatment (e.g. ageing, chemical, groundwater or surface flooding) or have reached the end of their serviceable life
- inadequate, inappropriate or poorly maintained drainage

This note focuses on the potential for voids and subsidence, but the potential for other effects such as rapid groundwater flow should not be ignored.

The type of hazard that the presence of these voids presents to the SRN is further significantly influenced by geology. Broadly speaking, the hazard type can be grouped as follows:

- **Chalk:** this is the most widespread of rocks prone to dissolution in England. Features resulting from the dissolution prone nature of the rock include dry valleys, permanent or seasonal springs, caves, sinkholes and dissolution pipes. Issues arising from dissolution of chalk include cavities, irregular rockhead and localised subsidence related to infilled cavities. Areas that are particularly vulnerable include those where there is material such as gravel or sand overlying the chalk, which can leave the cavities at a few metres depth.
- **Limestone**: this rock consists of calcium carbonate. The longest cave systems in England are associated with limestone, including in the Yorkshire Dales the Peak District and the Mendip Hills. The typical problem associated with limestone is sinkholes. Cavities formed in limestone can be larger than in other geologies due to the generally higher strength of limestone.
- **Dolomite** deposits pose similar risks to limestone, and areas where it is present can be susceptible to sinkholes.
- **Gypsum** is a highly soluble rock. Cave systems can form over a much shorter timescale (<100 years) than cave systems in other geologies and can cause subsidence over large scale areas. A case in Ripon in Yorkshire reported that a van-sized block ($3m^3$) of gypsum that fell from a cliff into the river below dissolved within just 18 months.

- **Rock-salt** – salt can dissolve quickly, leading to salt springs such as those prevalent in Cheshire. These can then become centres for brine extraction - see the Brine Extraction guidance note. Issues are common at the interface between the rock-salt and overlying strata, where fresh water has the potential to dissolve salt from the rock it comes in to contact with, leading to dissolution.

4.0 Key references and further information

Dissolution Features Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Dissolution Features Hazard Rating data description, 2017

CIRIA, C574 Engineering in Chalk, 2002.

British Geological Survey, Soluble Rocks, www.bgs.ac.uk, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE’s Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Engineered Rock Slopes Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential for Engineered Rock Slopes to impact the safety and performance of the Strategic Road Network (SRN). Together with the Slope Hazard Rating map and Rock Slope Hazard Index map, plus corresponding hazard assessment notes on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the products support effective management of the Engineered Rock Slopes risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Engineered Rock Slopes hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Engineered Rock Slopes
Part III: provides further background information specific to Engineered Rock Slopes, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Engineered Rock Slopes risks

Areas adjacent or in close proximity to Engineered Rock Slopes are susceptible to impacts caused by the failure of the slopes. Engineered Rock Slopes have usually been formed by cuts through surface rock formations. The background of Engineered Rock Slopes and their impact on the SRN is summarised in Part III.

A separate hazard guidance note is available for Engineered Soil Slopes.

The risk presented by Engineered Rock Slopes is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Engineered Rock Slopes and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.
- A Rock Slope Hazard Index (RSHI) evaluation was carried out in 2011 for Engineered Rock Slopes nationally. The assessment represents the most detailed assessment of rock slope condition to-date.

Rockfall on M6, Lune Gorge, 1997. Source: HAGDMS

Rockfall damages road sign. Source: Unknown

1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Engineered Rock Slopes related risk. Consideration of the hazard posed by Engineered Rock Slopes to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England rock hazard maps

Section of the Slope Hazard Rating map (2017)

Two HE specific hazard maps have been produced:

- the Slope Hazard Rating map* – includes both rock and soil slopes for a generalised slope assessment
- the Rock Slope Hazard Index map – based directly on the specialist Rock Slope Hazard Index assessment (RSHI)

These maps can be accessed on HAGDMS and their derivation is explained in detail in the hazard assessment notes available on the HA GDMS download page.

The maps are intended as high level hazard awareness maps only. **They do not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Engineered Rock Slopes along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Engineered Rock Slopes poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

* The latest version of the Slope Hazard Rating map should be used. Superseded versions will continue to be available on HAGDMS for reference only.

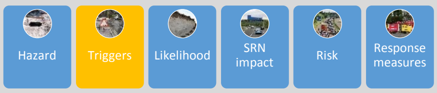
Part II Using the Slope Hazard Rating map and the Rock Slopes Hazard Index map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard ‘event’ can be defined as ‘*the event that could occur due to the presence of the hazard*’. The following are different hazard events related to the presence of Engineered Rock Slopes along the SRN, and these present different risks to the network:

- Incursion of rockfall / vegetation mantle material onto carriageway – potential obstruction and damage
- Subsidence of part or all of a carriageway, structure or other asset
- Impact damage to structures and above-surface SRN asset due to rockfall / falling slope debris



2. Consider potential external triggers of the hazard event

There may be little or no warning immediately prior to an Engineered Rock Slopes failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of an Engineered Rock Slopes hazard event:

- Freeze-thaw cycles
- Weathering and erosion
- Degradation / loss in performance of any stabilisation measures such as rock bolts and anchors (also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note)
- Vegetation issues e.g. root action or wind forces on trees anchored to the slope

Note that the above weather related triggers may be exacerbated by climate change.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Slope Hazard Rating map and the RSHI categories given on the Rock Slope Hazard Index map are not absolute indicators of the likelihood of a hazard event occurring, but a relative condition indicator of the slopes, compared to the rest of the network. It should also be noted that the slope hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of a rockfall, the following factors are relevant:

(A) The inherent likelihood of an Engineered Rock Slope failure

- Refer to the Slope Hazard Rating map and the Rock Slope Hazard Index map
- Evidence of movement (e.g. monitoring or any evidence recorded in Geotechnical Asset Database – GAD, or in Geotechnical Asset Management Plans for known rockfall areas)
- Poor slope condition / low inherent stability as indicated a geotechnical slope examination (HD 41/15) or Rock Slope Hazard Index (RSHI) – for slope-specific indication of condition
- Age of slope - supplementary condition indicator where a geotechnical examination is not available or not recent

(B) Presence of any mitigating / exacerbating features

- Presence, condition and effectiveness of slope improvement / stabilisation measures – as installed during construction / maintenance of the SRN or by third parties
- Size (height / volume) of slope and distance of slope from the SRN – to indicate the context and proximity of the carriageway relative to a potential landslide, and the likelihood that a rockfall would interact with the road network

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- Observed / forecast periods freezing temperatures
- Observed / forecast heavy or prolonged rainfall
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, such that they may leak
- Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)
- Blocked / insufficient / absent drainage

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible. Note that rock slope failures are considered to represent a greater likelihood of impacting on safety due to the common location above and adjacent to the highway. At a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- The size of the potential failure – a large failure presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of failure size requires local consideration and expert input.

- The location of the potential failure, and slope geometry – the slope angle, height affects and hardness of material the lateral horizontal travel of debris. Where material reaches a main running lane it presents both higher safety impact, and higher performance impact than one that affects a hard shoulder / remote from the carriageway.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.
- The serviceability and effectiveness of any control measures such as nets and ditches to limit the consequence of any falling material.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure (where rock slope supports the SRN)
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Engineered Rock Slopes presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England, service providers and land owners (where the slope is outside the SRN boundary).

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Engineered Rock Slopes risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Identification of third party land owners where the slope is located outside the SRN boundary, or that will be potentially impacted should an HE-owned slope fail. Also procedures for gaining access where required to third party land.

iii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).

iv. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.

v. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS. Note that the origin of rock slope hazards may be on 3rd party land.

Part III An overview of Engineered Rock Slopes in England

1.0 Engineered Rock Slopes

Engineered rock slopes along the road network are typically formed by cutting through surface or near surface rock formations. The rock cut is either self-stable against a design factor of safety or is stabilised through specific measures such as tension rock anchors or spraying shotcrete on the surface. This earthwork type is distributed along the SRN but primarily concentrated in the northern part of the country.

Rock Face south of Jeffrey's Mount, M6. Source: HAGDMS

HAGDMS presents two maps relevant to the hazard posed by Engineered Rock Slops:

- the Slope Hazard Rating map
- the Rock Slope Hazard Index map

The Slope Hazard Rating map is based on an analysis that has been carried out into the performance of the major geotechnical assets of Highways England, both rock and soil. The latest available version of this map should be used as it will reflect the most current analysis; however, HAGDMS also retains previous versions of the map for historical reference only (e.g. the 2014 map is available but is superseded.) The derivation of the Slope Hazard Rating is based on the slope shape and geology. This is explained in detail in the Slope Hazard Rating data description note on HAGDMS.

The Rock Slope Hazard Index map presents the results of a Rock Slope Hazard Index (RSHI) examination carried out in 2011, as described in the accompanying data description note. The RSHI examination is a detailed inspection of a rock slope and can provide a good indication of slope condition. It has been used previously by HE to aid geotechnical engineers assess the appropriate level of resilience management and maintenance regime. However, the examinations were carried out as a one-off exercise only, and so there is a risk that the results no longer reflect current condition. Therefore, the Rock Slope Hazard Index map may be used as a guide to support an assessment of condition and likelihood of failure, alongside the Slope Hazard Rating map that is based on more recent but less detailed slope data.

2.0 Engineered Rock Slopes and the Strategic Road Network

The hazard posed can be considered to arise from the potential for Engineered Rock Slopes failure on the Highways England estate with the potential to impede the highway, damage assets or cause injury. These hazards could be present due to:

- inadequate design and/or stabilisation methods (compared to current practice/guidance), which may correlate to the age of the slope
- the stabilisation measures or barriers employed have deteriorated since works were undertaken (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life

The risk that the presence of Engineered Rock Slopes that are susceptible to failures presents to the SRN is directly related to the size of the failure (e.g. size of the fallen rock) and its proximity to the network.

3.0 Key references and further information

Rock Slope Hazard Index map, 2017, HAGDMS / HAGIS

HAGDMS Rock Slope Hazard Index data description, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Engineered Soil Slopes Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential for Engineered Soil Slopes to impact the safety and performance of the Strategic Road Network (SRN). Together with the Slopes Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Engineered Soil Slopes risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Engineered Soil Slopes hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Engineered Soil Slopes
Part III: provides further background information specific to Engineered Soil Slopes, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Engineered Soil Slopes risks

Areas adjacent to or in close proximity to Engineered Soil Slopes are susceptible to impacts caused by the failure of the slopes. Engineered Soil Slopes have usually been formed by excavation in the natural topography (cuttings) or constructed by placing fill to form embankments. The background of Engineered Soil Slopes and their impact on the SRN is summarised in Part III.

For hazards associated with Natural Landslides or Engineered Rock Slopes see the corresponding guidance notes.

The risk presented by the failure of Engineered Soil Slopes is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

Soil slope failure, M25 (Highways England)

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Engineered Soil Slopes would have been designed according to the standards of the time to be sufficiently stable for their design life. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Engineered Soil Slopes related risk. Consideration of the hazard posed by Engineered Soil Slopes to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Slopes Hazard Rating Map

Section of the Slopes Hazard Rating map

An HE specific Slopes Hazard Rating has been prepared which includes both soil and rock slopes (however a separate rock slope–only map will shortly be available to accompany the Engineered Rock Slopes hazard guidance note). The Slopes Hazard Rating map can be accessed on HAGDMS*. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Slopes Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Engineered Soil Slopes along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Engineered Soil Slopes poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

* The latest version of the Slopes Hazard Rating map should be used. Superseded versions will continue to be available on HAGDMS for reference only.

Part II Using the Slopes Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Engineered Soil Slopes adjacent to (cutting slopes) or beneath (embankments) the SRN, and these present different risks to the network:

- Incursion of material onto carriageway (cuttings) – potential obstruction and damage
- Subsidence of part or all of a carriageway, structure or other asset (embankments) – could be sudden or progressive
- Impact damage to structures and above-surface SRN asset due to a moving soil mass / debris
- Instability and damage to sub-surface SRN assets including foundations and buried utilities (e.g. drainage, power, communications)

2. Consider potential external triggers of the hazard event

There may be little or no warning of an Engineered Soil Slope failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are the main potential external triggers of an Engineered Soil Slopes hazard event:

(A) Natural triggers

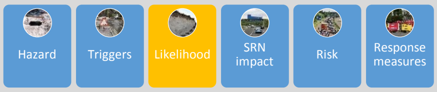
- Heavy or sustained rainfall/snowfall – may be during or following the storm event
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- A surface flooding event – may also have an man-made underlying cause
- Cyclic natural degradation (e.g. tidal erosion, freeze-thaw cycles, shrink-swell cycles)
- Erosion (surface or groundwater flow)
- Animal burrowing
- Earthquakes

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

(B) Human activity-related triggers

- Leakage from nearby water mains, sewerage and drainage.
- Change in surcharging or loading
- Removal of vegetation – may be contributing to slope stability
- Degradation / loss in performance of any stabilisation measures such as soil nails or anchors (also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note)
- Water seepage from service duct backfill which may act as a water reservoir
- Human activity nearby (e.g. excavation at toe of slope) – also includes third party activities outside the boundary fence, e.g. changes in ploughing patterns

Highways England Geotechnical Advisors can provide further information of potential triggering actions.



3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Slopes Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Engineered Soil Slopes, compared to the rest of the network. The Engineered Soil Slopes hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of slope failure or subsidence related to slope movement (mainly in embankments), the following factors are relevant:

(A) The inherent likelihood of an Engineered Soil Slope failure

- Refer to the Slopes Hazard Rating map
- Evidence of movement (e.g. monitoring or any evidence recorded in Geotechnical Asset Database (GAD), or in Geotechnical Asset Management Plans for known landslide areas)
- Poor slope condition / low inherent stability as indicated a geotechnical slope examination (HD 41/15) – for slope-specific indication of condition
- Age of slope / SRN section – supplementary condition indicator where a geotechnical examination is not available or not recent

(B) Presence of any mitigating / exacerbating features

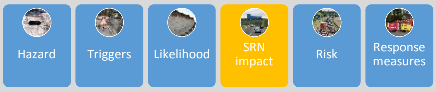
- Presence, condition and effectiveness of slope improvement / stabilisation measures – as installed during construction / maintenance of the SRN or by third parties
- Size (height / volume) of slope and distance of slope from the SRN – to indicate the context and proximity of the carriageway relative to a potential landslide, and the likelihood that a slope failure would interact with the road network

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

These may be considered by the type of triggering mechanism:

- Water-related inundation / saturation / destabilisation:
  - A history of flooding (also refer to the Groundwater Flooding hazard guidance note)
  - Observed / forecast heavy or prolonged rainfall – the impact of our changing climate on soil slopes is an important consideration. Evidence of past instability alone may no longer be sufficient.
  - Blocked / insufficient / absent drainage
  - Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements and may leak
  - Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)

- Loading of slope and undermining slope integrity:
  - Construction, new structures, or temporary plant may indicate loading beyond a stable limit (primarily an issue with improvement schemes)
  - Traffic loading (volume) increases



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – impact to the network (damage / obstruction) is linked to the volume of debris deposited from a slope above the carriageway, or area of SRN undermined by a slope failure below the carriageway.
- The location of the potential failure – a landslide impacting a main running lane presents both higher safety impact and higher performance impact than one that affects only a hard shoulder / remote from the carriageway.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure (where soil slope supports the SRN)
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Engineered Soil Slopes presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England, service providers and land owners (where the slope is outside the SRN boundary).

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures. Visual inspections are the primary source of assessment either to identify 'early warning signs' or to evaluate stability when a location is flagged for review (for more information refer to **HD41/15**).
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Engineered Soil Slopes risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Identification of third party land owners where the slope is located outside the SRN boundary, or that will be potentially impacted should an HE-owned slope fail. Also procedures for gaining access where required to third party land.
    iii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    iv. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    v. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Engineered Soil Slopes in England

1.0 Engineered Soil Slopes

Embankment slope failure stabilised with soil nailing, M25 (Highways England)

Engineered Soil Slopes along a road network are typically formed by cutting through a higher topography landscape (soil formation) or by placing fills and forming an embankment. The soil slopes are formed to a suitably stable angle either by consideration of the likely groundwater conditions and their natural properties or properties are altered by stabilisation methods such as the inclusion of reinforcement. Soil slopes are present throughout the SRN.

HAGDMS presents a thematic map layer categorising the Slope Hazard Rating into six ratings (Very Low to Very High, and No rating). The categories are based on an analysis that has been carried out into the performance of the major Geotechnical Assets of Highways England. The latest available version of the Slopes Hazard Rating should be used as it will reflect the most current analysis; however, HAGDMS also retains previous versions of the map for historical reference only (e.g. the 2014 map is available but is superseded.) The derivation of the Slope Hazard Rating is based on the slope shape and geology. This is explained in detail in the note on Slopes Hazard Rating data description on HAGDMS.

2.0 Engineered Soil Slopes and the Strategic Road Network

The hazard posed by Engineered Soil Slopes can be considered to arise from:

- The potential for Engineered Soil Slope failure above or beneath the Highways England estate with the potential to either cause sudden and catastrophic collapse, impede the highway or damage SRN assets. These hazards could be present due to:
  - inadequate design and/or stabilisation methods (compared to current practice/guidance), which may correlate to the age of the slope
  - management of water (surface or subsurface) – blocked, insufficient or inappropriate drainage systems. This could also be caused by changes in water level/flows over time (e.g. due to environmental changes) and that the existing drainage system has not been designed for this.
  - stabilisation measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life

The type of hazard that the presence of Engineered Soil Slopes that are susceptible to failures presents to the SRN is further significantly influenced by the size of the failure and its proximity to the network.

3.0 Key references and further information

Slopes Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Slopes Hazard Rating data description, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Groundwater Flooding Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Groundwater Flooding to impact the safety and performance of the Strategic Road Network (SRN). Together with the Groundwater Flooding susceptibility maps Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), they support effective management of the Groundwater Flooding risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Groundwater Flooding hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Groundwater Flooding
Part III: provides further background information specific to Groundwater Flooding, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Groundwater Flooding risks

Groundwater Flooding refers to both:

- The emergence of groundwater from within the ground at the surface
- The rise of groundwater levels beyond the 'normal' range such as to cause sub-surface water inundation.

An overview of Groundwater Flooding and its impact on the SRN is summarised in Part III.

This note does not address hazards related to fluvial flooding – where natural water courses (rivers, etc) are overloaded and adjacent land is inundated, nor pluvial flooding – where rainwater ponds on the surface.

Groundwater flooding, Oxford 2007. Ref: BGS

The risk presented by the potential for Groundwater Flooding is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Groundwater Flooding and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

1.0 Current ground risk management requirements:

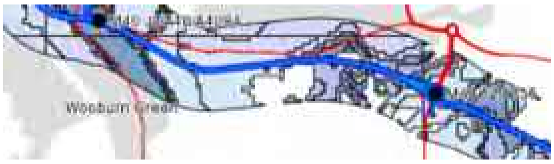
HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Groundwater Flooding related risk. Consideration of the hazard posed by

Groundwater Flooding to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 Groundwater Flooding susceptibility mapping



Section of the Groundwater Flooding susceptibility map

There are currently several maps available on the HAGDMS that show the susceptibility of the network to Groundwater Flooding . These are:

- ‘Areas Susceptible to Groundwater Flooding (Max)’, source: JBA
- ‘Groundwater Flooding Susceptibility’, source: BGS
- ‘Areas susceptible to groundwater flooding’, source: EA
- ‘Ground waterbodies’, source: Water Framework Directive (EA)

There is also a range of map products for other flooding hazards which can be access on HAGDMS. Guidance notes on their use is in preparation.

The maps are intended as high level hazard awareness maps only. **They do not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Groundwater Flooding along with all other ground-related hazards is an inherent part of risk management within Highways England’s geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Groundwater Flooding poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact the following:

- Water and Drainage Advisors available within Environment (& Drainage) Group and
- Geotechnical Advisors available within Highways England’s Geotechnics and Pavement Group.

Role of Highways England’s Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Using the Groundwater Flooding susceptibility maps to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur* due to the presence of the hazard'. The following are different hazard events related to the presence of Groundwater Flooding along the SRN, and these present different risks to the network:

- Surface inundation
- Sub-surface inundation and associated impact on buried infrastructure – such as the power network and drainage
- Structural damage from the reduction in bearing capacity of foundations – such as loss of pile skin friction and softening of the pavement foundation
- Subsidence associated with inundation of loosely compacted materials

2. Consider potential external triggers of the hazard event

Where specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Groundwater Flooding hazard event:

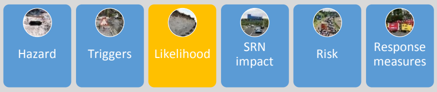
- Heavy or prolonged rainfall
- Changes in groundwater flow, e.g. through construction, long-term pumping (or cessation of pumping), and damming.

Note that the effect of rainfall may be exacerbated by climate change.

Groundwater Flooding is also a potential trigger of other geotechnical hazard events, as described in separate guidance notes for:

- Coal mining
- Non-coal mining
- Dissolution features
- Brine extraction

- Landfill sites – in particular a groundwater rise may promote the transport of leachate
- Natural landslides (soil)
- Aggressive / Corrosive soil and groundwater – in particular a groundwater rise may dissolve more aggressive / corrosive minerals and promote transport to receptors
- Compressible and collapsible ground
- Engineered soil slopes



3. Assess the likelihood of the hazard event occurring

The Groundwater Flooding susceptibility maps are not absolute indicators of the likelihood of flooding to occur, but relative indicators of the potential for Groundwater Flooding compared to the rest of the network.

To undertake a qualitative assessment of the likelihood of Groundwater Flooding, the following factors are relevant:

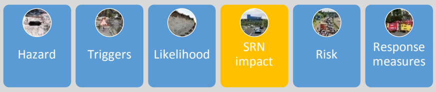
(A) The likely presence of Groundwater Flooding

- Refer to HAGDMS for Groundwater Flooding susceptibility maps
- Refer to HAGDMS for recorded flooding hotspots and flooding events
- Groundwater level monitoring data – see Coal Authority (where in proximity to coal mines) and Environment Agency
- Road level and topography around the road – this level of detail will not be captured within the Groundwater Flooding susceptibility maps.

(B) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- A history of flooding
- Recent prolonged or heavy rainfall / high seasonal or annual average rainfall
- Presence and condition of any existing or planned groundwater control measures, such as diaphragm wall, active pumping or cessation of dewatering, alleviation drainage

An understanding of the likelihood of a Groundwater Flooding hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The location of the potential flood. Standing water in a main running lane presents the most direct impact in terms of affecting traffic flow and safety, but groundwater elsewhere has the potential to damage SRN assets and utilities, cause electrical disruption, and can obscure trip hazards to maintenance workers and the public.

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* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

- There is typically very limited action that can be taken to dissipate Groundwater Flooding (e.g. pumping water is usually not an option), so the flood may continue for an extended period of time.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Type of drainage – presence and type of surface water run-off drainage. Innovative techniques are being tried to move the water off the carriageway quicker.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.
- Position of the road (e.g. roads at grade is more susceptible than roads on embankment) and its integration with the topography (could act as a drainage channel/ water path when the flooding occurs)
- The type of structure (with respect to foundation failure) – where groundwater undermines foundations the safety impact will be dependent upon what the structure carries or supports.

5. What is the risk (considering likelihood and impact) that Groundwater Flooding presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Drainage and Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers or drainage) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond to a potentially unexpected hazard event, development of response plans is recommended for areas of known Groundwater Flooding risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).

iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.

iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Groundwater Flooding in England

1.0 Why Groundwater Flooding occurs

Groundwater flooding refers to when the natural water table within the ground rises such that water emerges at the surface, or when the level is well above the 'normal' variations of the water table which is usually only considered when water inundates buried structures or utilities (see figure). Groundwater flooding is distinct from fluvial and pluvial flooding; fluvial flooding is the result of the overload of water courses (rivers, etc) and water inundating adjacent land, and pluvial flooding occurs when rain water ponds on the surface.

Groundwater flooding: due to rising water table in an unconfined aquifer. Source: BGS

When Groundwater Flooding occurs it is usually after extreme and/or prolonged rainfall events. It may manifest several days, weeks or even months after the 'triggering' storm as water from the catchment area slowly seeps into the ground causing the groundwater level to rise. A storm is much more likely to become a triggering event if the groundwater level is already very high, as may be the case in unusually wet seasons. This kind of flooding often takes a long time to dissipate as there is typically no immediate water course or drainage outlet to which the water can flow.

Groundwater flooding in Oxfordshire 2007. Source: BGS

In addition to rainfall-related causes, it is possible for human activities to cause Groundwater Flooding. The cessation of long-term pumping or dewatering will cause a temporarily lowered water table to rise again which may have an impact on infrastructure. This may be the case for example when a colliery is abandoned or extraction from wells stops. Also, areas of reclaimed land that were protected from tidal influences by pumping are increasingly being abandoned due to the associated costs.

Long-term leaking from water pipes and sewer pipes may also contribute to a rise in groundwater, though typically large volumes of escaping water are needed over a long time to cause an effect. Interruptions or changes to the natural groundwater flow regime may cause localised upward movement of water and flooding, such as through excavation, sheet piling and the construction of basements.

Although local geological settings and topography can have an impact on where Groundwater Flooding may occur, in general it typically occurs at valleys that are underlain by chalk or at river valleys that are composed of thick river deposits (thick alluvium and/or gravels for example) and depending on the alignment of the infrastructure it could cause disruptions to the network at areas that might not be as susceptible to other forms of flooding.

The Groundwater Flooding susceptibility maps can be accessed at HAGDMS. They show the susceptibility of the areas around the network to Groundwater Flooding and they are provided by British Geological Survey, Highways England, Environmental Agency and the Water Framework Directive – however they do not take into account the local foundation levels of the network or embankment heights.

2.0 Groundwater Flooding and the Strategic Road Network

The hazard posed by Groundwater Flooding arises from the potential for groundwater to inundate the highway or other SRN assets. On the carriageway, there is a risk to vehicles of aquaplaning, and for pedestrians and maintenance staff there is an inherent hazard of tripping as water may conceal obstacles. There is also a risk to buried and surface assets where they have not been designed for higher levels of groundwater levels, pressures, and/or water inundation. Groundwater Flooding can also result in the loss of foundation capacity leading to damage to the structures or infrastructure they support.

In general there is limited scope for design to protect the SRN carriageway from Groundwater Flooding, however raising roads on embankments can help mitigate the effects. Designed disruption of the natural groundwater flows such as through construction of barriers or pumping regimes may reduce local Groundwater Flooding. Further,

This note focuses on the direct impacts of inundation, but Groundwater Flooding may be a trigger for other ground hazards including embankment instability and the potential for contamination and chemical transport.

3.0 Key references and further information

Groundwater Flooding susceptibility maps, HAGDMS / HAGIS

Flooding from groundwater, Environment Agency, 2011

British Geological Survey, www.bgs.ac.uk, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Landfill Sites Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Landfill Sites to impact the safety and performance of the Strategic Road Network (SRN). Together with the Landfill Sites Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Landfill Sites risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Landfill Sites hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Landfill Sites
Part III: provides further background information specific to Landfill Sites, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Landfill Sites risks

Landfills are areas of land used to deposit waste material which are then covered over. Landfills may be sited within excavations (often filling former quarries) or mounded and landscaped over ('land raising'). They represent a long-term presence of potential contaminants that must be contained in accordance with UK law, and where the SRN is built on top of or adjacent to landfills, their stability poses a hazard to the road network. The background of Landfill Sites and its impact on the SRN is summarised in Part III.

Landfill under construction.
Source www.geograph.co.uk

The risk presented by the instability and subsidence of Landfill Sites is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Landfill Sites and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

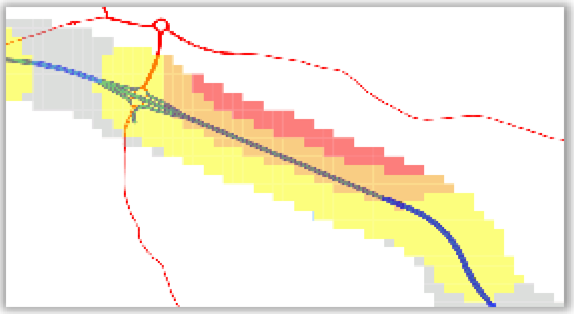
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Landfill Sites related risk. Consideration of the hazard posed by Landfill Sites to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Landfill Sites Hazard Rating Map



Section of the Landfill Sites Hazard Rating map

An HE specific Landfill Sites Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Landfill Sites obtained from datasets including Environmental Agency Historic Landfill Sites and Environmental Agency Authorised Landfill Sites. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Landfill Sites Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Landfill Sites along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Groundwater Flooding poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact the following:

- Environmental Advisors available within Environment (& Drainage) Group and
- Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

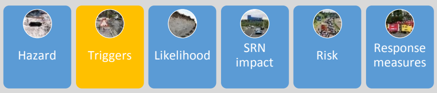
Part II Using the Landfill Sites Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Landfill Sites along the SRN, and these present different risks to the network:

- Collapse or settlement/subsidence of the landfill beneath the SRN (may be sudden or progressive)
- Differential settlement – particularly where spanning across the edge of landfill site (the 'high wall')
- Release of leachate, gas and/or other hazardous waste related components into the SRN environment (including drainage system) or to third party land



2. Consider potential external triggers of the hazard event

There may be little or no warning of a landfill-related hazard event, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a landfill-related hazard event:

- Vibration or disturbance, e.g. due to traffic, construction activities and excavation
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- A surface flooding event
- Leakage from nearby water mains, sewerage or drainage
- Sudden collapse of a void-containing waste element (e.g. a refrigerator that has not been properly pre-crushed)

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

The following are also potential external triggers specifically related the release of contamination:

- Puncturing of containment layers
- Puncturing, rupture or failure of leachate / gas collection pipework and system

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Landfill Sites Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Landfill Sites, compared to the rest of the network. The Landfill Sites hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a subsidence or contamination leakage, the following factors are relevant:

(A) The likely presence of Landfill Sites

- Refer to the Landfill Sites Hazard Rating map
- Evidence of leachate seepages on slopes or within drainage systems

(B) Inherent properties, characteristics, and legacy issues

- Age (and design life) of the landfill – indicative of engineering design standards followed and operator management, plus potential degradation of lining materials. The introduction of the Landfill Directive in 2002 represents best available techniques for landfilling. Other milestone changes in legislation are summarised in Part III.
- Type of landfill – indicative of both the waste mass ability to break down (e.g. organic material) and the potential to generate contaminants (with age also being relevant)
- A history of problems, instability, contamination leakages
- Location of landfill – contamination leakage to a sensitive receptor (SRN environment / protected aquifer, third party land) is less likely when the landfill is more remote
- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness (including age degradation) and completeness of any investigations and measures undertaken to stabilise landfills and address potential contamination issues

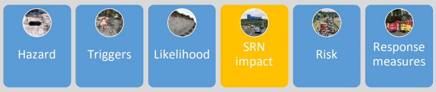
(C) Presence of any mitigating / exacerbating features

- A hydrogeological regime allowing water flow around a landfill perimeter – potentially promoting contaminant mobility

(D) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- A history of flooding (also refer to the groundwater flooding hazard guidance note)
- Recent / forecast heavy or prolonged rainfall
- Tap roots and deep roots that could potentially penetrate a landfill capping layer
- Animal burrowing (where capping layer is not sufficiently thick / deep – which may be possible with older landfill constructions)
- Traffic loading (volume) increases
- Construction / demolition activities, excavations and deep drilling, and temporary plant – particularly relevant for improvement schemes (especially 'Technology' schemes)
- New structures and permanent loads
- Blocked / insufficient / absent drainage
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements
- Groundwater extraction / dewatering, soakaways, irrigation

An understanding of the likelihood of a Landfill Sites hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- For landfill stability: the nature (or rate) of failure and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- For landfill stability: the size of the potential failure – a large collapse presents a much higher safety risk to potentially many more users of the network than a small collapse would. Estimation of collapse size requires local consideration and expert input.
- For landfill stability: heterogeneity of material – differential settlement caused by softer or harder masses within the waste material results in more damage to overlying pavement or structures compared to uniform settlement. The rigid 'high wall' at the edge of a landfill is likely to be a point of significant differential settlement.
- For landfill failure: The location of the potential failure – a collapse in a main running lane presents both higher safety impact, and higher performance impact than one in a hard shoulder or beyond.
- For contamination: The type of the waste – landfills are currently classed as either inert, non-hazardous or hazardous. Landfills constructed prior to 1974 were not subject to any classification requirements and could contain a variety of different types of material. In addition, some substances such as asbestos are considered toxic (but only as of 1985) but stable such that they do not represent a mobile (waterborne / airborne) contamination risk.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Proximity to environmental protection sites or protected aquifers – higher sensitivity to contamination and any remediation required will be more onerous
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

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* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

- Receptor space for potential contamination – harmful gases such as methane entering confined spaces, e.g. sewers will have a much a much more concentrated human safety impact than if released into open spaces.

5. What is the risk (considering likelihood and impact) that Landfill Sites presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Environmental and Drainage, and Geotechnical Specialists from both Highways England and service providers and where appropriate the Environmental Agency.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event. (Leachate is included as a specific observation item within geotechnical inspections)
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Landfill Sites risk. Response plans should include:

    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.

    ii. Identification of third party land owners where the landfill is located outside the SRN boundary. Also procedures for gaining access where required to third party land.

    iii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England’s suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).

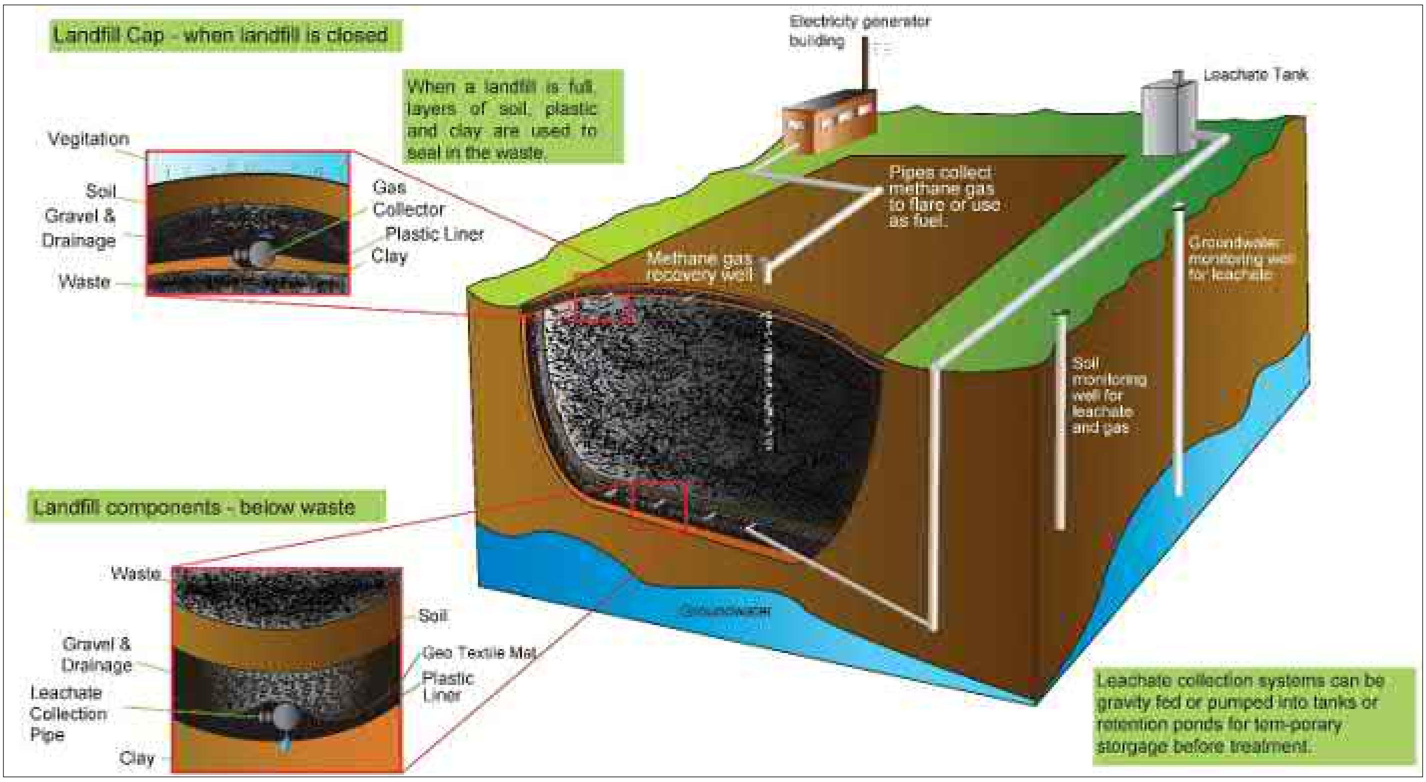
    iv. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.

    v. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Landfill Sites in England

1.0 Basic components of a modern landfill construction

The figure below shows the main features of a typical landfill constructed today. The presence, quality and durability of the encapsulation system of older landfill sites can only be expected to be in accordance with the legislative requirements at the time of construction, and subject to subsequent age deterioration.



Construction of a modern landfill. Source: www.re3.org http://www.geograph.co.uk/

Landfill Sites are susceptible to volume changes (reduction) as materials break down and liquids (leachate) and gas (e.g. air, methane, etc.) are expelled from the waste mass. Subsidence follows the construction initially as voids within the waste mass or voids within waste elements collapse simply under the landfill's own weight or any initial surcharge load that is applied. There is then volume reduction as the self-weight / surcharge squeezes out leachate. Subsequently, there is further volume reduction as the load is taken directly by the solid waste elements which rearrange and crush, decompose and expel more leachate/gas. The rate and degree to which the waste mass volume can reduce depends on the type of waste contained (e.g. municipal, industrial, organic, etc), the geometry of the landfill, and the surcharge loads and groundwater pressures applied.

2.0 Environmental legislation

There is a significant amount of primary and secondary environmental legislation that concerns landfills as well as wider waste management and pollution control. The specific obligations and requirements placed by UK law (for instance, the requirement for Materials Management Plans during construction) are beyond the scope of this guidance note; however the Highways England Environment (& Drainage) Group should be contacted directly for further information and advice.

The following describes the role of key legislation as is relevant to the improvement in standards in the engineering of landfills and the control of contamination:

(A) Legislation covering the construction of landfills:

The Control of Pollution Act 1974 (COPA) was the first piece of legislation that introduced the requirement for landfill sites to be licensed. Local authorities became the regulatory bodies to administer the Act. Licenses required operators of landfills to control the escape of landfill gas and discharges of water from the site, and a licence could be refused in the event that such pollution was likely. Landfills built prior to this Act and even for many years after were likely to contain toxic contamination with no containment engineering for pollution control. Further, certain materials treated as toxic waste today were not always considered so in the past; for example blue and brown asbestos was not banned until 1985.

In terms of the stability of the landfills, the publication of Waste Management Paper 26 in 1986 by the former Department of the Environment, although not statutory guidance, effectively established initial standards for landfill engineering. It described the main engineering components of landfills that continue to be important in current design, including:

- bulk earthworks
- underdrainage
- liners - mineral and synthetic
- leachate / gas management
- monitoring

However, planning authorities were not required to consider the impact of the landfills on the local environment until 1999, when Environmental Impact Assessment Regulations (SI 1999 No 293) came into effect. This was followed by the introduction of the Pollution Prevention and Control (PPC) 1999 Act that has changed the environmental permitting of industrial activities including landfill, that have a pollution potential. The principle of PPC is through the application of Best Available Techniques (BAT), which sets out standards of operation that are acceptable on an industrial sector basis.

Implementation of the Landfill Directive via the Landfill Regulations (2002) is considered to constitute BAT for landfilling. All new PPC permits for landfills have to comply with the technical measures outlined within Annex I of the Directive. Schedule 2 of the Landfill (England and Wales) Regulations 2002 sets out the containment measures required at landfill sites. These set out some minimum requirements, including the following:

- siting of landfills where a geological barrier is provided
- provision of a two component lining system
- no unacceptable discharge from the waste throughout the lifetime
- construction of a barrier in a manner to ensure that it remains stable

A detailed history of the development of landfill legislations is available from www.gov.uk – *Stability of Landfill Lining Systems: Report No. 1 Literature Review*, R&D Technical Report P1-385/TR1.

(B) Legislation concerning the management of contaminated land:

Management of contaminated land is closely linked to issues relating to landfill sites. The primary legislation was introduced in 1995 as an amendment to the Environmental Protection Act 1990 and became effective from 2000. The following is a summary of the legislation taken from 'Dealing with contaminated land in England' published by the Environment Agency in April 2016.

It [Part 2A of the Environmental Protection Act 1990] *provides a framework for identifying land where historical contamination has resulted in an unacceptable risk to human health or the environment, and aims to ensure land identified as 'contaminated land' under the regime will be remediated where possible. Local councils are the lead regulators for Part 2A.*

The overarching objectives of the Government's policy on contaminated land and the Part 2A regime are to:

(a) Identify and remove unacceptable risks to human health and the environment.
(b) Seek to ensure that contaminated land is made suitable for its current use.
(c) Ensure that the burdens faced by individuals, companies and society as a whole are proportionate, manageable and compatible with the principles of sustainable development

The Part 2A statutory guidance requires local councils to write an inspection strategy for their areas. Inspections involve local councils looking at previous land uses and activities that may have caused contamination and assessing the potential risks from these to people and the environment. Part 2A provides a legal definition of contaminated land. The accompanying statutory guidance introduces the idea of significant contaminant linkages that must be present in order to define land as contaminated land. Where all of these conditions are met, a local council can then determine the site to be contaminated land under Part 2A.

Once a site has been determined as contaminated land decisions can be taken about how to deal with it and who should pay. In some specific circumstances (that are defined in the Contaminated Land (England) Regulations 2006) the Environment Agency becomes the enforcing authority. This happens when a site is designated by the local council as a special site.

In either case, remediation should be carried out by the appropriate person(s). There are two classes of appropriate person:

1. *Class A: those persons who caused or knowingly permitted the pollution*
2. *Class B: a site owner or occupier – but would only be liable if a Class A appropriate person cannot be found for a particular significant contaminant linkage.*

The provision for remediation follows the 'polluter pays' principle. Where an appropriate person may be unable to pay for remediation, the regulators must consider hardship. The regulator may also be able to recover costs if they do the remediation. However, where no appropriate person can be found the cost of remediation may be met by taxpayers.

Remediation can be achieved by breaking the source-contaminant-receptor linkages. For example, removing or reducing the source of contamination, blocking the pathway between the contamination and the receptor, reducing the exposure of the receptor to the contamination or removing the receptor all together. The remedial actions are documented. Enforcing authorities have a duty to maintain a public register that records regulatory action taken regarding the remediation of contaminated land.

3.0 Landfill Sites and the Strategic Road Network

The hazard posed by Landfill Sites can be considered to arise from the potential for:

- instability of a landfill adjacent to or beneath the Highways England estate to either collapse suddenly and catastrophically or to cause settlement/subsidence. Instability could result from:
  - unidentified, and hence unmanaged, landfills
  - inadequate compaction and stabilisation methods (compared to current practice/guidance), which may correlate to the approximate date of works
  - the stabilisation measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. chemical, groundwater changes or surface flooding) or there has been further material decomposition and expulsion of leachate / gas
  - new unassessed landfill related activities
- failure to contain leachate / gas within the landfill or treatment plant, releasing harmful or toxic substances into the SRN environment or, where the landfill is under HE management, into third party land. Mobility of any released leachates in particular will be further increased where there is flooding or groundwater flow around landfill.

Management activities carried out for a landfill may have been undertaken by the original operator of the site, or subsequently, for example such works may have been included in the construction or subsequent maintenance of the SRN. The age of the landfill, and the age of the SRN can be useful guides to indicate the scope of works that may have been carried out and to what degree of effectiveness, in particular in relation to the regulations that applied at the time. For existing sections of the SRN, it is reasonable to assume that remediation has taken place where contaminated ground has previously been identified.

When constructing new roads, specialist advice may be required to identify sites that could become classed as ‘contaminated land’ where the change in use increases likelihood of exposure. In such instances, it can be a grey area to determine who is responsible for remediation.

This note focuses on the potential failure of pre-existing landfills, but potential hazard associated with the construction of new landfill site should not be ignored.

4.0 Key references and further information

Landfill Sites Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Landfill Sites Hazard Rating data description, 2017

Guidance on the management of landfill sites, CIRIA, 2012

Remedial engineering for closed landfill sites, CIRIA, 2001

Stability of Landfill Lining Systems: Report No. 1 Literature Review, Environment Agency, 2003

Dealing with contaminated land in England, Environment Agency, 2016

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE’s Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Natural Landslides Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential for Natural Landslides to impact the safety and performance of the Strategic Road Network (SRN). Together with the Natural Landslides Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Natural Landslides risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Natural Landslides hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Natural Landslides
Part III: provides further background information specific to Natural Landslides, its relevance to the SRN, and key sources of reference

A detailed commentary on the history and distribution, geography and hazards presented by landslides in the UK can be found in 'The National Landslide Database of Great Britain: acquisition, communication and the role of social media - (Pennington et al. 2015)' published in British Geotechnical Survey's NORA library.

Part I Highways England's approach to managing Natural Landslides risks

A landslide is a mass movement of rock and/or soil on a slope due to the force of gravity. Natural slopes above or below the level of the carriageway are distinct from engineered slopes failures as they have not been structurally designed or constructed. Landslides involving natural slopes are usually much larger than engineered slope failures and generally do not originate on the SRN. The background of Natural Landslides and their impact on the SRN is summarised in Part III.

Natural Landslide, Bournemouth, 2016. Source: BBC (Tracey Jones)

This guidance note addresses specifically natural soil slopes – natural rock slopes present a very minor risk to the SNR in England. For hazard associated with Engineered Soil Slopes and Engineered Rock Slopes see the corresponding hazard guidance notes.

The risk presented by Natural Landslides is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Natural Landslides and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

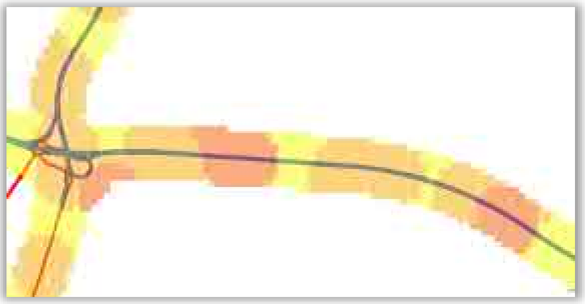
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Natural Landslides related risk. Consideration of the hazard posed by Natural Landslides to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Natural Landslides Hazard Rating Map



Section of the Natural Landslides Hazard Rating map

An HE specific Natural Landslides Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Natural Landslides obtained over several years from British Geological Survey (BGS). The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Natural Landslides Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Natural Landslides is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Natural Landslides poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Using the Natural Landslides Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of natural slopes along or beneath the SRN, and these present different risks to the network:

- Incursion of material onto carriageway – potential obstruction and damage
- Subsidence of part or all of a carriageway, structure or other asset where a natural slope supports the SRN – could be sudden or progressive
- Impact damage to structures and other above-surface SRN assets due to a moving soil mass / debris
- Instability and damage to sub-surface SRN assets including foundations and buried utilities (e.g. drainage, power, communications)

2. Consider potential external triggers of the hazard event

There may be little or no warning of a Natural Landslides-related event, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are the main potential external triggers of a Natural Landslides hazard event:

(A) Natural triggers

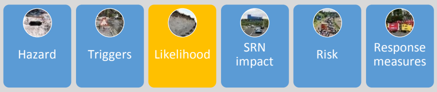
- Heavy or sustained rainfall/snowfall – may be during or following the storm event
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- A surface flooding event – may also have an man-made underlying cause
- Cyclic natural degradation (e.g. tidal erosion, freeze-thaw cycles, shrink-swell cycles)
- Erosion (surface or groundwater flow)
- Animal burrowing
- Earthquakes

Note that the above water related features (surface or groundwater, flooding etc.) may be exacerbated by climate change.

(B) Human activity-related triggers

- Leakage from nearby water mains, sewerage or drainage
- Change in surcharging or loading
- Removal of vegetation – may be contributing to slope stability
- Degradation / loss in performance of any stabilisation measures such as soil nails or anchors (also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note)
- Water seepage from service duct backfill which may act as a water reservoir
- Human activity nearby e.g. excavation at toe of slope – also includes third party activities outside the boundary fence, e.g. changes in ploughing patterns

Highways England Geotechnical Advisors can provide further information of potential triggering actions.



3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Natural Landslides Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Natural Landslides, compared to the rest of the network. The Natural Landslides hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of a natural landslide hazard event, the following factors are relevant:

(A) The likely occurrence of Natural Landslides

- Refer to the Natural Landslides Hazard Rating map
- Within the Highways England boundary: evidence of movement – e.g. condition of assets (pavement, geotechnical, drainage, and structures), known landslide sites as identified in GeoAMPs, monitoring or any other evidence recorded in the Geotechnical Asset Database (GAD)
- Outside the Highways England boundary: poor slope condition / low inherent stability – as indicated by factors that would be considered within geotechnical principal inspections (HD 41/15), 3rd party monitoring and reporting, remote survey data, etc.

(B) Presence of any mitigating / exacerbating features

- Presence, condition and effectiveness of slope improvement / stabilisation measures – as installed during construction / maintenance of the SRN, or by third parties
- Size (height / volume) of slope and distance of slope from the SRN – to indicate the context and proximity of the SRN relative to a potential landslide, and the likelihood that a slope failure would interact with the road network

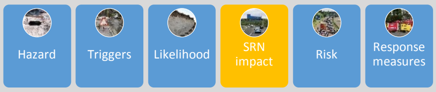
(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur
These may be considered by the type of triggering mechanism:

- Water-related inundation / saturation / destabilisation:
  - A history of flooding (also refer to the Groundwater Flooding hazard guidance note)
  - Observed / forecast heavy or prolonged rainfall – the impact of our changing climate on soil slopes is an important consideration. Evidence of past instability alone may no longer be sufficient.
  - Blocked / insufficient / absent drainage, also
  - Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements and may leak
  - Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)

- Loading of slope and undermining slope integrity:
  - Construction, new structures, or temporary plant may indicate loading beyond a stable limit (primarily an issue with improvement schemes) – within or outside the Highways England boundary
  - Traffic loading (volume) increases

It should be noted that Natural Landslides generally originate from slopes outside the SRN boundary and there is limited control over the management of stability triggers

An understanding of the likelihood of a Natural Landslide occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – impact to the network (damage / obstruction) is linked to the volume of debris deposited from a slope above the carriageway, or area of SRN undermined by a slope failure below the carriageway. Natural landslides, although rare, can potentially by very large.
- The location of the potential failure – a natural landslide impacting a main running lane presents both higher safety impact and higher performance impact than one that affects only a hard shoulder / remote from the carriageway.
- Consideration of potential diversion of the route, investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

5. What is the risk (considering likelihood and impact) that Natural Landslides presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England, service providers and land owners (where the slope is outside the SRN boundary).

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

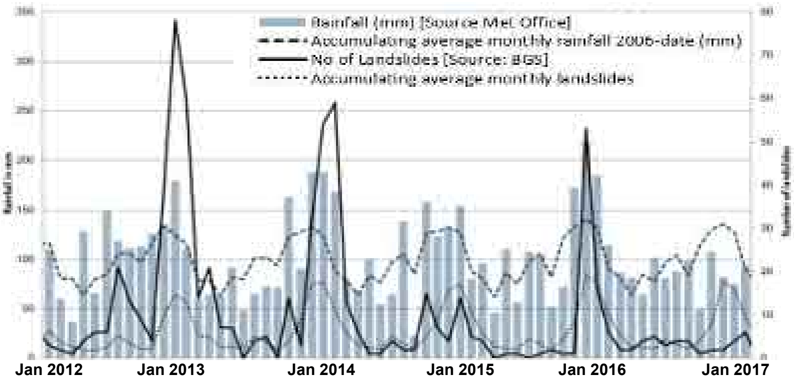
- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Natural Landslides risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Identification of third party land owners where the slope is located outside the SRN boundary, or that will be potentially impacted should an HE-owned slope fail. Also procedures for gaining access where required to third party land.
    iii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    iv. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    v. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III An overview of Natural Landslides in England

1.0 Background of natural soil slopes and failures

Natural soil slopes above and/or below the level of the carriageway are present on sections of the SRN throughout England. Unlike engineered slopes that have been made by excavating through the natural topography (cuttings) or constructed by mounding fill material (embankments), natural slopes were formed through geological processes without specific engineering design. Landslides that involve natural soil slopes are usually longer or deeper compared to engineered slope failures, and so tend to mobilise greater masses of soil. More often they occur progressively, although sudden failures can also occur.

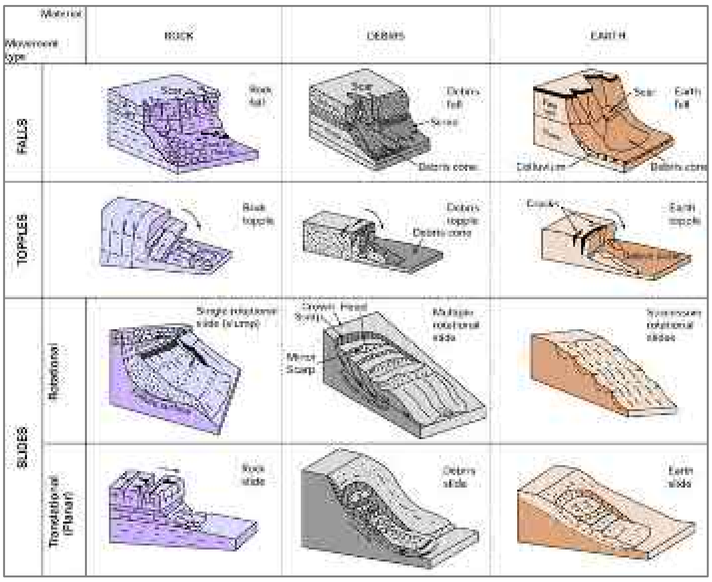
Natural slope landslide at Flint Hill Farm, Surrey, 1997. Source: HAGDMS

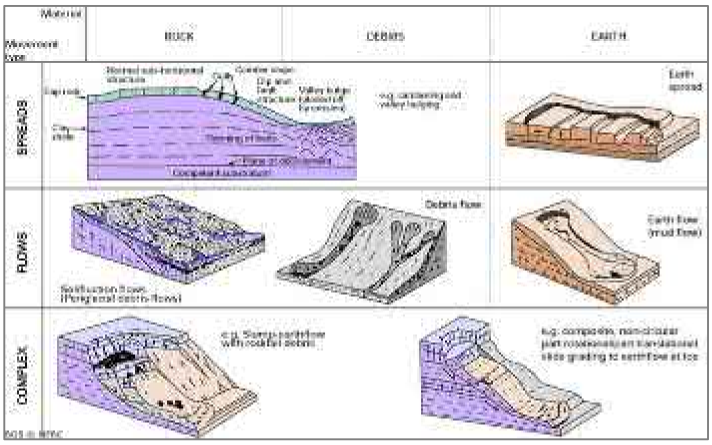


Landslides in the BGS UK database (includes failures of natural slopes and railway cuttings). Source: BGS

Landslides and especially large scale destructive landslides are not a common phenomenon in Great Britain. However, in recent years (e.g. the winters of 2012-13, 2013-14 and 2015-16 and the summer of 2012) there was a marked increase in the number of landslide events which corresponded to extensive periods of prolonged rainfall (see figure left). With the expected increase in extreme rainfall events due to climate change, England is likely to see more frequent Natural Landslides.

A summary of the common mechanisms of landslides is shown in the table below (as classified by the BGS). These have been generated based on the form of the movement of the recorded failures as well as taking into account the materials involved.





BGS adapted classification of natural landslides based on the material and movement type of the failure. (Source: BGS)

2.0 Natural Landslides and the Strategic Road Network

The hazard posed can be considered to arise from the potential for a landslide to occur which collapses onto or undermines and destabilised the Highways England estate. The landslide related hazards could be present due to:

- unidentified, and hence unmanaged susceptible slopes in close proximity to or below the network
- change to groundwater regimes (natural / artificial)
- undermining the slope through excavation
- inadequate stabilisation methods (compared to current practice/guidance), which may correlate to the approximate date of treatment and the assessed conditions then
- the stabilisation measures employed have deteriorated subsequently due to changes unforeseen at the time of works (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life

The type of hazard that the presence of slopes that are susceptible to landslides presents to the SRN is further significantly influenced by the angle, size and nature of the slope and its proximity to the network.

Natural slopes typically extend or exist beyond the SRN boundary, and usually outside of the responsibility and control of Highways England. Consequently the effectiveness and degree to which they are maintained is considerably variable. This presents a challenge to HE’s management of Natural Landslide risk.

3.0 Key references and further information

Natural Landslides Hazard Rating map, 2017, HAGDMS / HAGIS.

HAGDMS Natural Landslides Hazard Rating data description, 2017.

Pennington, C.V.L., Freeborough, K.A., Dashwood, C., Dijkstra, T.A., Lawrie, K., 2015. The National Landslide Database of Great Britain: Acquisition, communication and the role of social media. Geomorphology 249, 44–51.

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE’s Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Non-Coal Mining Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Non-Coal Mining to impact the safety and performance of the Strategic Road Network (SRN). Together with the Non-Coal Mining Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Non-Coal Mining risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Non-Coal Mining hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Non-Coal Mining
Part III: provides further background information specific to Non-Coal Mining, its relevance to the SRN, and key sources of reference

In addition, a detailed commentary on the history, geography and hazards presented by Non-Coal Mining in the UK can be found in the executive summary of the Arup Review of Mining Instability in Great Britain, prepared for the Department of Environment in 1990.

Part I Highways England's approach to managing Non-Coal Mining risks

There is a history of mining various types of rock and minerals within England that have left a legacy of mines, shafts and adits. The history of Non-Coal Mining and its impact on the SRN is summarised in Part III.

For hazards associated with Coal Mining or Brine Extraction refer to the corresponding hazard guidance notes.

The risk presented by the legacy of Non-Coal Mining is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

Void in central reservation of M2 due to a chalk mine. Source: Highways England

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Non-Coal Mining and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Non-Coal Mining related risk. Consideration of the hazard posed by Non-Coal Mining to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

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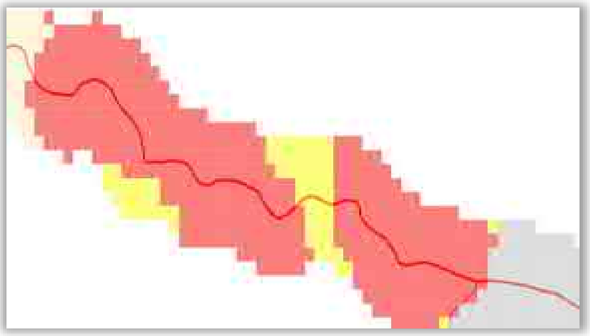
2.0 The Highways England Non-Coal Mining Hazard Rating Map



Section of the Non-Coal Mining Hazard Rating map

An HE specific Non-Coal Mining Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Non-Coal Mining obtained over several years from organisations including British Geological Survey, Environment Agency, Ove Arup & Partners, Peter Brett Associates and Wardell Armstrong LLP. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Non-Coal Mining Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Non-Coal Mining along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Non-Coal Mining poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
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- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

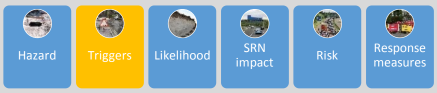
Part II Using the Non-Coal Mining Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Non-Coal Mining beneath the SRN, and these present different risks to the network:

- Collapse of a shallow mine working (may be either sudden or progressive)
- Settlement/subsidence related to presence of deep mines (typically progressive)
- The collapse of a mine shaft or mine adit (typically sudden)
- The appearance of mine water on or adjacent to the SRN



2. Consider potential external triggers of the hazard event

There may be little or no warning of a mine-related failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of a Non-Coal Mining hazard event:

- A surface flooding event
- Change in surface water flow and changes in drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Erosion
- Change in surcharging or loading
- Leakage from nearby water mains, sewerage or drainage

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.

Hazard | Triggers | Likelihood | SRN impact | Risk | Response measures

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Non-Coal Mining Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Non-Coal Mining, compared to the rest of the network. The Non-Coal Mining hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a mining collapse or related subsidence, the following factors are relevant:

(A) The likely presence of Non-Coal Mining

- Refer to the Non-Coal Mining Hazard Rating map
- Refer to area-specific report records held on HAGDMS
- Indicators that mines would not be captured by records and therefore not included within the Non-Coal Mining Hazard Rating map:
  - Areas of mining pre-1872 – i.e. prior to regulatory registration of mines
  - Areas where mining records are incomplete – such that low confidence that all mines are captured
  - Areas of small mine workings (<12 men) prior to 1993 – registration of mines was not required

(B) Inherent properties, characteristics, and legacy issues

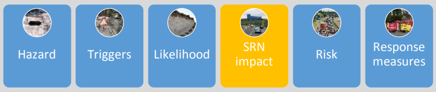
- Age of mining / method of extraction / date of abandonment – indicative of inherent stability and original measure to make the mine safe
- Mineral mined – indicative of construction techniques, geometry and frequency of shafts / adits if not known
- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness (including age degradation) and completeness of any investigations and measures undertaken to manage the mine
- Brine springs, brine extraction sites, or a hydrogeological regime allowing fresh water flow through an abandoned salt mine – may indicate stability issues relating specifically to salt mines. (A separate guidance note is available addressing the hazards associated directly to Brine Extraction.)

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

These may be considered by the type of triggering mechanism:

- Weakening of the mine structure, as may be indicated by:
  - A history of flooding (refer also to the Groundwater Flooding hazard guidance note)
  - Recent / forecast heavy or prolonged rainfall
  - Blocked / insufficient / absent drainage
  - Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding
  - Groundwater extraction / dewatering, soakaways, irrigation
- Destabilisation through additional loading, as may be indicated by:
  - Traffic loading (volume) increases
  - Construction / demolition activities, excavations, and temporary plant
  - New structures and permanent loads

An understanding of the likelihood of a Non-Coal Mining hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

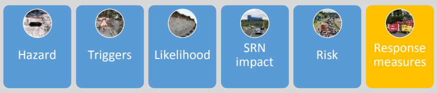
- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – a large failure presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of failure size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Non-Coal Mining presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).



6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Non-Coal Mining risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
    iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.
    iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III The legacy of Non-Coal Mining in England

1.0 History

There is a long history of mining in England, having taken place over 5000 years, in varying extents in different counties. Many different raw materials have been extracted from the ground, ranging from precious metals to mining for construction materials such as limestone, sandstone, chalk etc. Chalk was often mined wherever it outcropped – primarily in Southern England. Other rocks including limestone were mined Yorkshire and to a lesser extent in Lancashire, Greater Manchester, Derbyshire, West Midlands, Cumbria and Cleveland. Cornwall was the area most intensively mined for metalliferous ores, but places such as Devon, Somerset, Derbyshire, Staffordshire, the Pennines, Cumbria, Clwyd, Ceredigion and Montgomeryshire also have extensive evidence of historical mining.

Grinkle ironstone mine culvert collapse, North York Moors
(© http://www.geograph.org.uk/profile/22761)

The Arup Review of Mining Instability in Great Britain classified the mineral types into five categories; rocks (e.g. sandstone, limestone), metalliferous (non-ferrous) ores, iron ore outside coalfields, evaporites (e.g. rock salt or potash) and coal and its associated minerals. Coal and associated minerals is addressed within the Coal Mining hazard guidance note, and pumping of brine is addressed within the Brine Extraction hazard guidance note.

Pillar and stall mining of limestone, Gorebridge, 1945. Source: BGS

Mining of chalk was undertaken as a source of lime for agricultural purposes (soil improvement) and for construction materials e.g. lime mortar. These 'deneholes' and 'chalkwells' as the different shaped mines were known, were sunk to extract material throughout England from Medieval times. Shafts would have been 10-20m depth and unlined. Deneholes were frequently capped by placement of an upturned bush into the top and filling over with soil. Limestone was also frequently mined for similar purposes, but it has been mines at greater depths using extraction methods similar to coal mines e.g. pillar and stall.

Bell pits for iron ore extraction were common in 13th – 17th centuries. Metalliferous ores such as lead, zinc, tin and copper often occur in tabular veins within discontinuities in rock. They are typically steeply inclined and the techniques of mining reflect this. Access to the minerals is usually through shafts driven vertically through the vein that are connected through cross cuts. Characteristically there are a large number of veins in one area, which means that it is common for many shafts to be placed adjacent to one another. In other areas minerals do not occur in regular tabular veins. The mining in these areas reflect this irregularity and methods of extraction vary according to the geometry of the deposit.

Mines closed before 1872 will have more incomplete records. After that date, the Metalliferous Mines Regulation Act of Parliament was passed that included the requirement of mine owners to deposit plans with the state after mine closure. Incomplete records signifies an increased likelihood of unidentified and hence untreated mines and mine openings. Furthermore, older mines tended to be shallower, with increased number of shafts. However non-coal mines were not required to deposit plans if there had been less than 12 men employed below ground, and this relaxation was perpetuated in all subsequent legislation until 1993. This means that recent small mines may not necessarily be recorded.

It is also of note that the Coal Authority, whose powers were extended in 2011 to enable support to non-coal mine related issues, has no statutory obligations with respect to Non-Coal Mining, but may offer commercial consulting and response services.

2.0 Non-Coal Mining and the Strategic Road Network

The hazard posed by Non-Coal Mining can be considered to arise the potential for:

- voids beneath the Highways England estate with the potential to either collapse suddenly and catastrophically or to cause subsidence. These voids could be present due to:
  - unidentified, and hence unmanaged, mines or mine shafts (often older mines or mine entries are more difficult to locate)
  - inadequate stabilisation methods (compared to current practice/guidance), which may correlate to the approximate date of works
  - the measures employed have deteriorated subsequently due to changes since the time of works (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life
  - undetected fissuring in certain surface rocks resulting from ground strains caused by longwall mining at depth
- abandoned non-coal mine workings to produce potentially dangerous emissions, such as mine gas or polluting mine waters.
- former mine caverns or cavities to have subsequently been utilised for other purposes e.g. storage of hazardous materials or backfilled with hazardous or contaminated waste.

This note focuses on the potential for voids and subsidence, but the potential for release of hazardous gas or polluted waters or other contaminants should not be ignored – also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note.

The type of hazard that the presence of these mines presents to the SRN is further significantly influenced by the type of material that was mined, and the way in which it was extracted. Broadly speaking, the hazard type can be grouped based on the following categories:

- **Collapse of mine entries (shafts and adits):** mine entries are the most likely cause of mining related subsidence. They can often pass through weathered rocks and weak soils near to the ground surface. Entries may have been treated for stability but both treated and untreated shafts and adits can collapse.
- **Crown holes (localised collapses into mine voids):** These can occur when mines extracted using the pillar and stall method collapse. It is common that when abandoned, mines using this extraction method are uncollapsed or only partially collapsed. Later deterioration of the mine roof and pillars can lead to eventual total collapse. The ground movements due to collapse can take many years to manifest. If they fall into mine voids they can cause crownholes to appear. Most crownholes arise from mines at depths shallower than 30m, there have been recorded incidences of arising from mines at depths greater than 100m.
- **General subsidence:** Several types of mining can cause general collapse. For example if the roof and pillars in a mine collapse the whole overburden can subside. Alternatively total extraction methods can cause general subsidence. Total extraction methods are achieved by either mining the pillars that are left during partial extraction or by mining the mineral on a long face. The general subsidence can take the form of a wide saucer shaped depression of the land surface, which is different from the sharply defined discontinuities that are associated with crownholes. Total extraction can cause this type of subsidence because the overburden is generally allowed to collapse, although in some cases the mine roof is supported in the short term to reduce subsidence effects at the land surface. This subsidence is usually predictable and occurs within a few years of extraction, and is therefore less likely to be of concern for Highways England, although groundwater changes (e.g. climate change related or due to changes in groundwater abstraction) could reinitiate subsidence. Mining subsidence may result in differential settlement across structural geological discontinuities (e.g. faults or major joint sets), which could pose a hazard to surface assets.

At the time of mine abandonment, works such as capping of shafts and backfilling of workings may have been carried out, depending on when the mine was closed. Equally, these activities may have been undertaken at a later stage, for example at the time of construction of the SRN. Historical reports on HAGDMS may provide further information on this and any changes since construction. It is reasonable to assume that if during SRN works a mine was known to be present, there will have been investigation and stabilisation measures undertaken, with the following broad observations:

- Mine stabilisation undertaken before the publication of the CIRIA SP32 (1984) may have been less effective and more ad hoc.
- Mine stabilisation measures implemented before 1984 have now been in place for over 30 years and therefore carry uncertainties about the deterioration due to ageing or other external factors.
- Between 1984 and the first publication of the DMRB in 1992, there should have been an improvement in the investigation and stabilisation of mines based on the level of guidance available.
- Since the publication of the DMRB in 1992, (particularly HD22, management of geotechnical risks) there has been less uncertainty, better records on HAGDMS, and more effective and consistent investigation and stabilisation.
- Where stabilisation has been undertaken in the last 10 years, and has experienced less age-related deterioration the above-mentioned issues of deterioration of stabilisation are less significant, and records should be easily accessible to confirm adequate investigation and stabilisation.

3.0 Key references and further information

Non-Coal Mining Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Non-Coal Mining Hazard Rating data description, 2017

Arup, Review of Mining Instability in Great Britain, 1990

CIRIA SP32 Construction over abandoned mine workings, 1984

CIRIA C758 Abandoned mine workings – publication pending

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

Shrink/Swell Susceptible Soils Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Shrink/Swell Susceptible Soils to impact the safety and performance of the Strategic Road Network (SRN). Together with the Shrink/Swell Hazard Rating map and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Shrink/Swell Susceptible Soils risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Shrink/Swell Susceptible Soils hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Shrink/Swell Susceptible Soils
Part III: provides further background information specific to Shrink/Swell Susceptible Soils, its relevance to the SRN, and key sources of reference

A detailed commentary on the history and distribution, geography and hazards presented by Shrink/Swell Susceptible Soils in the UK can be found in 'UK Geohazard Note, Ground Shrinking and Swelling May 2012 by BGS' and 'BRE 1993 Low-rise buildings on shrinkable clay soils: BRE Digest, Vols. 240, 241 and 242. CRC, London' publications.

Part I Highways England's approach to managing Shrink/Swell Susceptible Soils risks

Shrink/Swell Susceptible Soils refers to material with high potential to decrease/increase in volume associated to when its moisture content decreases/increases. Shrinking or swelling may occur as the result of a single event, or repeatedly through cyclical (seasonal) variations. The background of Shrink/Swell Susceptible Soils and its impact on the SRN is summarised in Part III.

Crack in clay slope on M11
Source: HAGDMS

The risk presented by Shrink/Swell Susceptible Soils is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Shrink/Swell Susceptible Soils and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.

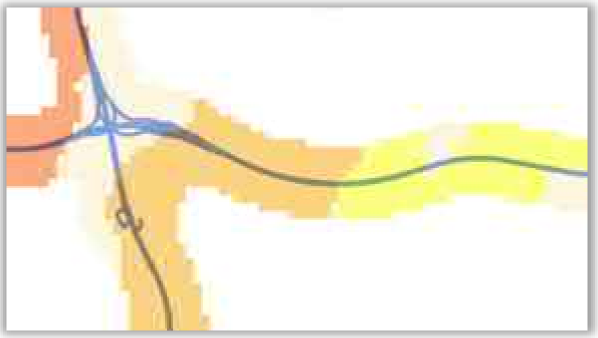
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Shrink/Swell related risk. Consideration of the hazard posed by Shrink/Swell Susceptible Soils to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England Shrink/Swell Hazard Rating Map



Section of the Shrink/Swell Hazard Rating map

An HE specific Shrink/Swell Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Shrink/Swell Susceptible Soils obtained from the British Geological Survey. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Shrink/Swell Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Shrink/Swell Susceptible Soils along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Shrink/Swell Susceptible Soils poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

Part II Using the Shrink/Swell Hazard Rating map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Shrink/Swell Susceptible Soils along the SRN, and these present different risks to the network:

- Embankment or cutting deformation and cracking
- Soil creep on steep slopes
- Heave/settlement damage to pavement structure foundations, or buried utilities

Shrink/Swell behaviour is also a potential trigger to a natural slope or engineered soil slope landslide – see corresponding hazard guidance notes.

2. Consider potential external triggers of the hazard event

By identifying specific triggers of a hazard event, they can then be monitored to improve the management of the risk. The following are potential external triggers of a Shrink/Swell hazard event:

- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Change in surface water flow, drainage and landscaping (including paving)
- Leakage / flooding from water mains, sewerage or drainage
- Water ingress from service duct backfill which may act as a water reservoir
- Prolonged periods of drought
- Seasonal variations in rainfall and vegetation growth
- Planting, removing, or severe pruning of trees, (particularly relevant to high water demand trees)
- Dynamic loading of pavement (when combined with other triggers)

Note that the above weather related triggers (surface or groundwater flooding, hot/dry summers etc.) may be exacerbated by climate change.

3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Shrink/Swell Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Shrink/Swell Susceptible Soils, compared to the rest of the network. The Shrink/Swell hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of a Shrink/Swell related hazard, the following factors are relevant:

(A) The likely presence of Shrink/Swell Susceptible Soils

- Refer to the Shrink/Swell Hazard Rating map
- Presence of 'high plasticity' clays[*] – where not specifically identified by the Shrink/Swell Hazard Rating map (e.g. that may have been used in the construction of embankments)

(B) Inherent properties and characteristics

- Slope gradient – steeper slopes have a greater tendency for soil creep through Shrink/Swell cycles
- Depth to Shrink/Swell Susceptible Soils – deeper soils are less affected by seasonal variations, and there is less impact for surface assets
- Former vegetation (type, density, age) – where the SRN built is on top of formerly vegetated soil, the water demand of the removed vegetation indicates the extent to which the soil may swell

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- High seasonal weather variations including unusually dry summers (and which are likely to become more extreme with climate change)
- A history of flooding (also refer to the groundwater flooding hazard guidance note)
- Planned / ongoing construction activities that affect soil moisture, e.g. significant excavation or dewatering, vegetation management
- Presence of drainage in poor condition (e.g. aged or damaged through construction-induced ground movements) and therefore may leak or cause local flooding
- Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)
- Presence of other artificial ground water management, e.g. soakaways, irrigation

An understanding of the likelihood of a Shrink/Swell hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where HAGDMS contains report records[†] demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.

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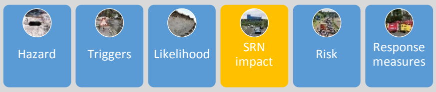
[*] Plasticity is a geotechnical property of cohesive materials indicating the variation of moisture content the soil can hold. 'High plasticity' soils have a greater capacity to absorb or expel water (and thereby swell or shrink) than 'low plasticity' soils.

[†] The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The size of the potential impact e.g. the extent of the susceptible soils or extent of high water demand tree or hedge line. Former tree or hedge boundaries are also susceptible to swell behaviour.
- The location of the potential impact and the type of asset (earthwork, pavement, structure, buried utility) affected – pavement deformation and cracking in a main running lane presents a higher performance impact than beneath a hard shoulder or beyond.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the potential disruption impact on the SRN.
- Reduction in effective service life of pavement – through (cyclic) softening of the pavement foundations

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement shows early signs of a failure.
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Shrink/Swell Susceptible Soils presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.

- **Response and recovery:** To manage the Shrink/Swell Susceptible Soils hazard, development of response plans is recommended for areas of known risk. Response plans should include:
  i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
  ii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).
  iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. Changes are unlikely to be rapid and this should influence the responses proposed. The time and resources that would be required to implement the options should also be considered.
  iv. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS.

Part III Shrink/Swell Susceptible Soils across England

1.0 Shrink/Swell behaviour in soils

The BGS provides the following context relating to the hazard of Shrink/Swell Susceptible Soils:

Shrink-swell occurs as a result of changes in moisture content of clay-rich soils. This is reflected in a change in volume of the ground through shrinking or swelling. Swelling pressures can cause heaving, or lifting, of structures, whilst shrinkage can cause differential settlement.

The amount by which the ground can shrink and / or swell is determined by the water content in the near-surface and the type of clay. Fine-grained clay-rich soils can absorb large quantities of water after rainfall [or other water inundation events] *becoming sticky and heavy. Conversely they can also become very hard when dry, resulting in shrinking and cracking of the ground. This hardening and softening is with associated volume change, is known as shrink-swell.*

Shrink / Swell damage to A2, Canterbury, 2015. Source: HAGDMS

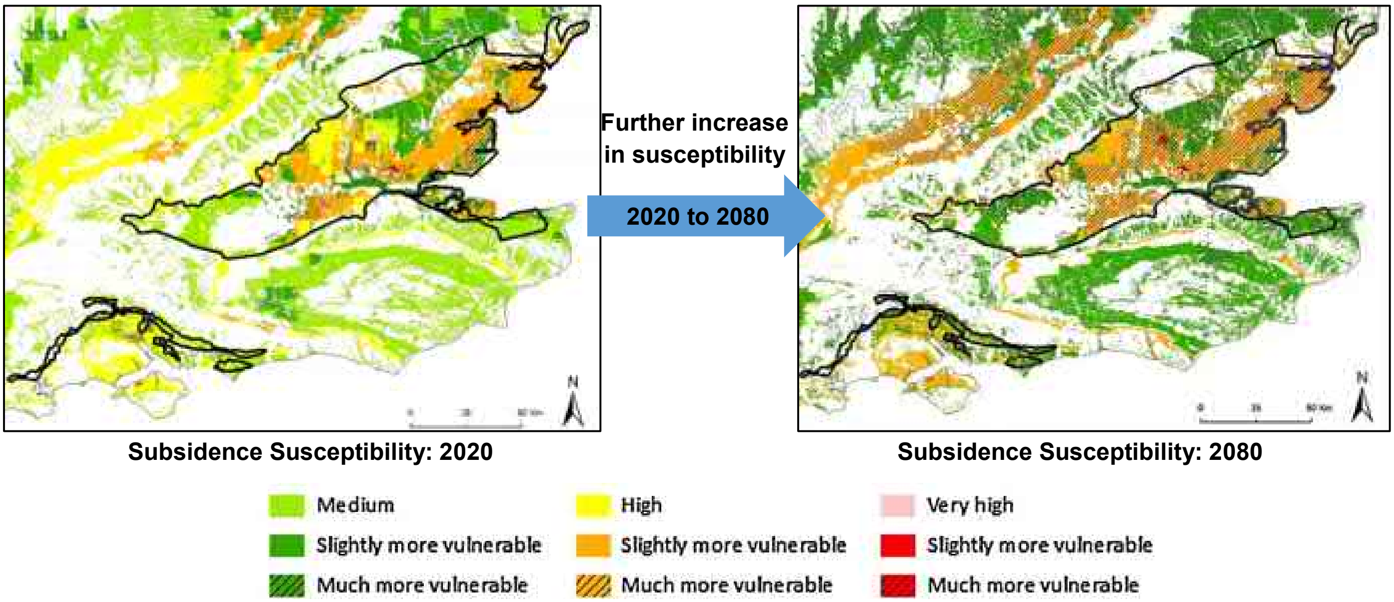
The south-east of the country is significantly more susceptible to shrink/swell due to their relatively younger 'clayey' formations (e.g. London Clay, Oxford Clay, Gault Clay, Kimmeridge Clay). In contrast, other parts of the country have older clayey formations that have become much stronger 'mudstones' which are less able to absorb/lose moisture.

The presence of shrinkable clay does not always present a hazard. As described by BGS, in some areas such as The Wash and under the Lancashire Plain, these deposits are buried deep beneath other soils that are not susceptible to Shrink/Swell behaviour. However, other superficial deposits such as alluvium, peat and laminated clays can be susceptible to soil settlement and heave (e.g. in the Vale of York, Pennine valleys and the Cheshire Basin).

2.0 Climate change

The impact of climate change is predicted to be significant in the UK climate. Extreme weather in today's climate is likely to become much more commonplace in the near future. Summers will be drier and hotter, and with greater rainfall variability, so the magnitude, the frequency and the impact of the Shrink/Swell hazard is likely to increase.

Harrison et al. (2012) produced model maps for the south-east of England by combining the BGS GeoSure dataset, and applying the UK Climate Projections (UKCP) scenarios for rainfall and temperature changes for the next century. The maps (below) predict the potential increase relative to 2011 in the degree of susceptibility of the region to Shrink/Swell Susceptible Soils and subsidence/settlement for the years 2020s (left) and 2080s (right) that may be caused by the climate change. It suggests that in the future there will be increasing susceptibility to Shrink/Swell behaviour.



Increase in Subsidence susceptibility relative to 2011 (UKCIP02 climate prediction high emissions scenarios)
Contains public sector information licensed under the Open Government Licence v1.0. UKCIP 2011. Coastline courtesy of The Digital Chart of the World (DCW); from: Harrison et al., 2012.

3.0 Shrink/Swell Susceptible Soils and the Strategic Road Network

The hazard posed from the potential of Shrink/Swell Susceptible Soils ground beneath the Highways England estate is that it may cause desiccation cracking, leading to water ingress and slope failure. In addition in can also cause damage to the road surface, foundations, or buried utilities. These Shrink/Swell deformations could be caused through:

- unidentified (at time of construction), and hence unmanaged areas susceptible to Shrink/Swell
- inadequate treatment methods (compared to current practice/guidance), which may correlate to the approximate date of treatment
- the treatment measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. changes in water content) or have reached the end of their serviceable life

Shrink/Swell is typically a gradual phenomenon, and causes damage gradually. There are usually visible indications of an issue long before any large-scale failure occurs. However, it is important that signs are recognised and addressed as, if left unchecked, they may develop into larger slope failures – see the Engineered Soil Slopes hazard guidance note.

The hazard that Shrink/Swell Susceptible Soils presents to the SRN is further significantly influenced by the geology, soil properties and water regime of the area. Broadly speaking, the hazard type can be influenced by the following factors:

- Type of material – all clays are susceptible to some shrinkage and swelling due to changes in moisture content. However, those with a higher proportion of expansive clay minerals, such as smectite, are more prone. This is indicated by a high ‘plasticity index’ (a geotechnical property of clays derived from laboratory testing)
- Thickness of the susceptible soils
- Cover to the susceptible soils – shallower soils are more prone to Shrink/Swell volume changes. High plasticity soils when at depth can exhibit little change and not necessarily constitute a hazard
- The potential change in groundwater levels, and the amount and distribution of rainfall (climate change will lead to a significant increase in the damage done by the shrinking and swelling behaviour at susceptible areas).
- Type of vegetation – extraction of water from the soil by vegetation depends on the species, size and density of the trees / other vegetation. Trees with higher water demand exacerbate seasonal variations because, in periods of dry weather, as the natural soil moisture lowers they draw still more water from the ground, yet in the wetter

winter months when the soil has higher moisture content, their water demand is much reduced, being out of their growing season

- Vegetation management – where vegetation has been removed and water is no longer being drawn up through roots, soil susceptible to Shrink / Swell will heave as it establishes a new moisture equilibrium. In addition, the decay of the root system also creates additional pathways for water ingress within the soil, encouraging further and more rapid swelling.

4.0 Key references and further information

Shrink/Swell Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Shrink/Swell Hazard Rating data description, 2017

Harrison, A M, Plim, J F M, Harrison, M, Jones, L D, and Culshaw, M G. The relationship between shrink–swell occurrence and climate in south-east England, 2012, Proceedings of the Geologists' Association, Vol. 123, 556–575.

British Geological Survey, UK Geohazard Note: Ground shrinking and swelling, www.bgs.ac.uk, 2017

British Geological Survey, Shrink-swell and climate change, www.bgs.ac.uk, 2017

Buildings Research Establishment, BRE Digest 240: Low-rise buildings on shrinkable clay, 1993

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk

H. Knowledge Transfer Sheet

Define

The aim of the task was to improve the knowledge of ground-related hazards that may impact the Strategic Road Network (SRN). The task exploited the hazard data held within the Highways England Geotechnical and Drainage Data Management Systems (HAGDMS/ HADDMS). Throughout the task expert opinion was a key input and regular stakeholder meetings utilised specific expert knowledge to steer the analysis and final deliverables.

Deliverables

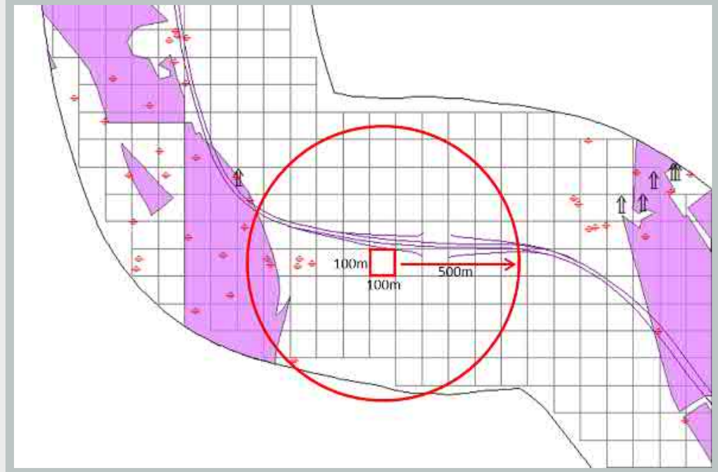
The task delivered a suite of 10 hazard maps which are now hosted online on HADDMS/HAGDMS and Highways England's internal GIS (HAGIS). Documentation of the task included a project initial document, a series of data description documents to accompany each hazard map and a final project report.

Planned benefits

The suite of hazard maps will enable a clear understanding to Highways England staff of the potential ground related hazards within the vicinity of the SRN. The supporting data description documents provide information on the derivation of the maps and the currency of the data that went into their production as well as acting as a signpost to Area's Geotech Advisors.

Methodology

The methodology used expert geotechnical understanding and a proven GIS capability to produce the hazard map suite. The potential ground related hazards were chosen and prioritised with the stakeholder group before production. All potential third party datasets available on HAGDMS were reviewed along with data held within the HAGDMS inspection and report archives. The datasets used in the map creation included several from the British Geological Society, The Coal Authority, The Environment Agency and HAGDMS.



The majority of the hazard maps employed a GIS workflow that ran a spatial query of multiple datasets related to each hazard type across the SRN. This result of which was then used to calculate a hazard category derived from an algorithm that used weightings from expert opinion on the type and frequency of the data. The validation of the mapping products utilised industry experts, data providers, and the Highways England stakeholder group to ensure the best possible product.

Findings and Analysis

The GIS analysis was run on 10 different ground related hazard types, these were: Coal Mining, Non-Coal Mining, Dissolution Features, Brine Extraction, Natural Landslides, Compressible/Collapsible Ground, Shrink/Swell, Landfill Sites, Rock Slope Hazard Index and an update to the Slope Hazard Rating. A screenshot of the Coal Mining hazard map hosted online on HAGDMS can be seen below showing a range of hazard categories across the area.

The analysis also included a research and development phase to advance the produced hazard maps. This involved the introduction of asset information to explore the potential "vulnerability" of the SRN to a particular hazard type. This was trialled with the Non-Col Mining Hazard. It was agreed with the stakeholders that at the current stage of development the pilot "vulnerability" map should not be implemented for use by the Highways England Community. However, this facilitated important discussion and scope for future development.

Conclusions and Recommendations

The hazard maps should be used as part of a high level hazard assessment. They do not replace the need for detailed site assessment and no parity should be drawn between hazard categories for different hazard types. The maps along with the data description documents and associated resilience guidance documents should be used to educate the user and act as 'Tier 0' information. The mapping suite does not convey the consequence or risk that the hazards may present.

Related projects

- Task 408: as-built geotechnical asset data
- Task 197: development of the Slope Hazard Rating
- Task 434: Drainage cross-asset risk
- Geotechnical resilience enhancement tasks
- Special Geotechnical Measures tasks

Next steps

- Completion of vulnerability maps
- Matrix of interactions between hazards and SGMs and initial map generation
- Further development and refresh of Slope Hazard Rating
- Initial assessment of residual geotechnical hazard

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