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:

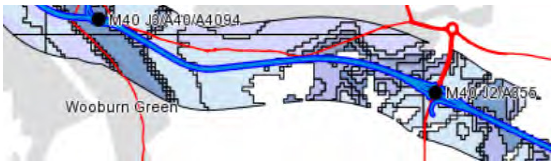
HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register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

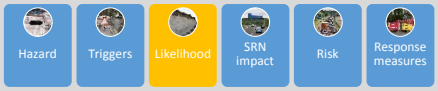
- Heavy or prolonged rainfall
- Changes in groundwater flow, e.g. through construction, long-term pumping (or cessation of pumping), and damming.

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.

* 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).

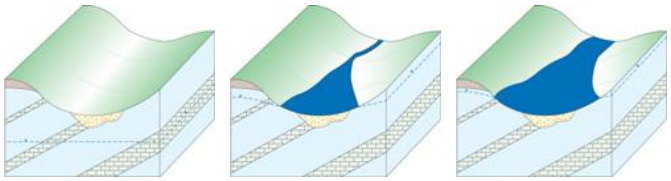
iii. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.

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*.

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