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.

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:

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

- 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:

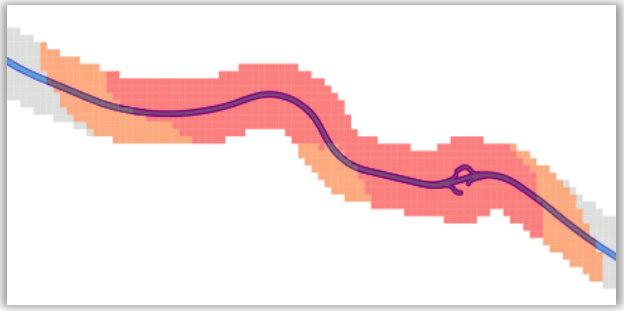
HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register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

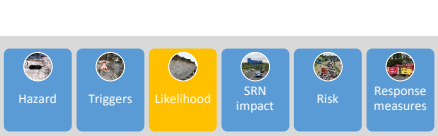
2. Consider potential external triggers of the hazard event

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.



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

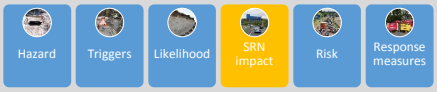
- A hydrogeological regime allowing fresh water flow through extraction cavities – enabling further salt dissolution
- Brine springs – indication of further natural salt dissolution

(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.

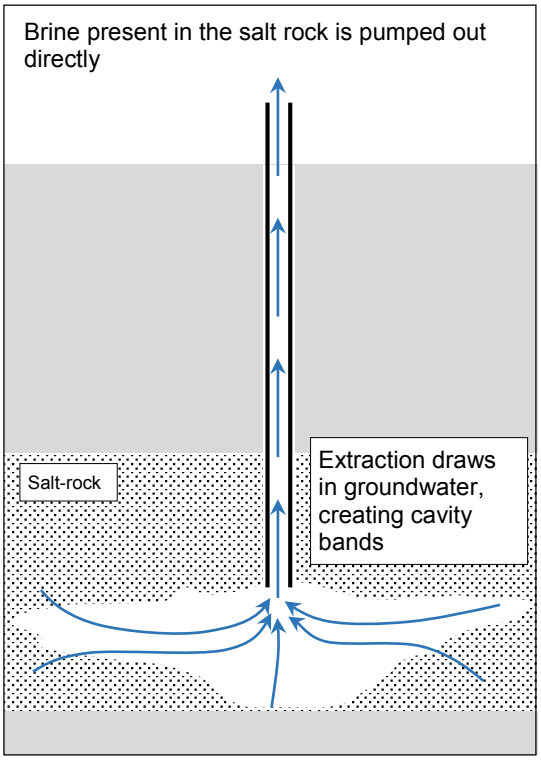
British salt extraction dates back to Roman times, and possibly before. Place names ending in 'wich' or 'wych' indicate natural brine springs, and it is around such springs that the towns of Droitwich, Nantwich, Northwich and Middlewich developed in Cheshire and West Midlands.

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.*

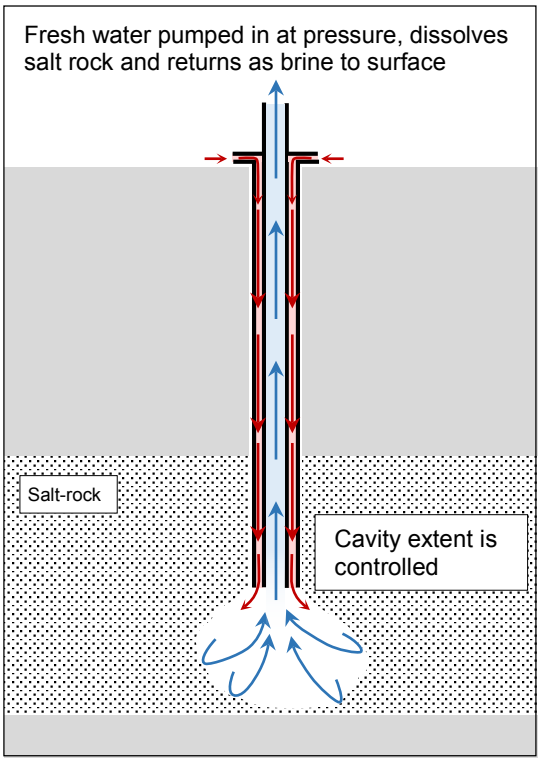
Wild, or uncontrolled, brine solution mining involved sinking boreholes and shafts down to the wet rock-salt surface and pumping the brine out [see figure: top]. *This wild brine method induced the flow of brine towards the extraction boreholes and linear subsidence belts spread out from the boreholes. 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*.

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