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Rapid evidence assessment and overview of groundwater flood risk management in England

FRS19217

Flood and Coastal Erosion Risk Management Research and Development Programme

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

This rapid evidence assessment (REA) was commissioned to bring together information about groundwater flood risk management in England. Surveys and interviews provided additional evidence and substantially more information than a typical REA (Collins, 2015). It follows the responsibility for groundwater flood risk management being divided, with the Environment Agency having a strategic role and lead local flood authorities (LLFAs) having a management role.

This project report provides a baseline understanding of groundwater flood risk management to support the National Flood and Coastal Erosion Risk Management Strategy for England (2020) with regard to groundwater flooding. It therefore focuses on England only, however the general findings may be of interest more widely.

The research carried out a comprehensive literature search of published peer reviewed literature and grey literature on groundwater flood risk management. Unpublished literature was also included where this was available. A questionnaire was sent to risk management authorities and partner organisations who have roles in groundwater flood risk management. Semi-structured stakeholder interviews supported this.

The research was carried out to answer the primary question:

'What are the current approaches to groundwater flood risk management in England?'

Six secondary questions, including 14 sub-questions were included in the review. These questions covered topics of governance, incident recording, risk assessment, forecasting and mitigation. The final question considered the main gaps in evidence against statutory duties and the ambitions of the Flood and Coastal Erosion Risk Management Strategy (2020).

A summary of the findings under these topics is provided in this executive summary.

The main report that follows presents the evidence gathered and concludes with recommendations for future work to fill the data, knowledge and process gaps identified by the research.

1 What are the current approaches to groundwater flood risk management in England?

There is evidence of approaches across all the areas of this investigation:

- governance arrangements
- recording flood incidents
- risk assessment (modelling and mapping)
- forecasting and warning
- implementing mitigation measures

The information gathered for this study shows that there is variety in the processes, systems, and practices used. The main findings against the areas of this investigation are summarised in the following sections.

1.1 Groundwater flood risk management governance

The evidence indicates that a wide range of parties are involved in groundwater flood risk management, not just the organisations with a statutory responsibility.

Managing groundwater flooding cannot easily be separated from other sources of flooding so risk management authorities (RMAs) do need to work together to manage groundwater flood risk. For example, water that starts out as groundwater can flow into rivers and drainage networks, resulting in flooding from rivers and surface water, which means several organisations with statutory duties for managing flood risk need to coordinate plans and responses. Interactions between the Environment Agency and LLFAs, and their interaction with other organisations involved in flood risk management should be reviewed and clarified. This would inform how groundwater flood risk management is carried out when groundwater is interacting with other flood sources.

The research shows there are various practices and approaches in groundwater flood risk management. It is recommended that existing informal literature regarding governance is reviewed, potentially expanded, updated and published, and that further research is carried out on whether the current groundwater flooding governance arrangements, set out in the Flood and Water Management Act (FWMA) 2010, need to be reviewed in light of developments in the last 10 years.

1.2 Recording groundwater flooding

There is evidence of LLFAs and councils collecting flood records in systems such as GIS databases. Although the source of flooding can be included in these reports, the source is often not known or not explicitly stated as being caused by groundwater flooding. This can be due to a lack of understanding of groundwater flooding or difficultly in separating it from other sources of flooding. This is likely to lead to a general under-reporting of groundwater flooding incidents. Guidance on identifying and reporting groundwater flooding, including being able to report flooding due to multiple (or uncertain) sources, would be useful for consistency in reporting.

There is evidence that information is gathered by various organisations during and after groundwater flooding incidents, such as records collated by water companies and Highways England. However, these records are often not widely available and specific to local RMAs. There is evidence of increasing collaboration, such as the use of Highways England GIS layers for flood reporting by Hampshire County Council.

There is no national system or process for collecting and collating groundwater flood records (or in fact records from any flood source). Local examples, such as the 'FORT' web portal scheme developed in Wessex, are being used to record groundwater incidents across the country at a county level and could be applied more widely.

Recording consistent information about groundwater flooding in systems that are accessible to all parties involved in groundwater flood risk management would support coordination, planning and response. Guidance on what information to record and how would be beneficial. Developing a historical groundwater flood map could bring together existing groundwater flood records.

1.3 Groundwater flood risk assessment

There are many spatial datasets of groundwater across England, at the national and local scales.

The current national maps of groundwater flood risk are commercial products and not freely available. This also means evidence is not accessible to robustly appraise the methods used, and therefore it is difficult to make a detailed accurate assessment of their suitability and accuracy. As a result, older products are used, like the Environment Agency's 'Areas Susceptible to Groundwater Flooding' maps. These can be useful especially when combined with surface water flood maps, to indicate where groundwater may pond or flow when emerging from the ground.

It would benefit groundwater flood risk management if a national groundwater flood map was freely available to improve the understanding of risk, under both present and future climate scenarios. This could provide the basis for groundwater flood risk management decisions, and it is recommended that the options for providing free groundwater risk information are explored. Maps of areas where groundwater flooding has occurred would be very useful for providing information to the public (especially during a groundwater flood event), for planning purposes and for RMAs.

National maps are not enough as they often cannot adequately capture the local specific nature of groundwater flooding. This depends on specific geology, catchment rainfall response, particular hydrogeological conditions, topography and drainage. Local risk assessment modelling is required to provide this level of detail. These generally require high levels of data input and funding to initially produce. Some LLFAs in places like London for example, have produced their own spatial data. These combine the most useful parts of several national mapping products to develop a product specifically suited to their situation.

Risk information doesn't have to be in the form of maps and models. There is considerable groundwater monitoring data available across England that helps practitioners understand flood risks. This does not translate directly into a map of Trigger levels can be used with modelling to create spatial risk information to indicate where groundwater flooding will occur.

Further work is required to determine how groundwater flood risk mapping could be improved to give a better understanding of likelihood and consequences, and therefore a picture of risk. The Environment Agency is planning to undertake a new national flood risk assessment that could provide the framework to undertake this.

1.4 Groundwater flood forecasting and warning

A number of forecasting systems are used. Much of the current forecasting and warning is carried out based on borehole data, combined with rainfall data. These are provided mainly by the Flood Forecasting Centre (with groundwater flood forecasting services provided by GeoSmart) or by the Environment Agency, in areas such as Wessex (where a spreadsheet forecasting tool is used). These systems require a good coverage of borehole telemetry data and rely on matching trigger levels in boreholes to initiation of nearby groundwater flooding. In areas that flood fairly regularly an accurate predictive system can be obtained. In these areas, there is a high level of local knowledge that can help understand and manage groundwater flooding. There are improvements to be made in the number of monitoring locations to cover areas currently not provided with forecasting, and monitoring locations need to be targeted in distinct groundwater response areas.

A hosting solution and funding for groundwater flooding within Environment Agency forecasting systems needs to be identified. The Wessex area maintain their spreadsheet-based groundwater flood forecasting model, it is not integrated to any national systems and does not run automatically. Environment Agency hydrology teams have CATCHMOD models, but these are not hosted anywhere either and are not set up to update automatically. Options for the future could include putting the groundwater flood forecasting models onto the Incident Management Forecasting System (IMFS) or including them in the future update to the National Groundwater Modelling System (NGMS). Hosting solutions would need funding. Currently the models are resourced by staff time which is thought to be unsustainable given other budget pressures (steering group feedback, 2020).

It is recommended that the current groundwater forecasting methods are reviewed and appraised to determine which represent best value for money; allow cross organisation working, collaboration and learning; and allow local information and data to be incorporated to help improve groundwater flood risk management.

Clearer information regarding where groundwater flood warnings and alerts are provided is needed, and this should be publically available. There is also some uncertainty in how groundwater flood warnings are issued and removed. It was noted that when fluvial flood risk is no longer an issue the flood alerts may be removed, even though groundwater flooding may still be a risk due to the delayed response. The approach used in Wessex is co-ordinated with fluvial catchments, where watercourses are monitored to assess when these high groundwater levels are unlikely to be a groundwater flood risk.

It is recommended that options are explored to integrate groundwater flood warnings into the main Environment Agency flood warning systems provided for fluvial flood warnings. Adding further boreholes on telemetry to improve access to online data should be considered. This will improve coverage and accessibility for groundwater flood forecasting.

1.5 Groundwater flood mitigation

There are case studies and evidence of groundwater flood mitigation measures being funded and implemented. However, there is very limited guidance on how to develop groundwater flood schemes. There is particular uncertainty regarding pumping of groundwater at property level and wider to reduce flooding, including options for discharge, licence implications and options for using existing infrastructure.

Responses to groundwater flooding incidents should be planned proactively so that the implications of the response measures can be properly considered in advance. It was highlighted that current property level resilience measures (such as pumping from basements) are generally only curing the symptoms, and not really effective for the community as a whole. Groundwater mitigation methods such as pumping in one location can impact on flooding in another, such as ponding of water, overwhelming drainage systems and exacerbating existing flooding within main rivers and ordinary watercourses. Evidence is needed on the quantitative benefits of pumping, to support any plans or strategies that identify it as a mitigation intervention. This is information is particularly crucial for informing multi-agency flood plans where pumping is needed as part of the emergency response to flooding. The regulatory and licensing situation regarding pumping groundwater flood waters also needs to be clarified.

The General Aquifer Research Development and Investigation Team (GARDIT) scheme, which reduces rising groundwater levels beneath London, is an example of high level cooperation between organisations. However, there is no guidance, regulatory mechanism or framework for carrying out similar work elsewhere. This would be useful for long-term management of rising groundwater levels from mine workings and in other urban areas, which is becoming a more prominent issue. Short-term schemes might be more appropriate for managing seasonal groundwater flooding, but may need to be in place for a number of months.

It is recommended that guidance is developed on how to implement groundwater flood schemes both at a property level and on a larger scale. This needs to support future cost-benefit assessments of groundwater flood mitigation and warning schemes. This could begin with sharing how groundwater flood liabilities and damages have been estimated by different organisations to share good practice. Consistency should be encouraged to improve how economic and financial impacts of groundwater flooding are assessed when there is limited data, and used to support funding bids and investment decisions.

There is limited evidence of how groundwater flood risk is being addressed within spatial planning beyond the statutory duties of the LLFAs under the FWMA 2010. The evidence review identified gaps in the detailed assessment of groundwater flood risk, and in understanding how other sources of flood risk are addressing interactions with groundwater flood risk. There was a perceived lack of assessment of groundwater flooding risk within development planning, and groundwater flooding was often being completely missed within planning application submissions. There are some examples of groundwater flood risk is being considered within strategic flood risk assessments (SFRAs) but there is little consideration or understanding of the impacts of climate change on groundwater flood risk. The impacts, if described at all, were generic trends of potentially increased groundwater levels due to increased precipitation during winter months. There was little evidence that the impacts of sea level rise on rising groundwater at the coast had been considered. It is recommended that good practice is shared across local planning authorities and further guidance is provided.

Planning and designing infiltration sustainable drainage systems (SuDS) in areas susceptible to groundwater flooding or groundwater protection zones needs careful consideration. Sites with a high water table are susceptible to flooding and may also damage deep SuDS components. If the surface of an infiltration system is too close to the water table a rise in water levels during particularly wet periods could cause groundwater to enter the infiltration system, reducing the amount of storage available. It could also cause floating of storage tanks. Groundwater must also be protected from contamination and pollutants (CIRIA, 2015) so SuDS need to be lined in areas where this could be a risk. If not planned and designed with this in mind, SuDS schemes can potentially increase groundwater levels and increase flood risk on, or off, the site. Some guidance on the impact of infiltration SuDS on groundwater flooding exists, and this could be expanded.

The evidence gathered indicated that there are gaps in knowledge, processes and data for managing groundwater flood risk. Better understanding groundwater flooding mechanisms and proactive management, with plans to mitigate and build resilience to adapt to flooding would improve this. Providing further guidance and support in this area may inspire action to improve resilience to groundwater flooding.

1.6 Ambitions of the National Flood and Coastal Erosion Risk Management Strategy

The National Flood and Coastal Erosion Risk Management (FCERM) Strategy (2020) outlines the statutory duties and ambitions for managing flood and coastal erosion risk in England for all sources of flooding.

The high-level ambitions focus on resilience and understanding how the risk and places will change in the future. One of the largest gaps in evidence in realising the ambitions of the FCERM strategy is the lack of understanding of groundwater flood risk will change in the future with climate change. This information is not available at a national scale. Furthermore, climate change risks and projections are not commonly integrated into groundwater flood risk assessments, or seen as being explicitly considered within SFRAs or flood risk management plans or strategies.

The research has shown that there are various organisations collecting information on groundwater flooding and using different approaches to identify, assess, plan for and mitigate against groundwater flood risk. Consequently, there is great variety in how the Environment Agency and the LLFAs co-operate and share groundwater flood risk information across areas, however, the survey results showed processes are not hindering progress. Legislation and funding were common constraints to delivering groundwater flood risk management and this should be further explored to determine why and what could be improved.

Capacity building in RMAs should be encouraged through peer to peer learning and sharing of good practice. This should be supported by specific training to develop groundwater flood risk specialists within LLFAs, the Environment Agency and other organisations to ensure that flood risk management and spatial planning adequately assesses, plans for, mitigates and responds to groundwater flooding.

Recommended future actions are summarised in section 7.3.

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Contributors:

- Those who participated in stakeholder interviews:
    - Anglian Water (Strategic Flood Risk and Operational Managers)
    - Environment Agency (Flood Risk Resilience at Wessex)
    - JBA Consulting (Technical Director of Hydrology and Hydrometry)
    - GeoSmart Information Ltd (Managing Director)
    - British Geological Society (Principal Groundwater Modeller)
    - Environment Agency (Senior Technical Specialist for Groundwater Resources – Thames area)
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Reviewers:

- Stephen Buss Environmental Consulting
- Representatives from the Hydrogeology Group, a special interest group within the Geological Society of London (Alex Davies, Mark Howarth, Glen Westmore, Simon Cook and Mark Lees).

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2 Introduction

Different parts of England have experienced groundwater flooding in recent years (2000 to 2001 2007, 2013 to 2014 and 2020). During this time, roles and responsibilities have changed and practices developed. In 2010, responsibility for groundwater flood risk management was split, with the Environment Agency having a strategic overview role and lead local flood authorities (LLFAs) having a management role. Until now, a review of who does what and where for groundwater flood risk management has not been available. The aim of this project is to provide an overview of current groundwater flood risk management to support the strategic and practitioner roles by raising awareness and sharing current practices. The research also identifies gaps in knowledge and operational activity that can be targeted in the future.

This section provides an introduction to the project and the evidence review process. It also describes how groundwater flooding happens in order to set the context for the rapid evidence assessment presented within later sections of the report.

2.1 Project aim

The aim of the project is to capture a picture of current practice for groundwater flood risk management in England, to build up a national perspective of the activities being carried out. This project report provides a baseline understanding of groundwater flood risk management to support the Flood and Coastal Erosion Risk Management (FCERM) Strategy for England (July 2020) with regard to groundwater flooding.

2.2 Scope

The project has been carried out mainly for the Environment Agency to inform the FCERM strategy and future research projects. This report and associated summary will also be shared with risk management authorities (Environment Agency, LLFAs (including county councils, unitary authorities, London borough councils and metropolitan borough councils), highway authorities, internal drainage boards, and water companies) to help build capacity in groundwater flood risk management and to share good practice.

The project focuses on England, although there is some mention of the wider international perspective.

The project broadly follows the method of a rapid evidence assessment (REA) (Collins and others, 2015) but is supported by consultation to provide an overview of the current practices, rather than a critique of current evidence for groundwater flood risk management.

3 What is groundwater flooding?

The project found that various definitions of groundwater flooding are used. A variation of the following British Geological Society (BGS) definition[1] was mainly used, and has been used for this study. Groundwater flooding is:

"The emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded".

There is normal variation in groundwater levels due to rainfall and seasonal recharge over the autumn to spring. Groundwater flooding occurs when the groundwater table rises to higher levels than normal. High groundwater levels may impact on sub-surface structures, for example, basements, tunnels or underground services. Groundwater can also emerge at the surface as springs, ponds or streams in locations which are normally dry. This includes alluvial groundwater flooding and clear water and aquifer flooding.

Natural seasonal waterlogging or poor drainage are not defined as groundwater flooding. Within this project, areas where groundwater levels are naturally high, such as in low-lying fen areas and areas of pumped drainage, have not been considered as areas of groundwater flooding. Additionally, flooding from groundwater-fed rivers would be considered fluvial flooding rather than groundwater flooding.

Groundwater flooding is a complex issue. It can interact with and be interrelated to different forms of flooding, such as from rivers or surface water. It can also interact with tunnels, sewers and other sub-surface infrastructure. Changes to the amount of groundwater taken for industrial use or public water supply can also affect groundwater levels. So, groundwater flooding can rarely be considered on its own without considering these other factors.

3.1 Causes of groundwater flooding

The causes of groundwater flooding are discussed in detail in Jacobs (2007) 'Making Space for Water' (HA5, consolidated report). These are summarised below.

3.1.1 Prolonged heavy rainfall

The main cause of groundwater flooding is prolonged heavy rainfall. More specifically, prolonged heavy effective rainfall which is the proportion of rainfall that is not taken up by plants and does not become run-off, and so infiltrates the ground to recharge groundwater. The critical duration of rainfall required to initiate aquifer groundwater flooding has been investigated (Hughes and others, 2011). The catchment response time and critical rainfall duration is likely to vary between catchments. In the Pang catchment, 3 months' heavy rainfall was associated with groundwater flooding. The study indicated that exceptional daily rainfall is not required for groundwater flooding (Hughes and others, 2011). However, it may cause groundwater flooding in some cases, for example, during extreme summer rainfall events such as in 2012 (example given in the GeoSmart reports to the Flood Forecasting Centre from south-west

[1] BGS definition of groundwater flooding

England). This mechanism may become more important in future with climate change (Steering group feedback, 2020).

Fluvial flooding is not necessary for groundwater flooding to occur. The rainfall durations causing chalk aquifer groundwater flooding are typically much longer and less intense than those that would cause typical river or surface water flooding.

High initial (antecedent) groundwater levels are also not necessary for groundwater flooding (Hughes 2011). Flooding can occur both in areas with high antecedent groundwater levels and areas with unexceptional antecedent groundwater levels. The timing and volume of recharge can be more important than antecedent groundwater levels.

3.1.2 High river levels

Permeable superficial deposit aquifer flooding (PSD) is driven mainly by prolonged high river levels, although high rainfall (which drives the high river levels) will also contribute to high groundwater levels. Prolonged high river levels are seen in larger rivers with bigger catchments and longer typical flood durations. River valleys in these areas are typically associated with PSD flooding. Where this occurs, it is important to consider interactions between fluvial and groundwater flooding to understand risk and take measures to improve resilience.

3.1.3 Sea level rise

In coastal regions, sea level rise associated with climate change will result in rising groundwater levels and potential flooding of low-lying areas. This is likely to be combined with surface water flooding and drainage issues, particularly at high tides. Where this occurs, it is important to consider interactions between fluvial, tidal, surface water and groundwater flooding to understand risk and take measures to improve resilience. A detailed study of Portsmouth (JBA, 2020) has investigated groundwater flood risk at present and following sea level rise. Current work in progress by BGS and the National Trust is also looking into this issue (interview response, 2020).

3.1.4 Human-induced changes

Changes to the groundwater environment due to human activities can also trigger groundwater flooding particularly if the activity changes the permeability or storage of the sub surface.

Reduced abstraction, such as for water supply or dewatering, can cause groundwater rebound. This can be a significant issue in areas where the groundwater table was extensively reduced in the past due to groundwater abstraction for industry such as that experienced in the chalk aquifers around London (N. Hoad, 2020). Groundwater rebound also commonly occurs in areas of historic abstraction as part of coal mining operations, referred to as mine water rebound (see MetroGreen, Mott Macdonald (2019), for an example of a mine water rebound risk assessment).

Programmes (for example, infiltration reduction plans) to line sewers can result in rising groundwater levels. This causes a passive abstraction reduction, because groundwater is no longer infiltrating into sewers. This could cause flooding of below ground structures where sewers have historically drained significant amounts of groundwater. Also, where surface water sewers have reduced capacity due to groundwater ingress it can result in surface water flooding.

Flood risk mitigation measures need to carefully consider impacts on all sources of flooding to ensure that by reducing one source of risk, others are not exacerbated. For example, land management that encourages flood water to be stored (to reduce surface run-off to watercourses and increases the time to peak flood levels) in areas susceptible to groundwater flooding can increase recharge to aquifers and raise the local water table.

Similarly, groundwater flooding can be exacerbated where infiltration sustainable drainage systems (SuDS) are implemented inappropriately where the groundwater table is too high (e.g. within 1m of the ground surface) or the permeability is too low (http://www.groundwateruk.org/groundwater-issues-suds.aspx)[2].

Where human activity could impact on groundwater flows and volumes, it is important to consider interactions between sewer, surface water and groundwater flooding as well as the interactions with infrastructure below the ground to understand risk and take measures to improve resilience.

3.2 Mechanisms of groundwater flooding

Groundwater flooding mainly happens in response to intense or unusually long periods of rainfall, often (but not exclusively) combined with already high groundwater levels, usually during mid or late winter. It is most likely to occur in areas underlain by permeable rocks or aquifers. These can be extensive, principal regional aquifers, such as chalk or sandstone, or local sand or river gravels in valley bottoms underlain by less permeable rocks. Other causes of groundwater flooding include the rebound of the water table following reduced/cessation of abstraction or structures causing barriers to groundwater flow (RAB, 2016).

There are 4 main types of groundwater flooding in England (Hughes and others, 2011):

- type 1 – Extreme high intensity and/or long duration rainfall resulting in extremely high groundwater levels in an aquifer and groundwater emergence
- type 2 – Groundwater flow in permeable superficial deposits (for example, alluvial deposits) bypassing river channel flood defences
- type 3 – Cessation of groundwater abstraction for water supply or mining dewatering purposes and consequent groundwater rebound
- type 4 – Underground structures resulting in barriers to groundwater flow, reduction in storage, or pathways for groundwater flow, which result in rises in groundwater levels and discharge

These are illustrated in the conceptual models shown in Figure 3-2 to Figure 3-1.

[2] Further information on how SuDS should be planned and implemented appropriately is available from susdrain and in CIRIA 2015.

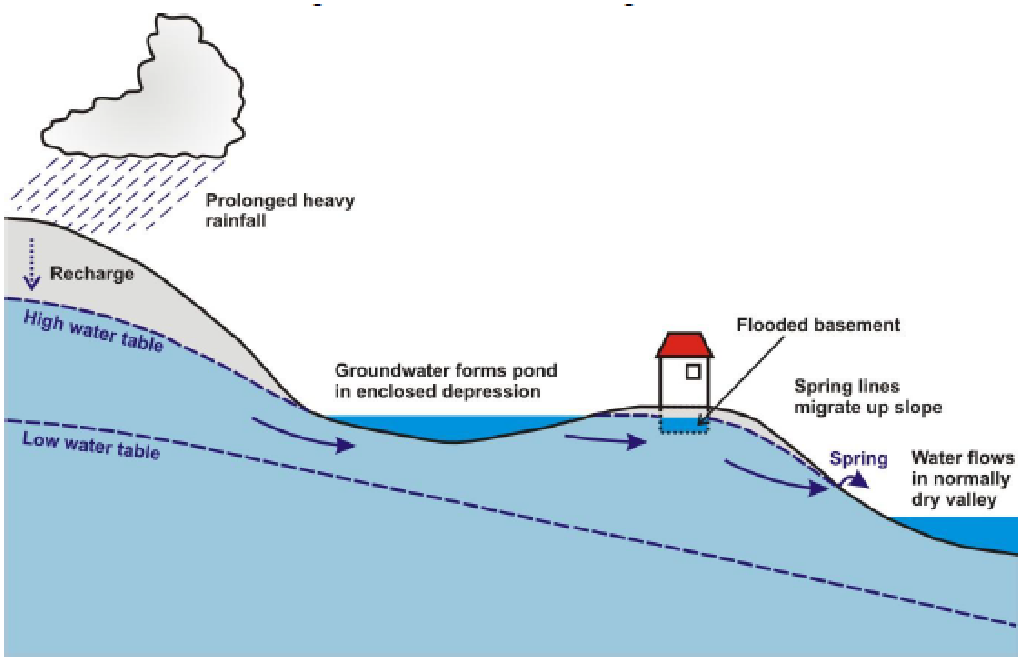

Figure 3-2 Type 1 - Extreme high intensity and/or long duration rainfall resulting in extreme groundwater levels in an aquifer and groundwater emergence. © JBA

Figure 3-2 describes type 1 groundwater flooding. Prolonged heavy rainfall may cause the water table to rise above the ground surface or above the floor level of underground structures such as basements. This type of flooding is most likely to occur in areas with a shallow water table or aquifers that are readily recharged but that have a low storage capacity. These aquifers will typically display large fluctuations in groundwater level. The chalk aquifer, in particular, shows this groundwater flooding response.

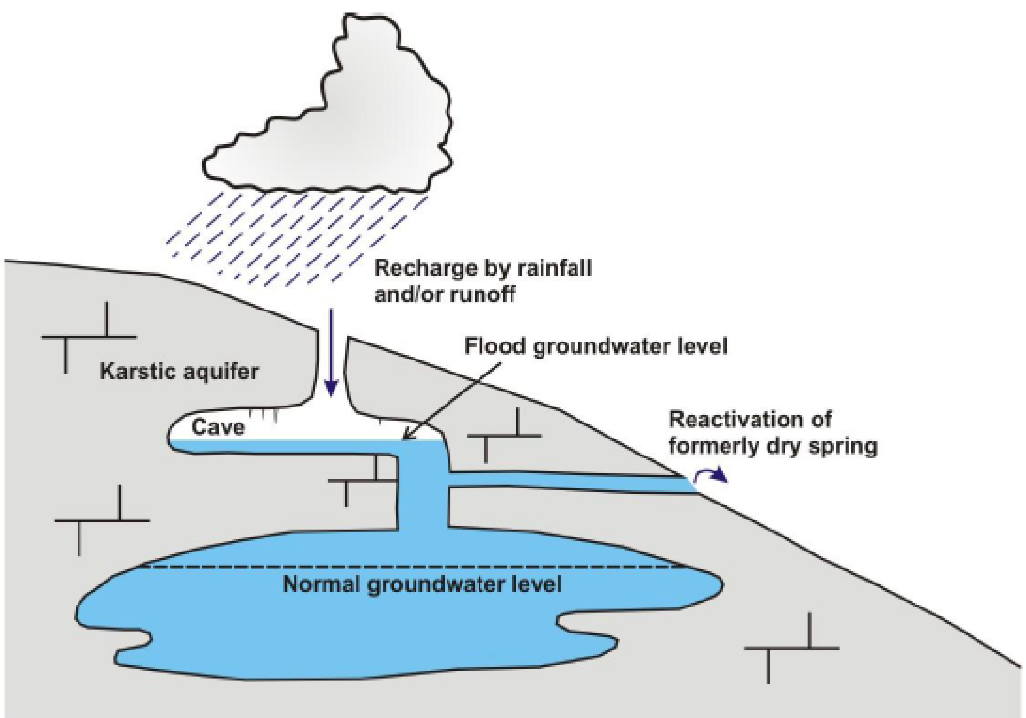

Figure 3-3 Type 1 - Mechanism of groundwater flooding in a karstic aquifer. © JBA

Figure 3-3 describes type 1 groundwater flooding in a karstic (limestone) aquifer. Prolonged heavy rainfall may raise the groundwater table, filling previously empty voids and activating preferential pathways. This can lead to previously dry springs being reactivated above the normal spring line. In the Cotswold Jurassic limestone extreme recharge leads to spring reactivation in deep valleys. Fracture flow within the limestone aquifer can lead to quick responses in spring reactivation and baseflow to rivers (the proportion of water in a river from the ground, rather than run-off) causing localised flooding to properties on valley sides and in valley bottoms.

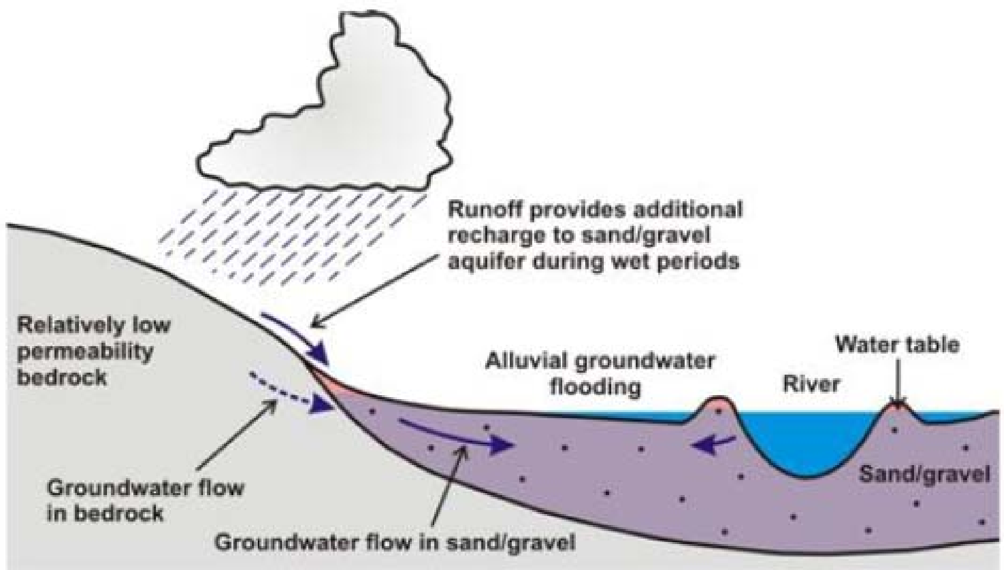

Figure 3-4 Type 2 – Groundwater flow in permeable superficial deposits bypassing river channel flood defences. © JBA

Figure 3-4 describes type 2 groundwater flooding. Groundwater flooding in permeable superficial (or alluvial) deposits occurs where permeable sediments are in hydraulic continuity with (connected to) a river, the sea or estuaries that sustains high groundwater levels within the aquifer for a long enough period of time. This can be common in places like the Thames Gravels. If groundwater levels exceed the elevation of the flood plain (or the floor level of underground structures such as basements), then groundwater flooding can occur. This can happen even when the river remains in-bank. This can be a problem in many permeable superficial deposits, particularly behind flood defences where the flow bypasses the defences by going underneath them.

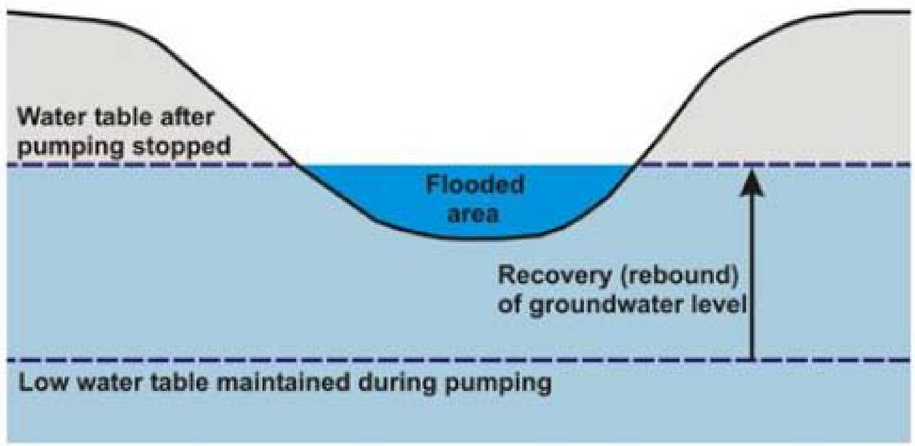

Figure 3-5 Type 3 – Cessation of groundwater abstraction for water supply or mining dewatering purposes and consequent groundwater rebound. © JBA

Figure 3-5 describes type 3 groundwater flooding. Generally this occurs where there is a cessation or reduction in pumping. This may occur widely in former industrial areas due to the loss of industry reducing demand, for example where groundwater abstraction or dewatering activities associated with mining are reduced. This will cause local groundwater levels to rise. Water could subsequently issue from previously dry spring lines, dry adits (horizontal passage leading into a mine for drainage) and shafts or enter previously dry opencast workings. This is known as 'mine water rebound'. Subsidence in mining areas has the potential to make groundwater rebound worse. Groundwater rebound is a concern in a number of formerly highly industrial areas with historically high levels of abstraction, including Birmingham, Coventry and London. In these cities, pumping is required to prevent groundwater flooding of assets which were constructed (for example, the London Underground) during times of higher pumping and lower groundwater levels in the past.

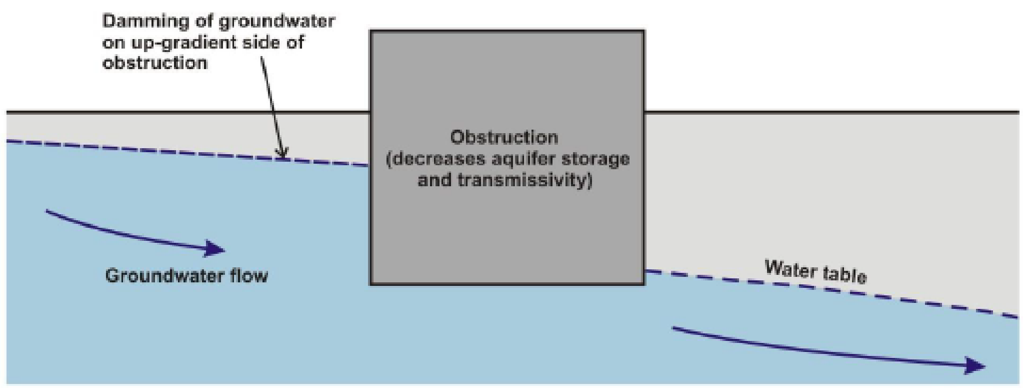

Figure 3-6 Type 4 – Underground structures resulting in barriers to groundwater flow, reduction in storage or pathways for groundwater flow, which result in rises in groundwater levels and discharge. © JBA

Figure 3-6 and Figure 3-7 describe type 4 groundwater flooding. Figure 3-5 shows that obstructions can reduce the volume available for groundwater storage and the ability of groundwater to flow through replacing aquifer material reducing the vertical thickness of the aquifer and removing storage. Where a large number of impermeable basements are constructed in thin aquifers this can reduce the effective aquifer permeability and storage, resulting in higher than previous groundwater levels. The reduced aquifer permeability can potentially be mitigated by building control measures to allow groundwater to flow around buildings, but the storage lost is harder to replace.

Figure 3-6 shows that man-made structures and interventions may also result in higher transmissivity (the rate at which water passes through an aquifer) due to flow along pipes and pipe trenches. Subsidence-induced fracturing following mining may also result in enhanced transmissivity and additional flow pathways. Underground structures, such as sewers, drainage networks, service trenches or pipes allow rapid groundwater flow and encourage groundwater to emerge where it is not normally found.

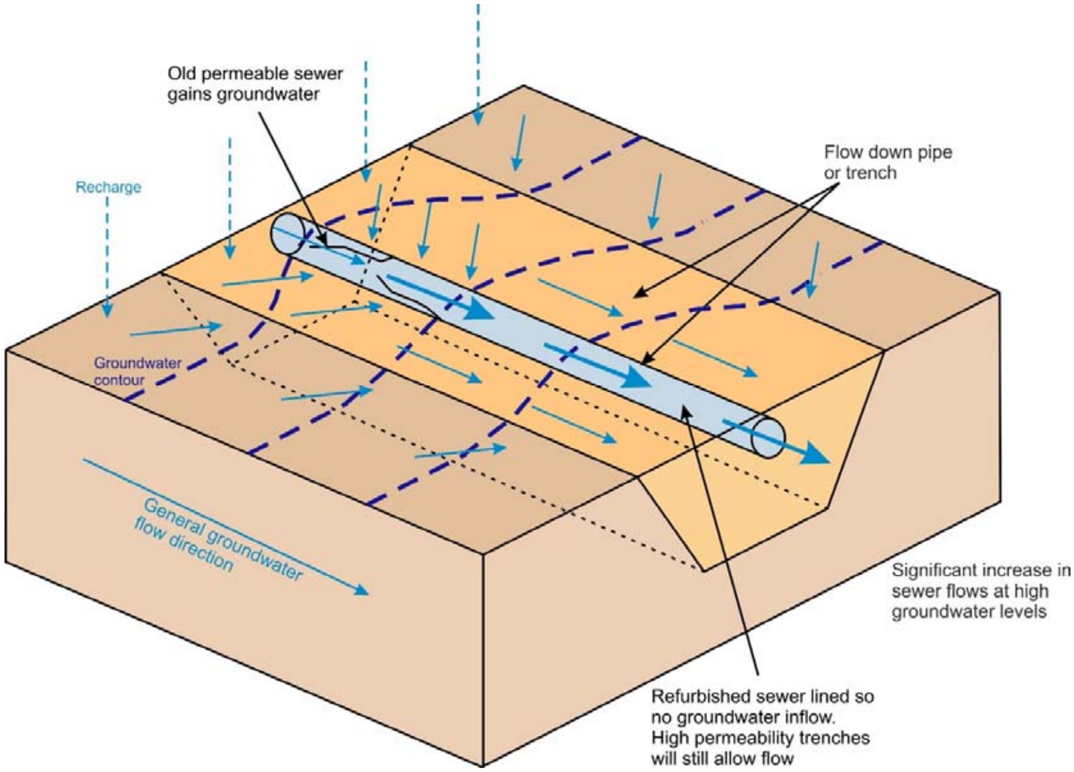

Figure 3-7 Type 4 – Underground service pipes (for example, sewers) and gravel trenches lead to preferential pathways. © JBA

The causes and mechanisms of groundwater flooding for the various aquifer types across Britain is detailed in Jacobs (2007) 'Making Space for Water' (HA5, consolidated report).

Further information on how groundwater flooding happens was provided by the project steering group (2020). Groundwater flooding may occur on its own. However, groundwater flooding often occurs at the same time as, and contributes to, other types of flooding:

- Groundwater emergence at the surface flows overland into the surface water drainage network and can contribute to surface water and fluvial flooding.
- High baseflow from groundwater can drive fluvial flooding in highly permeable catchments.
- High groundwater levels below ground may increase infiltration of groundwater to the sewer network and contribute to sewer flooding. Limiting infiltration to

sewers (for example through sewer lining programmes) may rebound groundwater levels and cause increased run-off above the ground.

- Permeable superficial deposit (PSD) flooding always occurs in conjunction with high river levels, although, the river levels may be below flood defences and not result in fluvial flooding. High sea levels also contribute to PSD flooding in coastal areas, even when the sea does not overtop defences.

Groundwater flooding happens in localised places. Not everywhere in England is susceptible to groundwater flooding, and it is often the local conditions (for example geology, hydrogeology, hydrological conditions and the built environment), and how multiple flood sources and local conditions interact, that cause groundwater flooding.

3.3 Impacts of groundwater flooding

Groundwater flooding may typically last for weeks or even months, leading to damage and costs that can be substantially higher than equivalent depth fluvial or coastal flooding (Green and others, 2006). The consequences of rising groundwater include (RAB, 2016):

- emergence of new or rarely experienced springs
- migration of stream sources high into the headwaters
- emergence of water at the surface
- large areas of standing water
- damage to crops
- inundation of roads and railways
- flooding of properties
- emergence of water into underground structures
- local drainage networks overwhelmed by rate of flow
- surcharging of sewerage
- failure of electricity supplies

Groundwater flooding may also have an extended impact on transport infrastructure, with roads and railways closed for extended periods. In addition to these losses, there are also clean-up costs, costs for alternative accommodation (which can be substantial for long periods of groundwater flooding) and some other small loss items (for example, damage to cars).

Ongoing groundwater flooding will reduce storage capacity within the groundwater system, which may lead to increased run-off and instances of surface water and river flooding.

4 Method

4.1 Rapid evidence assessment approach

A rapid evidence assessment (REA) follows a systematic review approach but is less resource-intensive, while maintaining rigour and transparency. The protocol (method) for this REA assessment is detailed in Appendix A and how it was applied is detailed in Appendix B.

This study broadly follows the method of Collins and others (2015), which describes in clear terms the necessary steps of an REA, along with the roles and responsibilities of all parties involved. The main parties are the review team, who carry out the review, and the steering group (see Appendix C), a group of technical experts that guides and assists the review team, where necessary, to ensure the outputs of the REA meet the needs of end users.

The project carried out a literature review (peer reviewed, grey and unpublished literature) alongside stakeholder engagement (online survey and interviews) to answer one primary and 14 secondary research questions. These secondary questions have been used to bring focus to the primary question and to cover the various aspects of groundwater flood risk management. This project has more stakeholder engagement than is typical of an REA as the stakeholders are an essential source of evidence. The questionnaire and semi-structured interview questions are detailed in Appendix C.

4.2 Research questions

4.2.1 Primary question

The primary research question of this study is:

'What are the current approaches to groundwater flood risk management in England?'

This is the overall question which the evidence review seeks to answer. The scope of this question was expanded and clarified by additional secondary questions.

4.2.2 Secondary questions

Secondary questions were identified by the Environment Agency to clarify the main question. They were not used as official secondary questions as defined in the REA approach (with a full separate search, screening, extraction and synthesis phase for each question) but used to gather evidence and provide a basis for the stakeholder engagement. The questions introduce an element of appraisal (and closed questions), which is absent in the primary question, and were used as a basis for categorising and analysing the evidence within the systematic map of all the data. The systematic map is an Excel spreadsheet containing a full list of data sources reviewed, including extracted evidence related to primary and secondary questions and critical appraisal scores. The secondary questions are presented in Table 4.1.

Table 4.1 Secondary questions

Topic	Question
Governance of groundwater flood risk management in England	1a. Who has roles and responsibilities for groundwater flood risk management in England? 1b. Have the current governance arrangements been appraised/reviewed?
Recording groundwater flooding/access to historic records	2a. Do records of flooding get reported? (Where, when, how - for example local/national databases?) 2b. Is there a consistent process for recording groundwater flooding?
Groundwater flood risk assessment (non-real time)	3a. What national scale risk assessment information exists? 3b. What local risk mapping techniques are used? 3c. What are the current risk assessment (modelling and mapping) approaches (including methods, software, data inputs and outputs, model scenarios, validation, publication, limitations), is climate change considered? 3d. Can we make an assessment of the number of properties susceptible to groundwater flooding for England now and under climate change?
Groundwater flood forecasting and warning (real-time)	4a. What groundwater flood forecasting systems exist (national and local scales, what data do these use/need)? 4b. What local processes exist for warning of groundwater flooding (are they integrated with systems for other types of flooding)?
Groundwater flood mitigation (risk reduction and resilience)	5a. Have groundwater flood risk management schemes been implemented (what, where, when)? 5b. Is there guidance on developing and implementing groundwater flood schemes? 5c. What practices are used for improving resilience (people and properties) to groundwater flooding? 5d. What are the requirements for considering groundwater in spatial planning?
Strategy implementation	What are the main gaps in evidence in the processes for managing groundwater flood risk against statutory duties and the ambitions of the Flood and Coastal Erosion Risk Management Strategy for England? *(Note, the strategy was draft in 2019 at the time of project award, and published July 2020. All analysis was made on the draft version but later checked against the published version).*

5 Evidence summary

Evidence that was considered the most relevant to address the primary question was analysed. This section describes the data analysis and characteristics of the evidence. Some notable articles with particularly high appraisal scores are also highlighted.

5.1 Overview – volume and characteristics of the evidence

Overall, the evidence comprised:

- 17 peer reviewed published sources
- 37 grey literature sources - this ranged greatly from comprehensive reports (sometimes with an element of peer review, for example, a steering group review or expert review or input) to webpage links
- 12 unpublished material sources which included short notes, PowerPoint presentations and other documents
- 6 semi-structured interviews - these were combined with grey literature sources to provide additional information. Where no literature was available the interview was included in the systematic map of data as an individual entry
- 260 questionnaire responses, of which 114 were complete responses and 146 part responses. The response to the questionnaire was very positive and provides a very useful insight into actual groundwater flood risk management practice. There were some gaps in geographical representation (south-west, north-west and north Yorkshire). The questions and spatial coverage of responses is shown in maps 1 to 5 presented in Appendix D. The results are presented in the following sections. Where the total number of responses to a particular question is less than indicated here, this is because not all respondents answered all questions.

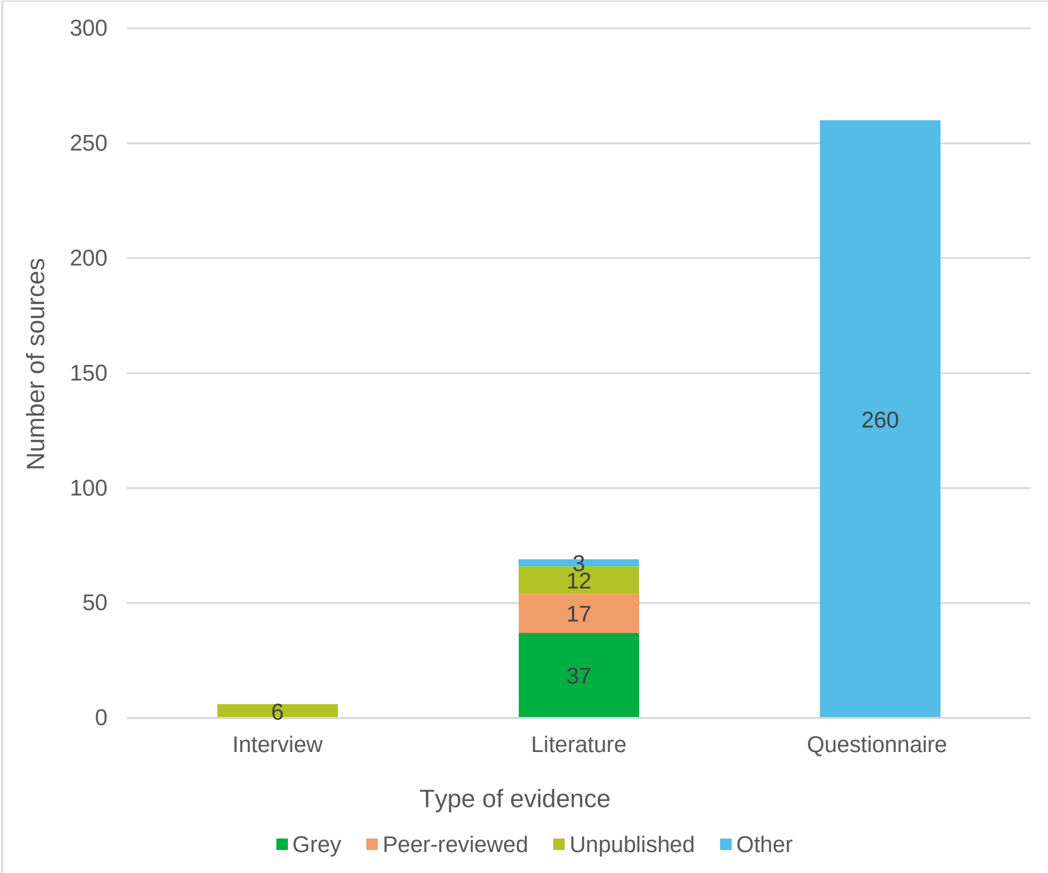

Figure 5-1 Distribution of evidence regarding groundwater flood risk management

Figure 5-1 highlights the following:

- most of the evidence comes from responses to the questionnaire from stakeholders
- most of the written literature is grey, indicative of the recent developments in groundwater flooding and the practical nature of groundwater flood risk management
- unpublished evidence was gained from literature and interviews

Peer reviewed literature is often a summary of the more detailed grey literature or reporting in general on more commercially sensitive groundwater flood work. Therefore, there may be some duplication of the peer review literature with the grey literature and interview information.

Interviews with important stakeholders have been very useful for obtaining an overview of groundwater flood risk management in their particular area, and in accessing details of information for which comprehensive documentation is not readily available.

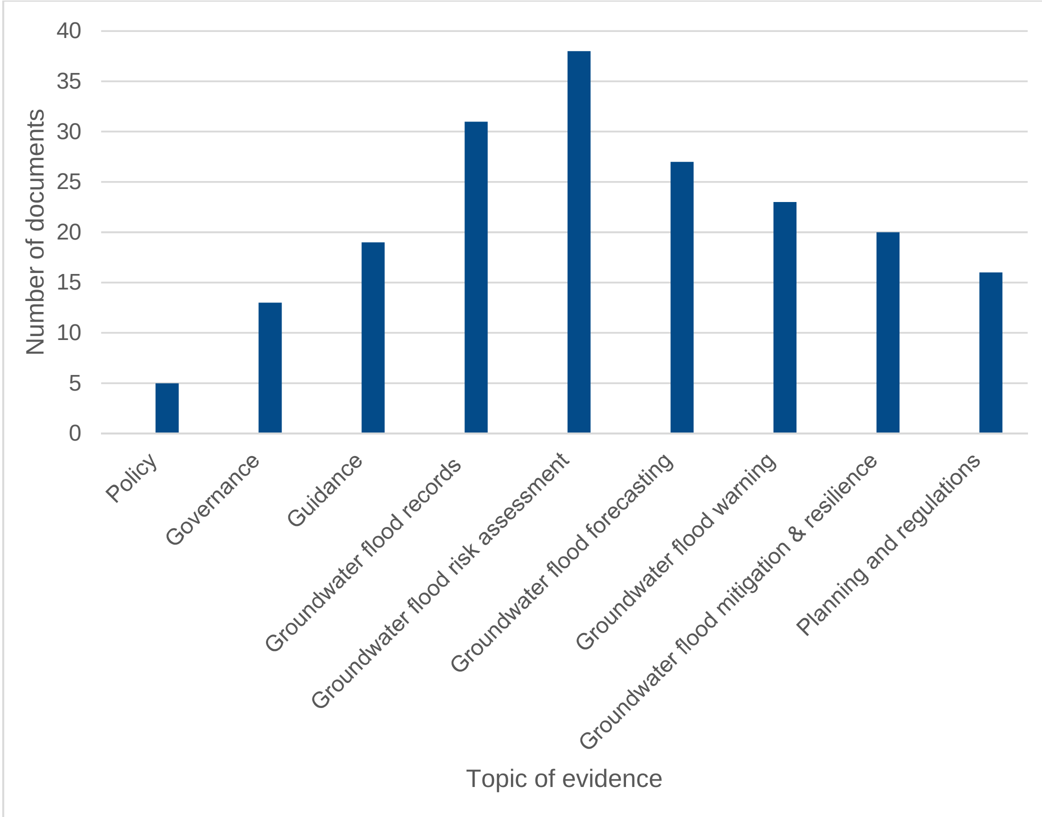

Figure 5-2 Summary of evidence base - Literature and interviews

The topics of evidence in the literature and interviews varied across the different categories (Figure 5-2). The most common theme was groundwater flood risk assessment (38), followed by groundwater flood records (31) and groundwater flood forecasting (27). Policy was the least common theme, with only 5 pieces of evidence in this category.

The questionnaire was split into 10 different topic areas, with respondents given a choice if they wanted to answer questions relating to this topic. The number of responses in each topic area varied significantly (Figure 5-3). In the first 3 topics, respondents were not given a choice in answering, therefore these saw a full response (260). However, the following topics saw much lower response rates, with only 58 people choosing to answer questions on groundwater flood forecasting, the topic with the lowest response. The highest response number after the first 3 introductory topics was ‘opportunities and barriers to deliver groundwater flood risk management’ which had 150 responses.

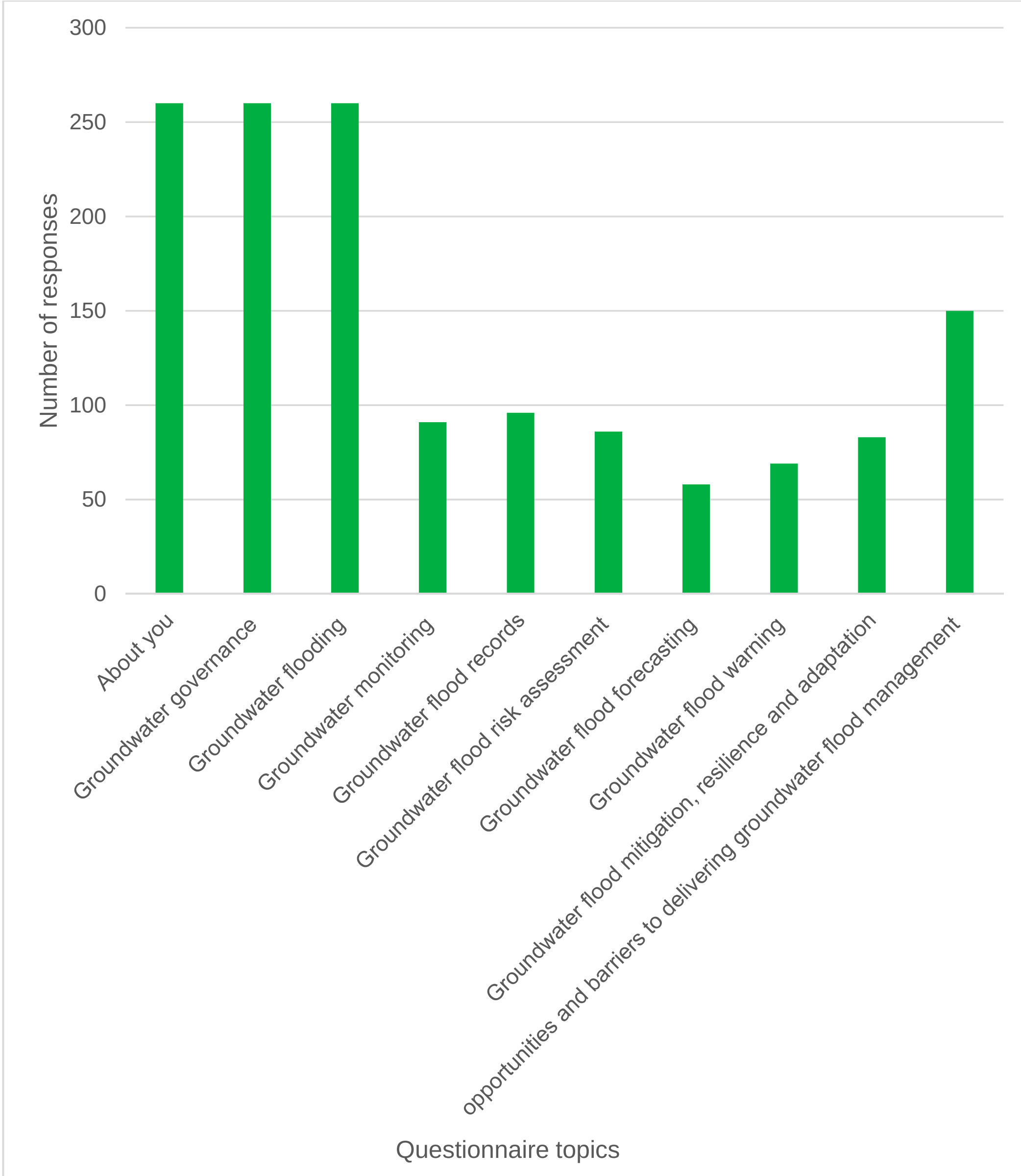

Figure 5-3 Summary of evidence - Questionnaire responses

The number of respondents for each topic area was calculated as the average number of answers to the series of questions within each topic. Additionally, in the questionnaire results output, it was stated as 'YES' if they did select and answer, and 'NO' if the participant had not. This could mean that some responses have been counted when the questions were not answered. The questionnaire results are presented in this report as the percentage of respondents who answered the question.

The responses that provide contextual information are provided below. These include information about the organisations that responded, the scale, and the type of groundwater flooding they have experienced in their area. The others are provided in section 5, Results.

A high proportion of responses (38% or 99 people) to the survey were from staff within the Environment Agency (Figure 5-4). This should be considered when interpreting the results. This compares to 18% of responses (46 people) from LLFAs (for the purposes of the survey and analysis this was broken down into County Councils, Unitary Authorities, London Borough and Metropolitan Borough Councils as shown in Figure 5-4).

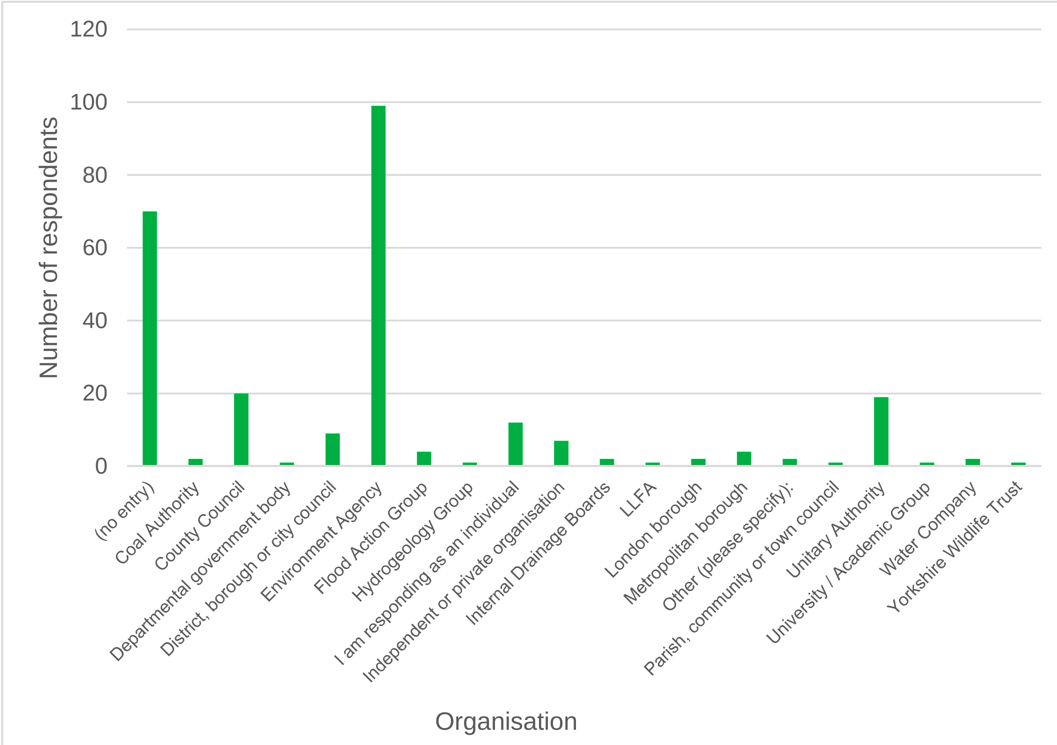

Figure 5-4 Organisation of respondents to the questionnaire

In terms of how much the respondents have been exposed to groundwater flooding issues, 81% of respondents (120 people) indicated that there were areas of groundwater flood risk in their area of work, 5% (8 people) said there was no groundwater flooding and 35% (20 people) didn't know. Map 5 in Appendix D has been produced to show areas of highest groundwater flood risk across England.

When respondents were asked how much of an issue groundwater flooding was, 36% said it was a significant issue, 33% considered it to be a moderate issue and 25% of people thought it was only a slight issue. One participant stated that groundwater flooding was not an issue at all (Figure 5-5).

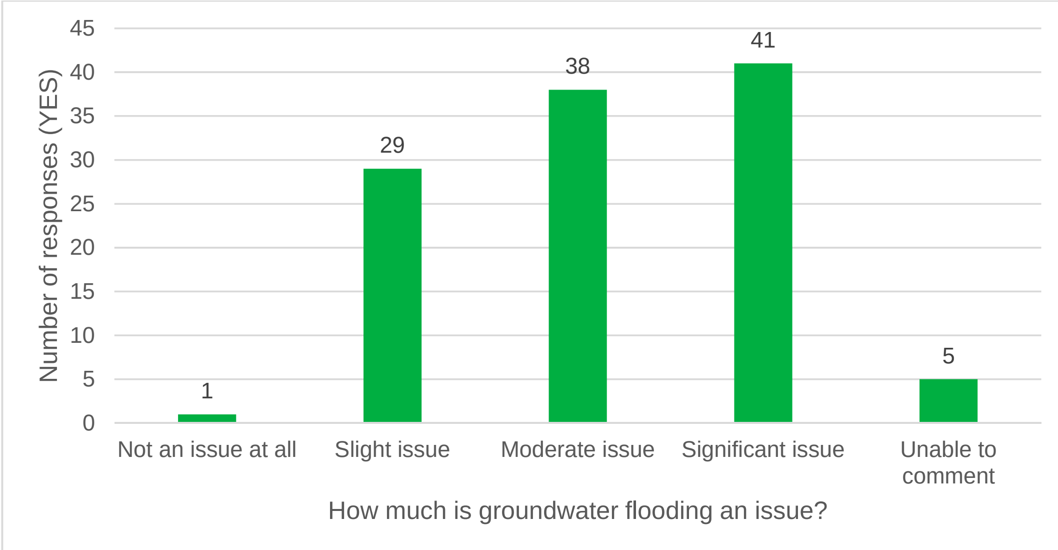

Figure 5-5 How much is groundwater flooding an issue?

To understand the context of the answers in terms of the mechanisms of flooding (presented in Section 2.2) the survey asked about the types of flooding affecting the areas where the respondents work.

The most common type of groundwater flooding encountered was aquifer flooding, but permeable superficial deposit flooding and flooding due to the built environment were also important. Groundwater rebound was also encountered in a significant number of cases (see Figure 5-6).

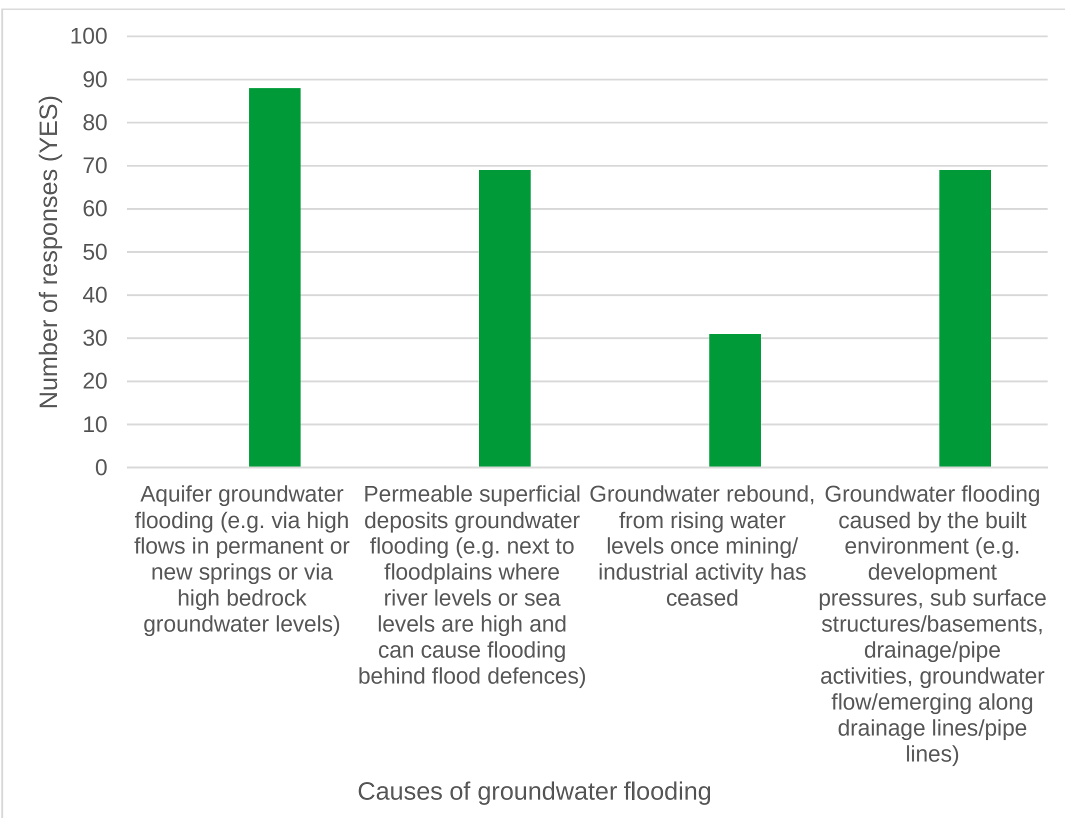

Figure 5-6 Bar chart of types of flooding

Interestingly, 72% of questionnaire respondents said that groundwater flooding had occurred at the same time as flooding from other source(s), 5% said it hadn't, and 22% didn't know.

When asked about the other types of flooding that happen at the same time as groundwater flooding, 90% (64 people) said surface water flooding, and 85% (60 people) said river flooding. Sewer flooding was identified by 59% (42 people) as occurring at the same time as groundwater flooding, while tidal flooding and sea surges were less common (25% or 18 people).

6 Results

6.1 Overview

Since the primary research question is an open question, it is answered through a series of secondary questions. This research aims to understand current groundwater flood risk management across a number of themes, including governance, risk assessments, forecasting, incident and asset management. Consequently, the results of the secondary questions provide the response to the primary question:

'What are the current approaches to groundwater flood risk management in England?'

The evidence to provide the results to the secondary questions and ultimately the primary question is documented below.

6.2 Who has roles and responsibilities for groundwater flood risk management in England?

The research on the governance of groundwater flood risk management in England is focused here into secondary questions. This section describes the findings for secondary question 1a.

Secondary question 1a: Who has roles and responsibilities for groundwater flood risk management in England?

The main aim of this question is to help summarise current roles and responsibilities for groundwater flood risk management so that any future work can be targeted at the appropriate organisations and groups.

6.2.1 Summary response

Overall, the evidence indicates that a wide range of parties are involved in groundwater flood risk management, not just the organisations with a statutory responsibility.

6.2.2 Summary of the evidence

The National Flood and Coastal Erosion Risk Management Strategy for England (Environment Agency, 2020) (Annex A) outlines the roles and responsibilities for those managing flooding and coastal change. Many organisations and stakeholders support the activities of those with legal responsibilities.

Strategic overview

Under the FWMA 2010 the Environment Agency is responsible for managing flood risk from main rivers and sea, including where flooding is made worse by high groundwater levels. The Environment Agency also has a strategic overview for all sources of flooding, including groundwater flooding, and is responsible for preparing the National Flood and Coastal Erosion Risk Management Strategy for England. The latest strategy was published in July 2020 and describes the existing roles and responsibilities in relation to flood and coastal risk management activities (annex A: [Environment Agency – National Flood and Coastal Erosion Risk Management Strategy for England (publishing.service.gov.uk)](https://www.gov.uk)).

As the strategic risk management authority, the Environment Agency provides advice and support to other risk management authorities (RMAs). Guidance and data is shared with others, such as LLFAs to help develop local flood risk management strategies (Environment Agency, 2016), or provide flood alerts (Environment Agency, 2020). Under the Civil Contingencies Act 2004 the Environment Agency maintains arrangements to warn the public and provide information and advice. Within the strategic overview role, the Environment Agency have developed groundwater warning services in certain locations to provide information and advice to the public (Environment Agency, 2020).

The Environment Agency also has expert groundwater scientists, collects groundwater level data, runs computer models to assess and predict groundwater levels and provides updates on the groundwater situation. This is primarily to understand and manage water resources, and can often focus on low flow modelling but it is also used to inform flood risk management if they can calibrate well to high flows. The Environment Agency also holds information on the extent and impacts of historic groundwater flooding (Environment Agency, 2020).

The Environment Agency will work in partnership with RMAs to find ways to manage groundwater flood risk when it interacts with flooding from rivers and the sea and there is an economic case to do so.

Coordinating management

Under the FWMA 2010, groundwater is classified as a ‘local’ flood risk. Section 13 requires relevant authorities to co-operate with any other relevant authority which is exercising flood or coastal erosion risk management functions. Section 9 states that LLFAs (county councils, unitary authorities, London boroughs and Metropolitan boroughs) are required to develop, maintain and apply strategies for local flood risk management in their area. They are responsible for preparing preliminary flood risk assessment and flood risk management plans for local flood risk sources (Flood Risk Regulations 2009), and for carrying out works to manage the risks (Land Drainage Act 1991)

Each LLFA manages groundwater flood risk in its own way (though there is some consistency across London). Where there are multiple sources of flooding, one of which is river flooding, the Environment Agency can have a co-ordinating role sharing data and analysis (Environment Agency, 2016). The Environment Agency areas sometimes have different approaches to this (Buss, 2019).

Neither the Environment Agency nor LLFAs have powers, duties or current resources to control groundwater levels to prevent flooding to land, property or infrastructure (Environment Agency, 2020).

Spatial planning

County Councils are statutory consultees for planning authorities and response to the drainage design for major planning applications (Town and Country Planning (Development Management Procedure) Order 2015). District Councils are planning authorities and are responsible for developing the local plan, evidenced by a Strategic

Flood Risk Assessment (SFRA). Risk Management Authorities and others can support this process with information and on risks from all sources of flooding.

Incident response and investigations

Some risk management authorities have a statutory role to play in planning for emergencies. The Civil Contingency Act 2004 sets out the roles and responsibilities of different organisations in responding to emergencies such as floods and coastal change events. The duties here are about assessing risks, planning for them and warning the public. There is no specific duty to respond. It splits responders into two categories and imposes a different set of requirements on each category. Some risk management authorities are category 1 responders (Environment Agency, county councils, unitary authorities, district councils) or category 2 responders (water and sewerage companies, Highways England, Transport for London and Secretary of State for Transport).

Category 1 and 2 responders come together within local resilience forums (LRFs). LRF members aim to plan and prepare for localised incidents and catastrophic emergencies. They help responders collaborate to identify potential risks and produce emergency plans to either prevent or mitigate the impact of any incident on their local communities.

The Environment Agency have incident procedures (‘concept of operations’) to support response to flooding within their role as a Category 1 responder. For example, during the significant groundwater flooding in 2013 and 2014 (e.g. in the Lower Thames (Environment Agency, 2016)) a national groundwater technical cell of specialists from a variety of organisations was brought together to give advice to government on groundwater flooding. During localised events, area planning cells and technical cells that contain groundwater specialists to support the response to flooding by the Environment Agency and LRFs (Environment Agency, Incident Management Handbook 2020).

In terms of investigating flood incidents, Section 19 of the FWMA 2010 describes the LLFA’s responsibilities.

Section 19 states:

(1) On becoming aware of a flood in its area, a lead local flood authority must, to the extent that it considers it necessary or appropriate, investigate -

(a) Which risk management authorities have relevant flood risk management functions, and

(b) Whether each of those risk management authorities has exercised, or is proposing to exercise, those functions in response to the flood.

(2) Where an authority carries out an investigation under subsection (1) it must -

(a) Publish the results of its investigation, and
(b) Notify any relevant risk management authorities.

The LLFA can use these Section 19 flood investigation reports to identify future mitigation or recovery activities.

Other roles, which don’t have legal requirements are described below.

Flood forecasting

The Flood Forecasting Centre (FFC) was established as a response to the Pitt Report (Pitt, 2008). A recommendation within this report was that the Environment Agency should work together with the UK Met Office to improve its technical forecasting, modelling and warning capabilities for all sources of flooding. The FFC has responsibilities for forecasting and advising its customers of the likely incidence and severity of flooding from all natural sources, namely fluvial, surface water, coastal/tidal and groundwater (RAB, 2016).

Managing water levels

Internal drainage boards (IDBs) are public bodies that manage water levels in an area, known as an ‘internal drainage district’, where there is a special need for drainage. IDBs carry out works to reduce flood risk to people and property, and manage water levels for agricultural and environmental needs within their district. There are 112 IDBs in England whose districts cover 1.2 million hectares (9.7% of England’s landmass). They play an important role in reducing flood risk to over 600,000 people and nearly 900,000 properties. They operate and maintain over 500 pumping stations, 22,000km of watercourse, 175 automatic weed screen cleaners and numerous sluices and weirs (ADA, 2020).

Managing the impacts of groundwater flooding

Other parties also manage groundwater flood risk separately. These include water companies, the emergency services, highways authorities and Highways England, transport infrastructure companies such as Network Rail, insurers and others.

Water companies are particularly concerned with ingress to sewers, although the programme of lining sewers will reduce this. They are also concerned in situations where groundwater flooding may compromise water sources, such as abstractions with electrical pumps.

Transport infrastructure operators, including Network Rail, London Underground and Highways England may encounter groundwater flooding in their assets.

Groundwater flooding is often specifically excluded from standard property insurance, but may be included where groundwater ingress is from over the ground surface (Green and others, 2006). Flood Re, a joint initiative between the Government and insurers was launched in 2016 to make the flood cover part of household insurance more affordable. This is governed by the flood reinsurance regulations (2015) which states that flooding from below ground is included in insurance cover, except for gradual seepage or rising damp.

Groundwater flood risk is now usually included within environmental reports for home buyers (for example, Landmark, Future Climate Info).

Working with others

Groundwater flooding was an issue that was brought to COBR (cross-departmental committee that responds to national emergencies) in July 2012 and again in January/February/March 2014. The committee is helped by knowledge from data providers such as the British Geological Survey (BGS), GeoSmart and JBA (Buss, 2019).

6.2.3 Survey responses – roles and responsibilities in practice

Organisations involved in groundwater flood risk management

The number of questionnaire respondents indicating which organisations are involved in groundwater flood risk management are shown in Figure 6-1.

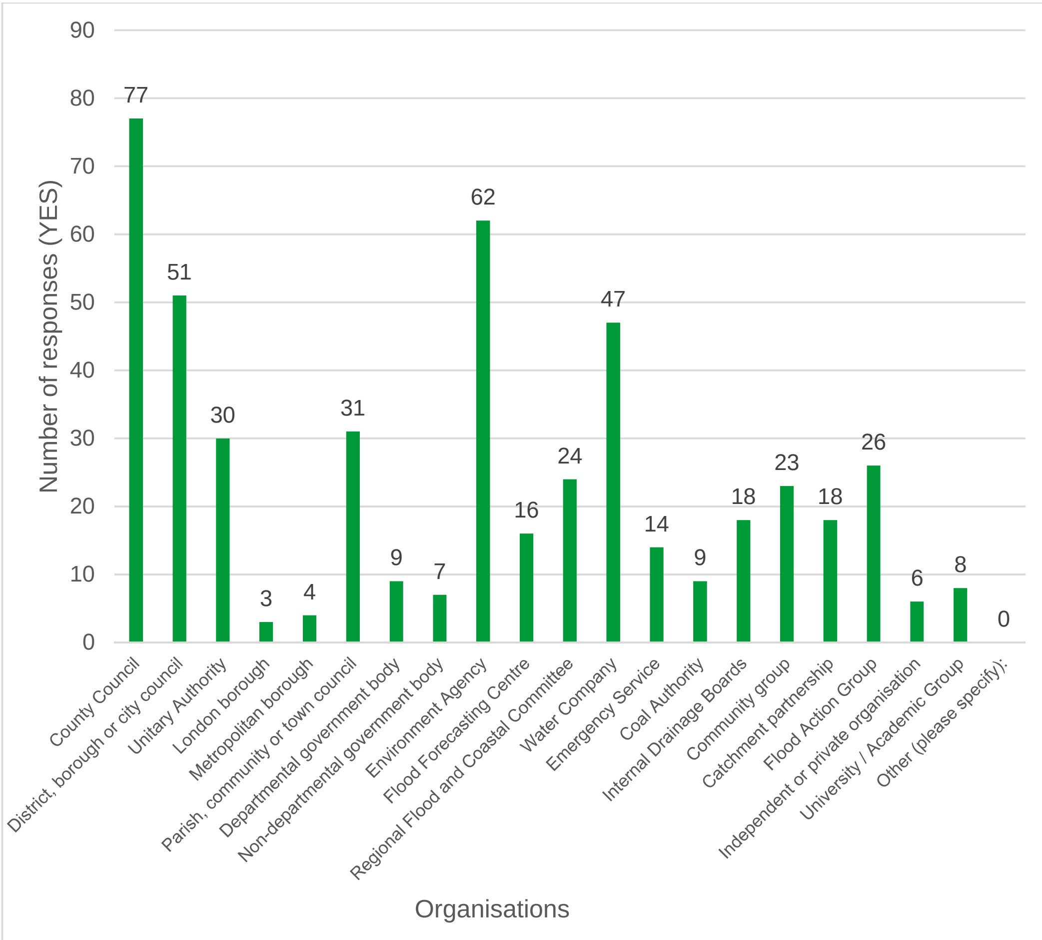

Figure 6-1 The organisations involved in groundwater flood risk management

The questionnaire responses above confirm that the local authorities with responsibility for groundwater flooding and the Environment Agency are involved in groundwater flood risk management. This suggests that, in practice, a much wider range of organisations are involved in groundwater flood risk management than those with statutory responsibilities.

Of the respondents who answered the relevant question 52% (81 people) indicated that their organisation had a statutory responsibility for groundwater flooding, 35% (54 people) did not, and 13% (20 people) didn't know.

To support these activities:

- 60% (102 people) had experience of groundwater flood risk management
- 74% (125 people) had access to, or used, others with specialist experience of groundwater flooding

- 31% (53 people) had specific training in groundwater flooding, while 69% (116 people) did not. Of the respondents who had received specific training, half (27 people) were from the Environment Agency.

To manage groundwater flooding 68% (104 people) indicated they worked with other organisations, 32% (48 people) did not. When respondents were asked who they worked with the county councils (77 people), Environment Agency (62 people) and water companies (47 people) were the most common responses. Other local authorities, including district, borough or city councils, unitary authorities and parish, community and town councils were also working to manage groundwater flood risk. Those organisations less commonly identified include government bodies, emergency services, independent or private organisations and academic groups.

Skills and resources

The questionnaire respondents generally suggested that many areas of groundwater flood risk management are not very well understood (Figure 6-2). A majority of respondents believed all areas of groundwater flood risk management are ‘not well understood’, except for ‘recording groundwater flooding’ where a majority of respondents believed the area needed ‘better implementation’.

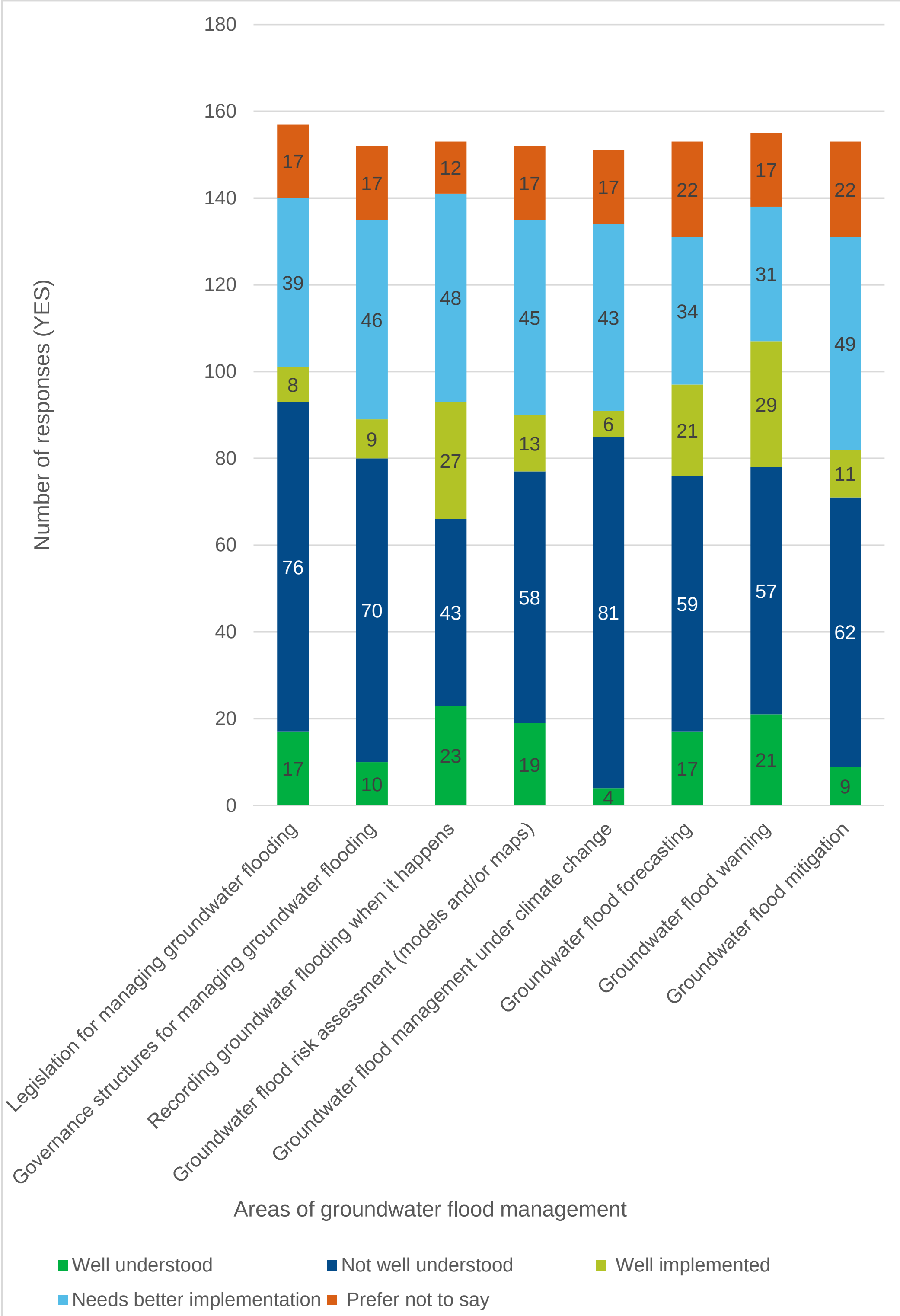

Figure 6-2 How well are different areas of groundwater flood risk management understood (knowledge/skills) and implemented (processes/systems in place)?

Very few respondents thought the different areas of groundwater flood risk management were well understood, with only 15% (23 people) stating that recording groundwater flooding when it happens was well understood. Groundwater flood warning was seen as ‘well implemented’ (19% of respondents) and ‘well understood’ (14% of respondents). The area least well understood was groundwater flood risk management under climate change, with low responses for both ‘well understood’ and ‘well implemented’.

6.2.4 Implications of findings

To effectively manage groundwater flooding, it is important to understand how it interacts with other types of flooding and to coordinate management accordingly. Water that starts out as groundwater can flow into rivers and drainage networks, resulting in flooding from rivers and surface water. The evidence found lots of organisations playing a role in groundwater flood risk management, often in coordination with others, but not necessarily within their legal responsibilities. There has been no formal appraisal of these ways of working, or governance structures, so it is difficult to determine whether the processes that have developed are working effectively.

The survey showed that 13% of respondents didn’t know if their organisation had statutory groundwater flooding responsibilities or if their area was at risk of groundwater flooding, which indicates that further clarification or information is needed.

6.2.5 Gaps and future work

The national flood and coastal erosion risk management strategy for England sets out the existing roles and responsibilities for all sources of flooding. However, groundwater flooding is often difficult to distinguish and or manage independently of other flood sources and the roles and responsibilities are not clear where sources need to be managed in conjunction with each other.

Further information should be provided to all organisations that have a responsibility for groundwater flood risk management to help improve awareness and understanding of groundwater flood risk and how this can be managed in conjunction with other sources of flooding. Relationships between parties should be formalised to agree management actions where groundwater flooding interacts with other flood sources. This could be supported by promoting information and good practice through existing activity and networks. Interactions between responsible parties should be made explicit to inform follow on engagement. This would particularly help to improve understanding and communication when responding to flooding.

6.3 Have the current governance arrangements been appraised/reviewed?

The main aim of this question is to understand what work has already been done to review and appraise the current governance arrangements for groundwater flood risk management so that any future work in this area can account for existing evidence.

The research on governance is focused here into secondary questions. This section describes the findings for secondary question 1b.

Secondary question 1b: Have the current governance arrangements been appraised/reviewed?

6.3.1 Summary response

There has been no formal appraisal of the current groundwater flood governance arrangements. The current governance arrangements for flood and coastal erosion were reviewed or appraised for all sources of flooding within the Pitt Review and in research to develop the FCERM strategy for England. However, these reviews or appraisals do not often focus on groundwater or provide much appraisal on the governance arrangements of groundwater flood risk. There is informal unpublished literature of the governance arrangements of groundwater flood risk, which identifies challenges around the role of specific RMAs and various governance arrangements based on region.

6.3.2 Summary of evidence

The FWMA 2010 contains provisions to implement recommendations from the Pitt Review to improve the management of local flood risk from all sources.

As a requirement of section 7 of the FWMA 2010, the Environment Agency has a statutory duty to develop, maintain, apply and monitor a national flood and coastal erosion risk management strategy. The current adopted National Flood and Coastal Erosion Risk Management Strategy for England was published in July 2020. To inform the development and implementation of the strategy, the Environment Agency carried out research to understand effective flood governance. The research included both a national level analysis and a focus on innovative local case studies, covering all sources of flooding and coastal erosion. Advances in partnership working, designing multi-benefit projects and operating at a catchment scale have demonstrated some successes. However, challenges around defining the responsibilities of different authorities, balancing national and local priorities and joining up policy areas remain. Through consultation, the Environment Agency found that urban, fluvial and coastal flooding are better considered in flood risk management than groundwater flooding (Environment Agency, ‘understanding effective flood and coastal risk governance’, ongoing research).

Reporting on specific appraisal or review of the governance of groundwater flood risk has not been identified by this rapid evidence assessment.

6.3.3 Implications of findings

The findings show that there are practices in groundwater flood risk management at the local level particularly within LLFAs. Informal literature and research tells us that the current governance arrangements are delivering local practices, however there have been no formal published reviews. The local development of groundwater flood risk management means that the level and quality of service provided to people in locations at risk of groundwater flooding differs across the country. This is to be expected (higher risk areas may need more processes and investment), however, consistent approaches could create efficiencies and a common agreed standard of service which could then be built upon locally.

6.3.4 Gaps and future work

To gather further evidence of whether the current ways of working are delivering effective groundwater flood risk management a review of the current governance arrangements should be made, particularly in light of the developments over the last 10 years. It is recommended that existing informal literature regarding governance is reviewed, potentially expanded, updated and published. This should review the roles and responsibilities and interaction between the Environment Agency, LLFAs, and other organisations involved in groundwater flood risk management. Guidance would be needed to support any changes made as a result.

Aspects to consider include:

- Funding for roles and responsibilities, including access to local flood levy funds.
- Capacity and capabilities
- Integration with managing other flood source
- Potential for efficiencies (e.g. coordination of activities nationally vs local delivery)
- Collation and sharing groundwater flood records

6.4 Recording groundwater flooding/access to historic records: Do incidents of flooding get reported?

The main aim of this question is to summarise the current activity for recording incidents of groundwater flooding. This can be an important activity in informing risk assessments, forecasts, warnings and targeting mitigation measures. Improving knowledge in this area will help to target any future work.

The research on recording groundwater flooding is focused into secondary questions. This section describes the findings for secondary question 2a.

Secondary question 2a: Do incidents of flooding get reported?

6.4.1 Summary response

Groundwater flooding is recorded by 20 types of organisation (Figure 6-3), with respondents indicating that councils (county, district, borough, city, unitary authority, parish, community and town) are most frequently (44% of total responses) involved in recording groundwater flooding followed by the Environment Agency (21% of responses).

6.4.2 Summary of evidence

In 2003, Jacobs (in Defra report LDS23) recommended compiling a systematic database of groundwater flooding (Jacobs Gibb Ltd, 2004 and 2007). In 2010, Halcrow reinforced that recommendation so that accurate thresholds for the onset of groundwater flooding could be established.

Since the LLFA roles were adopted in 2010, LLFA councils have collected more data but it has been collected and complied in a variety of ways. This is typically collected following groundwater flooding, or repeated flooding incidents, rather than continuous monitoring. Often, there is a reactive response to capturing data, rather than proactive data capture to plan and prepare for groundwater flooding.

Other parties also record information related to groundwater flooding. Water companies are likely to know where sewer infiltration is greatest in the winter. Anglian

Water (interview 2020) collates incident records reported by customers, although these are symptom-focused and do not include the source of flooding such as groundwater (response documents may refer to the type of flooding). Other infrastructure companies, such as Network Rail and the Highways England, record where flooding has occurred during groundwater flood events, such as in winter 2014 and winter 2020, for instance in tunnel/cutting inflows. However, specific groundwater flooding may not be identified.

Questionnaire information

The respondents indicated that a wide range of organisations they knew recorded groundwater flood incidents. Figure 6-3 shows that the organisations identified by the most respondents was the Environment Agency (27% or 70 people), followed by county councils (22% or 56 people), district, borough or city councils (16% or 41 people) and water companies (13% or 33 people). LLFAs are active in recording groundwater flooding, but other non-statutory organisations, including local government are also recording flooding.

These results are similar to those found when asking respondents which organisations they work with on groundwater flood risk management. This could suggest that those involved with management are more likely to record incidents of groundwater flooding, or this could be a result of participants having more awareness of the processes within those organisations that they work with.

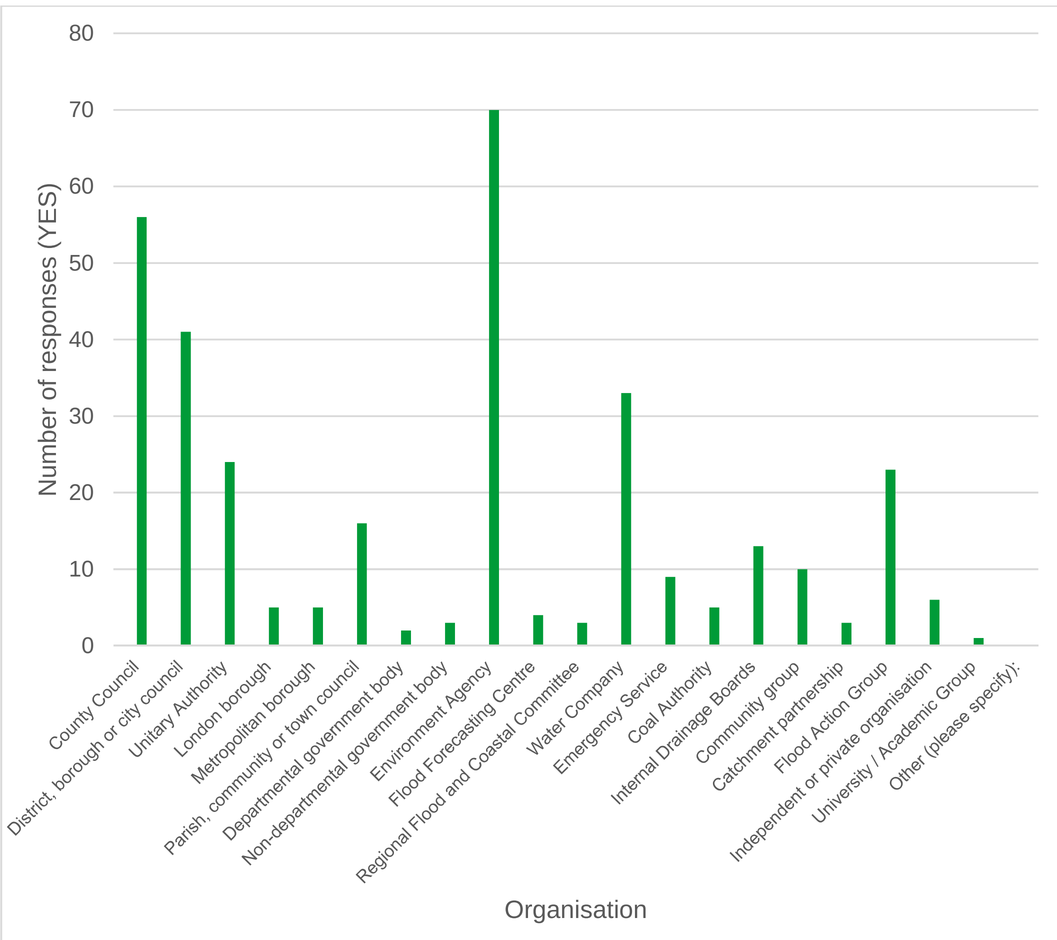

Figure 6-3 Organisations that record incidents of groundwater flooding

The survey found that 83% of respondents said that their own organisation recorded groundwater flood incidents, while 10% did not and 7% didn't know.

The timing of when data on groundwater flooding is actually recorded varied across organisations (Figure 6-4). For those that stated their own organisations recorded data, there was only a very small difference between information recorded during an incident (77%) and after an incident (78%). 65% received data from other organisations during an incident and 69% received data from other organisations after an incident. In addition, 74% of respondents received data from the public during an event, and 72% of respondents received data from the public after an event.

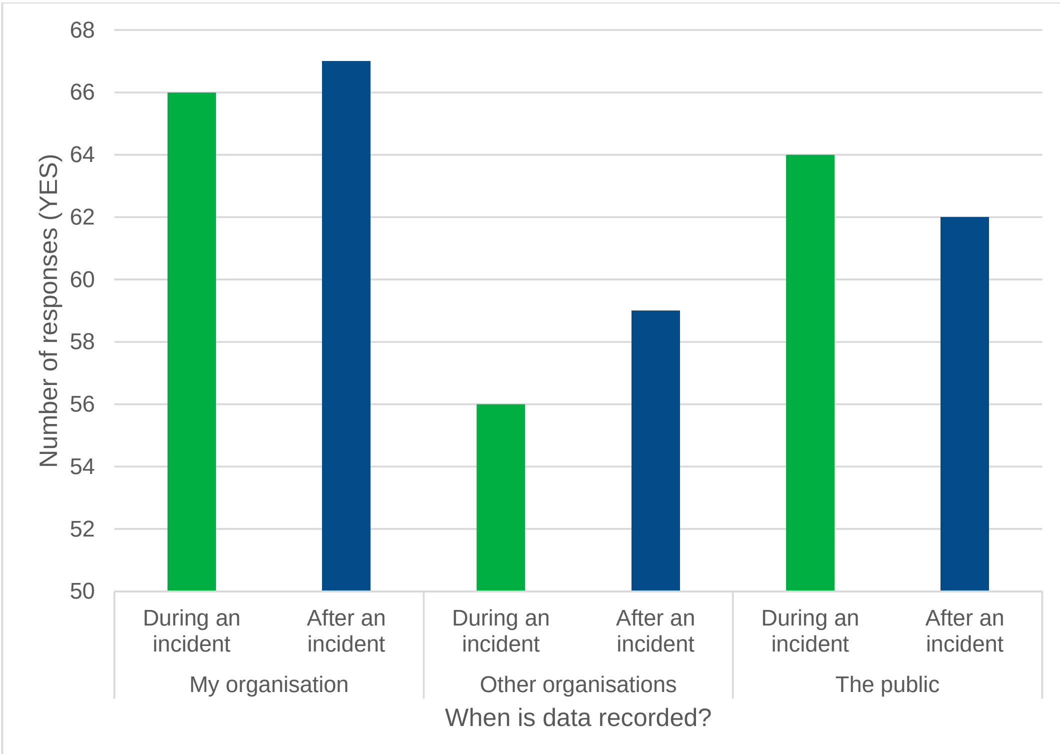

Figure 6-4 When data is recorded regarding groundwater flood incidents

The questionnaire respondents were asked how the data records are used. Figure 6-5 shows this is most commonly to understand areas at risk (72%). Other uses included to raise awareness (52%), to inform mitigation planning (45%), to validate risk maps (42%) and for section 19 reporting (42%). These uses were all relatively evenly split.

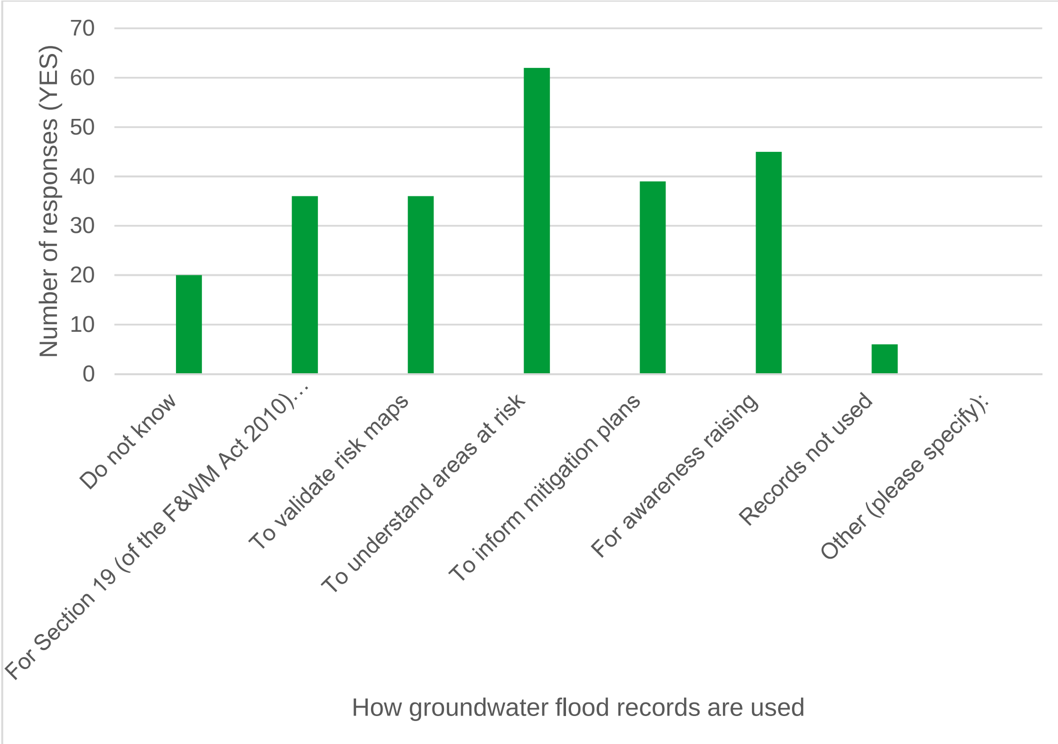

Figure 6-5 How are the groundwater flood records used?

6.4.3 Implications of findings

Reports of flooding do not often explicitly state the cause to be groundwater flooding which means there is a general underreporting of groundwater flooding incidents. This can be due to a lack of understanding of groundwater flooding mechanisms or difficultly in separating it from fluvial flooding. It is important to improve this because such data is commonly used to understand areas at risk, raise awareness and inform mitigation plans.

Multiple parties record incidents in a variety of ways. This is not easily accessible or coordinated. This means it is difficult to obtain an overview of known groundwater flooding locations and inform risk assessment or decision making.

6.4.4 Gaps and future work

Although lots of organisations collect groundwater flood records, these are not collected together or shared to improve the national understanding of groundwater flooding. This is true for all flood records, no matter the flood source. There is a lot of information available which could be brought together and interrogated to help better characterise and communicate flood risk. A responsible organisation should be identified.

This information could be captured using a common reporting platform to improve consistency and make data sharing easier. This would help improve understanding and future planning for incident response, as well as better understanding areas at risk and informing mitigation plans (for example, including the informing of capital programme bids).

Guidance on how to identify and report groundwater flooding, including being able to report flooding due to multiple (or uncertain) sources, would improve consistency. This would support improved reporting in systems ensuring the information is recorded in a way that allows meaningful interpretation more readily than the current ad-hoc reporting.

This could further be supported by training on how to identify and manage groundwater flooding compared to other sources of flooding.

6.5 Recording groundwater flooding: Is there a consistent process for recording groundwater flooding?

The main aim of this question is to summarise the current activity for recording incidents of groundwater flooding. It does not attempt to compare this to similar activity for other flood sources. It is important to know if there are consistent processes because this data informs risk assessments, forecasts, and warnings and can be used to target mitigation measures. Improving knowledge in this area will help to target any future work.

The research on recording groundwater flooding is focused into secondary questions. This section describes the findings for secondary question 2b:

Secondary question 2b: Is there a consistent process for recording groundwater flooding?

6.5.1 Summary response

A number of different ways of recording (Figure 6-6) and systems of recording (Table 6.1) groundwater flooding have been identified. Data on groundwater flooding is supplied by organisations and the public both during and after flood events (Figure 6-4). However, most questionnaire respondents indicated that they recorded similar information regarding groundwater flooding (Figure 6-7). The information is stored in a range of reports and databases. There is no consistent process for recording groundwater flooding.

6.5.2 Summary of evidence

The responses to the questionnaire show that processes for recording groundwater flooding vary (Figure 6-6) (note not all respondents chose to answer this question). The most common response was that flood incidents are recorded in a database (63%). However, this was closely followed by GIS map-based system (59%). Some of the other methods of recording appear to be less widely used, including email (37%), phone calls (30%) and letter (21%). Some of the methods that might be considered more innovative, such as through an app or social media, were at the lower end in terms of number of responses, however there was some recognition of these being used.

Questionnaire participants were also asked about the type of data that is recorded regarding groundwater flood incidents (Figure 6-7). The results from this question show that the most common types of information recorded are the location of flooding (91%) and the date of flooding (87%). The source of water and impacts of the flooding (both 67%) were also common among responses, meanwhile the depth of water (45%) and duration of flooding (53%) were not mentioned as often by respondents. These results could indicate that information that is easier to obtain is recorded more often.

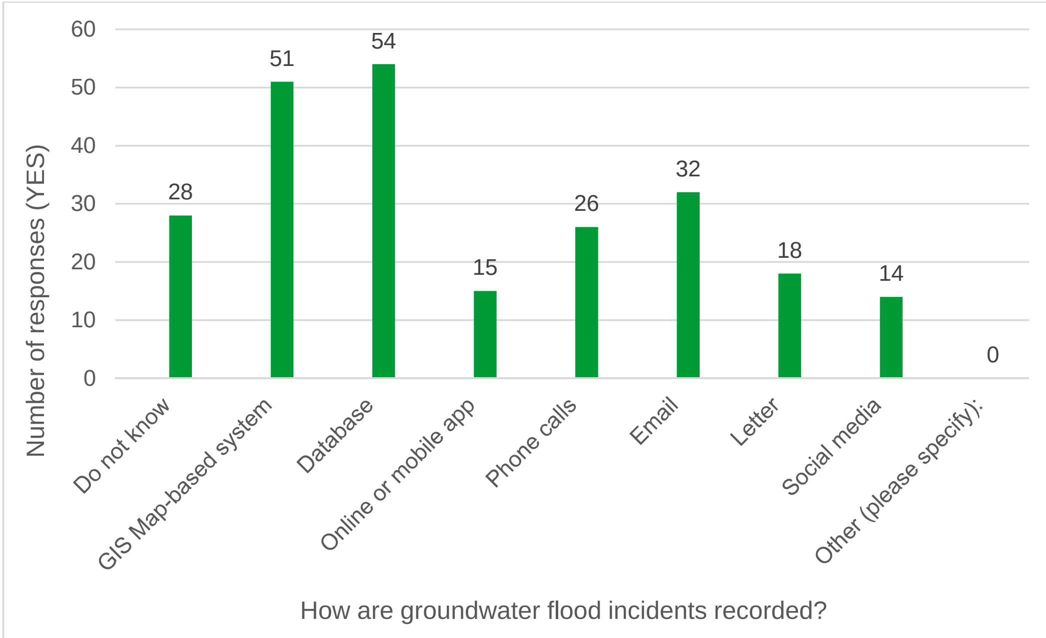

Figure 6-6 How are groundwater flood incidents recorded?

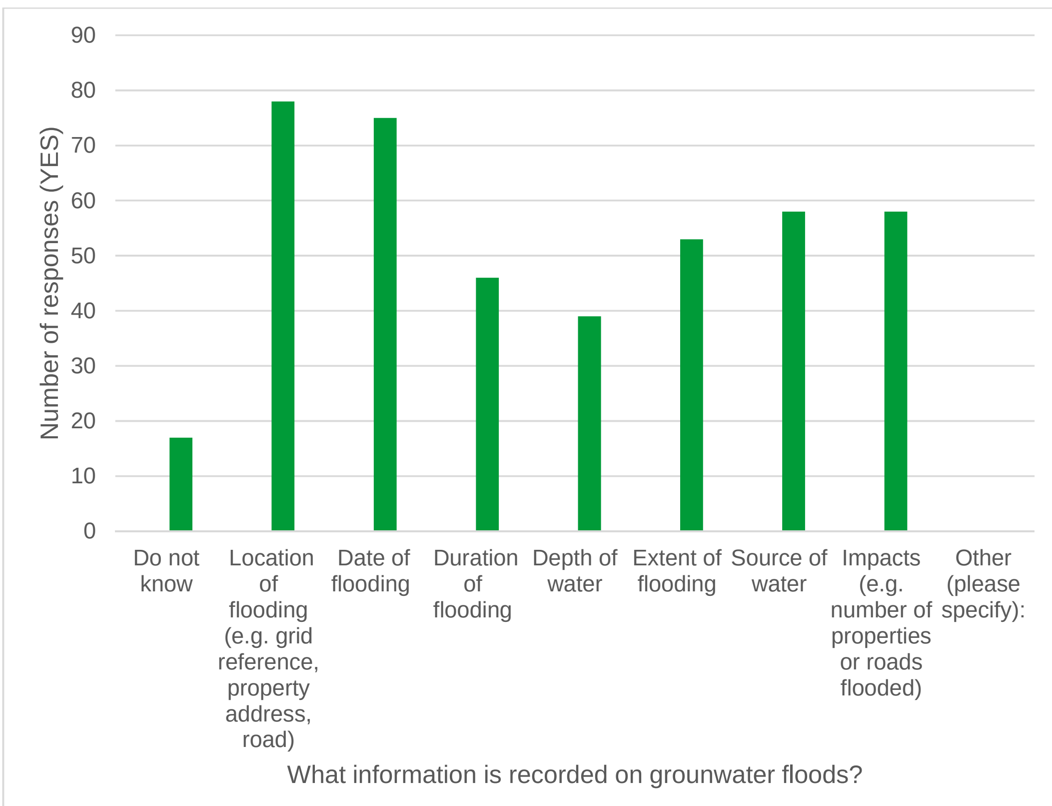

Figure 6-7 What information is recorded about a groundwater flood incident?

Literature information

A number of the literature data sources made reference to reporting groundwater flooding. The areas of England where survey respondents indicated 'Yes' to "Do you (or your organisation) record groundwater flood incidents?" is shown in Map 1 (Appendix D). This map shows the number of responses for each LLFA area, with the most respondents (7 and above) in the south of England and Lincolnshire, with Wiltshire and Hampshire having the highest response. This corresponds to areas with a greater likelihood of groundwater flooding. Table 6.1 provides details of systems for recording groundwater flooding.

Table 6.1 Methods of recording groundwater flooding – reporting incidents at the time/after – Literature data

System for recording groundwater flooding	Where is it used?	Details of system	Comment
FORT (previously SWIM)	South-west England, Lancashire and Cumbria	Comprehensive reporting system, including the ability to report groundwater flooding. See case study below.	Allows visualisation and reports of historic flood events in an area and reporting at property level. Helps LLFA wardens in reporting and accessing records. Use could be extended to other LLFA areas.
.gov.uk reporting portal	National	Government website, directs people to their local council to report groundwater flooding.	Redirects to local councils, does not serve as a database.
Online GIS systems (council)	Local councils - for example Hampshire County Council (interview 2020).	An online GIS layer is accessible by the public to report flooding, with the option to include source.	Originally a Highways database now used for public flood reporting. Can add that groundwater is the source of the flooding but often public do not know this.
FRIS (Flood Reconnaissance Information System)	Environment Agency south-west region	Records flooding events, including source of event, for example, groundwater, surface water.	Groundwater flooding may not be identified if the source of flooding is unclear.
Section 19 reports	Under section 19 of the FWMA 2010 LLFAs can produce a flood investigation report following significant flood events.	Reports carried out by and available from LLFAs, often on the web.	Depending on the level of detail regarding the groundwater flooding these can be a very useful place to capture information. Although it is often difficult to distinguish groundwater flooding from other sources, and these reports are not always readily available.

The Environment Agency teams in the south-west retain recordings of flooding events on the FRIS (Flood Reconnaissance Information System) database, which includes the source of the flooding (for example, groundwater, surface water, and fluvial). The Bristol City Council Strategic Flood Risk Assessment (SFRA) Level 1 (2009) identified no flooding incidents recorded as being caused by groundwater in the FRIS database, or any other data set. However, it identified the limitation of these data sets in identifying groundwater flooding events since there is often uncertainty as the effects are often either indistinguishable from, or coincident with, other sources of flooding (Halcrow Group Limited, 2009).

Section 19 reports

Section 19 of the FWMA 2010 gives LLFAs duties to investigate and produce reports on flooding where it considers it necessary or appropriate. The investigation examines the cause of flooding, the role of flood RMAs involved and what is proposed in response to the flood (https://www.eastriding.gov.uk/council/plans-and-policies/other-plans-and-policies-information/flood-risk/flood-risk-investigations/).

An example of a detailed section 19 groundwater flooding report is the Flood Investigation Report for the Burton Fleming winter (2012 to 2013) flooding (East Riding of Yorkshire, 2013). This report provides:

- when and where the flooding happened and for how long
- an assessment of groundwater levels in response to the extreme rainfall prior to the flood
- the geological context and causes of flooding
- the history of flooding (for example, residents thought that Gypsey Race floods about every 50 to 60 years).

Other section 19 reports have been analysed using machine learning techniques to extract text relating to groundwater flooding. The 4 section 19 reports analysed included:

- Section 19 Flood Investigation Report: Hailsham (2017)
- Flood investigation Report: Greater Manchester (2015)
- December 2015 Floods in Lancashire Section 19 Investigation (2016)
- Section 19 Flood Investigation Report Hengest Avenue (2017)

This analysis highlighted references to a variety of watercourses. Both winter and summer months are mentioned, as are words relating to potential flooding locations: properties, cellars, internally and overland. References to sewers, fluvial, pluvial and surface suggest links to other types of flooding.

Section 19 reports can provide a very useful means of documenting what happens in a flood, the mitigation measures taken and what was learned. They also provide useful information for targeting future work on flood risk assessment, forecasting, warning and mitigation, if sufficient information is available and documented within the report. LLFAs can use these to identify data, knowledge and process gaps and target future flood risk management investment.

A spatial index of Section 19 reports could help to identify locations of significant groundwater flooding and where assessments have been made. This may also be helpful for developers and development management teams if no other data on groundwater flood risk is available. However, Section 19 reports are not mandatory so there would still be limitations with this approach.

Ad hoc reporting of groundwater flooding

There are also multiple cases in unpublished, grey and published literature where organisations and individuals have collated information following groundwater flooding. This information is contained in a series of reports or documents, which may be more or less accessible. However, these reports may include considerable data, analysis and interpretation regarding groundwater flooding. Some notable analysis of records of groundwater flooding include:

- McKenzie and others (2015) estimated the percentage of properties in susceptible area vulnerable to groundwater flooding by comparing existing susceptibility mapping with records/reports of groundwater flooding and systematic surveys
- Macdonald and others (2012) looked at the occurrence of groundwater flooding of areas in an urbanised flood plain of the River Thames in Oxford, using an extensive data set gathered during major flooding in 2007
- Ascott and others (2017) assessed the controls in time and space on regional scale groundwater flooding. It used data from the 2013 to 2014 flood events, at the outcrop of the chalk aquifer in the south-east of England
- Hughes and others (2011) completed a study of groundwater flooding of the chalk aquifer underlying the Pang and Lambourn catchments in Berkshire, UK, using surveys to show the importance of local knowledge in understanding groundwater flood mechanisms

Further details of other records of groundwater flooding are given in the project systematic data map (separate project output).

The systems identified above are mainly local not national. There are some national databases that contain groundwater data (Table 6.2), but these are not typically used for recording groundwater flooding data.

Table 6.2 Examples of national data records

System for recording national data	Where/when is it used?	Details of system	Comment
CEH/National River Flow Archive (NRFA)	Post flood event report.	Technical analysis of flooding based upon National River Flow Archive data set.	Mostly used for reporting on fluvial flood events, little on groundwater flooding. However, could be a source of information in catchments dominated by groundwater.
BGS/National Groundwater Level Archive	Not specifically used for flooding but 28 index wells provide data for the hydrological summary of the UK.	Groundwater observation network, 166 sites in England, mostly not impacted by abstraction.	This is a national groundwater archive, although not all data is freely available on the internet. Data is sourced from the Environment Agency. Not currently used, particularly for groundwater flooding.

6.5.3 Case study: Flood Online Reporting Tool (FORT)

Secondary question: is there a consistent process for recording groundwater flooding incidents?

Source of information: literature and interview

Organisation(s): Environment Agency with help from the Dorset County Council GIS team.

Date: 2013

Hyperlink to further detail: https://swim.geowessex.com/uk

Location: Wessex, Devon, Cornwall, Essex, Cumbria and Lancashire.

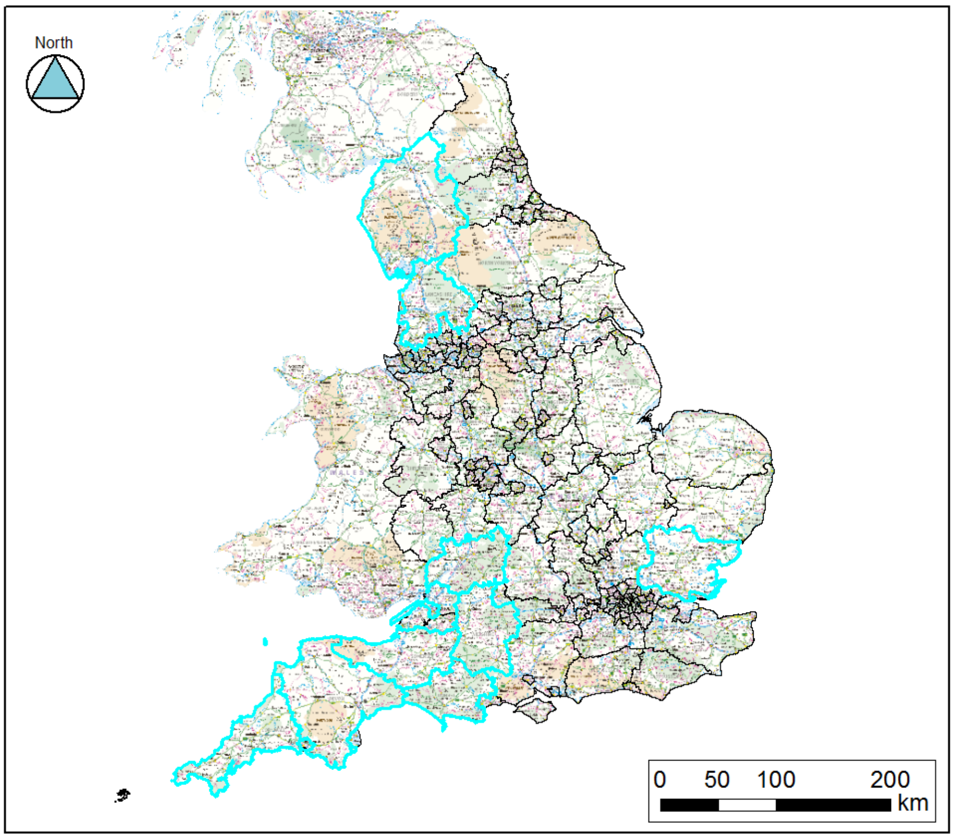

Figure 6-8 Locations where the FORT tool is used

This tool was developed in 2000 and called SWIM (Severe Weather Information Management). It was updated in 2013 to FORT (Flood Online Reporting Tool).

It is an Oracle Geo database web platform, hosted by Dorset County Council (GeoWessex), used by local authorities and the Environment Agency across the south-west and also has been used in Cumbria and Lancashire. Work is ongoing to allow new areas access to this service whenever it is requested by the relevant flood risk management authorities (further details provided on the website providing in the “hyperlink” section below).

The FORT system has 5 goals:

1. **Report**: to allow members of the public, flood wardens and flood risk management authorities to enter details about property flooding in one place.
2. **Analyse**: allows flood risk authorities to quickly analyse flood data, which can then be used in reports that help inform flood risk management strategies.
3. **Plan**: reports and analysis can be used when assessing new planning options and when assessing proposed flood alleviation schemes.
4. **Protect**: all records are spatially referenced allowing them to be used as a basis for localised protection schemes from community work to individual property protection.
5. **Network**: the system can be a used to help multiple agencies in their combined response to flooding both during and after an event. Data entered into the system is shared appropriately, providing an overall picture of what problems exist over a geographical area. This helps agencies better prioritise assistance both during and after an event. The system doesn't stop there, as it also includes tools to help flood risk authorities work closer with community and volunteer groups to tackle the causes of flooding at the local level.

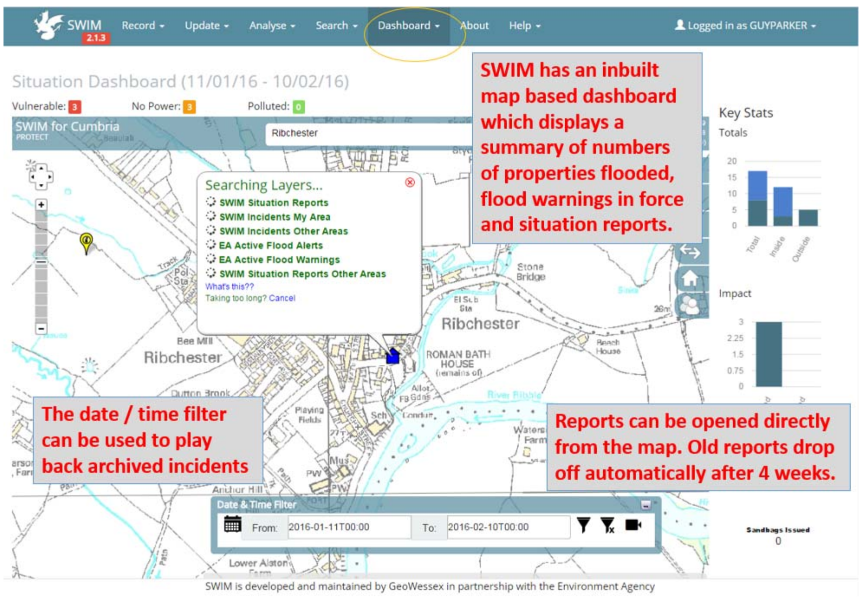

Figure 6-9 Dashboard and functionality of the FORT tool

Wardens are able to produce flood area reports, with specific details such as impacts on properties and types of flooding, while also being able to quickly share and use data such as searchable photographs and contacts. This can then be quickly disseminated to all partners, such as local authorities, fire services and water suppliers, with the portal having intelligent data forms that share information only to the relevant parties. This platform is the approved data collection tool across the south-west Flood Risk Managers area (Wessex and Devon, Cornwall & Isles of Scilly) and gets its funding from the South West and Wessex Regional Flood and Coastal Committees, with the amount determined by the number of participating local authorities. Although it has been used by other areas (for example, Cumbria) following periods of flooding, any funding from these has been a one-off or use has been allowed on a voluntary basis.

6.5.4 Implications of findings

A number of organisations record groundwater flooding for a range of purposes. The records are contained within separate reports (some available online) and a number of separate databases. Some systems, such as bespoke GIS databases (for example, Hampshire County Council) are used by individual LLFAs, while others such as FORT are used in a number of counties. Much of this information is available, but often not in one location and not all online, with various methods of recording groundwater flooding events. The majority of groundwater flood recording is managed by the LLFA.

The consequence of records within numerous databases of different types is that organisations may not have access to or be aware of the flooding records available within their area of interest. Where groundwater flood records have limited information or have not been entered by someone with prior knowledge of groundwater flooding mechanisms the records may be less reliable. The decentralised nature of the records and variability in quality mean that key historic information on groundwater flooding could be missed, which would otherwise inform planning and mitigation measures.

6.5.5 Gaps and future work

There is no national process for recording property level flooding. Even within the agencies there is not a standard data structure that is used to record information consistently. Data required by the Environment Agency, LLFA and utility companies is not well communicated.

Existing reporting mechanisms, such as Section 19 reports, could be used to improve understanding in groundwater flood risk and mitigation efforts, but this needs data to be collected consistently and synthesised. Guidance on identifying groundwater flooding, and what information should be recorded, specifically in section 19 reports, would improve consistency and quality in reporting.

Data protection (including requirements under the general data protection regulation) needs to be considered when sharing property level data across agencies. There is no standard procedure or platform to share data securely.

A single centralised source of groundwater flooding event information could further add value to these records. Ideally, this would bring together information from existing LLFA reporting tools (if they produced common outputs) and be accessed by stakeholders in groundwater flood risk management. It may not be appropriate to make this (or all elements of this) public, but it could have a public-facing interface that avoids the issues identified around potential property blight, and a component only accessible by LLFAs and other stakeholders to help inform groundwater flood risk management.

Peer to peer learning could also support stakeholders. Guidance or examples of how groundwater flood records is used or could be used to support decision making could be captured and shared. The UK groundwater forum[3], an existing network, could be a good place to provide further information and encourage discussion.

Collective, consistent information on groundwater flood records would be useful for:

- underpinning local flood risk management
- rapidly identifying areas of groundwater flood risk, which may cross county boundaries, to identify authorities to coordinate with
- inform where to target flood forecasting and warning

[3] http://www.groundwateruk.org/About-the-Groundwater-Forum.aspx

- informing spatial planning
- retaining knowledge, particularly if groundwater flooding occurs infrequently

Information on flood records would provide county councils in particular the information to help them fulfil their roles as lead local flood authorities for groundwater.

6.6 What national scale risk assessment information exists?

The Environment Agency does not currently produce national groundwater flood risk information. The main aim of this question is to summarise the information and activity for groundwater flood risk assessment. Understanding flood risk is crucial for flood risk management, underpinning decisions to prepare, respond and recover from groundwater flooding. This summary may help RMAs to understand the current availability of data and practice to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 3a.

Secondary question 3a: What national scale risk assessment information exists?

6.6.1 Summary response

Two national groundwater flood risk maps exist (Table 6.3). However, they are older and less detailed than the commercial products.

Three commercial national groundwater flood risk maps exist (Table 6.4). They are not freely available, and their methods are not published in full. They provide an indication of areas where groundwater will be near, or at, the surface following extreme recharge.

6.6.2 Summary of evidence

Environment Agency data

Since the mid-2000s the Environment Agency has published national scale flood risk maps; firstly for fluvial flooding, and subsequently for coastal, surface water and reservoir flooding. These have been regularly updated, improved and refined as data and technology allowed.

In 2004, Jacobs produced Groundwater Emergence Maps (GEMS) for Defra to show the causes and extent of flooding. These show areas that are susceptible to groundwater flooding. Although these maps do not have full national coverage, they do have significant value in understanding the likely groundwater levels in a groundwater flooding event (especially in the south-east of England), and were widely used in the 2014 groundwater flooding event (steering group feedback, 2020).

In 2010, the Environment Agency developed a very broad scale groundwater flood risk map known as the 'Areas Susceptible to Groundwater Flooding' (AStGwF) map. This was produced solely for the purposes of the preliminary flood risk assessment in 2011 to meet the European Floods Directive (Directive 2007/60/EC) and the Flood Risk Regulations (2009). The map was produced to support high level screening to identify areas with significant flood risk and that warrant further assessment. The AStGwF product drew on commercial products available at the time, Environment Agency data and mapped groundwater flood outlines, to provide an indicative rating of groundwater flood risk for tiles on a 1km^2 grid. This was available for public download online (from gov.uk), but is currently available to councils only on request. This mapping is noted to have significant technical weaknesses and is advised not to be used for groundwater flooding assessment (steering group feedback, 2020). Work is underway to create a new national flood risk assessment by 2024 for all sources of flooding, with present day and future climate scenarios, however it will not include groundwater in the first release. It is expected that this will be able to incorporate groundwater risk mapping developed by others, like LLFAs, if it meets criterion set by the national flood risk assessment (steering group feedback, 2020).

The products in Table 6.3 are made available to some parties and are still, at times, used within SFRAs for councils, often with considerable caveats as to their applicability and reliability. However, they continue to be used as they are cheaper than other products and provide a first level of screening for groundwater flooding.

The evidence for national scale risk assessment information was gained from the literature search, questionnaire responses and semi-structured interviews.

Table 6.3 Preliminary groundwater flood risk mapping information

Product owner/ Product name	How to obtain product	Description	Comment
Jacobs GEMS, 2004	Detailed in the report, available as a PDF.	A general map of susceptibility to groundwater flooding.	This was a first attempt at mapping groundwater flooding; however, it does not have full national coverage and tends to over-estimate flooding. It is still occasionally used in SFRAs.
Environment Agency Areas Agency 'Areas Susceptible to Groundwater Flooding' AStGwF, 2010	LLFAs can request this from Environment Agency but must note its limitations.	Strategic-scale 1km^2 grid map of groundwater flooding shows the proportion of each 1km grid square, where geological and hydrogeological conditions indicate that groundwater might emerge. It does not show the likelihood of groundwater flooding, only isolated locations within susceptible areas are actually likely to flood (JBA 2017).	Use only with other information, for example, local or historical data. It should not be used as sole evidence for any specific flood risk management, land use planning or other decisions at any scale. This mapping is noted to have significant technical weaknesses (including the effects of averaging data over 1km^2 which means narrow areas of significant flooding, e.g. down valleys, may not be highlighted) and is advised not to be used for groundwater flooding (steering group feedback, 2020). Can help to identify areas for assessment at a local scale where finer resolution data sets exist (JBA, 2017).

Commercial data

There are 3 commercially available risk mapping products that have national coverage. All have been available for a number of years and existed in a number of versions. The products are generally available to buy (often per unit area), either direct from the organisation that developed them or through resellers.

The methods used to produce these products are not fully documented online so could not be reviewed within the peer-review and grey literature. Some information on the JBA groundwater flood risk map is available in the Making Space for Water report which details trials of its development (Jacobs, 2007). Access to this information was obtained by semi-structured interviews with important stakeholders.

The details of the most recent map versions are given in Table 6.4.

Table 6.4 National-scale groundwater flood risk mapping information

Product owner	Name of product(s)	How to obtain product	Description
GeoSmart (previously part of ESI)	GeoSmart GW5, GeoSmart GW200S	Enquiries made directly via their website at geosmartinfo.co.uk or resellers.	Groundwater flood risk mapping at 5m and 200m resolutions. Both products cover Great Britain.
BGS	BGS susceptibility to groundwater flooding	Website: bgs.ac.uk Enquiries via e-mail to digitaldata@bgs.ac.uk	Groundwater flooding susceptibility data set, available as a 50m grid covering Great Britain.
JBA Consulting	JBA 5m groundwater flood risk map	Enquiries made directly via their website at jbaconsulting.com or resellers.	Groundwater flood risk mapping at 5m resolution, covering Great Britain. See Map 6 (Appendix D) for a 1km downscaled version of the JBA map.

The GeoSmart (GW5) and JBA (5m) national products are both based on 1 in 100-year return period flood event scenarios (see Table 6.6 for a more detailed comparison). There are risk maps of various return period events for some distinct geological areas, such as JBA's groundwater flood map in the Chalk aquifer in south-east England at 75, 100 and 200-year return periods. The national-scale groundwater flood risk maps provide a gradation of risk, for example, from groundwater levels near to the surface, at the surface, and above the ground surface. SFRAs often use this data, particularly level 1 SFRAs. Each of the level 1 SFRAs used a groundwater map, a majority using the Environment Agency's AStGwF and others BGS's Susceptibility to Groundwater Flooding.

Out of all the questionnaire respondents' organisations 62% used maps, models or other products to determine the risk of groundwater flooding, 31% did not, and 7% didn't know. 56% used national model/map products, 37% did not and 7% didn't know. The number of national model or mapping products used by questionnaire respondents, by the organisation that provides them, is shown in Figure 6-10. It shows that of those that responded saying they used national model or mapping products, the majority (81%) use Environment Agency and BGS groundwater flood risk mapping.

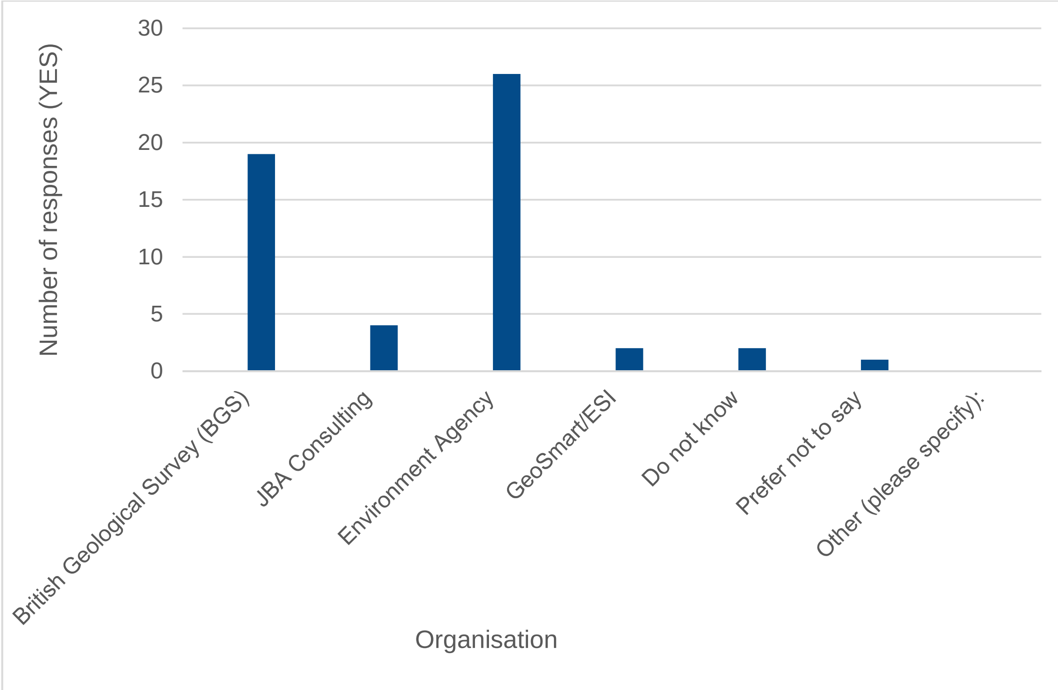

Figure 6-10 Number of national model or map products used, by organisation

Much proactive risk assessment is carried out as part of the planning and conveyancing systems. The national groundwater flood risk mapping carried out by GeoSmart and JBA is resold via various land quality organisations to the home buyer and developer markets, including Landmark (GeoSmart, 2020), Future Climate Info and Bluesky (JBA, 2020). Commercial mapping is also resold through combined flood risk mapping products for insurers, such as Ambiental's UKFloodMap4, which incorporates GeoSmart's 5m groundwater flood risk mapping product.

6.6.3 Implications of findings

The absence of available groundwater flood maps was flagged as an issue during the 2020 winter groundwater floods. The Environment Agency were unable to ask the public to check their flood risk as there were no national groundwater flood maps (project team, 2020). Freely available national risk maps are available for other sources of flooding which means that a consistent service across all flood sources is not provided.

National mapping has been developed by GeoSmart (previously ESI) and JBA Consulting, which aims to establish groundwater flooding in terms of risk, with a 1 in 100-year flood event criteria, but are only available at cost. The cost and uncertainty regarding the methodology of the commercial products can be barriers to their usage. As an alternative, the free BGS/Environment Agency groundwater susceptibility maps are used, despite them being less detailed and less accurate products.

There are considerable technical difficulties and uncertainties in mapping groundwater flood risk, so it is important that the methodology used in developing mapping products is clearly documented including any limitations. At present, as the national products are all commercially developed (without a published detailed methodology), there is no forum for discussing accuracy, limitations, weaknesses and potential errors in the risk mapping.

6.6.4 Gaps and future work

Currently, there is no freely available national risk information on groundwater flood risk, and currently no plans to provide one. This gap has partly been filled by the private sector, who provide national maps, but at a cost with less transparency around the methods used.

Even the most developed groundwater flooding risk maps produced are not as specific, or accurate, in terms of predicting flood risk in the way the current maps for fluvial flood risk do. This is due to the technical complexity of predicting exactly where groundwater flooding occurs, with local geology, the built environment and drainage influencing the actual occurrence of flooding (section 3.1), not just high groundwater levels.

A freely available groundwater flood risk map would help LLFAs and the Environment Agency assess the risk of groundwater flooding for developing strategic plans and mitigation options. This should be made available to LPAs to use in strategic flood risk assessments. If publically available it would help communities understand their risk and take appropriate action (for example sign up to flood warnings or invest in property level resilience measures).

To help practitioners, additional data such as water companies' sewer improvement works, data from the Coal Authority on mine water rebound, and depth to groundwater (to indicate areas for borehole monitoring) could be included (Hydrogeology group, 2020). This would be particularly beneficial for informing local plan development.

If this is not possible in the short term, existing available information could be used to undertake a screening exercise. This could use risk factors associated with groundwater flooding (for example, geological controls such as low storage capacity, sands and gravels associated with rivers, historical flooding, naturally high groundwater levels, and high levels of development where there are shallow aquifers).

Such information would help LLFAs to target where focussed detailed groundwater flood risk modelling would be needed. This information would then be used in the Environment Agency's national flood risk assessment, or risk of flooding maps. This is the same process used for the Environment Agency's Risk of Flooding from Surface Water maps, which also show a suitability score based on the model performance and input data of the area of interest.

This could be provided as a high level communication tool to the public, along with some descriptions of the groundwater flooding mechanisms and whether these are a risk factor. Ideally, this information would be presented on a live mapping portal that would be updated as new information is available.

Further research would be helpful in identifying or developing a suitable groundwater flood risk map. Using this map appropriately would also require explanation and education. It would not be helpful to map large areas as being at risk of groundwater flooding, where no groundwater flooding has actually occurred. Further work would help to identify a suitable way forward.

6.7 Groundwater flood risk assessment (non-real time): What local risk mapping techniques are used?

The main aim of this question is to summarise the information and activity for groundwater flood risk assessment. Understanding flood risk is crucial for flood risk management, underpinning decisions to prepare, respond and recover from groundwater flooding. This summary may help RMAs to understand the current availability of data and practice to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 3b:

Secondary question 3b: What local risk mapping techniques are used?

6.7.1 Summary response

The evidence indicates that detailed local risk mapping has been carried out in a number of locations. Local risk mapping is often informed and adapted from the national groundwater risk mapping products, such as the maps produced for London (iPEG, using Jacobs and JBA flood risk mapping) and Northamptonshire (ESI/GeoSmart). The local specific nature of groundwater flooding, which depends on specific geology, catchment rainfall response, and particular hydrogeological conditions, topography and drainage is amenable to local risk assessment.

6.7.2 Summary of evidence

Of questionnaire respondents 44% (24) indicated that they produced their own groundwater flood model/maps. Over half of these were from the Environment Agency (see Figure 6-11). They indicated that generally their own maps are 'fairly accurate' (36% of respondents), some (9%) thought that they overestimated groundwater flooding, and almost half (48%) didn't know.

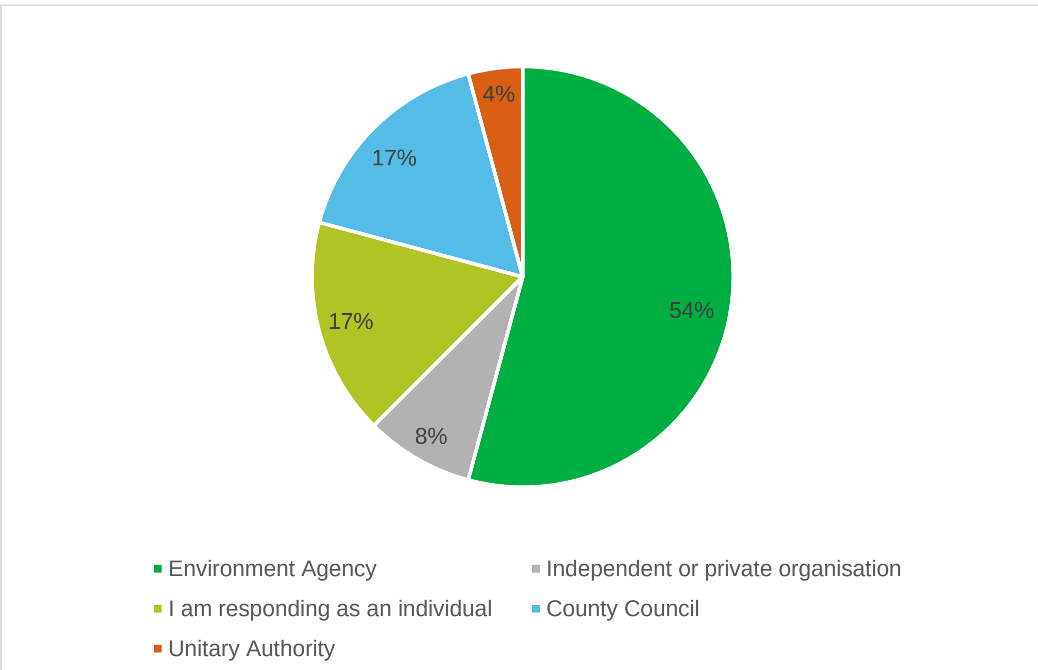

Figure 6-11 Organisations that produce their own models and maps

Detailed local mapping has been carried out in places and is described in more detail below.

Northamptonshire

ESI Ltd (2016b) was instructed by Northamptonshire County Council (NCC) in February 2015 to carry out an assessment of groundwater flooding in Northamptonshire. The importance of groundwater flooding at the county scale was assessed, with 3 main mechanisms of groundwater flooding identified: flooding via permeable superficial deposits (PSD), high spring flows and high bedrock groundwater levels. The groundwater flood risk (GWFR) from these 3 mechanisms was mapped for an indicative 1% annual probability, with 2 GIS outputs: a 5m x 5m map classifying the GWFR in 6 categories (very high, high, moderate, low, very low and negligible) and a supporting layer indicating the mechanism causing the GWFR.

The maps represent a precautionary approach, assuming the county could be subject to more extreme groundwater flooding than yet recorded. Approximately 79% of the county is considered to be at a negligible risk of groundwater flooding.

Site visits were carried out at 3 areas of known groundwater flooding (Great Billing and Brackenhill Close in Northampton; and Wollaston). These helped to identify the groundwater flood mechanisms, validate the results of the groundwater flood risk mapping, assess potential generic flood mitigation measures that may be successful in Northamptonshire, and help calculate the cost of flood damages.

Oxford

In Oxford, BGS, together with the Environment Agency, has carried out significant mapping and monitoring of alluvial (permeable superficial deposits) groundwater flooding (Macdonald and others, 2012). This has included detailed geological modelling and LiDAR topographic data, combined with 235 groundwater and surface water monitoring points, observations of flooding (including a questionnaire) and preliminary groundwater flood mapping.

Wessex

The Environment Agency’s Wessex area has used the regional Wessex Basin coupled MODFLOW-4R groundwater model to produce risk plots where groundwater is within a couple of metres of the surface. This has had varying success owing to the regional nature of the model, with not particularly good calibration of groundwater levels in some areas (questionnaire response, 2020). This highlights that using regional water resources groundwater models to predict groundwater flooding may be difficult where the regional model has a large grid size and coarse resolution spatially and also long time steps, e.g. monthly or sometimes weekly, which make it difficult to model actual local onset and peak of groundwater flood events.

Hampshire

The Environment Agency’s Solent and South Downs area has developed a series of threshold levels on boreholes that can then be used to monitor and describe the progression of groundwater flood up chalk valleys. This can help to inform warning and response as the threshold levels are linked to specific receptors. For example ‘at Xm AOD road A has to be forded, then at Ym AOD village B has flooding, and at Zm AOD the village C up the valley has flooding’. Where this always happens in the same sequence and, if the groundwater level is rising as fast as it usually does, there is a relatively consistent delay between events. This temporal dimension adds considerable value for the local communities.

Hampshire Local Flood Risk Management Strategy (Hampshire County Council, 2013) has also collated and mapped records of groundwater flooding and estimated associated costs. Specifically in Portsmouth, the County Council analysed an extensive record of groundwater levels from 55 boreholes across Portsmouth (monitored over the period 2015 to 2019) to establish conceptual models, groundwater table range maps and areas of potential groundwater emergence (JBA 2020).

Buckinghamshire and West Berkshire

Morris and others (2018) modelled and mapped groundwater flooding at the ground surface in chalk catchments of Southern England (Buckinghamshire and West Berkshire). Their approach included frequency analysis of regional observation borehole data, calculating groundwater emergence flows and hydraulic modelling of groundwater flows at the surface to produce flood depth maps. These groundwater emergence and routing maps were calibrated on measured groundwater flow and observed flood extents that occurred in 2014. The maps are anticipated to be used to plan for and manage future groundwater flooding events. This method works very well in chalk areas where emergence is fairly uniform and routing the groundwater discharge through a surface water model will show where it flows once it emerges. This could be a useful method to produce groundwater risk maps at larger scales. However, where groundwater emergence is not uniform (e.g. fault/spring driven) this would need to be accounted for.

Modelling of mine water rebound

Questionnaire respondents indicated that they carried out risk mapping/modelling of groundwater flooding from mine water rebound. A number of highly detailed studies have modelled mine water rebound. This usually involves consultation with the Coal Authority, the main source of flood risk data associated with mine water risks in these areas, including details of any current mitigation measures, such as local pumping regimes.

Mine water rebound risk mapping is included within flood risk management strategies for new developments in areas at risk, commonly in the north-east, such as the proposed MetroGreen development (Mott Macdonald, 2019) in Gateshead. This included mapping mining blocks managed by the Coal Authority, potential mine water discharge points and associated pumping schemes that need to be considered within the risk assessment, should this pumping cease and increase the risk of groundwater emergence due to rebound.

Modelling for strategic flood risk assessments

It was beyond the scope of this project to review all SFRAs, surface water management plans (SWMPs), local flood risk management strategies (LFRMS) and other flood risk assessments and plans. However, these documents potentially have significant amounts of information regarding groundwater flooding, particularly historical flooding and costs, and may have considerable analysis of groundwater flooding, including risk assessment.

The West London Strategic Flood Risk Assessment is one example. This used the Greater London Authority 2011 'Increased Potential for Elevated Groundwater' data set which is 50m resolution. It provides spatial mapping on areas of 'consolidated aquifers', 'permeable superficial' and 'consolidated and permeable superficial others' within the Greater London Area (Metis Consultants, 2018).

Using monitoring data to understand flood risk

Information from the questionnaire indicates that various organisations use and collect monitoring data for groundwater flood risk management purposes. 78% (73 people) used groundwater monitoring data (their own or others), 17% did not (16 people), and 5% (5 people) didn't know if they did or not. 63% of the respondents' organisations (60 people) collected groundwater monitoring data, 32% of the respondents' organisations (30 people) did not and 5% (5 people) didn't know. Of the organisations that collected monitoring data, two-thirds of the responses were from the Environment Agency, with others including local authorities, individuals and water companies. The data is generally used for groundwater flood forecasting, warning and modelling/mapping.

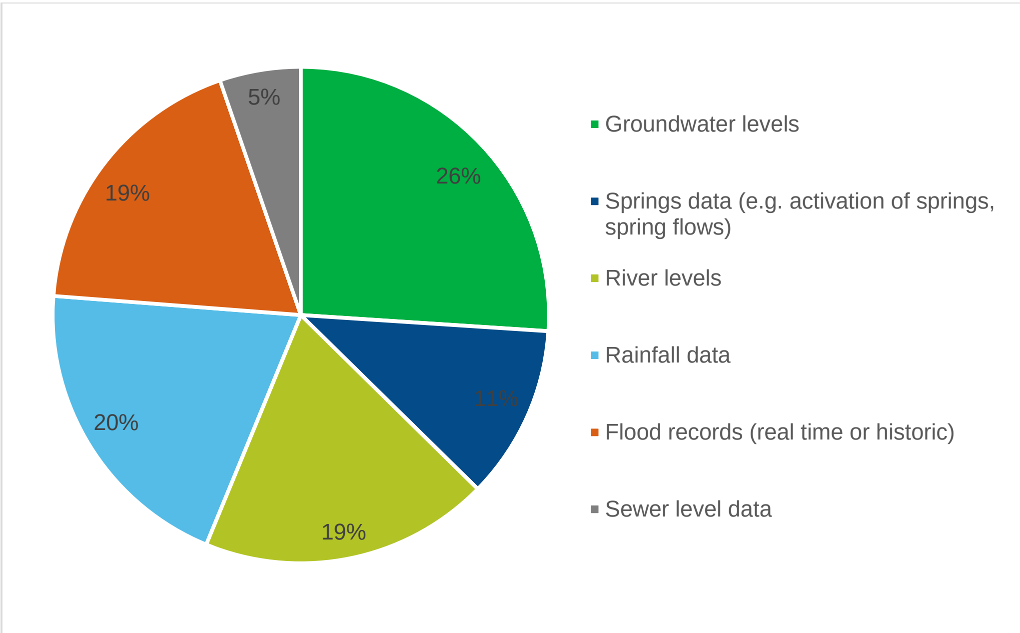

Figure 6-12 What type of monitoring data do you use for groundwater flood risk management purposes?

The type of monitoring data used for groundwater flood risk management purposes, as provided in the questionnaire responses, is shown in Figure 6-12. In many areas, it is borehole groundwater level monitoring data, and particularly upward trends in groundwater levels, combined with rainfall, which are used to forecast groundwater flooding. The following section considers borehole records.

Halcrow (2010) indicated that there were 656 Environment Agency monitored boreholes (that is, about 11% of the total monitoring borehole network) identified as having flood risk management as one of their business drivers. RAB (2016) states that there were currently around 380 boreholes with telemetered level recording, 140 of which (37%) were in the chalk aquifer.

The Environment Agency released live borehole data to the public shortly after the 2014 floods. The Environment Agency API (application programming interface) was developed shortly after this, providing a portal for accessing telemetered data. In May 2020 418 groundwater level datasets were online and immediately available.

Additionally, LLFAs have locally installed boreholes, with the aim of monitoring groundwater. A significant body of data from 55 boreholes has been collected by Portsmouth City Council (JBA 2020).

6.7.3 Case study: London Potential for Elevated Groundwater (iPEG) maps

Secondary question: What local risk mapping techniques are used?

Source of information: literature

Organisation(s): Greater London councils / JBA / Jacobs

Date: 2011

Hyperlink to further detail: [Enfield surface water management plan]

Location: Greater London.

Figure 6-13 Location where iPEG maps are used

London councils have combined via the Drain London project to produce specific groundwater emergence maps, known as 'increased Potential for Elevated Groundwater' (iPEG) maps, to help determine the areas within Greater London that are possibly at risk of groundwater flooding (Capita Symonds, 2012).

The iPEG map shows those areas within the borough where there is an increased potential for groundwater to rise sufficiently to interact with the ground surface or be within 2m of the ground surface. The assessment was carried out at a Greater London scale. The 4 data sources listed below have been used to produce the 'increased Potential for Elevated Groundwater' (iPEG) map:

- British Geological Survey (BGS) Groundwater Flood Susceptibility Map
- Jacobs Groundwater Emergence Maps (GEMs)

- Jeremy Benn Associates (JBA) Groundwater Flood Map
- Environment Agency/Jacobs Thames Estuary 2100 (TE2100) groundwater hazard maps

The iPEG has been combined with records of historic groundwater flooding. The discrepancy between recorded historic incidents and potential areas of future incidents may be attributed to the following:

- past incidents may be a result of localised flooding mechanisms (or other flooding mechanisms) which have not been assessed as part of the production of the iPEG mapping
- the iPEG mapping does not represent local geological features and artificial influences (for example, structures or conduits) which have the potential to heavily influence the local rise of groundwater
- the iPEG map only shows areas that have the greatest potential for elevated groundwater and does not necessarily include all areas that are underlain with permeable geology
- the flood source attributed to some past incidents may not be accurate

Within the areas delineated, the local rise of groundwater will be heavily controlled by local geological features and artificial influences (for example, structures or conduits) which cannot currently be represented. This localised nature of groundwater flooding, compared with fluvial flooding, suggests that interpretation of the map should similarly be different. The map shows the area within which groundwater has the potential to emerge, but it is unlikely to emerge uniformly or in sufficient volume to fill the topography to the implied level. Instead, groundwater emerging at the surface may simply run off to pond in lower areas. For this reason, within iPEG areas, locations shown to be at risk of surface water flooding are also likely to be most at risk of run-off/ponding caused by groundwater flooding. Therefore, the iPEG map should not be used as a 'flood outline' within which properties at risk can be counted. Rather it is provided, together with the surface water mapping, to identify those areas where groundwater may emerge and, if so, what would be the major flow pathways that water would take.

6.7.4 Implications of findings

The evidence indicates that detailed local risk mapping has been carried out in a number of locations and is thought to be 'fairly accurate' (project survey, 2020).

There is considerable groundwater monitoring data available, however, there is a difference between high groundwater levels and actual groundwater flooding. Trigger levels or modelling are required to turn high groundwater levels into a risk of flooding information, which may take considerable investment to produce. Even when trigger levels are used to indicate a risk of groundwater flooding, this does not translate directly into a map of where groundwater flooding will occur.

Any local risk mapping would need to be supplemented with local knowledge to develop an understanding of how and where groundwater emergence may occur. In many cases this is held by developers who know where local groundwater levels are when working on housing developments. This local knowledge could be better captured by LPAs and shared with other organisations (Hydrogeology group, 2020).

The questionnaire respondents indicated that they collected and used monitoring data for groundwater flood risk management purposes. This data was frequently collected by the Environment Agency, but, in some areas, the Coal Authority, water companies, local authorities and individuals provided monitoring data. Although there are various organisations collecting monitoring data this is not always freely available, and may limit the data available in some areas for use in risk assessment and management.

6.7.5 Gaps and future work

Maps of areas where groundwater flooding has occurred would help to provide information to the public (especially during a groundwater flood event), support planning purposes and RMAs manage flood risks. Specific locations of previous groundwater flooding are helpful in indicating where groundwater flooding may occur in the future under similarly wet conditions.

In locations where a specific trigger level can be related to onset of flooding at a particular location, information on how the flood may progress, for example 'in 12 hours flooding is likely to have reached X location' could be provided. This could be useful groundwater warning messages and to help local communities prepare and respond to flooding. Not all locations of groundwater flooding have a consistent trigger level, regular timescale or extent of flooding identified so this would need further investment.

Local risk models and maps of groundwater flooding would be very useful for the same purposes. These should be used to consider how groundwater flooding may interact with other flooding sources (flooding from rivers, the sea, smaller watercourses and sewers). These could be used to identify where groundwater emergence occurs and whether it exacerbates existing flood risk from other sources. This would support flood risk assessments for flood risk mitigation and proposed future development.

These would need to be interpreted and used by people with specialist knowledge in groundwater hydrology, or supported with information about how to interpret the maps. There is a particular challenge around groundwater flooding as emergence may not coincide with the flood receptor. Any materials produced will need to have very clear explanations of the implications of groundwater emergence.

Further work into how these maps could be developed would be beneficial, including considering whether accurate local groundwater flood risk maps can be developed.

6.8 What are the current risk assessment approaches, and is climate change considered?

The main aim of this question is to summarise the information and activity for groundwater flood risk assessment. Understanding flood risk is crucial for flood risk management, underpinning decisions to prepare, respond and recover from groundwater flooding. This summary may help RMAs to understand the current availability of data and practice to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 3c:

Secondary question 3c: What are the current risk assessment approaches and is climate change considered?

6.8.1 Summary response

There are a number of ways of modelling groundwater flooding which have been developed. These include GIS-based risk mapping for non-real time national scale products, and lumped parameter regression models and bespoke spreadsheet tools, using borehole data to predict when groundwater flooding may occur to inform real-time forecasting. Regional groundwater models (for example, MODFLOW models) are also used to assess the potential for flooding impacts due to mine and urban groundwater rebound. Current available models assess groundwater flooding for present day climates. Modelled and mapped information on groundwater impacts in future climate scenarios is very limited.

6.8.2 Summary of evidence

There are a number of ways of modelling groundwater flooding which have been developed. These include:

- GIS-based risk mapping on a grid basis (JBA, BGS, GeoSmart), where areas that groundwater has the potential to be near the ground surface are highlighted. These models can indicate where new groundwater flooding may occur given extreme groundwater levels. However, they struggle to indicate specific onset of flooding in particular locations. These models are particularly used for screening groundwater flood risk. They do not currently account for climate change.
- Lumped parameter regression models based upon borehole data (CATCHMOD and derivatives, AquiMOD), where the groundwater level at a borehole is predicted based on rainfall recharge and when thresholds are exceeded warnings are issued to the catchment or area associated with that borehole. These models can show when flooding at known locations of groundwater flooding is likely to occur. Historical data is needed to link the trigger groundwater level with the onset of flooding at a particular location. Spreadsheet models are a simpler version of these models. These models are particularly linked to flood warning and forecasting. The main value of regional-scale models, such as the Environment Agency water resources models, is to provide boundary conditions and hydraulic parameters to inform more local detailed groundwater flooding models, for example, as used by Newcastle University (steering group feedback, 2020).
- Regional groundwater models using aquifer groundwater models, such as NGMS, MODFLOW, Zoom. These have particular potential for modelling mine and urban groundwater rebound. Their rapid use in response to a groundwater flood event is not yet widespread, and while providing good coverage of many principal aquifers, they do not cover all of England. Their future use would be limited to areas of particular concern.
- Other modelling such as Monte Carlo (statistical) simulations has been used in some locations on particular projects. There is also ongoing development of coupled hydrological systems as part of the Hydro-JULES framework, which aims to include a national scale groundwater process model able to address groundwater flood risk under current and future climate change conditions.

There are a number of national and more local groundwater models available for England, some of which are specifically developed with regard to groundwater flooding, and others which have a wider application (see Table 6.5). The models are not freely available to the public. Some of these models are actively used in groundwater flood forecasting systems, which are detailed further in section 6.10.

Table 6.5 Groundwater (flooding) models

Organisation	Model	Comments
GeoSmart (previously part of ESI)	Groundwater Flood Forecasting Tool – lumped-parameter water balance model predicting groundwater levels at main boreholes. Uses live data of recent rainfall and 14-day forecasts. The model is initialised using the most recent telemetered groundwater level at a	From the various examples reported on (ESI 2016a), a number of shortfalls in the model were reported. For example, poor simulation of groundwater rise; inability to represent the slow recharge

Organisation	Model	Comments
	borehole and recent rainfall data together with 14-day rainfall forecast, and historical potential evaporation based on long-term temperature data. The model can also produce a probabilistic forecast over a 30-day period, using historical daily rainfall data to perturb and extend the original 14-day rainfall forecast. The groundwater model is then run using each realisation of 30-day rainfall to produce an ensemble forecast of groundwater levels for each borehole. Forecast groundwater levels in each indicator borehole are used to evaluate groundwater flood risk in catchments associated with that borehole. For each of those catchments, the modelled groundwater levels in the borehole are compared to a specific threshold groundwater level to provide information on the probability and expected severity of groundwater flooding over the forecast period. Detailed investigations have looked at how the model would have performed in historical floods.	component; better representation of the slow passage of infiltrated rainwater through the unsaturated zone; model not fit for purpose during summer convective rainfall; and inadequate representation of groundwater/surface water interactions during periods of extreme groundwater levels. For the pilot study 5 case studies were developed on the unconfined chalk aquifers. Some of the deficiencies in the GeoSmart models have since been addressed by GeoSmart, working with the Flood Forecasting Centre (FFC) and the Environment Agency (Steering group feedback, 2020).
Environment Agency	CATCHMOD is a lumped parameter model and the Environment Agency's main river flow prediction tool. It uses a series of simple models to represent the soil, unsaturated zone and saturated zone. The Environment Agency produces groundwater projections for its water situation reports which are based on lumped models with individual site calibrations and a climate ensemble (historic re-sampling) approach (RAB 2016, Environment Agency 2005).	Used by the Environment Agency nationally and at local area level at around 65 boreholes.
Environment Agency	Thames Catchment Model uses modelled groundwater inputs for flow forecasting using an operational version of CATCHMOD at 15-minute intervals. An MSc project (Hyslop, 2012) developed the Thames Catchment Model/CATCHMOD for groundwater flood forecasting on a single borehole in the Lambourn Valley. The groundwater level is derived from the model output of river discharge using a rating curve.	The model is not directly used for forecasting. A series of indicator boreholes are monitored for threshold exceedance. This alerts hydrogeologists who use their local knowledge to decide whether to issue a flood alert to the public and partners. The flood alert is followed up with a briefing note, identifying areas where flooding might occur.
Environment Agency	In the Cambridgeshire and Bedfordshire Area, a 2011 MSC project (Williams, 2010) developed a groundwater flood forecasting model, using CATCHMOD, for Newmarket and Bury St Edmunds.	Flood alerts are issued when threshold exceedance is observed, rather than from the model predictions. However, the model is used to predict the duration of flooding.
Environment Agency, BGS, CEH and Met	AquiMOD and predecessor R-Groundwater – these are lumped catchment models developed by BGS for individual boreholes.	IPR is held by BGS. Thresholds for flood warning purposes need to be

Organisation	Model	Comments
Office – Hydrological Outlook	Upton and others 2011 used a lumped parameter model to predict the 2000 to 2001 flooding. It has been used with 70 boreholes, mostly on chalk (40) but also on other aquifer types: Jurassic, Magnesian & Carboniferous magnesium and carboniferous limestone, and Permo-Triassic sandstones – in other words, all principal aquifers. It is best for chalk and sandstones, least accurate for fractured limestones. It can be downloaded for free: https://www.bgs.ac.uk/research/environmentalModelling/aquimod.html#download	obtained from local sources (for example, Environment Agency and local government). Ideally, it requires 30 years of data to calibrate a borehole model, but BGS suggest it can use inferred parameters.
Environment Agency Wessex and Solent & South Downs Area	A statistical spreadsheet model is used to forecast levels at specific indicator boreholes on a 5-day horizon, based in part on the 5-day forecast from the Met Office, but more importantly the horizon that partner organisations wanted to enable planning and preparing for a flood. This is detailed further in section 3.7.1 as a case study.	The Wessex Area monitors 36 indicator boreholes, the Solent & South Downs Area a single borehole at Hambledon for flood prediction and warning.
Environment Agency Patcham Brighton	A multiple linear regression model was used where the annual maximum groundwater levels was a function of preceding annual minimum and winter rainfall. Monte Carlo simulations were then used to predict a range of annual maximum groundwater levels based on a range of possible winter rainfall scenarios up to 9 months in advance. Artificial neural networks were applied to predict annual groundwater level maxima before the model was used for forecasting (Adams and others, 2010).	
BGS	Hydro-JULES is a NERC-funded research programme, with the aim of building a three-dimensional community model of the terrestrial water cycle to underpin hydrological research in the United Kingdom. Hydro-JULES will be implemented by CEH in partnership with BGS and NCAS. There are 2 strands carried out by BGS regarding groundwater: one is to produce a groundwater flow, heat and transport model of the sub-surface of the British mainland and the second is to include groundwater in Land Surface Models (LSM) at a global scale (CEH, 2020). Hydro-JULES Implementation Plan	Work in progress, no current reporting. Will consider groundwater flooding.
Environment Agency	National Groundwater Modelling System (NGMS): a bespoke user interface used for regional catchment aquifer models, using MODLFOW/4R recharge model coding. Most models were developed for water resources management, and often demonstrate poor performance at higher groundwater levels. They are not calibrated	The models could be run more frequently for groundwater flood forecasting purposes, but would need to be developed and recalibrated to bring in live data feeds (RAB 2016). Some models are used for mine water rebound.

Organisation	Model	Comments
	in detail for specific locations and detailed borehole responses (RAB 2016).	
BGS	GeoRise - The analysis of groundwater level time series simulated by applying recharge values using rainfall and potential evaporation values estimated using future climate data enables the GeoRise system to identify areas that are under future flooding risk. The main product is a national scale map showing the risk of flooding as low, moderate or high.	It is not intended to give a detailed and definite possibility of groundwater flooding occurring. For this smaller scale, detailed models should be used to investigate the flooding risks associated with the areas identified by GeoRise. Mansour and others (2017) assessed the feasibility of this proposed method using the chalk aquifer as a case study.

Mansour and Hughes (2018) assessed the application of the BGS distributed recharge model ZOODRM to produce recharge values (potential recharge) for Great Britain (England, Scotland and Wales). The model was run with the rainfall and potential evaporation for the Future Flows Climate data sets (11 ensembles of the HadCM3 Regional Climate Model or RCM) to produce predictions of aquifer recharge under climate change. Generally, it was found that the recharge season is shorter for future predictions, from the current 5 to 7 months to 3 to 4 months. This could make aquifers more vulnerable to droughts if rainfall fails in one or 2 months rather than a prolonged dry winter as can occur now. It was suggested that groundwater hydrographs may become spikier, which may lead to increased risk of groundwater flooding. However, groundwater flooding was not assessed in detail in this report, and it was a recommendation that further work should be carried out to assess how the frequency of groundwater flooding is affected by climate change.

A comparison of the national groundwater flood risk mapping approaches is given in Table 6.6. A common perceived limitation is the difficulty in incorporating local small scale features into a national scale model or map of risk. Variations locally in parameters such as permeability, rainfall and topography can be difficult to capture in broad scale models, which leads to uncertainty, for example, at a property level. In all cases, the national flood risk mapping is regarded as an indicator of the need for further assessment, rather than a guarantee of groundwater flooding, as it is not as clear cut as current surface water flood modelling methods, which have well defined flood outlines and depths associated with specific return-periods. In all the national groundwater flood mapping products there is a tension between trying to include all areas which actually experience groundwater flooding, whilst not including large areas which have never flooded. In an effort to include all areas which may actually flood, often groundwater flood products indicate a possibility of groundwater flooding over a much wider area (and greater number of properties) than has ever actually flooded.

This illustrates well the problem with the Environment Agency's areas susceptible to groundwater flooding dataset. By taking the majority statistic per grid square the areas where groundwater flooding is expected to be widespread (i.e. floodplains) are identified at risk, rather than the narrow chalk valley bottoms where in reality more groundwater flooding happens. This can be resolved by mapping at smaller grid scales.

Table 6.6 National scale groundwater flood risk mapping approaches

	GeoSmart (previously part of ESI)	BGS	JBA Consulting
Method	Combines a likelihood of flooding during a 1 in 100-year return period scenario with the underlying uncertainty in groundwater flooding. The severity of the flooding is then based on the underlying aquifer (transmissivity), range and extent of properties to come to overall risk.	Developed groundwater surface map based on geological permeability and distance from watercourses. Used conceptual models of PSD and clear water flooding to determine groundwater flooding susceptibility.	Groundwater table generated under 1 in 100-year flood event conditions. This is then compared against ground levels to establish potential depth to groundwater for a given area.
Software	Python coding for processing and modelling, ArcGIS for visuals.	ArcGIS for processing and visuals.	ArcGIS for processing and visuals, R statistical package for rainfall modelling.
Data inputs	Groundwater levels from monitoring boreholes, LiDAR DTM (5m), BGS 50k geology, river levels.	Groundwater levels from monitoring boreholes, BGS 50k geology, BGS permeability index data set, DTM, river base levels.	Rainfall, LiDAR DTM (5m), BGS 50k geology, river levels, OS vector mapping.
Data outputs	5m GIS raster grid and polygon of groundwater flood risk score bands.	50m GIS raster grid of groundwater flood susceptibility bands.	5m GIS raster grid and polygon of depth to groundwater/flood risk score bands.
Validation	Database of groundwater flood events is maintained (for example, sourced from projects, or the internet). This feeds into a 6-month update cycle, where discrepancies are highlighted, and calibrations are made where necessary.	The BGS has data on the locations of previous groundwater flooding events gathered through research projects and discussions with environment regulators and local authorities. This information has provided a means to validate the susceptibility data set.	Calibrated against monitoring borehole data and observed flood events.
Limitations	Uncertainty in underlying permeability in the geology. Local variations in topography, uncertainty in where groundwater seepage occurs and accumulates. It is advised that the model is calibrated with local primary data,	One of the main limitations is scale. It is difficult to combine the detail of small scale modelling with national scale modelling. Often small scale features can determine areas of groundwater emergence, but are difficult to include within large aquifer	Broad national scale, local models and mapping may be more accurate (for example, chalk catchments with varied responses). Where superficial deposits are thin, only the underlying bedrock characteristics are considered.

	GeoSmart (previously part of ESI)	BGS	JBA Consulting
	where available, to improve results.	scale models. Need constant refinement and improved parameterisation of large aquifers.	
Climate change considered?	Not considered in the product. Although guidance can be provided on impacts of climate change, which will vary spatially.	Not considered in the product.	Not considered in the product. The rainfall grid model could be updated to produce recharge under climate change scenarios.

As an example of national groundwater flood risk mapping a downscaled version (1km grid) of JBA's 5m risk mapping is shown in Map 6. It shows the most common risk category per kilometre grid square across the UK, with risk categorised based on how near the ground surface groundwater levels are likely to be in a 100-year return period flood event. This downscaled map gives a general overview of groundwater flood risk across LLFA areas and is not intended for groundwater flood risk assessment.

6.8.3 Implications of findings

There are many groundwater flood models and maps for England, but no recent most up-to-date maps are available freely. As a result, older and probably less useful products are often used.

Some LLFAs, for example London, have developed their own maps, combining the most useful parts of several national mapping products to develop a product specifically suited to their situation.

The national maps of groundwater flood risk that are available are commercial products. Therefore the method used to produce the final products is not freely available, and so it is difficult to make a detailed accurate assessment of the suitability and accuracy of each. All national mapping techniques are caveated as serving as a tool to identify areas requiring further assessment of potential groundwater flood risk, as they are generally not fit for purpose to assess the likelihood at property level. This is due to local variation in parameters such as geological features and small-scale topographical changes, which can make identifying specific groundwater seepage fronts and springs where groundwater emergence may occur difficult to identify. However, no further assessment is made of the potential for groundwater flooding in areas which are mapped as not having any significant groundwater flood risk (Buss, peer review feedback, 2020).

Detailed local groundwater flood risk mapping has been carried out in a number of locations and is thought to be fairly accurate. The local specific nature of groundwater flooding depends on specific geology, catchment rainfall response, and particular hydrogeological conditions, topography and drainage so lots of supporting information is needed to feed into detailed risk assessment. As these generally require high levels of data input and funding to initially produce they are not commonly available.

Currently, there are modelling approaches in the private sector that look to consider these local factors, but presently there is no overarching publically available dataset to bring together local detailed assessments produced by LLFAs. At present it is hard to demonstrate a need for modelling in the same way there is with other forms of flooding that have a published risk map. This means groundwater flood risk may be overlooked.

6.8.4 Gaps and future work

Mapped and modelled information on a national scale would help to identify areas where further detailed local assessment is required. This currently does not exist as a free resource to risk management authorities and there are currently no plans to produce or provide such a dataset.

If this information were available, LLFAs and other stakeholders could use it to target investment in more detailed assessments to determine how the risk manifests at a much smaller scale where topographic controls and other local factors come into play. Groundwater models at this scale could also be combined with surface water flood maps, to indicate where groundwater may pond or flow when emerging from the ground.

Any new national dataset being developed, such as the Environment Agency's national flood risk assessment, should amalgamate the local assessments and be made publically available to build a more detailed understanding of groundwater flood risk to support management activity.

6.9 Can we make an assessment of the number of properties susceptible to groundwater flooding?

The main aim of this question is to summarise the information and activity for groundwater flood risk assessment. Understanding flood risk is crucial for flood risk management, underpinning decisions to prepare, respond and recover from groundwater flooding. This summary may help RMAs to understand the current availability of data and practice to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 3d:

Secondary question 3d: Can we make an assessment of the number of properties susceptible to groundwater flooding for England, now and under climate change?

6.9.1 Summary response

Overall, the evidence indicates that it is difficult to estimate the number of properties at risk of groundwater flooding accurately (current estimates of those affected by groundwater flooding are between 122,000 and 289,000). This is partly due to the site-specific factors (specific rainfall patterns, local geology, drainage, topography) which determine whether groundwater flooding occurs, making comprehensive modelling difficult. This is also because the historical records of groundwater flooding are not long enough to identify all locations at risk from previous flood events. There are no national estimates of properties susceptible to groundwater flooding under climate change scenarios.

6.9.2 Summary of evidence

In estimating the number of properties at risk from groundwater flooding (and potentially associated damages), it is important to identify if the risk is from groundwater flooding alone, or from groundwater combined with other sources of flooding. In many locations, groundwater flooding may be combined with other sources of flooding, such as river flooding (for example, for locations at risk of alluvial aquifer flooding) and surface drainage flooding (drainage may be overloaded by groundwater) as well as other sources of flooding. It is likely that fluvial and other sources of flooding damages include some element of groundwater flood damages.

Number of properties at risk

An initial estimate of properties at risk of flooding within the Groundwater Emergence Maps (GEMS) was 1.6 million based on estimates of near surface groundwater levels in major aquifers, of which 380,000 were overlying the chalk in southern England and considered most at risk (Jacobs GIBB Ltd, May 2004, for Defra, summarised in Morris and others 2007).

BGS, together with the Environment Agency, (McKenzie and Ward, 2015) has refined the estimated number of properties at risk of groundwater flooding (see Table 6.7 and Table 6-8). These estimates were taken from BGS groundwater flood susceptibility mapping combined with the National Receptor Database (NRD) of properties and infrastructure to give data on potential occurrence of groundwater flooding. The number of properties potentially at risk of groundwater flooding was then refined using:

- actual records of groundwater flooding: but not all households may report flooding. Additionally, since groundwater flooding events are rare, resulting from unique distributions of rainfall, and not systematically recorded before 2000 to 2001, groundwater flooding in the future may occur in new locations. Records may not distinguish flooding from other sources, such as main rivers, ordinary watercourses, and surface water flooding. Flooding may have multiple sources
- surveys during groundwater flood events – aerial surveys only useful for groundwater flooding at the surface, shallow groundwater, sewer surcharge and flooded basements will not be identified
- reports on groundwater flood events and hydrogeological conditions

Table 6.7 Properties in areas susceptible to groundwater flooding (from McKenzie and Ward, 2015)

	Residential properties	Non Residential properties	Total	Also floods from river and sea	Total less river and sea
Clearwater Chalk and Limestone - Emergent	375,000	125,000	**500,000**	81,000	**420,000**
Clearwater Chalk and Limestone - affecting infrastructure	423,000	141,000	**564,000**	63,000	**501,000**
Clearwater other aquifers	488,000	163,000	**651,000**	70,000	**582,000**
Permeable Superficial deposits	2,981,000	994,000	**3,975,000**	768,000	**3,206,000**

However, the report states: "Groundwater flood susceptibility does not translate directly into numbers of properties affected in a flood incident. Each flood event will have its own unique hydrological characteristics, so flood magnitudes vary. In addition, the impact of groundwater flooding on properties in an area is influenced by the nature of local drainage systems and by the extent of community adaptation. Natural drainage systems can, depending on topography, allow groundwater to drain away quickly, or may have limited capacity and cause surface ponding. Artificial drainage, either through ditches and culverts or sewer systems may act to artificially lower the water table. Houses and infrastructure can be raised above flood level. Because of these factors groundwater floods often have a greater impact on properties in rural areas. In urban areas, a greater density of drains and sewers and more adaptation through building construction may mitigate flooding."

In the 2013 to 2014 clear water chalk groundwater flood in Oxfordshire, Berkshire and the South Downs the proportion of susceptible properties actually affected by flooding varied widely, but overall was between 5% and 15%.

In other locations, such as Humberside in 2007 and the lower Thames in 2014, large numbers of properties in susceptible areas were affected, but the majority of these properties were also at risk from the sea and river flooding. However, in areas of high baseflow the river flooding may be driven by groundwater. The study made an assumption that the number of properties at risk of groundwater flooding in other (non-chalk or limestone aquifers) was only 2 to 4% of total properties if other sources of flooding were not present.

It is noted that, in terms of permeable superficial deposit (alluvial aquifer) flooding, these deposits are generally in river valleys and so highly likely to be also at risk of fluvial flooding in the lower lying areas, which would also potentially have higher groundwater levels. In fact, it is normally the high river levels that drive permeable superficial deposit flooding.

Table 6-8 Estimate of properties affected by groundwater flooding (from McKenzie and Ward, 2015)

Estimated properties affected	Total less river and sea	5%	10%	15%	Also floods from river and sea
Clearwater Chalk and Limestone	921,000	46,000	92,000	138,000	144,000
Estimated properties affected	**Total less river and sea**	**2%**	**3%**	**4%**	**Also floods from river and sea**
Clearwater other aquifers	582,000	11,600	17,500	23,200	70,000
Permeable Superficial deposits	3,206,000	64,100	96,200	128,200	768,000

Overall, BGS has estimated the number of properties at risk from groundwater alone to be between 122,000 and 289,000. It also suggested that up to 960,000 properties could be at risk from a combination of groundwater and rivers or sea (Environment Agency, 2016a).

Other estimates include:

- ESI estimated 260,000 properties at risk of groundwater flooding (Environment Agency, 2016a). However, it should be noted that ESI estimates treat fluvial flooding where there is a high baseflow component as groundwater flooding. The Environment Agency, however, includes this cost within fluvial, not groundwater, flooding (steering group feedback, 2020).
- The Committee for Climate Change estimated the number of properties at risk from groundwater flooding as 250,000 (Environment Agency, 2016a).

In the questionnaire:

- 21% (18) of respondents could estimate the number of properties at risk of groundwater flooding in their area of work
- 6% (4) of respondents could estimate the number of properties susceptible to groundwater rebound
- 2% (2) of respondents could estimate the number of properties susceptible to groundwater flooding in the future with climate change. This included representatives of Central Bedfordshire Council and Hampshire County Council. The source of this information was not made available through the survey

Costs of groundwater flooding

There is some uncertainty regarding how the damages per property due to groundwater flooding relate to damages due to other sources of flooding. The Committee for Climate Change (CCC) have argued that as aquifer flooding is relatively clear water is it less damaging than muddy river water. In contrast ESI have argued that as groundwater flooding is of longer duration then it causes more damage to properties. ESI have produced a note suggesting that the annual damages associated with groundwater flooding are £530 million. They argue that around 75% of these costs are due to the influence of groundwater on other sources of flooding.

The Environment Agency reproduced the ESI calculation, replacing the most uncertain data inputs with upper and lower estimates to understand the range of possible results. This method produced results between £70 million and £10 billion. The Environment

Agency concluded that this demonstrated that the range of possible costs shows a clear evidence gap; but that the lower end of the range was still significant (5% of total damages). The top end of the range is unrealistic demonstrating the need for empirical data not just theoretical estimates based on modelling. The Committee for Climate Change (CCC) has previously estimated the annual cost of groundwater flooding as £156 million.

Work by BGS and the University of Loughborough (Royse et al, 2014) has developed a proof of concept of catastrophe modelling (along the lines of insurance company risk modelling) to provide an assessment of likely groundwater flood damages using the Berkshire Downs as a case study. This concept used integrated environmental modelling (IEM) techniques with an open modelling framework to explore groundwater flood damages under a variety of scenarios.

6.9.3 Implications of findings

Overall, the evidence indicates that it is difficult to estimate the number of properties at risk of groundwater flooding accurately (current estimates of those affected by groundwater flooding are 122,000 to 289,000 as described above). The wide range of values differ due to variations in methods and assumptions. For instance, in the ESI estimates where there is a high baseflow component fluvial flooding is classified as groundwater flooding, whereas the Environment Agency only includes this within fluvial flooding impacts assessment (steering group feedback, 2020).

There is very little understanding on the behaviour of groundwater in response to climate change and how this may impact on flood risk. There does not appear to be a national estimate of those at risk with climate change impacts, with only 2 council area survey respondents indicating that they could estimate those at risk under climate change. This means that risk management activity to prepare, plan for, respond to, and recover from groundwater flooding is limited and restricted by the information that is available.

Detailed local knowledge appears very important when predicting which properties are most at risk of flooding from groundwater. This means that it is often individuals in organisations that are relied on to provide this insight and support management activity. It also means that methods of estimating the number of properties at risk are inconsistent and it can be difficult therefore to collate this information and present a consistent picture of risk across areas.

There is considerable uncertainty in the numbers of properties at risk of groundwater flooding now and in the future, the potential damages and costs of groundwater flooding, and how extensive a problem groundwater flooding is nationally both in todays’ and tomorrows’ climate.

6.9.4 Gaps and future work

To address uncertainties in how the scale of groundwater risk is understood a reliable, accurate, consistent method for estimating the number of properties at risk of groundwater flooding nationally, including the impact of climate change should be developed.

This would need to be done on a national groundwater flood risk spatial dataset of groundwater risk using current and future climate scenarios. There is limited value in producing new estimates from the existing data due to the limitations already discussed. Consistent approaches for assessing groundwater flood risk under climate change scenarios would need to be developed and agreed by risk management authorities. This would be particularly beneficial for spatial planning too.

On the whole, climate impacts on groundwater are not well understood and further work is needed in this area. For example information on water resource forecasting in chalk could be used to understand if water tables will rise more frequently, or quickly. It could also be used to understand if the groundwater level will be generally subdued relative to present day due to reduced recharge resulting from less effective rainfall and greater runoff due to more intense storm events. Understanding the wider changes in the groundwater environment would be helpful to inform future areas of focus for groundwater flood risk.

6.10 What groundwater flood forecasting systems exist)?

The main aim of this question is to summarise the information and activity for groundwater flood forecasting and warning. Forecasting and warning are important activities in creating places that are resilient to flooding. This summary may help RMAs understand the current availability of data and practice for groundwater flood forecasting and warning to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 4a:

Secondary question 4a: What groundwater flood forecasting systems exist?

6.10.1 Summary response

Overall, the evidence indicates that there are some highly effective means of groundwater flood forecasting at varying scales. Currently in 2020 at different scales, the Environment Agency (local), Environment Agency (national) and FFC (national) all have roles in forecasting groundwater flooding.

Environment Agency areas have different approaches, mostly developed prior to the proposal for standardisation by Halcrow (2010). The outcome of the forecasts is fed into the Environment Agency flood alert and warning system.

National systems, such as GeoSmart/FFC national forecasting service, provides forecasts for specific locations, and the Hydrological Outlook provides a summary of general groundwater level trends. Local systems are widely used, especially in the chalk areas of South England. There are well developed approaches in Wessex (especially for Wiltshire and Dorset) (Environment Agency, 2019a) and Solent and South Downs (Buss 2019). In 2014, Thames Region had an evolving response where the approach was developed during the floods (Environment Agency 2020 draft).

6.10.2 Summary of evidence

Flood forecasting systems exist both nationally and locally, developed to varying degrees. The questionnaire indicated that 37% (21 people) use the joint Environment Agency/Met Office Flood Forecasting Centre's groundwater flood forecasting (provided by GeoSmart), 16% (9 people) use another system, 42% (24 people) don’t use any system and 5% (3 people) didn’t know. The areas of England where evidence was found regarding groundwater flood forecasting is shown in Map 2 (Appendix D).

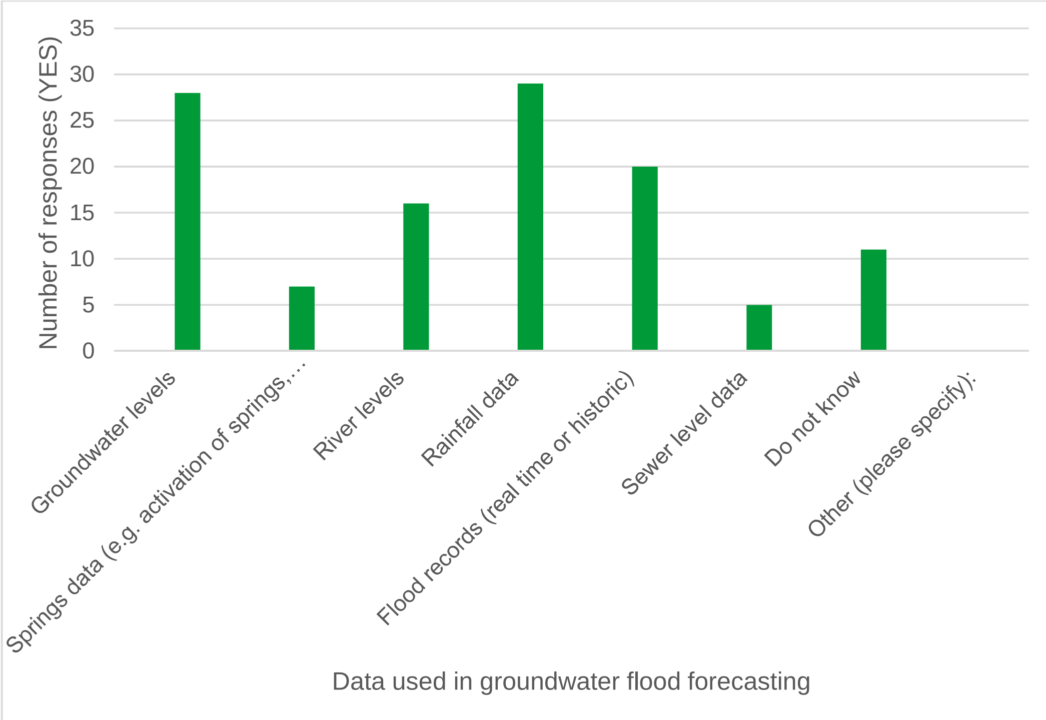

Figure 6-14 What data is used in the groundwater flood forecasting system you use?

The data used in groundwater flood forecasting based on questionnaire responses is shown in Figure 6-14. The most common data used was groundwater levels (28 or 93% of those that responded to say they used either the joint Environment Agency/Met Office Flood Forecasting Centre's groundwater flood forecast or another forecasting system) and rainfall data (97% or 29 people). Some of the less common data used included sewer level data (17% or 5 people) and springs data (23% or 7 people).

A summary of active forecasting systems is given in Table 6.9, which use modelling techniques described in section 6.8. A more detailed description of the FFC/GeoSmart and Wessex forecasting systems are described further in the text below.

Table 6.9 Groundwater flood forecasting

Forecasting tool	Coverage	Comment
GeoSmart (incorporated into FFC services)	National - available through GeoSmart or through the FFC package. Provided 12 hourly.	Forecasts provided as csv, GIS and PNG images, with the option to view through a web mapping interface.
Groundwater current status and flood risk prepared by the Environment Agency, CATCHMOD lumped parameter models.	National - available online here	Useful summary of general trends not specifically predictive in any one location.
Hydrological Outlook, CEH - AquiMOD	National - available online here	Useful but general. Provides a summary of groundwater trends in the UK.
Wessex spreadsheet tool	Local - Wessex Solent & South	A statistical spreadsheet model is used to forecast levels at specific indicator boreholes

Forecasting tool	Coverage	Comment
	Downs Area. Run daily once thresholds are met.	on a 5-day horizon, using the 5-day forecast from the Met Office, actual groundwater levels, latent rainfall and calibration factors. Outputs include a range of best, worst and most probable levels.
Thames Catchment Model (CATCHMOD derivative)	Local - derived from monitoring data in the Lambourn Valley	The model is not directly used for forecasting, although a series of indicator boreholes are monitored for threshold exceedance, alerting hydrogeologists who then use their local knowledge to decide whether to issue a flood alert to the public and partners. The flood alert is followed up with a briefing note identifying areas where flooding might occur.
Cambridgeshire and Bedfordshire Model (CATCHMOD derivative)	Local - derived from local data at Newmarket and Bury St Edmunds	Flood alerts are issued when threshold exceedance is observed, rather than from the model predictions. However, the model is used to predict the duration of flooding.

Flood Forecasting Centre / GeoSmart groundwater flood forecasting

The Flood Forecasting Centre (FFC) is provided with groundwater flood forecasting services through GeoSmart, which has been ongoing for 5 years. FFC uses the groundwater flood forecast service to support operational decision making on groundwater flood risk for the Flood Guidance Statement (FGS) and FFC Monthly Outlook products (providing a 30-day high-level look ahead). The service provides the FFC with updated national groundwater conditions as well as a national forecast of potential flooding to inform them when to approach Environment Agency local teams to discuss and agree the groundwater flood risk for the next 5 days.

RAB was commissioned by the Environment Agency and the Met Office (2016) to review and appraise groundwater flood forecasting services in England. It found that there are models that the FFC can use to predict groundwater flood risk to use in the Flood Guidance Statement (FGS). The lumped parameter models appear to be the best and simplest approach to forecasting at a local level, but results can be amalgamated and interpolated across a region for the high-level risk analysis and dissemination to strategic managers. Where they exist, forecasting services tend to follow the operational framework set out in the Operational Instruction/Halcrow Report (2010). This follows the principles used for fluvial flooding and so will dovetail with the FFC and the FGS. This review concluded that a lumped model would most likely provide the level of accuracy and detail required by the FFC for the FGS (and wider consultancy) and that, of the lumped models available, there was little between them.

Since then, a contract was awarded to GeoSmart to maintain a real-time national forecast model of groundwater flooding probability, run on a daily basis. This shows the probability of groundwater flooding within a specified area (catchment/sub-catchment scale) within the next 15 days (where telemetry is available). Data used includes rainfall/flood forecasting data provided by the FCC (Environment Agency/Met Office) for a 14-day forecast. This is extended to a 30 days' forecast using historic weather statistics, which is required for groundwater flood risk. Also, real-time groundwater levels from borehole telemetry (mainly Environment Agency boreholes) can be combined with sewer data (this is normally carried out by the client when required).

The forecast can be viewed through an online map interface, with a hydrograph for each telemetry borehole, showing current borehole levels with Environment Agency classifications (low, normal, high). A trigger level is then used to indicate when groundwater flooding may occur at this location. The impact thresholds are provided by the Environment Agency/Met Office FFC, otherwise trigger points are based on data from historic flooding events. Where no records of previous events exist a 95% trigger level is used. This is approach is consistent with national methods of surface water flooding warning (GeoSmart interview, 2020).

Others

Regions on the chalk aquifer, including Dorset, Wessex, Hampshire, Wiltshire, Thames, Kent and Sussex all use Environment Agency borehole data for forecasting and informing flood warnings and alerts (project survey, 2020). According to the interview with the Environment Agency, it has a series of monitoring boreholes in the chalk which are telemetered and have been selected to give advance notice about possible groundwater flooding (Hoad, 2020). There are action levels associated with these boreholes and when one of these levels is exceeded, specific actions need to be taken. Three action levels are crafted to suit that particular locality based on field evidence: trigger (lowest), threshold (middle), and critical (highest) (Hoad, 2020). These groundwater flooding alerts are published online once any of the 3 action levels are exceeded. These boreholes are monitored at least daily and additionally the forecasting tool uses Met Office predicted rainfall data for the upcoming 5 days to provide alerts if needed. Once boreholes are beyond the threshold levels, the Environment Agency writes a briefing note to provide an account of what technically occurred in the short-term (up to 5 days) based on the action levels, and potentially provides an indication of risk based on experience and knowledge (Hoad, 2020). This procedure is in line with the Environment Agency guidance on operating the groundwater flood warning service (2011b).

East Riding of Yorkshire Council (ERYC) uses its own groundwater level monitoring and associated trigger warning levels for the chalk aquifer (project survey, 2020). However, subsequent experience of using trigger levels in Burton Fleming indicates that groundwater levels can reach the trigger level where flooding occurred in 2012 to 2013 (ERYC, 2013) but no flooding occurs. This indicates that groundwater flooding is complex and groundwater levels at one specific location are not the only factor controlling the onset of flooding (steering group, 2020).

The Jacobs GEMs (2004) maps were used effectively to model scenarios of predicted groundwater levels during the 2014 groundwater flooding event. This helped the Environment Agency (especially the Thames Area team) work with local authorities to plan where to focus efforts to manage groundwater flooding (steering group feedback, 2020).

Some LLFAs have installed their own boreholes (for example, Portsmouth City Council) and have warning monitoring systems with trigger levels, others rely on data from other parties (questionnaire responses).

There are indications that more groundwater data is being made more widely available for forecasting, such as more borehole data may be put online through the 'Rivers for Change' project, and additional boreholes may be telemetered through the Water Infrastructure Fund over the next 3 years (steering group feedback, 2020).

6.10.3 Case study: Groundwater flood forecasting and warning in Wessex

Secondary question: What groundwater flood forecasting systems exist?

Source of information: literature and interview

Organisation(s): Environment Agency (Wessex)

Date: To date

Hyperlink to further detail: Email: enquiries@environment-agency.gov.uk

Location: Wessex (Dorset and Wiltshire).

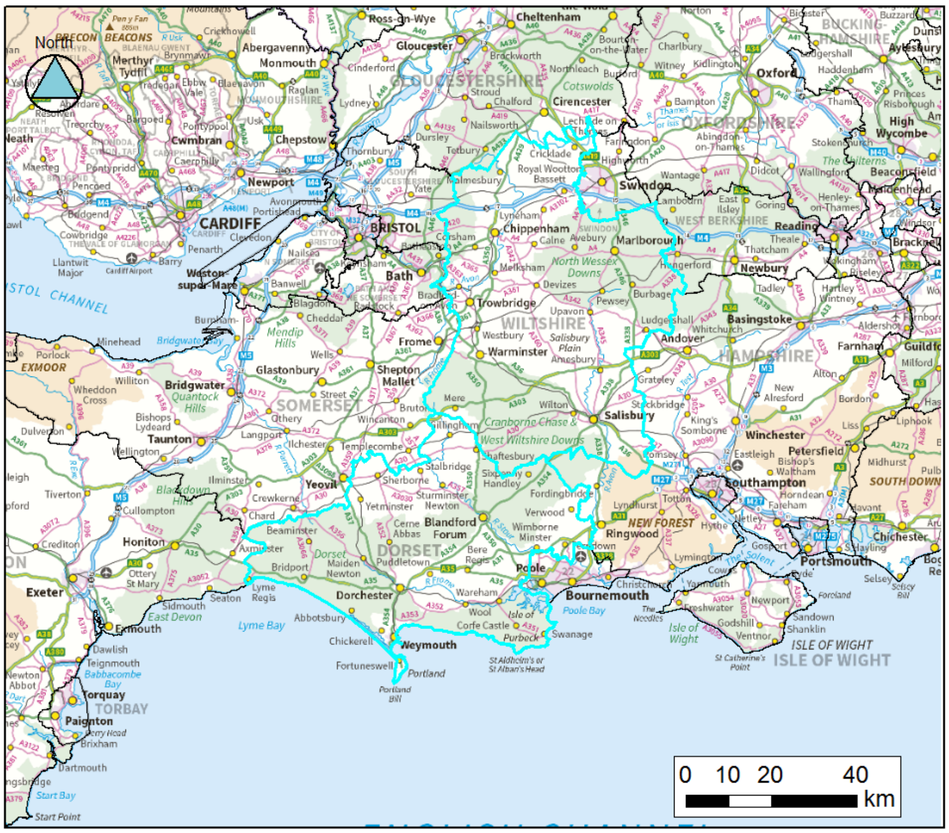

Figure 6-15 Locations covered by the Wessex groundwater flood warning system

In the Wessex area, there has been an increasing need for good groundwater flood forecasting and warnings. There is a large number of properties requiring groundwater abstraction pumps that need consistent management and maintenance over time. It is difficult to find ideal trigger levels for pumping, as pumping at the wrong time may unnecessarily dewater the aquifer and waste electricity. Ideally, the groundwater flood warning system should be consistent with the current fluvial warning service.

In Wessex, historic groundwater flooding events have shown that there are 3 distinct chalk areas, with different rainfall levels and groundwater responses. The older fractured chalk with greater rainfall has a much quicker emergence response time (2 to 3-week difference to other chalk areas). There is therefore a need to establish discrete geological warning areas based on response type, with separate warnings. To improve this there is a need for a more targeted network of monitoring boreholes, to better characterise the different response areas. Significant events in these areas should then be used for setting impact thresholds.

The Environment Agency (Wessex) investigated various options, including CATCHMOD, but in the end decided to use a more deterministic, spreadsheet based solution (see **Figure 6-16**). An empirical process model was developed in collaboration with Wood (previously Amec Foster Wheeler) consultants.

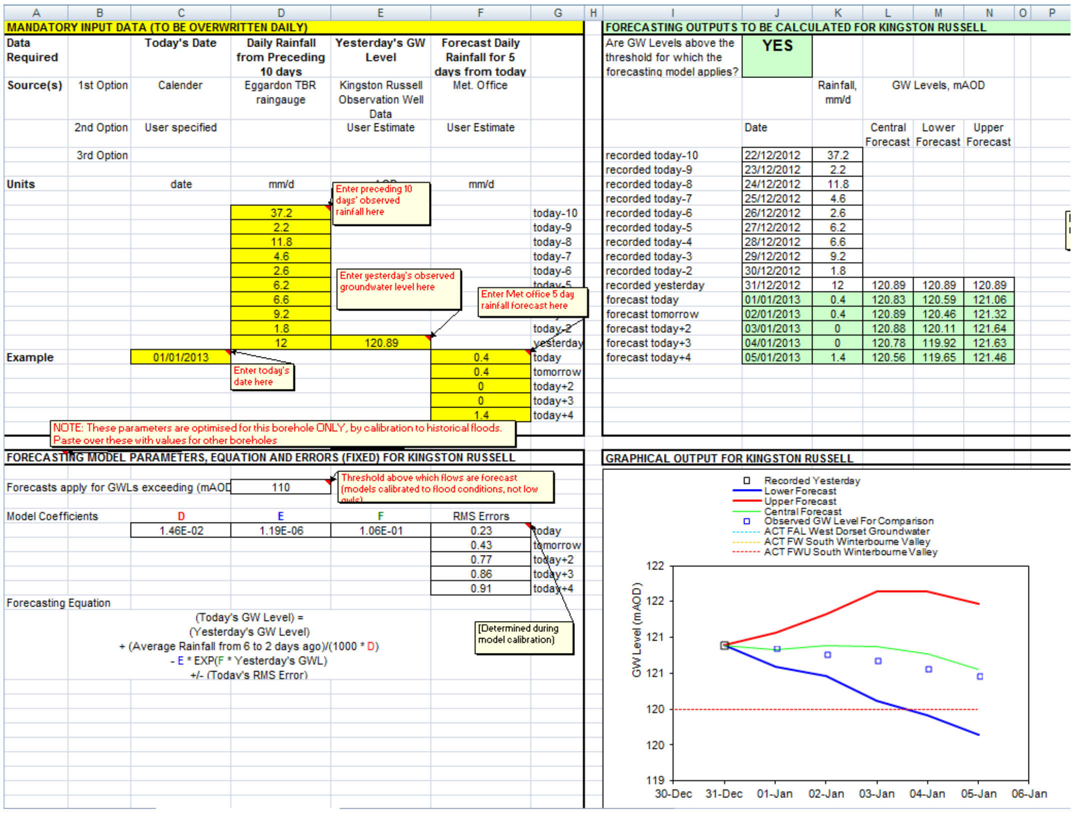

Figure 6-16 Groundwater Flood Forecasting Tool data sheet

The model is mainly based on observed data:

- actual groundwater levels at a monitoring borehole
- latent rainfall at an in-catchment rain gauge
- forecast rainfall over the next 5 days
- local calibration factor

The model generates 3 outputs:

- reasonable best case
- reasonable worst case
- most probable

Outputs are compared to an impact threshold (for example, the onset of property flooding). Other thresholds could be developed in collaboration with Environment Agency/LLFA partners such as Wessex Water, with indications such as groundwater infiltration in sewers, highway flooding and septic tanks failing.

Data is mostly generated from telemetry, with a summary of all locations sent to partners, and serves as a forecast tool for groundwater flood warnings. The thresholds for removing groundwater flood warnings may use local rivers as an indicator, as when the fluvial flooding peak has passed the groundwater table may remain high for some time afterwards without being an immediate flood risk.

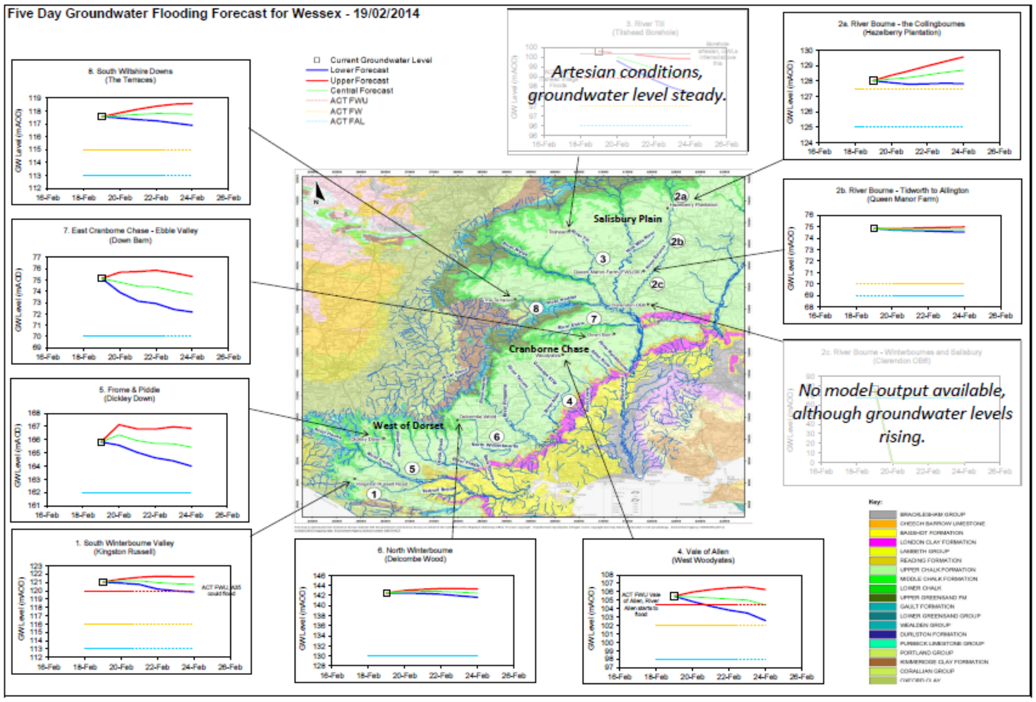

Figure 6-17 Example 5-day groundwater flooding forecast for Wessex

6.10.4 Implications of findings

Overall, the evidence indicates that there are some highly effective means of groundwater flood forecasting at varying scales. In general, it may be easier to forecast groundwater flooding relative to fluvial flooding due to the longer lead time response. Although making accurate predictions may be harder due to the complexity of groundwater responses.

National systems, including those such as FFC/GeoSmart national forecasting service, provide catchment and borehole hydrograph forecasting for the next 15 days. This service is a commercial product licensed through GeoSmart as part of the FFC package. Although the service is available nationally, this is still limited to locations/catchments with sufficient data telemetry. GeoSmart states that it is currently available in 302 catchments and areas currently without any telemetry, such as, for example, a large area of East Anglia having no live monitoring of groundwater levels (GeoSmart interview, 2020). The Environment Agency currently has no access to the FFC/GeoSmart forecasts, unless licence fees are paid to GeoSmart (steering group feedback, 2020). The current licensing arrangement does not allow free access to the forecasting service, and so limits integrating local Environment Agency experience with the service.

Local systems are widely used, especially in the chalk areas of south England, where detailed studies have been carried out on long-term borehole data and historic flood events to establish analytical approaches to characterise local groundwater flood responses. These have the benefit of being cheaper and simpler to run, but often more accurate in predicting local responses in groundwater, especially in areas of rainfall variation and complex geological properties such as the chalk. This includes the spreadsheet forecasting tool developed in Wessex, which uses borehole telemetry and local rainfall gauges, along with rainfall forecasts and bespoke calibration factors for the varying characteristics of the distinct chalk catchments across the area. This data is then fed directly to partners, with bespoke trigger levels developed as required. Although the Wessex area has an extensive monitoring network, it was noted that there are still improvements that can be made to the spatial coverage of groundwater monitoring locations, with more targeting of specific geological areas required to characterise changes within areas of varying responses types in the chalk catchments (Parker interview, 2020).

The concept of a catchment groundwater flood response time is useful in terms of understanding how much effective rainfall over what time period is needed to result in aquifer groundwater flooding. The main data needed are rainfall and historical groundwater flooding records. Groundwater borehole hydrographs can also be useful in indicating groundwater flooding hydrograph responses. In the months before groundwater flooding groundwater levels may rise earlier in the autumn than normal. Groundwater levels rose higher and stayed elevated for longer than normal during chalk aquifer flood events. The implication of this is that analysis of effective rainfall over the response time of the catchment, combined with historical flooding data, and key borehole hydrographs can predict when groundwater flooding in a catchment may occur. This is a very local approach to forecasting groundwater flooding but potentially cost effective, accurate and worth further investigating.

6.10.5 Gaps and future work

Halcrow was commissioned by the Environment Agency (2010) to review and appraise groundwater flood warning and forecasting service policies and tools. Although this study is 10 years old some of the gaps identified and recommendations for future work still stand and are replicated by findings of this study. These are to:

- Develop groundwater flood warning policies that are directly compatible with, and complementary to, fluvial flood warning policy and practice. This has been done in some places (for example, Wessex) but could be expanded to other locations.
- Record and collate, monitor and assess groundwater as outlined in the 'Consolidated Report'. Implement the findings of HA5, 'Making Space for Water' HA5 (Jacobs, 2007) and retain, store and share groundwater flooding data for modelling and forecasting.
- Ensure local numerical groundwater modelling is in a suitable form to be used for groundwater flood forecasting.
- Use screening tools (such as Groundwater Emergence Maps) to identify groundwater susceptible catchments, and support this with hydrogeologists' knowledge to understand groundwater flooding behaviour and support risk assessment.

Further evidence gathered through this study has found that there is a need to identify a hosting solution and funding for groundwater flooding in Environment Agency forecasting systems. The proposed FFC groundwater flood forecasting modelling system could be integrated with existing Environment Agency area procedures more widely. However, there still needs to be a decision about where to host operational groundwater flood forecasting models in the Environment Agency (for example, IMFS, NGMS, FFC/GeoSmart models). Funding sources for this development is also an issue (steering group feedback, 2020).

There is currently good practice locally, for example Wessex Area Groundwater and Contaminated Land team maintaining a spreadsheet-based groundwater flood forecasting model. However, this is not on any systems, and does not run automatically. Also, hydrology teams have CATCHMOD models, but these are not hosted anywhere and are not set up to update automatically. Options for the future could include putting the groundwater flood forecasting models onto the Incident Management Forecasting System (IMFS) or including them in the future update to the National Groundwater Modelling System (NGMS). The models will require funding to make this to happen, whereas currently they are resourced by staff time in Wessex Area, and hydrology teams (which is unsustainable given other budget pressures) (steering group feedback, 2020).

Understandably, forecasting tools have been developed where groundwater flooding is a greater risk. The development of local tools by necessity should be seen as a resource to inform a national approach - there is unlikely to be one "catch-all" solution to forecasting. Local approaches are probably best suited to using local knowledge.

Approaches developed to date should be reviewed to see if they have been constrained by factors such as budgetary constraints, and whether best practice is being shared between areas. Keeping forecasting approaches as simple as possible and closely related to real world observation and historical behaviour is likely to give best outcomes and value for money. Telemetry and automation is important to help build baseline data and deploy forecasting tools. Commercial solutions should form part of a blended solution alongside local models.

6.11 What local processes exist for warning of groundwater flooding?

The main aim of this question is to summarise the information and activity for groundwater flood forecasting and warning. Forecasting and warning are important activities in creating places that are resilient to flooding. This summary may help RMAs to understand the current availability of data and practice for groundwater flood forecasting and warning to support them in their work.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 4b:

Secondary question 4b: What local processes exist for warning of groundwater flooding?

6.11.1 Summary response

Groundwater flood warning is not comprehensively included within the national flood warning information service. The Environment Agency provides a public-facing flood alert service for groundwater in some areas. Flood warnings exist at different scales, with FFC warnings for gearing-up national and county emergency services, while locally flood wardens (for example, in Dorset and Wiltshire) advise communities and families on actions to take on the ground. Generally, groundwater flood warnings are issued by the same system as other types of flood warning.

6.11.2 Summary of evidence

Groundwater flood warning is not comprehensively included within the national flood warning information service, provided by the Environment Agency. Groundwater alert areas are limited to southern England (mainly Wessex, Hampshire, Oxford, London and Kent) and groundwater flood warning areas are only available in Wessex, and are shown in Map 7 (Appendix D) (Environment Agency 2020). Files that show the location and extent of groundwater flood warning and alert areas are available as open data. Some groundwater flood warnings are presented on the River Levels UK website.

The Environment Agency provides guidance on operating a groundwater flood warning service to incident management and resilience teams, who currently provide local warning and/or informing arrangements for areas affected by groundwater flooding. The operational framework sets out the sequence of actions required to operate the service, as illustrated in Figure 6-18. The framework identifies 5 operational stages, escalating from routine monitoring to issuing, updating and removing flood alerts and warnings. The briefing (Environment Agency, 2011b) provides further information on each of the stages.

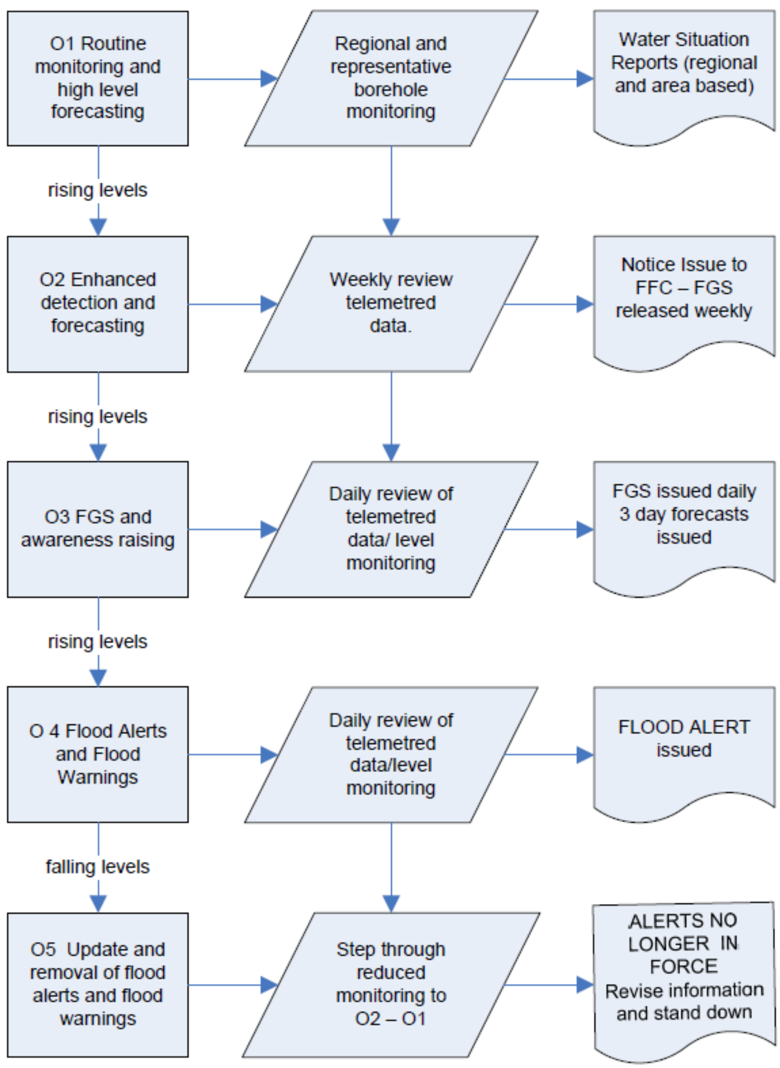

Figure 6-18 Operational framework for the groundwater flood warning service

The guidance was produced to encourage any groundwater flood warning services to be consistent with the national groundwater flood warning service framework. It sets out what is required in the locations before a warning service can be provided. The locations must:

- have a conceptual groundwater flooding model to identify indicator boreholes and to relate recorded groundwater levels to flood events

- have a single observation (indicator) borehole (as a minimum) which is representative of the entire groundwater flood catchment. This must be equipped with telemetry and used for flood monitoring/forecasting purposes

- have critical and threshold levels set on the indicator boreholes. These will be used to prompt actions and issue warnings which meet the required lead times

- use the Environment Agency system for disseminating flood alerts and flood warnings for flooding from groundwater. This can be supplemented by local arrangements such as briefings notes and flood wardens.

The guidance also advises how to define alert and warning areas. There is no consistent guidance about what to put in the warning messages.

The Environment Agency also provides real-time (updated every 15 minutes) flood monitoring and warning via API as open data. This is re-packaged and distributed by Shoothill. This covers:

- flood warnings and flood alerts
- flood areas to which warnings or alerts apply
- measurements of water levels and flows
- information on the monitoring stations providing those measurements

The areas of England where there is evidence of groundwater flood warning are shown in Map 3 (Appendix D). This map shows the number of sources of evidence reviewed relating to groundwater flood warnings for each LLFA area. It shows that the most evidence was found in Hampshire, Wiltshire, Dorset and Lincolnshire (6 to 14 pieces of evidence). Presenting the information in this way helps to illustrate where there is practice happening. The number of evidence sources can help to indicate the level of evidence supporting those practices.

Flood warnings exist at different scales, with FFC warnings for gearing-up national and county emergency services, while locally flood wardens (for example, in Dorset and Wiltshire) advise communities and families on actions to take on the ground (Guy Parker interview, 2020). The modelling and forecasting on which flood warnings are based is described in section 6.8 and 6.10 respectively.

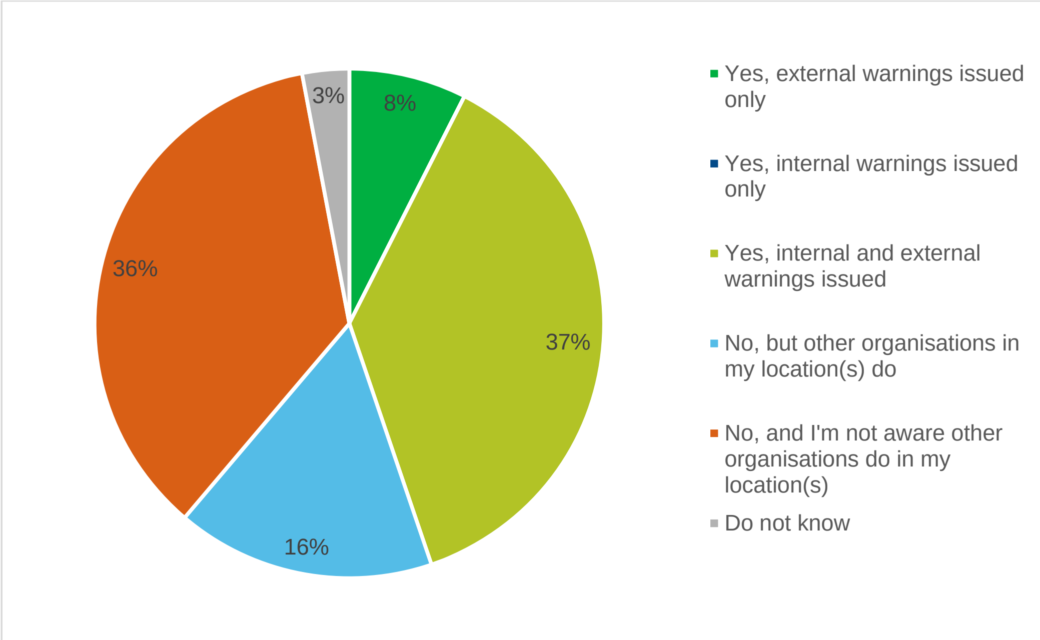

Figure 6-19 Does your organisation issue groundwater flooding warnings?

The proportion of questionnaire respondents that issue groundwater flood warnings is shown in Figure 6-19. 37% of respondents said they issue internal and external warnings, while 36% said that they didn't know of any other organisations issuing warnings in their area. Of the respondents to this question 77% were from the Environment Agency.

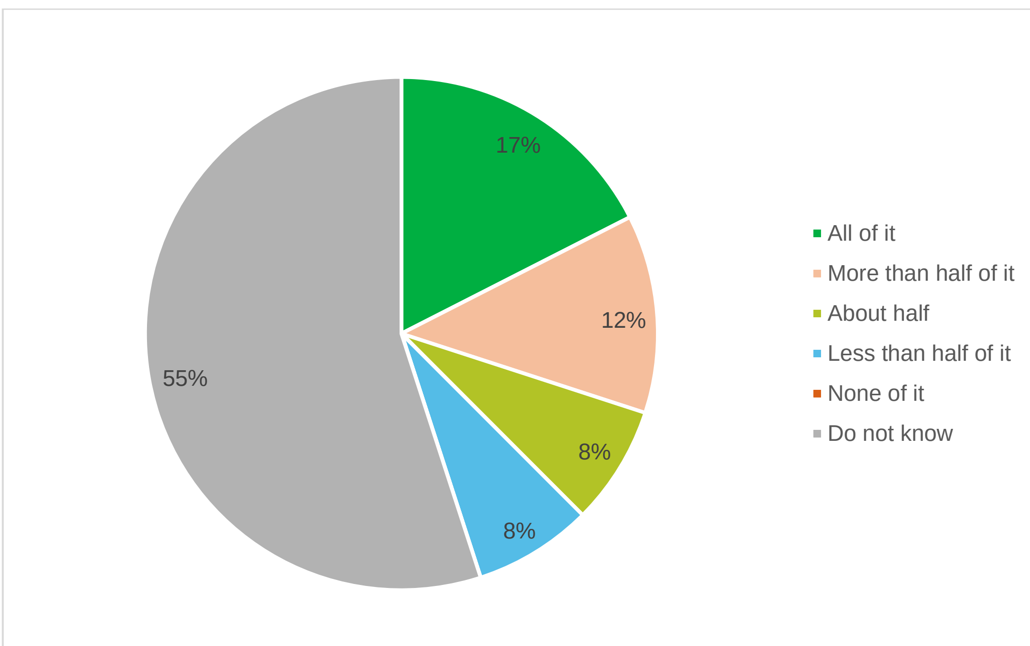

Figure 6-20 The proportion of the areas susceptible to groundwater flooding that can receive warnings

The number of areas susceptible to groundwater flooding that can receive flood warnings is shown in Figure 6-20. Over half (55%) didn't know the proportion of susceptible areas that can receive warnings, while 31% said that at least half of the areas that are susceptible can receive warnings.

73% of questionnaire respondents (30 people) indicated that groundwater flood warnings were issued by the same system(s) used for warning about other types of flooding, 2% (1 person) said they weren't and 24% (10 people) didn't know. In addition to being asked specific questions about flood warning systems, respondents were also able to leave additional comments about groundwater flood warnings.

Several locations appear in the comments, including 'Thames', 'Cotswold' and 'Wessex' which could suggest the types of locations where groundwater flood warnings are commonly used (see Map 3 for specific LLFAs within these areas, and number of sources of evidence relating to the use of groundwater flood warning systems). Additionally, words such as 'limestone', 'chalk' and 'aquifer' also indicate the types of areas where groundwater flood warnings are used.

However, the absence of groundwater flood warnings and alerts in many places was highlighted in the early 2020 groundwater floods. Additionally, some individuals within the Environment Agency did not know where they provided groundwater flood warnings and alerts.

6.11.3 Implications of findings

Groundwater flood warning is not comprehensively included within the national flood warning information service, although there are 13 areas where the Environment Agency provides a public-facing flood alert service for groundwater. Flood warnings exist at different scales, with FFC warnings for gearing-up national and county emergency services, while locally flood wardens (for example, in Dorset and Wiltshire) advise communities and families on actions to take on the ground.

Survey results show that roughly a third of respondents' organisations issued internal and external warnings, while a further third didn't know of any organisations issuing warnings in their area. Approximately half didn't know the proportion of susceptible areas that can receive warnings, while a third said that at least half of the areas that are susceptible can receive warnings. Generally, groundwater flood warnings are issued by the same system as other types of flood warning.

There is uncertainty about the use of groundwater flood warnings, and when to remove alerts. It was noted that when fluvial flood risk is no longer an issue the flood alerts may be removed, even though groundwater flooding may still be a risk due to the delayed response. In other settings, aquifers may retain a high water table some time following a high rainfall event and not be an immediate flood risk, even when above a set trigger level. In Wessex, the approach has been to combine monitoring of surface watercourses to assess when these high groundwater levels are unlikely to be a groundwater flood risk.

This means that there is not one consistent (in geographic scale and application) approach to providing, issuing and removing groundwater flood alerts and warnings which could hamper effective planning and response by communities and risk management authorities.

6.11.4 Gaps and future work

Similarly to the previous secondary question on forecasting and warning, more could be done to tie in local forecasting and warning approaches with those that already exist for fluvial and coastal flooding. Similarly, the recommendation for flood warning policies that are directly compatible with, and complementary to, fluvial flood warning policy and practice is applicable here.

Consistency should be improved particularly where several difference approaches are used within the same organisation, for example within the Environment Agency.

Clearer, consistent information regarding where groundwater flood warnings and alerts are provided, and approaches used to providing and removing them, should be publically available. To raise awareness with RMAs, training could be provided.

Sharing good practice within organisations and cross-organisations would support these improvements.

6.12 Have groundwater flood risk management schemes been implemented?

The main aim of this question is to summarise the information and activity for groundwater flood mitigation (reducing the likelihood or consequences, or both). This summary may help RMAs and others to understand the current guidance and practice for planning and carrying out mitigation measures to manage or reduce groundwater flood risk.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 5a:

Secondary question 5a: Have groundwater flood risk management schemes been implemented?

6.12.1 Summary response

Groundwater flood risk mitigation schemes have been implemented at various scales across England, although formal schemes have been limited compared to river flood management (only 20 of the 260 questionnaire respondents indicated that groundwater mitigation, resilience or adaptation schemes had been implemented).

Schemes often focus on the impact following groundwater flooding, such as property resilience measures, and relief of infrastructure such as removing flood waters from underground assets and roads. Proactive mitigation of groundwater flooding can be seen in schemes such as the GARDIT strategy in London. Local flood risk management strategy reports may include methods to reduce the likelihood of groundwater flooding.

6.12.2 Summary of evidence

Mitigation of groundwater flooding tends to be reactive in areas where groundwater flooding is rare. Ephemeral water channels (dry stream beds that fill after heavy or prolonged rain) can become blocked or partially filled, making them less able to transmit water when groundwater levels are high. In such situations, the response to an unexpected groundwater flood event is reactive, and may involve pumping (East Riding of Yorkshire Council, 2013). After events, mitigation may involve improving surface water drainage of the affected areas, for example, Compton in Berkshire after 2001 and Buckskin in Basingstoke after 2014 (Buss 2019).

A very detailed study of permeable superficial deposits flooding was carried out in Oxford, in the Thames catchment in 2012. The flood plain here is underlain by permeable shallow sands and gravels, and a significant number of properties were affected by flooding from rising groundwater. The options for mitigating this form of flooding included measures to increase the rate of conveyance of flood waters through Oxford. This is primarily to reduce fluvial flood risk but is also recognised as a way of reducing groundwater flood risk within the city (Macdonald and others, 2012).

Questionnaire respondents indicated that groundwater flooding was often linked, or occurred, at the same time as other sources of flooding.

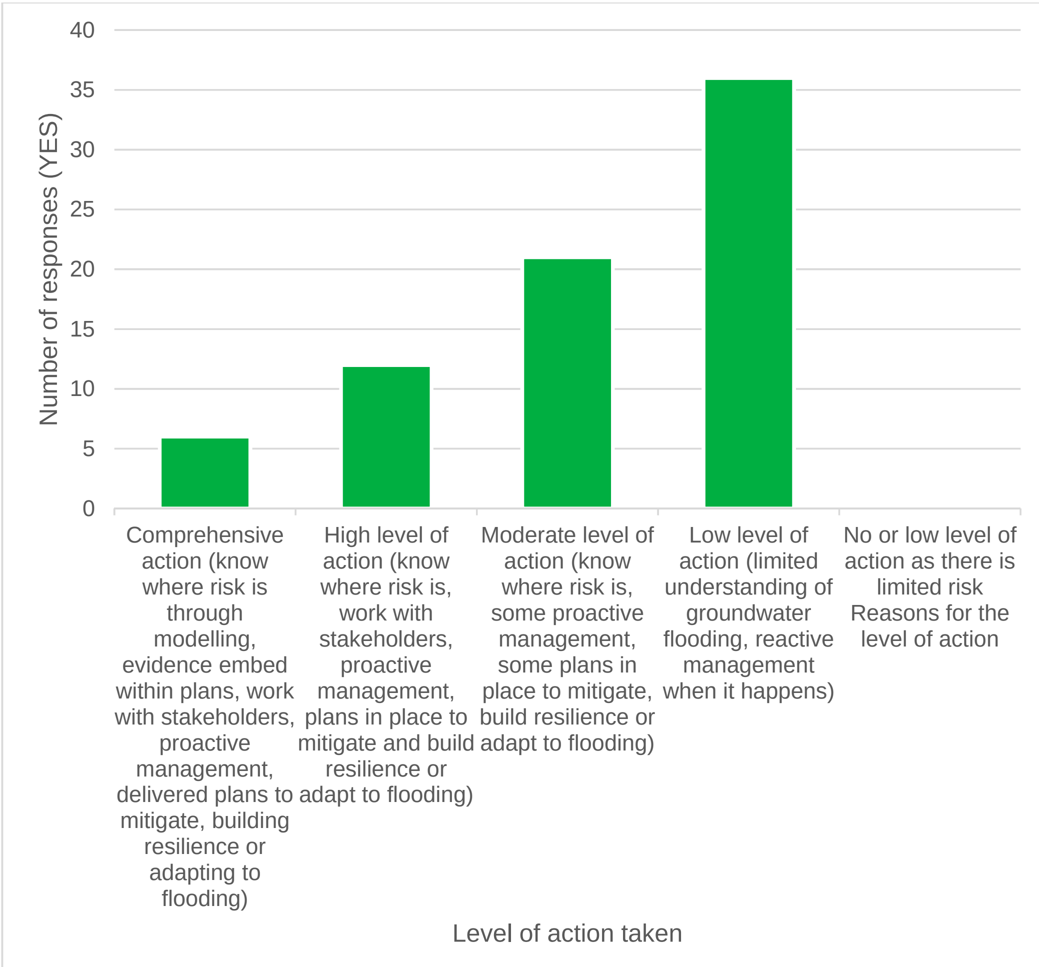

Figure 6-21 Perceived level of action taken regarding groundwater flood risk management across survey respondents

The questionnaire responses show that generally, it was thought that a low level of action was taken regarding groundwater flood risk management (Figure 6-21). The most common response among respondents was that there is a low level of action (48% or 36 people), which was significantly higher than the number of responses suggesting that the level of action was comprehensive (8% or 6 people) or high (16% or 12 people).

There have been limited formal groundwater flood risk management schemes compared to river flood management schemes. 25% (20 people) indicated that groundwater mitigation, resilience or adaptation schemes had been implemented, 33% (26 people) didn't know, and 42% (33 people) identified no known formal schemes since 2010. However, further evidence found the design of the new Hull flood defences took into account extreme groundwater discharge rates, and the outline design for the proposed Oxford flood alleviation channel took into account the change in risk of groundwater flooding (Buss, 2019). Other evidence also found other preventative measures being undertaken by water companies to reduce problems with sewage infiltration.

The location of groundwater flood risk management schemes is shown in Map 4 (Appendix D). A summary of responses and evidence found in specific locations is provided below.

London

The GARDIT strategy is an example of strategic, proactive mitigation. The GARDIT strategy was defined by Thames Water, the Environment Agency and London Underground with the support of other organisations, as a 5-phase plan to bring rising groundwater levels under control (Jones, 2020).

South-west

For example, Wessex Water has infiltration reduction plans to reduce the risk of groundwater entering public and private sewers and drains and potentially causing sewer flooding (Steering Group, 2020). These plans target catchments that are vulnerable to groundwater flooding. Groundwater infiltration into sewers reduces their capacity as storm drains, potentially making surface water flooding worse. Wessex Water inspects and seals sewers where groundwater is infiltrating, inspecting over 72km in 2018 to 2019 and sealing almost 10km of sewers (Wessex Water, n.d.). However, as water companies are looking to reduce infiltration to sewers this may result in increases in groundwater flood emergence elsewhere. Water companies also use flood forecasts to inform operational response and planning of tanker requirements.

South-east

During the 2014 groundwater flooding in West Thames there were measures to pump groundwater by West Berkshire Council (in Lambourn and Great Shefford). West Berkshire Council used the West Berkshire Groundwater Scheme pipeline at Great Shefford to divert water from housing. Additional pumping by Thames Water at a public supply borehole at this location was permitted by the Environment Agency in order to prevent the borehole flooding at this time. Fire crew also provided pumping for around a month in some locations. There is currently no mechanism to use the West Berkshire Groundwater Scheme for groundwater flooding as it was constructed to alleviate low flows only.

There was also pumping from Thames Water sewers by Basingstoke and Deane Borough Council into tankers, although this was costly per unit volume of water; some pumping to the River Loddon was also carried out (Environment Agency 2020 draft). The experience highlighted that pumping in one location can affect other areas. Topography and infrastructure may result in ponding of water, and blockages to flow may occur or give way, causing ponding or surges of water. Measures to manage groundwater flooding by pumping groundwater need to take into account where the water should discharge and whether there is capacity to receive the water without causing flooding elsewhere. In permeable groundwater catchments, when groundwater flooding is initiated, drainage and river network may already be full.

The Solent and South Downs area of the Environment Agency have historically taken a proactive approach to preparing communities to reduce the risk of groundwater flooding by installing basement pumps (steering group feedback, 2020).

Hampshire County Council has developed a comprehensive local flood risk management strategy action plan (Hampshire County Council, 2013), which includes details of flood warning and current or proposed flood alleviation measures. This was updated into a local flood and water management strategy in 2019 (Hampshire County Council, 2019). It covers all types of flooding but has a strong focus on groundwater flooding.

East England

The Greater Norwich strategic flood risk assessment identifies that pumping by the internal drainage board (IDB) in the Broadland area is believed to maintain the water table at a relatively lower level, reducing the risk of groundwater flooding (Norfolk County Council, 2015).

Anglian Water pumps from its network during periods of groundwater flooding (such as during the flooding of winter 2019 to 2020), and transfers water via tanker or directly to watercourses (Anglian Water interview, 2020).

North-east England

The Burton Fleming section 19 report (East Riding of Yorkshire, 2013) describes the action taken during the 2012-2013 flooding. Hull Fire and Rescue Service initially carried out high volume pumping for 5 days, which the Environment Agency then continued for over a month, and East Riding of Yorkshire Council for another month. Water levels remained high in the Gypsey Race for 6 months. East Riding Yorkshire Council had telemetry in the watercourse which flooded (but which is usually dry). However, given the absence of flooding in the village for previous decades, there were general alarms to indicate water levels were rising, but no specific alarms. Following the flood event, specific thresholds levels were set, with the aim of providing effective warning of any future flooding. However, although a level has been suggested that may correspond to the onset of flooding, when this level has been reached in recent years, it has not resulted in flooding. Further work is needed to understand the mechanisms (for example, antecedent (initial) conditions) that drive groundwater flooding in this case (steering group feedback, 2020). Options for reducing the likelihood of flooding in future were investigated.

Groundwater flooding in Burton Fleming highlighted the importance of:

- difficulties in predicting groundwater flooding which may not have occurred in the last 50 years
- telemetry data for flood warning
- borehole data for groundwater levels and the lag in groundwater response to prolonged rainfall. However, subsequent experience of using trigger levels in Burton Fleming indicates that groundwater levels can reach the trigger level where flooding occurred in 2012 to 2013 but no flooding occurs. This indicates that groundwater flooding has a complex mechanism and groundwater levels at one specific location are not the only factor controlling the onset of flooding (steering group, 2020)
- multiple parties coordinating a pumping response

Mine water rebound is a particular problem in the north-east of England, although it is also an issue in Manchester and Staffordshire (S Buss, 2020). Groundwater flooding from mine water rebound is managed by pumping schemes implemented by the Coal Authority, within areas of historic mining. These may include regulated groundwater levels via groundwater abstractions, such as those in Gateshead (Mott Macdonald, 2019). The questionnaire respondents highlighted that pumping groundwater was carried out on an ongoing basis in areas of urban and mine water groundwater rebound. There was considerable concern that arrangements (including funds) for pumping rebound water, particularly mine water, were limited. If pumping stopped or was reduced, it was thought that groundwater flooding would occur.

In some locations dewatering to keep one piece of infrastructure dry has benefits for other potential flooding receptors. For example, dewatering of the Mersey Tunnels may be keeping basements and the BT tunnel under Liverpool dry. Also, dewatering of the Birmingham BT tunnel may be keeping some of Birmingham's basements dry (S Buss, 2020).

It is important to highlight that no evidence was found that demonstrates how effective reactive schemes are that intended to alleviate groundwater flooding (i.e. pumping from public water supplies).

6.12.3 Case study: Buckskin Flood Alleviation Scheme

Secondary question: Have groundwater flood risk management schemes been implemented?

Source of information: literature and interview

Organisation(s): Hampshire County Council, Basingstoke and Deane Borough Council, Environment Agency, Thames Water Utilities Limited, Sovereign Housing Association, South East Water Limited.

Date: 2018 to 2020

Hyperlink to further detail: Hampshire flood strategy for buckskin
Further detail is provided in Appendix E

Location: Basingstoke, Hampshire

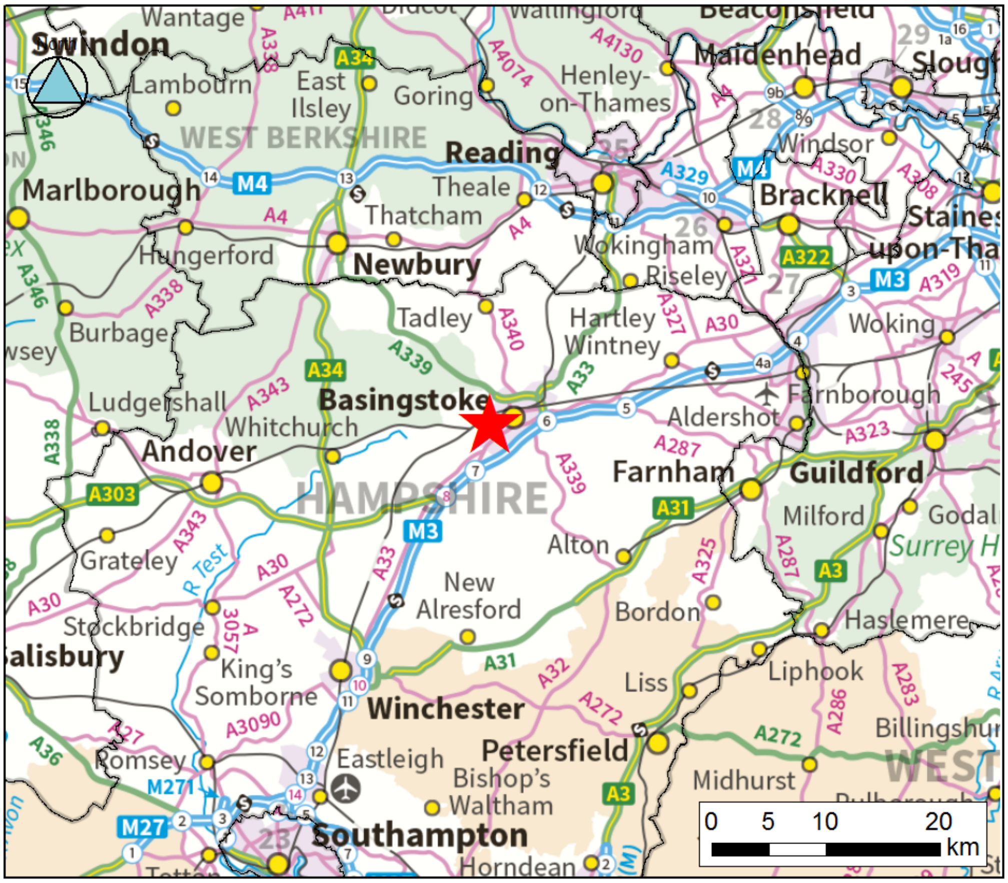

Figure 6-22 Location of the Buckskin flood alleviation scheme

In the winter of 2013 to 2014 Buckskin and the surrounding area was badly affected by flooding. A multi-agency group has been working together with local residents to understand the cause of the flooding and to develop solutions. The group is made up of Hampshire County Council, Basingstoke and Deane Borough Council, the Environment Agency, Thames Water Utilities Limited, Sovereign Housing Association and South East Water Limited.

In June 2017, the multi-agency group committed to work together to promote and develop the agreed scheme.

Aim of the scheme

The aim of the scheme is to better protect people, properties, businesses and infrastructure from the risk of flooding should there be a repeat of the events of 2013 to 2014. This is supported by planning procedures that prevent increase in flows to groundwater from higher up the catchment (for example, requirements on infiltration SuDS on the chalk catchment must not exacerbate the groundwater flooding issues).

The main objectives of the scheme are to:

- reduce the risk of flooding in a weather event similar to that of 2013 to 2014 without increasing the risk of flooding elsewhere
- reduce the impacts of flooding on the residents of Buckskin, their properties, businesses and infrastructure
- improve resilience to flooding

Groundwater model

An initial feasibility study was carried out by Hampshire County Council which investigated further the causes of the flooding and assessed the flood mechanisms during the event. A number of possible mitigation options were then identified. The likely effectiveness of these options, as well as any potential adverse impacts on the surrounding areas, was considered. These options focus on managing the flood flows above ground during an event, without groundwater assessment. On external review, the Environment Agency identified the need for some quantitative assessment of the groundwater flooding, which was carried out by Atkins (2016).

To meet these aims, a bespoke groundwater model of the Buckskin area was developed using a number of existing models and a bespoke, high level, 2D only, model of the area upstream of the current Environment Agency 1D-2D River Loddon model has been constructed to allow sufficient above ground analysis of groundwater flows in the Upper Loddon.

A number of mitigation options were assessed using the Buckskin model:

- carrier pipe option
- storage area option
- groundwater abstraction option

Project approval

A project appraisal of the scheme was approved in April 2018. Estimated scheme costs were £6 million funded from central government, the Thames Regional and Coastal Committee and the multi-agency partners. The project was due to complete in summer 2020.

Design

The scheme will seek to reduce the risk of flooding by:

- diverting water away from the properties on the estate into a new large drainage pipe
- providing gullies and collection points along the flow path route in the Buckskin estate footpaths
- improving the connection to the ditches to the north of the Buckskin estate so that floodwater can be effectively drained away

A schematic conceptual diagram of the proposed scheme is shown in Figure 6-23.

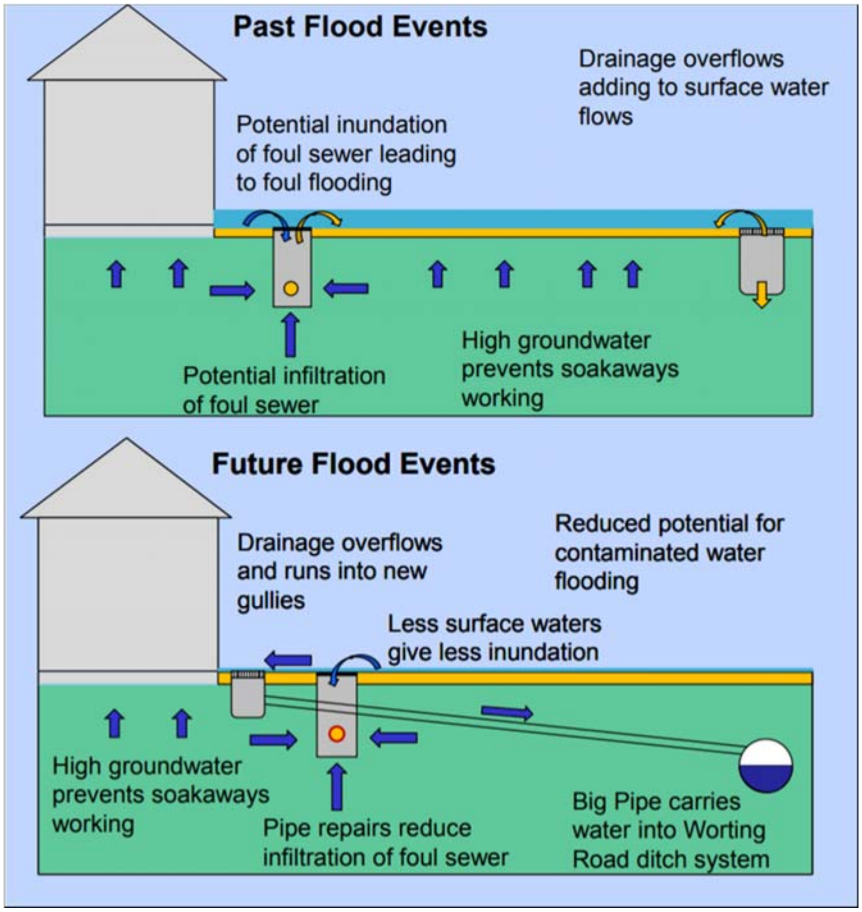

Figure 6-23 Schematic conceptual diagram of the Buckskin scheme

6.12.4 Implications of findings

The majority of questionnaire respondents felt that there was a low level of action taken in regard to groundwater flood mitigation.

Mitigation schemes often focus on reducing the impact of groundwater flooding after a flood, such as installing property resilience measures and easing impacts on infrastructure (for example removing flood waters from underground assets and roads). This means that the damages and costs of groundwater flooding have already occurred. However, pumping may be fairly short-lived in time (days to months) and locally undertaken.

Proactive mitigation of groundwater flooding can be seen in schemes such as the GARDIT strategy in London, which aims to control the groundwater rebound in the area through a collaborative pumping strategy. In this case the risk to large, sometimes very old, buildings and infrastructure in London, and the potential cost of damages, was sufficient that it was thought necessary by the GARDIT organisations to lower groundwater before flooding occurred. This has the benefit that damages and costs of groundwater flooding are avoided, but on-going costs of continual pumping large amounts of water from a number of boreholes were incurred. Proactive pumping avoids the situation where pumping is initiated when the drainage network is already full and not able to take any more water without making other flooding worse. Such preventative pumping has the potential to lower groundwater levels over a wide area of aquifer.

The likelihood of groundwater flooding can be reduced through identifying mitigation approaches in local flood risk management strategies. For example, IDBs managing pumping in the Broadland area to maintain the water table at a lower risk level (Norfolk County Council, 2015).

6.12.5 Gaps and future work

Mitigation action to improve resilience to groundwater flooding should be planned proactively so that the activity is properly informed. This should include information on the mechanisms of flooding, and how groundwater interacts with other flood sources, and any potential implications of mitigation activity. As previous sections have concluded, this information rarely exists and needs investment to produce.

Targeted modelling of potential groundwater flood responses, such as additional pumping of existing (e.g. public water supply) boreholes could be used to assess the how effective they would be and identify any other impacts (intended or otherwise) before they are used. This should be undertaken if groundwater pumping is identified in multi-agency flood plans as a response mechanism, to avoid situations where reactive pumping overwhelms drainage systems and exacerbates existing flooding at another location. Initial guidance may be needed to support Local Resilience Forums adequately consider groundwater flooding in multi-agency flood plans before detailed modelling is undertaken.

Better understanding groundwater flooding mechanisms, and where flooding is most likely to have significant consequences can be used to create a route map, or adaptive plan to provide proactive management to increase resilience against groundwater flooding.

Providing further guidance and support in this area may inspire action to improve resilience to groundwater flooding. This should clarify the regulatory and licencing situation regarding pumping groundwater flood waters.

6.13 Is there guidance on developing and implementing groundwater flood mitigation schemes?

The main aim of this question is to summarise the information and activity for groundwater flood mitigation (reducing the likelihood or consequences, or both). This summary may help RMAs understand the current guidance and practice for planning and implementing mitigation measures to manage or reduce groundwater flood risk.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 5b:

Secondary question 5b: Is there guidance on developing and implementing groundwater flood schemes?

6.13.1 Summary response

There is guidance publicly available on understanding groundwater flooding and what to do, including property level resilience measures. However, there appears to be limited guidance regarding developing and implementing larger groundwater flood mitigation schemes.

6.13.2 Summary of evidence

There is considerable guidance aimed at the general public regarding a basic introduction to groundwater flooding and what to do. There is some general advice given by the Environment Agency in 'Flooding from Groundwater' (Environment Agency, 2011a) for property owners, including pumping at a property.

There appears to be limited guidance regarding developing and implementing larger groundwater flood mitigation schemes. These could involve, for instance, wider borehole pumping to lower water levels over a wider area.

The flood and coastal erosion risk management appraisal guide (flood-and-coastal-erosion-risk-management-appraisal-guidance) provides information on how to complete an appraisal for a flood risk management strategy or project in England. It also explains how to create a business case to support an application for FCERM funding in line with government policy. One of the first steps is to understand and define the appraisal need. This involves gathering information to understand:

- the probability of flooding and erosion
- how this probability could change through climate change, population change, development and regeneration, and the condition of any existing FCERM assets
- the positive and negative consequences of flooding and erosion
- how and why these consequences could change over time
- how opportunities could benefit FCERM operations

Between 1 April 2018 and 31 March 2019, the Environment Agency worked with other RMAs to complete 202 FCERM schemes, 2 of these specifically addressed groundwater flooding. Evidence found for other questions asked in this project showed that there is often limited data to understand the probability of groundwater flooding and how this can change with climate change, which could make assessments for pro-active groundwater flood mitigation difficult.

To support mitigation scheme appraisal, there are methods in online multi-coloured manual to undertake cost benefit analysis. When estimating of the costs of groundwater flooding it is important to consider the longer durations of groundwater flooding to ensure the expected damages, and damages avoided (benefits) are calculated accurately.

A detailed study in Hambledon, Hampshire (Green and others of the Flood Hazard Research Centre (FHRC), 2006) indicated that the extended duration of groundwater flooding resulted in substantially higher flood losses than would have been predicted using standard Middlesex depth-damage data current at that time. It was concluded that a flood duration of 1 one week resulted in losses that were 240% of the building fabric damages expected using Multi-Coloured Manual (MCM) data current at that time. For a flood lasting three 3 months, the building fabric damages increased to 360% of those estimated using MCM data. The report stated that the FHRC would develop a new data set within the MCM to allow users to access the groundwater damages data in 2007. There are now options in the MCM to select 'very long duration' options (3 days plus) which can be used to account for higher damages. However, this project has not found evidence of the new dataset that was referenced in 2007.

In the Hambledon study by FHRC they found rising groundwater was "specifically excluded from standard domestic residential property insurances; and it would seem that to be an insured risk, the groundwater must first flow across the surface of the land before entering the building that is insured" (Green and others of the Flood Hazard Research Centre (FHRC), 2006).

However, since then, Flood Re, a joint initiative between the Government and insurers and governed using the flood reinsurance regulations (2015) have been introduced to enable affordable flood cover in household insurance. Flood insurance is a useful mechanism for building flood resilience and can help stimulate action to reduce food risk.

6.13.1 Implications of findings

There is guidance publicly available on understanding groundwater flooding and what to do, including some property level resilience measures which means that property owners could access the information to take action to protect themselves and their properties from groundwater flooding, if they understood there to be a risk. However, these need to be suitable to use in groundwater flood areas so that water does not emerge and cause damage. The availability of pumping of groundwater to mitigate flooding is still an area of uncertainty regarding requirements for licencing and discharge consent. This uncertainty hampers the development of some property level measures.

Better guidance on developing and implementing groundwater flood mitigation schemes at the community scale could help risk management authorities access government funding for proactively reducing the risk of groundwater flooding.

6.13.2 Gaps and future work

Some of the information supplied to the general public on groundwater flooding and what to do should be reviewed and where needed, updated. Information should support property owners understand their risk from groundwater flooding and point them to recent groundwater flooding assessments and susceptibility mapping.

Guidance (new or clarified in existing documents) is needed to support risk management authorities develop and implement community scale groundwater flood mitigation schemes. These should include examples of how liabilities are assessed in cost:benefit appraisal when there is limited information on the scale of groundwater flood risk. It should also clarify the operational processes for the regulatory framework for larger groundwater pumping schemes.

Guidance could be targeted or provide specific information by flood mechanism, by geological setting, by geography or other local factors that influence the likelihood, scale and consequences of groundwater flooding.

This could be presented as a hierarchical assessment (as regional scale assessment requirements are different to property level) and set out data requirements as this is one of the key barriers to effective groundwater risk assessment to date.

Without sufficient data it is not possible to develop meaningful predictive tools or effectively manage and mitigate groundwater flooding. Guidance that focuses on ensuring an adequate evidence base is developed will provide the basis for groundwater flood risk management. Drawing on good practice in areas where understanding is better developed would help implementation elsewhere. Any guidance should be developed jointly between stakeholders involved (for example the Environment Agency, LLFAs, water companies, and the Coal Authority).

6.14 What practices are used for improving resilience (people and properties) to groundwater flooding?

The main aim of this question is to summarise the information and activity for groundwater flood mitigation (reducing the likelihood or consequences, or both). This summary may help RMAs understand the current guidance and practice for planning and implementing mitigation measures to manage or reduce groundwater flood risk.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 5c:

Secondary question 5c: What practices are used for improving resilience to groundwater flooding?

6.14.1 Summary response

General advice is provided by ‘Flooding from Groundwater’ by the Environment Agency and the Local Government Association (2011a), with the options for reducing the damage to properties outlined. However, during a groundwater flood event some of the recommended discharge options may also be overwhelmed, or in flood (such as local watercourses or drains), and the guidance does not state whether permission to discharge pumped groundwater will be available.

Overall, a wide range of mitigation measures has been used to limit the impact of groundwater flooding. These appear to have focused mainly on property level, including resistance measures (to keep water out), property level resilience measures (to limit the impact of flooding) and property level pumping, with some strategic activity through drainage and wastewater management plans. Passive measures to control groundwater via drainage, channelling and barriers are also used.

6.14.2 Summary of evidence

General advice is provided by ‘Flooding from Groundwater’ by the Environment Agency and the Local Government Association (2011a). Options for reducing the damage to property are outlined, including raising or sealing floors. Recommendations include non-return valves on drainage, drainage measures and pumping groundwater flood water. The document states that if pumping groundwater flood water you should contact: the Environment Agency regarding discharge to main rivers or boreholes; the local authority regarding discharge to ditches, watercourses or piped watercourses; the water company regarding discharge to sewers; and the Highways Authority regarding highway drains. In practice, during a groundwater flood event some of these discharge options may also be overwhelmed, or in flood. ‘‘Flooding from Groundwater’ does not state whether permission to discharge pumped groundwater will be available.

Pumping from homes in Wessex (Parker, 2020) is the most common form of groundwater flood relief, sometimes with French drains to a sump that houses the abstraction, with water diverted to a road or river. This is only effective when the water is below the ground level, and typically if the basements are tanked (Buss, peer review feedback, 2020). The second most common form of flood relief is pumping from a basement. Some methods allow basements to fill up with minimal pumping and use them as temporary storage, and often allow them to dry out again in summer. Hoad (2020) highlighted that these kind of property level resilience measures are generally only curing the symptoms, and not really effective for the community as a whole. The common limitation is the issue of where to pump the water to, as local watercourses and roads are often already inundated, and may make other issues worse such as surface flooding downstream and causing roads to become unusable.

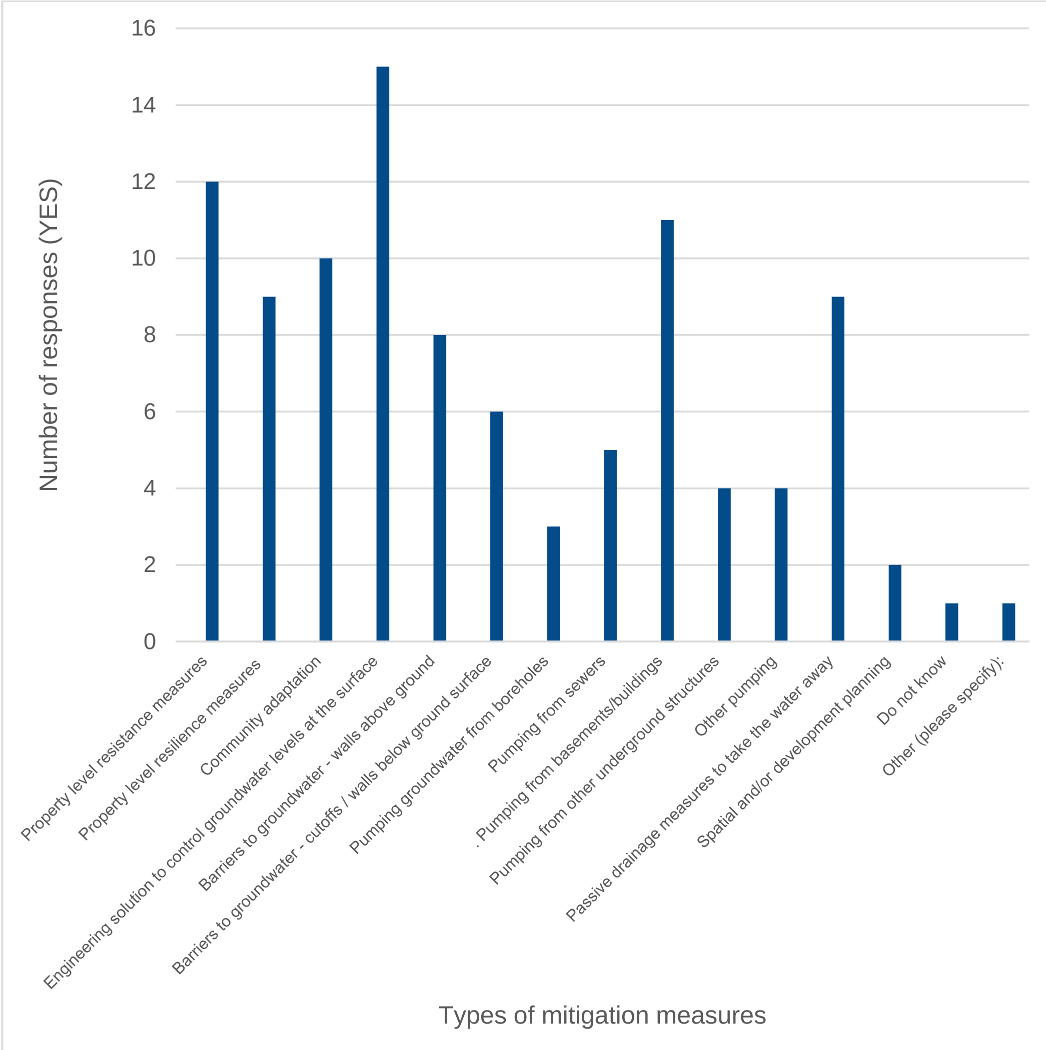

Figure 6-24 **Types of mitigation measures that have been used for groundwater flooding**

When asked about the types of mitigation measures used for groundwater flooding (Figure 6-24). The most popular response was using an engineering solution to control groundwater levels at the surface (75% of respondents who said groundwater mitigation, resilience or adaptation schemes have been implemented), followed by property level resistance measures (60% of respondents) and pumping from basements and buildings (55% of respondents). Some measures that the respondents indicated were less common included spatial and/or development planning (10% of respondents) and pumping from groundwater from boreholes (15% of respondents).

Additionally, questionnaire respondents and literature indicated the following:

- In areas of Wessex, chances of groundwater flooding are relatively high in any given winter and residents/vulnerable population are relatively well prepared with basement pumps installed and property level protection common.
- Deployment of a temporary barrier once groundwater levels rise above identified thresholds.

- Use of sandbags where groundwater is flowing over ground.
- Pumping – carried out by 3 different organisations as the situation evolved over several months at Burton Fleming (East Riding Yorkshire Council, 2013).

At a strategic level, water companies are developing drainage and waste water management plans (DWMP) that set out how organisations will work together to improve drainage and environmental water quality. The Wessex Water DWMP includes infiltration reduction plans to reduce the risk of groundwater entering public and private sewers and drains, and are used to influence spatial planning. Information is available online that identifies priority catchments, the previous years' groundwater situation, and how the area is performing in terms of flooding incidents. Their online GIS portal indicates 'infiltration reduction areas' that show where Wessex Water will need to be consulted on planning applications to ensure development does not increase groundwater infiltration and the risk of sewer flooding (steering group feedback, 2020).

6.14.3 Implications of findings

The survey showed that several approaches are used to mitigate against groundwater flooding including property resilience and resistance measures, barriers, community adaptation and pumping.

The survey responses reported that many communities that experience flooding regularly are "relatively well prepared" (project survey, 2020). In many places however, groundwater flooding is very infrequent and information is not available to inform residents, which means that some communities are likely to be unprepared. This was the case in Burton Fleming (East Riding of Yorkshire Council, 2013) and Buckskin in Hampshire where flooding had not occurred for 50 to 60 years (Buss, 2020).

Pumping is widely used to alleviate groundwater flooding but can cause problems elsewhere and not always effective for the community as a whole. The common issue of where to pump the water to, as local watercourses and roads are often already inundated, and may exacerbate other issues such as surface flooding downstream and causing roads to become unusable. It is important to consider timescales when planning groundwater mitigation measures. Groundwater flooding is potentially a long duration event so while pumping to nearby rivers may not be possible when the river is in peak flow, there may be scope to alleviate the groundwater flooding when rivers have receded.

Recovery measures are also being used at individual property level, such as water-resistant plastering and raising electrical sockets and associated wiring. However, the pressure that rising groundwater levels can exert can lift floors, float empty septic tanks and empty SuDS retention tanks, and retrospectively sealing basements or ground floors can be ineffective. (Environment Agency 2011).

6.14.4 Gaps and future work

Alternative mechanisms to pumping should be identified. This could include potential secondary networks of flood discharge sewers to convey water in affected areas (Hydrogeology group feedback 2020).

Larger scale relief measures may be a longer term goal, where property level measures can provide some short term resilience. There is scope to learn from existing approaches (for example GARDIT), and to use legacy infrastructure (for example in mine water rebound areas).

Existing guidance, such as 'Flooding from Groundwater' (Environment Agency, 2011a) should clarify whether pumped groundwater discharges are permissible.

6.15 What are the requirements for considering groundwater in spatial planning?

The main aim of this question is to summarise the information and activity for groundwater flood mitigation (reducing the likelihood or consequences, or both). This summary may help RMAs understand the current guidance and practice for planning and implementing mitigation measures to manage or reduce groundwater flood risk.

The research on groundwater flood risk assessment is focused into secondary questions. This section describes the findings for secondary question 5d:

Secondary question 5d: What are the requirements for considering groundwater in spatial planning?

6.15.1 Summary response

The LLFA has a duty to lead and coordinate the management of local groundwater flood risk, including preparing local flood risk management strategies (LFRMSs), which should identify where groundwater sources are a significant risk. Mapping groundwater flood risk is integral to spatial planning and crucial for developers when considering a proposed development. It is often informed by Environment Agency/BGS susceptibility mapping and supplementary local monitoring data. However, the evidence indicated that groundwater flooding may be completely missed in planning applications, and, where it is identified, often dismissed due to a lack of expertise to address or resolve the issue.

6.15.2 Summary of evidence

Under the EU Floods Directive and UK Flood Risk Regulations, LLFAs must prepare preliminary flood risk assessments (PFRAs) and local flood risk management plans for formally identified flood risk areas where the risk of flooding from local sources (groundwater, surface water, and ordinary watercourses) is significant.

The National Planning Policy Framework (NPPF) and accompanying Planning Practice Guidance (PPG) emphasise the responsibility of the LPA to ensure that flood risk is understood and managed effectively using a risk-based approach throughout all stages of the planning process. Consequently, LPAs carry out SFRAs to help them prepare their local plan.

For a separate research study, the Environment Agency collated a list of SFRAs and strategic planning policies to demonstrate how all flood sources are considered in spatial planning (Environment Agency, 'using flood risk information in spatial planning', unpublished). Of these, 30 documents referred to groundwater flooding, and 16 of those documents were assessed to be 'good' or 'excellent' quality against the NPPF (5 of the 16 were updated within the last 3 years). In addition, SFRAs submitted with the questionnaire responses were reviewed to understand the current requirements for considering groundwater in spatial planning.

Level 1 SFRAs collate and analyse the most up-to-date flood risk information from all sources to provide an overview of flood risk issues within the LPA, resulting in evidence to inform the emerging local plans. These aim to ensure flood risk is taken into account when considering development options. SFRAs use a variety of groundwater flood risk mapping data, including the 'Areas Susceptible to Groundwater Flooding' (AStGwf) data set. This AStGwf data set was produced as a high level screening tool to use for the preliminary flood risk assessment in 2011. It shows groundwater flood areas on a $1km^2$ grid and the proportion of each $1km^2$ grid where geological and hydrogeological conditions indicate that groundwater might emerge. It does not show the likelihood of groundwater flooding occurring and does not take into account the chance of flooding from groundwater rebound. The dataset covers a large area of land, and only isolated locations within the overall susceptible areas are actually likely to suffer the consequences of groundwater flooding. For these reasons, there are limitations to using it in spatial planning decision making, but continues to be used by local planning authorities.

The mapping of the various flood risks, including groundwater flood risk is integral to spatial planning and for developers when considering a proposed development. The datasets used to inform SFRAs included:

- Areas Susceptible to Groundwater Flooding (AStGwf) dataset by the Environment Agency
- BGS Susceptibility to Groundwater Flooding Map
- Defra's Groundwater Emergence Map (GEM)
- Groundwater Vulnerability Zones and Groundwater Source Protection Zones (SPZ)
- JBA Groundwater Flood Map
- London 'Increased Potential for Elevated Groundwater' (iPEG) maps

A number of SFRAs reviewed noted the coarseness (1km resolution) of the AStGWf data set, in particular, but others as well. These mapping data sets were often used together with other information, such as the geological and hydrogeological setting, local and historical data, and flooding records. In accordance with Planning Policy Statement 25, consultation with leading stakeholders includes a review of flooding from all sources, including groundwater.

Level 2 SFRAs analyse the level of flood risk associated with allocated development sites within the study area, in accordance with the NPPF and PPG. With level 1 SFRAs as the initial source, other data such as geological indicators can be used to assess the potential for groundwater flooding to occur at allocated development sites.

The Joint West London SFRA is one of the 5 documents identified within the Environment Agency's assessment of 'excellent' quality and shortlisted for good practice. It identified spatially the risks to groundwater flooding using the Environment Agency 2017 'Susceptibility to Groundwater Flooding' maps (1km resolution), GLA2011 'Increased Potential for Elevated Groundwater' (50m resolution, iPEG), and Environment Agency 2015 Source Protection Zones. A recommended strategic policy is that "Boroughs should use their local plans to ensure developments with a high susceptibility to groundwater flooding demonstrate that increased groundwater mitigation and management measures have been implemented to protect people from groundwater flooding. Any known groundwater and flow routes should be safeguarded to ensure groundwater flood risk is not increased on site or elsewhere" (Metis Consultants, 2018).

At the site level, councils such as Camden, are requiring basement impact assessments (BIA) to be undertaken to demonstrate that groundwater levels are not raised significantly by basement development (Buss, peer review feedback, 2020).

Developers are required to provide evidence that infiltration SuDS do not increase groundwater levels and increase flood risk on or off of the site. Although generally SuDS are encouraged as a means of drainage (JBA 2017), infiltration SuDS may not be appropriate in areas of groundwater flooding without careful planning and design. The requirement to screen for groundwater flood risk and SuDS may be included in SFRAs. The BGS provides spatial data on where SuDS are appropriate. Many local authorities (including Hampshire, Sutton and Croydon) are informally asking for risk assessments to show that developments that include infiltration SuDS will not exacerbate groundwater flooding (Buss, peer review feedback, 2020).

Questionnaire responses indicated that there were only limited powers given to LLFAs under the FWMA 2010. Although groundwater flooding is investigated by LLFAs through their SFRAs and LFRMSs, many respondents from the questionnaire indicated that groundwater flooding is being completely missed in planning applications. One respondent said "if it is identified, it tends to be brushed off by developers, with no one having the expertise to challenge them" (project survey, 2020). There are instances where new developments are believed to be displacing groundwater flows onto adjacent properties, but there is no expertise (and very limited funds) available to prove this and therefore put the emphasis on the developers to resolve the issue. Sub-surface development may also result in raised groundwater levels higher up from the development.

There are some cases where improvements in policy development have been enabled from having hydrogeologists embedded within local authority planning departments (Hydrogeology group feedback, 2020). Whilst not in England, an example was shown at the Urban Groundwater and 2019 Ineson Lecture where a hydrogeologist was placed in the planning department at Glasgow Council during local planning policy development. The talk was given by Helen Fallas – Chief Geologist Scotland, BGS. Entitled "New city planning policy processes – creating a prescient awareness of groundwater for future places and people."

6.15.3 Implications of findings

There is some evidence, and good evidence, of SFRAs assessing groundwater flooding so that it is considered within the sequential test for steering development to areas of lowest flood risk. However, this is not common practice across all areas which means that groundwater flooding may not be considered for spatial planning or development management. Where it is identified in flood risk assessments for individual planning applications, in some cases it cannot be properly considered or mitigated due to a lack of expertise.

This indicates that developments on sites of high susceptibility to groundwater flooding are potentially going ahead without considering future flood risks, which may increase risk at the site or elsewhere following development.

Where groundwater flooding risks are not considered, potential mitigation and management measure opportunities will be missed, which could protect people and infrastructure from groundwater flooding in the future. Currently, the onus is on the developer to resolve issues after construction has completed which means that these are not being identified or dealt with consistently or strategically.

Where local requirements exist for detailed risk assessments, the impact of infiltration SuDS on groundwater levels can be properly considered to ensure flood risk is not increased. However, this is not standard practice everywhere.

Sub-surface development may also result in raised groundwater levels higher up from the development, potentially causing new areas at risk of groundwater flooding.

6.15.4 Gaps and future work

Poor understanding of groundwater and lack of resources to inform meaningful assessment make it difficult to consider properly in spatial planning at present.

Clear guidance on what should be considered, along with simple explanations to inform planning officers would be a positive step forward.

Developers and planning authorities should have guidance or training that improves their understanding of the locations of groundwater flooding, the variations in groundwater levels and the seasonal variations in groundwater. The ultimate aim is to help them identify the presence of risk. If ground water does come out at surface then flooding and property flooding will occur. If groundwater comes to within 3m below surface then it can affect property structure or infrastructure.

This should be supported by a requirement for suitably qualified professionals to undertake assessments in more complex or larger developments. This could be defined by a series of triggers akin to the current flood risk assessment requirements but focussed on groundwater flood risk (hydrogeology group feedback 2020). Additional guidance on what should be included in planning submissions concerning groundwater flooding would help to assess whether planning applications are adequate. This could include specific guidance on:

- screening for high groundwater levels and groundwater flood risk
- sub surface structures, cut-off walls, pipes and other features which may interact with the groundwater environment – either blocking or transmitting groundwater flow
- measures which may increase groundwater recharge, such as drainage to ground, (including infiltration SuDS) and their appropriate implementation

6.16 Achieving the ambitions of the Flood and Coastal Erosion Risk Management Strategy (2020)

At the time of gathering this research the National Flood and Coastal Erosion Risk Management Strategy for England was in draft (Environment Agency, 2019). Before this research project completed the final strategy was published so the information presented here was updated after the evidence review.

The strategy sets out future approaches to FCERM considering the level of risk and how it might change in the future; the risk management measures that may be used; roles and responsibilities; future funding; and the need for supporting information. The strategy requires RMAs and others to work together to implement actions to meet the aims and objectives.

The draft FCERM strategy has 3 high-level ambitions:

- climate resilient places
- today's growth and infrastructure – resilient to tomorrow's climate
- a nation ready to respond and adapt to flooding and coastal change

Secondary question 6: What are the main gaps in evidence in the processes for managing groundwater flood risk against statutory duties and the ambitions of the Flood and Coastal Erosion Risk Management Strategy?

Our aim was to summarise the main gaps in evidence that have been highlighted through this project, and would be needed to implement the strategy. The evidence here will help to identify and prioritise important areas of work that will be needed to support the implementation. The research is focused into one secondary question:

6.16.1 Summary response

The FCERM strategy outlines the statutory duties and ambitions for implementing flood and coastal erosion risk management in England for all sources of flooding. It does not identify separate management approaches or objectives for separate flood sources, including groundwater flood risk management. The strategy has ambitions that focus on climate resilient places. Information gathered in this study showed that there is little evidence of climate change being accounted for in groundwater risk assessments and spatial planning. This will need to be addressed to ensure the ambitions can be met. There are many organisations collecting information on groundwater flooding and various methods of identifying and assessing groundwater flood risk. Consequently, there is great variety in how the Environment Agency and the LLFAs co-operate and share groundwater flood risk information across areas.

6.16.2 Summary of evidence

The evidence review has collected and collated a considerable body of data. There is not comprehensive coverage of data across England, but this is consistent with groundwater flooding not being a problem in all areas of England. The research has shown that there are various organisations collecting information on groundwater flooding and various methods of identifying and assessing groundwater flood risk. The distribution of areas where data has been collected against groundwater flood risk (JBA 1km mapping) is shown in Map 5 (Appendix D).

Roles and responsibilities for managing flooding

The evidence for this review included informal and unpublished reviews of the current governance, with the interviews providing further qualitative review. However, no formal, independent review of the current governance arrangements for groundwater flood risk has been completed or published to date. This is an evidence gap that, if filled, could inform the strategy implementation and coordinate the roles (official and unofficial) that are being undertaken in groundwater flood risk management.

A single picture of flood and coastal risk

The Environment Agency is currently developing a new national flood risk assessment that will provide a single picture of current and future flood risk from rivers, the sea and surface water, using both existing detailed local information and improved national data. This will not include information on groundwater flooding.

Understanding groundwater flood risk (the probability and consequences) both independently and together with other sources of flooding is a large evidence gap.

Developing plans for climate resilient places

The local flood strategies, flood risk management plans and SFRAs must consider groundwater flooding. However, there are no standardised or common methods that are being used to assess groundwater flood risk and use information to support decision making. There is great variety in how the Environment Agency and the LLFAs co-operate and share groundwater flood risk information across areas. Climate change risks and projections are not commonly integrated into groundwater flood risk assessments, or seen as being explicitly considered within SFRAs or flood risk management plans or strategies. It is often noted in plans, strategies and risk assessments that groundwater could have contributed to other sources of flooding with limited evidence.

One of the largest gaps of evidence in realising the ambitions of the FCERM strategy for managing the risks of groundwater flooding is the lack of understanding of groundwater under climate change, as evidenced by the questionnaire responses.

Climate change is not accounted for in the GIS-based risk mapping of groundwater flood risk (for example, JBA, BGS, GeoSmart). There are very few examples within the evidence where climate change has been accounted for. The Mansour and Hughes' (2018) study modelled various climate projections to produce predictions of aquifer recharge under climate change. There is also ongoing development of coupled hydrological systems as part of the Hydro-JULES framework, which aims to include a national scale groundwater process model able to address groundwater flood risk under current and future climate change conditions.

Climate change will also impact on groundwater flooding via sea level rise. This has been investigated in a limited way in some areas (for example, Portsmouth, JBA, 2020) but not in a systematic way across the country.

Information on climate impacts on groundwater will be essential to produce plans for delivering climate resilient places. There is currently no plans nationally to fill this gap.

Improving flood resilience

Improve place making: There are both evidence gaps and process gaps for assessing groundwater flooding fully within spatial and development planning. Information in terms of risk maps is sparse and therefore not included when applying the sequential test to local development to areas of lowest risk.

Better protect: Proactive planning and modelling to better understand potential responses and impacts of these is an evidence gap. Some groundwater flooding mitigation methods such as pumping can have unintended consequences. It can lead to ponding of water, overwhelm drainage systems and exacerbate existing flooding within main rivers and ordinary watercourses (depending on the method of discharge). This is not well understood and could be better planned before implemented.

Ready to respond: There is a process gap in coordinating groundwater flood warnings. Groundwater flood warnings have been developed in some areas however, they are not as consistent fluvial warnings – each area does their own thing. This could be better integrated into the main Environment Agency flood warning systems to improve consistency of service. Also groundwater flood incidents are not recorded consistently nor is data shared across organisations. This information, if available could support decision making for flooding response, similar to how historic fluvial and coastal flood maps are used.

Recover quickly: There is some evidence of property level protection being installed to improve mitigation against groundwater flooding. There is also some evidence of information sharing with communities about how they can improve their resilience. However, this guidance needs updating and should be done so with all stakeholders involved in groundwater flood risk management.

Survey responses – what can help or hinder groundwater flood risk management

To support the evidence, the questionnaire asked what helps and what hinders the delivery of groundwater flood risk management. This information can help support and target any further action under the FCERM strategy implementation plan.

Questionnaire respondents were asked to rank from 1 to 10 (1 = most helpful; 10 = least helpful) what they thought best helped to manage groundwater flood risk. The result of this can be seen in Figure 6-25. Funding, resources, skills and legislation most help to deliver groundwater flood risk management.

Interestingly, very few respondents scored 'processes' anything between 1 and 5, which suggested it may be of least help. This should inform future activity, which shouldn't be driven by improving processes.

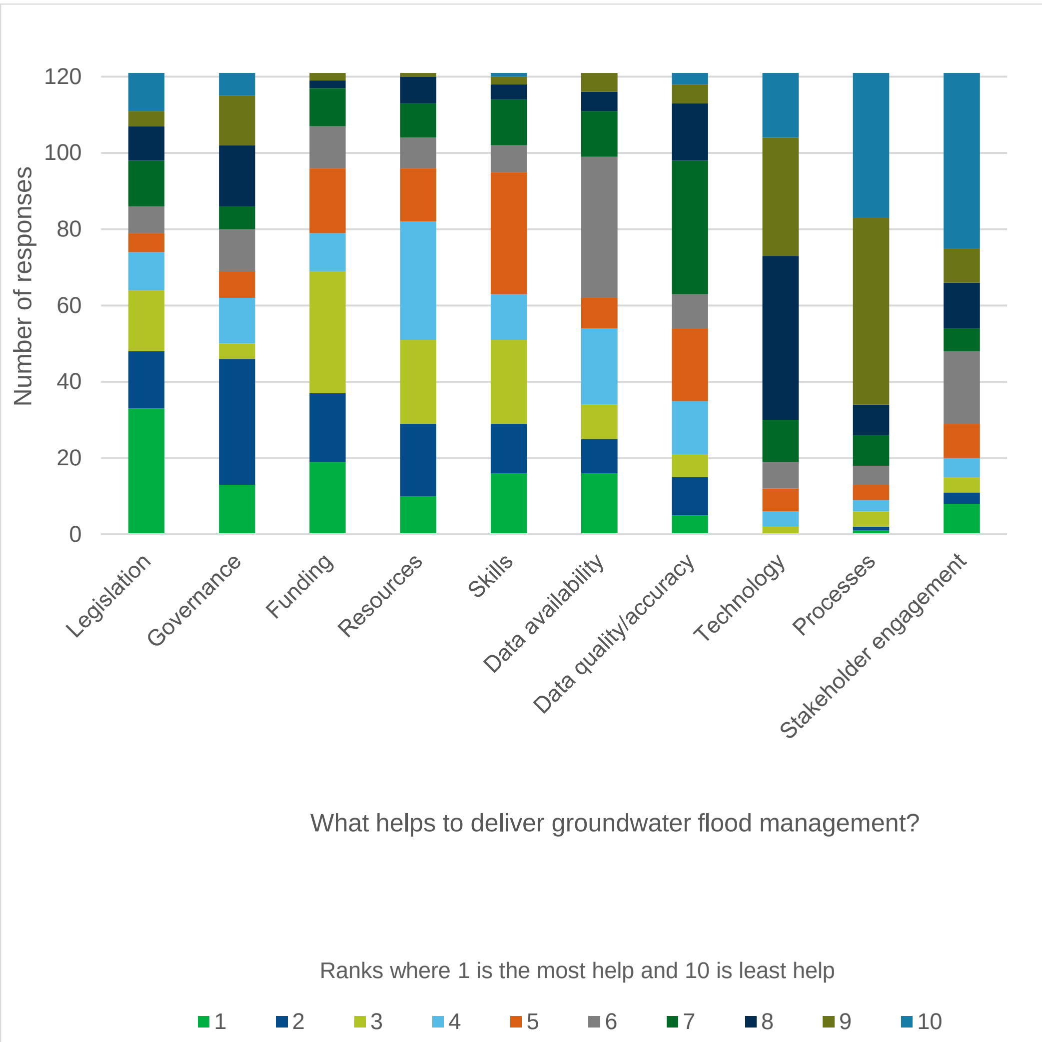

Figure 6-25 In your opinion, generally what helps to manage groundwater flood risk (ranked from 1 to 10, where 1 is what most helps, and 10 is what least helps)?

Questionnaire respondents were also asked what most hindered groundwater flood risk management. The results from this can be seen in Figure 6-26. Legislation, governance, funding and resources are the main areas that most hinder groundwater flood risk management and so should be the focus of any improvement activity.

Participants indicated that stakeholder engagement is not limiting factor, nor are processes.

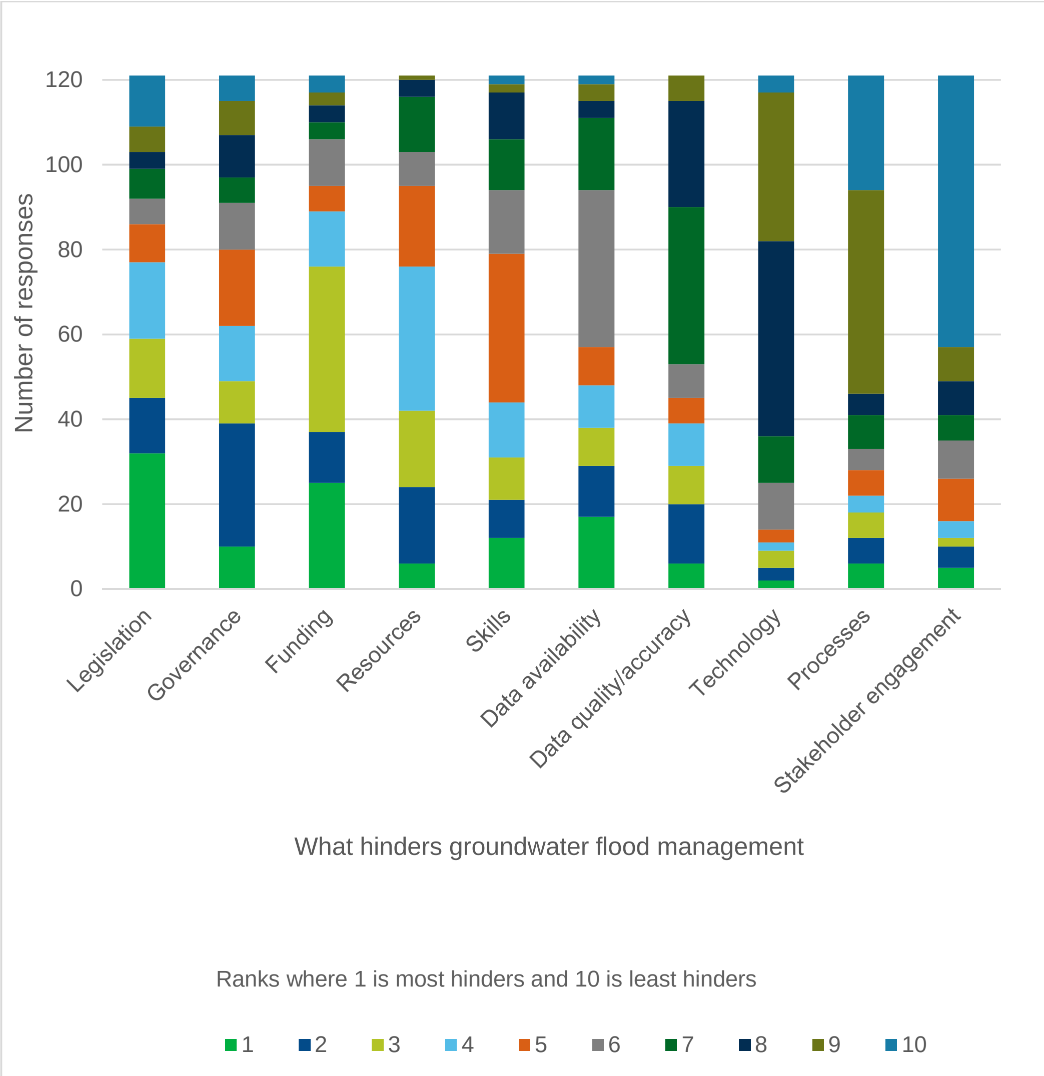

Figure 6-26 In your opinion, generally what hinders groundwater flood risk management (ranked 1 to 10, where 1 is what most hinders, and 10 is what least hinders)

Aspects ranking similar across both the 'what helps' and 'what hinders' questions is present across almost all of the options. This would suggest that there is a very mixed view on what really helps or hinders groundwater flood risk management the most and that further consultation would be beneficial before implementing any changes.

The questionnaire showed that processes least hindered groundwater flood risk management, suggesting that current ways of working are adequate. This is interesting because there are several organisations with several processes operating at the same time, some in conjunction, others very disparately, this however doesn't appear to affect how groundwater flood risk management operates. There is great variety in how the Environment Agency and the LLFAs co-operate and share groundwater flood risk information across areas, and sharing the learning from this research may highlight where approaches could be better coordinated. This may not increase efficiency but may improve coordination across teams and organisations, plus improve consistency in customer service.

There are no specific actions in the strategy for groundwater flood risk management. The findings from the study should be used to support any further implementation planning where targeted actions are needed, and specific approaches or actions needed to enable the aims of the strategy to be achieved for groundwater flood risk management. Suggested targeted actions are described in the conclusion.

6.17 International perspectives

International experience of groundwater flooding was not included within the main REA question, however some evidence was found within the literature review. Where this was picked up, it has been reported below. This is not a full review of international evidence regarding groundwater flooding but does provide some international context.

6.17.1 European experience

The 2015 report to the European Parliament and the Council on the progress in implementing the Floods Directive by the European Commission (European Commission 2015) states that there have been a multitude of approaches across Europe in assessing the risk of flooding and implementing the requirements of the Floods Directive. Flood hazard and flood risk maps have been prepared by most member states, with the potential flooding from rivers being most often mapped.

Member states were asked to report on historical floods: from 2000, the least common source of flooding was groundwater, at only 1% of historical floods. Only 0.3% of the sources of floods and potential impacts associated with areas of potential significant flood risk, identified in the preliminary flood risk assessments, were associated with groundwater flooding. In Europe, there is limited outcrop of chalk, so this may be expected. However, several large rivers may cause PSD flooding.

Maps showing the hazards and risks of flooding should have been prepared and made available to the public by December 2013. The report identified the UK as one of only 6 member states that had published groundwater flood risk maps, 16 states had not assessed groundwater flood risk, one deemed it not relevant, and 5 had not reported progress.

In Ireland, during significant groundwater flooding in the winter of 2015/2016 the lack of data on groundwater flooding and fit-for-purpose flood hazard maps were identified as serious impediments to managing groundwater flood risk in vulnerable communities. In response Geological Survey Ireland, as the leading national authority on groundwater science, initiated a groundwater flood project, GWFlood, with Trinity College Dublin and Institute of Technology Carlow (Naughton and others 2017). Historic flooding maps, monitoring data, models and predictive flood maps (for current climate) are available on the Geological Survey website.

In the literature, historical reports of groundwater flooding are more prevalent than groundwater forecasting, and those that have been located relate to flood frequency analysis (Najib and others, 2008) and predictions of spring flow (Lallahem and others 2003). A literature search (RAB, 2006) identified papers from French authors reporting on statistical analysis to predict extreme groundwater surge (Najib and others, 2008) and on forecasting spring flow (but not groundwater levels) from a small chalky watershed (Lallahem and others 2003).

After extensive groundwater flooding in 2000, a study was commissioned to investigate the contribution of groundwater to the floods experienced in the Somme basin in Northern France. In 2009, Korkmaz and others applied a coupled surface – unsaturated – groundwater model (MODCOU) to simulate the 2000 to 2001 floods, obtaining a satisfactory representation of groundwater behaviour, its effect on surface flow, and the magnitude and spatial extent of groundwater emergence at the surface during the flood. In 2010, Habets and others evaluated the performance of a series of 4 different lumped conceptual models and a distributed model to generate soil moisture and run-off. They also looked at the models' ability to reproduce flood levels over a 20-year period. Calibration was achieved by comparing the modelled and observed groundwater levels and also river flows. These models were all limited by a relatively simple representation of the unsaturated zone. All 4 different lumped conceptual models produced reasonable simulations of groundwater levels but consistently overestimated in periods immediately after flooding. The distributed model produced baseflow predictions comparable to the observed and demonstrates an international approach to risk mapping.

6.17.2 USA and Canada

Work in the San Francisco Bay area (Plane, Hill and May, 2019) looked at superficial groundwater levels in boreholes near to the coast and used interpolation of this data to develop a depth to groundwater surface. This indicated some limited areas with groundwater levels at the surface and considerable areas where groundwater level was within 1m of the ground surface. The study concluded that an anticipated sea level rise of 1m following climate change would lead to considerable additional areas at risk of groundwater flooding. Particular impacts identified included groundwater emergence, inflow of groundwater to underground infrastructure such as sewers, mobilisation of contamination in the subsurface and soils, and movement inland of the saline interface. Sea walls and coastal defences were not thought to protect against groundwater flooding.

This study has parallels with the JBA study of superficial groundwater levels in Portsmouth (2020).

In Canada, significant groundwater flooding (PSD) occurred in Alberta in 2013 (Abboud and others, 2017). This led to a study in Calgary which surveyed 189 that were affected by groundwater flooding. This reported resilience strategies to reduce the risk of flooding in the future. These included:

- monitoring groundwater levels in flood-prone areas. This would help to differentiate sewer backup from groundwater flooding via wastewater collection systems and to provide groundwater flooding warnings
- specifying minimum home basement elevation with respect to river stages for specified flood return intervals
- appropriate home construction.

6.18 Emerging technologies

The scope of this REA is to assess current approaches to groundwater flood risk management, and identifying good practice and knowledge gaps. The review has also revealed some evidence of relevant emerging concepts and technologies being developed in the UK that are not currently being used. These are summarised briefly here (this is not a comprehensive review and the relevant organisations should be contacted for further information).

Continued rapid increases in computer power, improved remote sensing technologies, and the move towards widely available cloud computing and distributed web-connected sensors (for example, the ‘internet of things’), opens up possibilities of ultra-high resolution integrated process-based modelling linking atmosphere, surface, and groundwater, linked to real-time data streams from a range of sensors. While extensive research has been carried out on these areas for fluvial and surface water flooding, these are emerging areas of work for groundwater.

Several models are available, or in development, capable of simulating hydrological behaviour relevant to groundwater flood risk, including MODFLOW, Zoom, SHETRAN, and Hydro-JULES. While they can be used nationally, these are probably most useful for local assessments, including water resources aquifers and urban or mine water related groundwater rebound.

Operational regional groundwater models have been developed over many years, mainly for water resources management; most are based on the MODFLOW model and are embedded into the National Groundwater Modelling System (NGMS). As they are mostly not calibrated in detail for high flows, they often demonstrate poor performance at higher groundwater levels. However, as they embed substantial information on groundwater systems, they could be developed further for groundwater flood forecasting purposes, but would need additional calibration and testing, and to bring in live data feeds (RAB 2016).

Mansour and Hughes (2018) assessed the application of the BGS distributed recharge model ZOODRM to produce recharge values (potential recharge) for Great Britain (England, Scotland and Wales). The model was run with the rainfall and potential evaporation for the Future Flows Climate data sets (11 ensembles of the HadCM3 Regional Climate Model or RCM) to produce predictions of aquifer recharge under climate change. Generally, it was found that the recharge season is shorter for future predictions, from the current 5 to 7 months to 3 to 4 months. This could make aquifers more vulnerable to droughts if rainfall fails in one or 2 months rather than a prolonged dry winter as can occur now. The analysis of groundwater level time series simulated by applying recharge values using rainfall and potential evaporation values estimated using future climate data was used in the GeoRise system to identify areas that are under future flooding risk. The main product is a national scale map showing the risk of flooding as low, moderate or high. For this smaller scale, detailed models should be used to investigate the flooding risks associated with the areas identified by GeoRise. Mansour and others (2017) assessed the feasibility of this proposed method using the chalk aquifer as a case study.

Newcastle University is developing capabilities for national and local scale modelling using the SHETRAN hydrological model (Ewen and others, 2000), which integrates subsurface and surface flows. A national capability to simulate all catchments efficiently and consistently has been developed (Lewis and others, 2018), and this is being enhanced to include digital geological models at a local scale. Testing of linking SHETRAN outputs with a high-resolution hydrodynamic surface flood model has been carried out to assess flood risk from multiple sources, including groundwater (Smith, 2020); similar work is in progress in parts of the north-east coalfield. The PhD study by Smith (2020) also included a national assessment of locations which may be vulnerable to flooding from multiple sources.

Hydro-JULES is a current NERC-funded research programme that aims to build a 3-dimensional community model of the terrestrial water cycle to underpin hydrological research in the United Kingdom. Hydro-JULES will be implemented by the UK Centre for Ecology & Hydrology (CEH) in partnership with the British Geological Survey (BGS) and the National Centre for Atmospheric Science (NCAS). There are 2 strands carried out by BGS regarding groundwater: one is to produce a groundwater flow, heat and transport model of the sub-surface of the British mainland and the second is to include groundwater in Land Surface Models (LSM) at a global scale (CEH, 2020). For further information, see Hydro-JULES Implementation Plan.

These modelling approaches are moving towards capabilities for more rapid simulations of high-resolution coupled responses that could support stochastic (statistical) methods for risk assessment. To use them in forecasting will require further developments in assimilating real-time data feeds from a range of sources, including rainfall, borehole groundwater levels, and sewer systems.

Any deployment of emerging technologies needs to be underpinned by a robust understanding of the groundwater flooding mechanisms and geological and anthropological controls. They must have good conceptual basis and evidence base to be helpful in better understanding the risk of groundwater flooding. Using these approaches in operational systems would require local knowledge and understanding of groundwater flooding mechanisms.

7 Conclusions

7.1 Overview

This rapid evidence assessment (REA) was commissioned to bring together a comprehensive range of information regarding groundwater flood risk management in England. This project report provides a baseline understanding of groundwater flood risk management to support the National Flood and Coastal Erosion Risk Management Strategy for England (2020) with regard to groundwater flooding.

The REA was carried out following, in general, the Collins' (2015) method to answer the question:

'What are the current approaches to groundwater flood risk management in England?'

Six secondary questions, including 14 sub-questions were included in the review. These questions cover governance, incident recording, risk assessment, forecasting and mitigation. The final question considers the main gaps in evidence against statutory duties and the ambitions of the National Flood and Coastal Erosion Risk Management Strategy (2020).

To answer the primary and secondary questions, the rapid evidence assessment appraised evidence including:

- 17 peer-reviewed published sources
- 37 grey literature sources
- 12 unpublished material sources
- 6 semi-structured interviews
- 260 questionnaire responses, of which 114 were completed responses and 146 were part responses

The peer-reviewed published sources provided a good basis to understand the current approaches to groundwater flood risk management in particular locations in England, included in specific groundwater risk assessments. However, the grey literature, unpublished reports, interviews and largely the questionnaire responses provided a more comprehensive understanding of the governance structures, recording of groundwater flood events, groundwater flood forecasting and warning, local risk mapping techniques, and other local practices for improving resilience to groundwater flooding. The questionnaire responses were critical to this evidence review, providing rich qualitative and quantitative data in understanding the diverse approaches to groundwater flood risk in England.

The volume of evidence obtained from questionnaires and interviews compared to peer review literature is indicative of how groundwater flood risk management is developing in practice. Grey literature, where experience and activities of stakeholders active in groundwater flood risk management is recorded, is a very valuable resource. However, not all groundwater flood risk management activities are evidenced in any published literature.

This indicates that additional reporting and documenting of groundwater flood risk management activities is needed. This would benefit stakeholders engaged in groundwater flood risk management and help to share best practice and learning.

7.2 Findings and implications

Overall, progress has been made in recent years to understand and manage groundwater flood risk. The LLFAs have taken significant steps since 2010 when the FWMA gave them duties to coordinate the management of local flood risk, including groundwater. There is evidence of groundwater risk mapping, data collection and assessments of groundwater flood risk, new warning and alert systems and schemes to improve resilience. Many developments in data (for example, national risk maps) and systems (for example, forecasting) have been made in the private sector. However, commercial sensitivities and payments are restricting these being used and applied more widely. The Environment Agency, with a strategic role in groundwater flood risk management, has the largest network of monitoring and issues groundwater flood warnings.

There is also considerable evidence of organisations working together and sharing data, particularly the Environment Agency, LLFAs, water companies, the Coal Authority and others.

The evidence showed that approaches differ across organisations and across the country. The variety reflects the complex nature of groundwater flooding, which is often interacting with other flood sources, and typically occurring at a local scale. In many locations groundwater flooding happens in combination with river flooding (where locations are at risk of alluvial aquifer flooding), tidal flooding (where sea levels are high raising groundwater levels) and surface drainage flooding (where drainage may be overloaded by groundwater) (Halcrow Group Limited, 2009). This was also reflected in the questionnaire responses that indicated groundwater was often linked to, or occurred at the same time as, other sources of flooding.

This has an impact on the governance and implementation of groundwater flood risk management. Roles and responsibilities are set out in the FWMA 2010, with lead local flood authorities having a duty to coordinate flood risk management for local flood risk, including groundwater, and the Environment Agency providing a strategic overview role for managing all sources of flooding. The evidence shows that several organisations are often involved in managing the risks of flooding from groundwater, and that there is no consistent approach to planning, preparing, responding or recovering from groundwater flooding.

This means that locally (at LLFA or catchment scale), systems, data and processes have been developed in places to provide risk maps, flood monitoring and recording, warning systems, and mitigation schemes. In places, the risk information is used to inform spatial and development planning, but this is limited. Examples have been presented in this report to share across RMAs to encourage peer to peer learning and sharing of processes and information.

The research has not shown conclusively whether the lack of guidance or national consistency is hindering groundwater flood risk management. However, publishing guidance or sharing documented processes on all aspects of groundwater flood risk management would certainly support practitioners.

Although there is evidence of significant activity in groundwater flood risk management in England, the review has highlighted some areas where there is less information and areas where to target future work when implementing the National Flood and Coastal Erosion Risk Management Strategy. Possible areas of future work are summarised in the next section.

7.3 Summary of recommended future work

The recommended areas of future activity have been identified from the research to improve groundwater flood risk management.

The project identified 25 activities to fill gaps in data, processes and skills found through the evidence review. These are presented against the 6 objectives in table 7-1 below. This is not a detailed roadmap, so does not provide exact timescales and resource needs but does suggest the priority of the activities, likely resource implications and approximate timescales based on feedback from the steering group. Higher priority has been given to activities that:

- Will make major improvements to groundwater flood risk management;
- Benefit numerous organisations, including RMAs; and
- Support ambitions of the national FCERM strategy.

The activities with shorter timescales and low resources indicate potential quick wins. Those with high resource needs (time and or money) and longer timescales are activities that should start in the short term and make progressive improvements but will take longer to deliver. Each activity has a hyperlink to the section of the report where the main evidence and further detail can be found. The 10 high priority activities that deliver major changes or potential quick wins are described further below table 7-1.

It is expected that the prioritised activity list will be used primarily by the Environment Agency to inform discussions about future action, and relevant teams will engage with any wider stakeholders as necessary within each activity. The Environment Agency has been identified as the lead organisation for the majority of the activities. To deliver these activities support will be needed from other organisations that have statutory and non-statutory roles in groundwater flood risk management, including professional bodies and technical network groups (for example CIWEM, the Geological Society and the International Association of Hydrogeologists). Not all the actions identified in will require a top-down governance approach and could for example be progressed by commercial companies, academic institutions, or by individual RMAs.

Table 7.1 Recommended future work activities

Objective	Activities to achieve objective	Priority	Resource needs	Timeframe to implement	Lead delivery organisation
There is a clear framework for delivering groundwater flood risk management in England.	Carry out further research on the current groundwater flooding governance arrangements. This includes reviewing existing informal literature regarding governance, expanding and updating it if needed. Use this to recommend standard protocols and approaches for groundwater flood risk management.	High	Medium	Short	Environment Agency
	Formally review the current groundwater forecasting approaches: - Consider the level of accuracy provided, use of local information, value for money and who is best placed to provide the service. - Identify a long term hosting solution and funding for local groundwater forecasting and warning systems within the Environment Agency. - Ensure that local information and data can be incorporated into future forecasting approaches.	Medium	High	Short	Environment Agency
Risk management authorities have access to existing data to plan, prepare and respond to groundwater flooding.	Improve processes for recording groundwater flood incidents consistently so that data can be better shared and used across organisations. Deliver with training and guidance.	High	Low	Short	Environment Agency
	Investigate the options for providing freely available groundwater flood risk spatial data in England that includes present day and climate change scenarios.	High	Low	Medium	Environment Agency
	Bring together groundwater flood records and interrogate these to better characterise and communicate groundwater flood risk. Consider whether existing local systems could be developed into a common national flood reporting tool for RMAs.	Medium	High	Long	Environment Agency
	Gather and share evidence on how different organisations have estimated groundwater flood costs and benefits to support risk assessments and scheme justification.	Low	Low	Short	Environment Agency
	Improve access to telemetry data and historic borehole levels online.	Medium	Medium	Short	Environment Agency or LLFAs
	Use national scale information (including screening tools such as groundwater emergence maps) to identify catchments susceptible to groundwater flooding. Use this to target more accurate local groundwater flood risk maps and model development.	Low	Low	Deliver when plans or strategies being developed.	LLFAs and LPAs

Objective	Activities to achieve objective	Priority	Resource needs	Timeframe to implement	Lead delivery organisation
Risk management authorities have new data and evidence to better plan, manage and respond to groundwater flooding.	Incorporate local assessments of groundwater flooding into the Environment Agency's new national flood risk assessment (planned for 2024).	High	Medium	Medium	Environment Agency
	Develop evidence on how climate change will affect the frequency and nature of groundwater flooding. Provide guidance on how this should be used in risk assessments, strategic plans, spatial plans and schemes.	Medium	Medium	Short	Academic institutions
	Produce new national and local spatial data of groundwater flood risk (integrated with other flood sources) where needed to underpin risk management decisions. - New modelling should be informed by water companies' sewer improvement plans, Coal Authority mine water rebound data and depth to groundwater. - New modelling should be delivered in a way that is suitable for groundwater flood forecasting as well as risk assessment.	Medium	Medium	Long	National data: - Environment Agency or commercial companies Local data: - Any operational RMA
	Expand the existing boreholes network in groundwater flood prone areas to inform forecasting and warning.	Medium	High	Medium	RMAs
	Develop a national historical groundwater flood map. This could be supported by a spatial index of Section 19 reports.	Medium	High	Long	Environment Agency / other RMAs
The public receive consistent service and can be better prepared for flooding.	Review and update information supplied to the general public on groundwater flooding and what to do. Clarify whether pumped groundwater discharges are permissible.	High	Low	Short	Environment Agency
	Provide information on location and coverage of groundwater flood warnings and alerts. Include clear information about approaches used to issue and remove them.	High	Low	Short	Authorities that provide flood warnings
	Provide specific risk and warning information about how the flood may progress in locations where a specific trigger level can be related to onset of flooding at a particular location (for example 'in 12 hours flooding is likely to have reached X location').	Medium	Low	Short	Authorities that provide flood warnings

Objective	Activities to achieve objective	Priority	Resource needs	Timeframe to implement	Lead delivery organisation
	Better coordinate groundwater flood warnings (provided by the Environment Agency and others) with fluvial flood warning systems so that they are integrated and consistent.	Medium	Medium	Long	Environment Agency
	Share information on groundwater flooding (past, current, future risk data) and potential resilience measures with local communities to help them prepare and respond to groundwater flooding.	Medium	Medium	Ongoing	LLFAs lead, Environment Agency support
Support is provided that enables groundwater flood risk to be mitigated or reduced.	Provide initial guidance to LRFs to enable groundwater flooding to be adequately considered in multi-agency flood plans.	High	Low	Short	Environment Agency
	Develop guidance on how to implement groundwater flood mitigation schemes – both at a property level and on a larger scale (for example a village, or specific valleys, or towns with urban rebound, or whole aquifers which experience mining water rebound). This should provide examples of scheme appraisal, and clarify operational processes for the regulatory framework for larger groundwater pumping schemes.	High	Low	Short	Environment Agency
	Develop guidance on how groundwater flooding should be considered within spatial planning and development management so that it can be assessed within local plans and used to create local planning policies. Existing planning guidance on SuDS should be expanded so that the impact of SuDS on groundwater flooding are carefully considered.	High	Low	Short	MHCLG / Defra
	Any scheme, mitigation plan or flood plan that identifies needs for pumping should quantify the benefits of pumping for reducing risk and be informed by evidence (modelling) on the impacts of groundwater pumping during times of groundwater flooding.	Low	Medium	Long	RMAs / Local Resilience Forums
Organisations have the skills and knowledge to deliver groundwater flood risk management.	Deliver high level overview training sessions (e.g. one day capacity training days) to RMAs.	High	Low	Medium	Environment Agency
	Risk management authorities should share best practice around groundwater flood risk management.	Medium	Low	Short	All RMAs
	Assess provision of groundwater training for specialists within RMAs, fill any gaps against needs, and deliver the training.	Medium	Medium	Long	Professional bodies or commercial companies

The list below provides a summary of high priority activities from table 7-1, which could lead to significant progress in groundwater flood risk management or provide potential quick wins to benefit several organisations and the public more widely.

High priority activities: Environment Agency lead delivery organisation

- The Environment Agency, in their strategic overview role, should formally review the current governance arrangements for groundwater flood risk management. This should focus on roles and responsibilities under the current legislation, but formalise the roles being undertaken by organisations in a non-statutory capacity. The findings should be used to recommend standard protocols and approaches specifically for flood risk assessment, monitoring groundwater flood risk, and sharing groundwater flood risk information. This should be the first activity undertaken as it will set the framework for the other activities.

- The Environment Agency, in their strategic overview role, should improve processes for recording groundwater flood incidents consistently so that data can be better shared and used across organisations. This information should be used for risk assessments, incident planning and response. Consider whether existing local systems could be developed into a common national flood reporting tool (ideally for flood records from all flood sources, not just groundwater). Any system would need to be available to all organisations with roles or responsibilities for flood risk management, would need to be developed in consultation with RMAs (particularly for system requirements and implementation) and deployed with training and guidance.

- The Environment Agency, in their strategic overview role, should investigate what options are available for providing freely available groundwater flood risk spatial data in England that includes present day and climate change scenarios. Free spatial data, similar to that provided for flood risks from rivers, sea, surface water, and reservoirs, would help RMAs to assess groundwater flood risk in strategies, plans and spatial planning. Options could include making existing commercial data available, and producing new spatial data. This could take some time to negotiate or deliver but would be a significant step forward in supporting groundwater flood risk management.

- The Environment Agency should incorporate local assessments of groundwater flood risk into their new national flood risk assessment for all sources that is planned to deliver in 2024. This will not provide any new national spatial dataset of groundwater flood risk so it is imperative that it can include data from other organisations. The Environment Agency will need to publish clear expectations and guidance if the data needs to be in specific formats and have specific content. Others will need to be mindful of the expectations when commissioning or delivering new modelling to make sure it can be shared, incorporated and published. The Environment Agency should use any new groundwater data to develop a robust, consistent method for estimating the number of properties at risk.

- The Environment Agency should review and update the information supplied to the general public on groundwater flooding and what to do ('Flooding from groundwater' document, 2011). This would require minor changes but would be simple to deliver (low resources and short timescale) and better inform the public and help them prepare and respond to flooding. The guidance should clarify whether pumped groundwater discharges are permissible to ensure that this is undertaken in a way that does not increase flood risk elsewhere.

- The Environment Agency, as a category 1 responder, and in their strategic overview role should provide initial guidance to enable local resilience forums to consider groundwater flooding adequately in multi-agency flood plans. This could be delivered in the short term with minimal resource, by updating the online government guidance. This should signpost to where groundwater flood risk information is available, available flood warning procedures and considerations for carrying out mitigating activities (for example pumping).

- The Environment Agency, in their strategic overview role should develop guidance on how to implement groundwater flood mitigation schemes at a property level and on a larger scale (for example a village, or specific valleys, or towns with urban rebound, or whole aquifers which experience mining water rebound). This could be delivered in the short term to benefit the 2021-2027 capital programme. Guidance should provide specific support for undertaking groundwater scheme appraisal, and clarify the regulatory framework for larger groundwater pumping schemes and how this affects operational processes.

- The Environment Agency, in their strategic overview role should deliver high level training sessions such as one day capacity training days to RMAs. The purpose of this would be to remind organisations of existing statutory duties and how to access existing data and guidance, share good practice, and encourage RMAs to carefully consider groundwater flood risk in any strategies, plans, policies, flood mitigation activity, and incident response.

High priority activities: other organisations lead delivery

- Any organisation that provides a groundwater flood warning and/or alert service to the public should provide information publically on the location and coverage of it to encourage people to sign up to the service. This could be similar to the spatial open data provided by the Environment Agency, and immediately provide a clearer service to the public and the organisations that provide warnings. Clear information should be published that details the approaches used to issue and remove the flood alerts and warnings to encourage transparency and consistency between providers of warning services.

- The Ministry for Housing, Communities and Local Government (MHCLG) should develop guidance for local planning authorities on how to adequately include groundwater flood risk in spatial planning and development management, assessments, plans, and policies. This is a high priority action to ensure that new development is not located in areas at risk of groundwater flooding. Any new guidance developed on sustainable drainage systems (by Defra or MHCLG) should include information about planning and using SuDS in areas susceptible to groundwater flooding.

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9 List of abbreviations

AStGwF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Society
CEH	Centre for Ecology and Hydrology
Defra	Department for Environment, Food and Rural Affairs
DTM	Digital Terrain Model
DWMP	Drainage and waste water management plan
ERYC	East Riding of Yorkshire Council
FCERM	Flood and coastal erosion risk management
FFC	Flood Forecasting Centre
FGS	Flood Guidance Statement
FHRC	Flood Hazard Research Centre
FIM	Flood incident management
FORT	Flood Online Reporting Tool
FRIS	Flood Reconnaissance Information System
FWMA	Flood and Water Management Act 2010
GARDIT	General Aquifer Research Development and Investigation Team
GEMs	Groundwater Emergence Maps
GIS	Geographical information systems
GS	Google Scholar
GW	Groundwater
iPEG	Increased Potential for Elevated Groundwater
IPR	Intellectual property rights
LFRMS	Local flood risk management strategies
LLFA	Lead local flood authority
LPA	Local planning authority
LRF	Local resilience forum
MCM	Multi-Coloured Manual
NERC	Natural Environment Research Council
NFRA	National River Flow Archive
NGMS	National Groundwater Modelling System
NPPF	National Planning Policy Framework
PPG	Planning practice guidance
PICO	Population, intervention, comparator, outcome
PPS	Planning Policy Statement
PFRA	Preliminary flood risk assessment
REA	Rapid evidence assessment
RMA	Risk management authorities
RFCC	Regional flood and coastal committee
S19	Section 19 report
SFRA	Strategic flood risk assessment
SPZ	Source protection zone
SWIM	Severe Weather Information Management
SWMP	Surface water management plans
TE2100	Thames Estuary 2100
WWS	WorldWideScience

10 Glossary

Aquifer	A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.
Effective rainfall	Rainfall potentially contributing to groundwater recharge, comprising rainfall minus evapotranspiration. Effective rainfall = groundwater recharge + runoff
Evapotranspiration	The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.
Lead local flood authority	LLFAs are county councils and unitary authorities. They lead in managing local flood risks (that is, risks of flooding from surface water, ground water and ordinary (smaller) watercourses). This includes ensuring co-operation between the risk management authorities in their area.
Local resilience forum	Multi-agency partnerships made up of representatives from local public services, including the emergency services, local authorities, the NHS, the Environment Agency and others. These agencies are known as Category 1 responders, as defined by the Civil Contingencies Act.
Rapid evidence assessment	A balanced assessment of what is known (and not known) in the scientific literature about an intervention, problem or practical issue by using a systematic method to search and critically appraise empirical studies.
Spring	A spring is a location at the land surface where groundwater discharges from the aquifer, creating a visible flow.
Systematic map	An Excel spreadsheet database containing a full list of data sources reviewed as part of a REA, including extracted evidence related to primary and secondary questions and critical appraisal scores.
Water table	The water table is the upper surface of the zone of saturation. The zone of saturation is where the pores and fractures of the ground are saturated with water.

Appendices

A REA protocol

A.1 Background

The Environment Agency wants to capture the current situation regarding groundwater flood risk management in England to build up a national perspective of the work being carried out. This project aims to provide a baseline understanding of groundwater flood risk management to support the flood and coastal erosion risk management (FCRM) strategy with regard to groundwater flooding.

This document outlines the protocol for the rapid evidence assessment (REA) for groundwater flooding for the Environment Agency. As per the Environment Agency's specification, the review will follow the guidance of Collins and others (2015) to identify the current approaches to groundwater flood risk management in England. An REA protocol rigorously details the approach to be used by the review team. The Environment Agency requires an REA **and** overview of groundwater flood risk management in England. As such, the project will provide an overview of groundwater flood risk management in England via, but not restricted by, an REA.

The project is mainly for the Environment Agency to inform the implementation of the (FCRM) strategy and future research projects. However, this final report and associated summary and presentation will be shared with risk management authorities to help build capacity in groundwater flood risk management and to share good practice.

The project has an England focus, although there may be some mention of the wider international perspective, as that is highlighted in the literature search. However, the project will not specifically search for international literature. Natural Resources Wales did not want to participate in the project as they considered groundwater flooding not to be a significant concern in Wales.

A.2 Rapid evidence assessment approach

A rapid evidence assessment (REA) follows a systematic review approach but is less resource-intensive, while maintaining rigour and transparency. Detailed REA guidance is provided in Collins et al. (2015).

This study broadly follows the method of Collins et al. (2015), which describes in clear terms the necessary steps of an REA, along with the roles and responsibilities of all parties involved. The main parties are the review team, who carry out the review, and the steering group, a group of technical experts that guide and assist the review team where necessary, to ensure the outputs of the REA meet the needs of end users.

Following the rapid evidence assessment (REA) approach, the main tasks include the following:

- The review team and steering group agree the research questions to be addressed in this study.
- The review team develops a protocol outlining its approach to the study and agreed with the steering group.
- The review team completes a search for relevant evidence.

- The review team screens the evidence, retaining only evidence relevant to the research questions.
- The review team systematically extracts evidence relating to the research questions into a systematic map.
- The steering group completes an additional review on the evidence extracted and provides missing sources thought to be crucial to the project.
- The review team critically appraises the evidence, evaluating in terms of relevance to the research question and robustness of the approach applied.
- The review team collates the evidence to produce summary information describing the volume and characteristics of the evidence base.
- The review team draws conclusions from the results of the evidence review.
- The review team communicates the evidence review findings.
- The steering group reviews the draft report before the project is completed.

This systematic approach ensures the conclusions of the review are as robust as possible.

A.2.1 Applying the REA approach

The REA will provide a framework and focus for the overview. However, it is noted that an REA is typically used to answer a specific and closed question, rather than to gather evidence of what activities are being carried out. It was agreed in the project start-up meeting (05/09/19) that the primary and secondary questions identified will be answered using the REA approach, but that the analysis is not limited to this method. The project's primary and secondary questions have been discussed and reviewed extensively within the Environment Agency and so are crucial to the project. Areas where the project may diverge from the REA approach are:

1. An open primary question. Closed questions are typically used so that a definite answer may be obtained. This project has a focus on gathering data.
2. 15 secondary questions (only 1 or 2 are recommended in the approach by Collins and others). It was agreed at the first steering group meeting (SG1) that the project will look at all the questions at the same time and not review the evidence multiple times (this is a deviation from the strict REA approach).
3. The nature of how to appraise the evidence gained (further information later in this protocol). All evidence regarding groundwater flood risk management in England will be of some relevance to the review, so screening out some evidence may not be appropriate.
4. Grey literature and stakeholder engagement are likely to be the main sources of literature for the project, rather than peer review literature. While the REA approach does allow for stakeholder engagement, this is usually not the main source of information.

A.2.2 REA team

The review team includes Susan Wagstaff (Project Manager), Rachelle Ngai (Evidence Reviewer), and Brendon McFadden (Evidence Reviewer). The expert panel will consist of Duncan Faulkner (Flooding and REA and Project Director), Hannah Coogan (Expert Elicitation/stakeholder engagement), and Maxine Zaidman (Groundwater flooding).

A.3 Objective

A.3.1 Primary question

The primary research question of this study identified in the initial scope was **'What are the current approaches to groundwater flood risk management in England?'**

The primary research question is traditionally a closed question containing the relevant Population, Intervention, Comparator, Outcome (PICO) elements. The primary question chosen for this review is an open one (does not have a yes or no response) to give an overview of what practices are used, but PICO elements have been used to define the scope of the review. These are identified in Table A-1.

Table A-1 PICO elements of REA primary question

Question	What are the current approaches to groundwater flood risk management in England?
Population	England
Intervention/exposure	Approaches to groundwater flood risk management
Comparator	Absence of approaches to groundwater flood risk management
Outcome	Approach, method, strategy, assessment, guidance, reduction in groundwater flood risk

The overall outcome of the study is this document describing how groundwater flood risk is managed in England.

A.4 Scope

The detail of the scope will be determined by the primary and secondary questions, but a draft is given below.

Table A-2 PICO descriptions of REA primary question

Elements	Scope
Geographical reference	The primary research question refers only to England. Only evidence from England will be searched. If in searching for evidence in England significant gaps are encountered, we could consider looking at best practice from Wales or Scotland, however this would be outside the agreed scope and cost. As groundwater flooding is generally a greater problem in England than elsewhere in the UK, we would not anticipate this being a problem. Following discussion with the Environment Agency's Project Manager at the start-up meeting we would propose that if during the search we find significant international literature relating to groundwater flood risk management we would note this, but not spend significant time reviewing it. Reviewing international literature is outside the current scope. At the small end of the location scale, data regarding single properties, or sites, will not generally be included (Agreed with Environment Agency's Project Manager in start-up meeting).

Elements	Scope
Language restrictions	The evidence search will be limited to the English language, as it is expected that the vast majority of sources are written in English since the geographical reference is England. If any particular relevant sources are identified that are not written in English, this will be raised with the steering group and translation options will be discussed.
Date restrictions	The evidence relating to the primary question will be restricted to recent literature published in the last 10 years since there has been an increased emphasis on groundwater flooding since the Flood and Water Management Act 2010 and the 2018 revision of the National Planning Policy Framework (NPPF). As indicated in our proposal, the main exception would be Defra's 'Making space for water - Groundwater flooding' reports (2006), Defra's 'Strategy for Flood and Coastal Erosion Risk Management - Groundwater Flooding Scoping Study' (2004) and Jacobs Groundwater Emergence Maps (GEMS) if no updates to these reports are found. It is noted that there may be significant data following the 2000 to 2001 groundwater flooding. It is noted that LLFAs were set up in 2010, with most established by 2012, so evidence before this may not be held by the LLFAs unless there was a good handover of data.
Population restrictions	Areas which are naturally waterlogged on a seasonal or semi-seasonal basis will be excluded as these are not groundwater flooding (see conceptual model in tender). Applying the source-pathway-receptor model considering only flooding where the source is groundwater flooding, with the pathway an aquifer (rather than a river). It is noted that there are many situations where groundwater flooding is combined with other types of flooding, for example, fluvial flooding which is significantly driven by groundwater in permeable catchments, and sewer flooding that is significantly driven by groundwater. However, our evidence search will be limited to looking specifically for groundwater flooding.
Outcome restrictions	We would restrict our primary search to natural groundwater flooding (that is, flooding relating to aquifers - principal and alluvial). We will search on terms such as 'groundwater flooding'. Reference will be made to industrial and mining rebound (where evidence is obtained while searching for 'groundwater flooding', but this will not form a major focus of the review, although allowance can be made for one case study on rebound[4] . With regard to this, we will search on groundwater flooding but not on 'mine rebound'. Similarly, development effects, for example, basements taking up aquifer storage resulting in flooding, interaction with (storm) sewers/drains/pipes/trenches will be included in the review where this evidence is obtained while searching for 'groundwater flooding'. However, we will not consider evidence at a very local scale relating to single properties/sites.

4 Tender clarification email from Hayley Bowman to Susan Wagstaff 24/5/19.

Elements	Scope
Other restrictions	As specified in the tender, we would propose only a focused review of grey literature with regard to strategic flood risk assessment (SFRA) documents where these are identified as having significant groundwater flooding information. Following the project start-up meeting with the Environment Agency's Project Manager it is noted that a parallel Environment Agency project has already reviewed SFRAs to some extent with regard to groundwater flooding and this information will be made available to the project. We will review up to 10 SFRAs and Section 19 reports in total. We would review in detail 10 peer reviewed papers (as indicated in the tender). This is to allow adequate time for grey literature.

Following the SG1 meeting it was noted that there are a number of areas outside of the current project scope which could be beneficial to explore, if this project identifies these areas as evidence gaps. These areas will be documented with regard to potential recommendations for future work. They include:

1. international approaches to groundwater flooding, particularly urban groundwater management
2. groundwater in combination with other types of flooding. Are some of the damages attributable to fluvial flooding in permeable catchments mainly from the groundwater input?
3. detailed consideration of groundwater rebound
4. development of guidance regarding how groundwater flooding should be reported (if this is identified as an evidence gap)

A.5 Conceptual model

The conceptual model was produced to help the project determine how the policy, practice and science (current at the time of research – September 2018 to April 2019) related to the evidence review topic interact and influence each other in England.

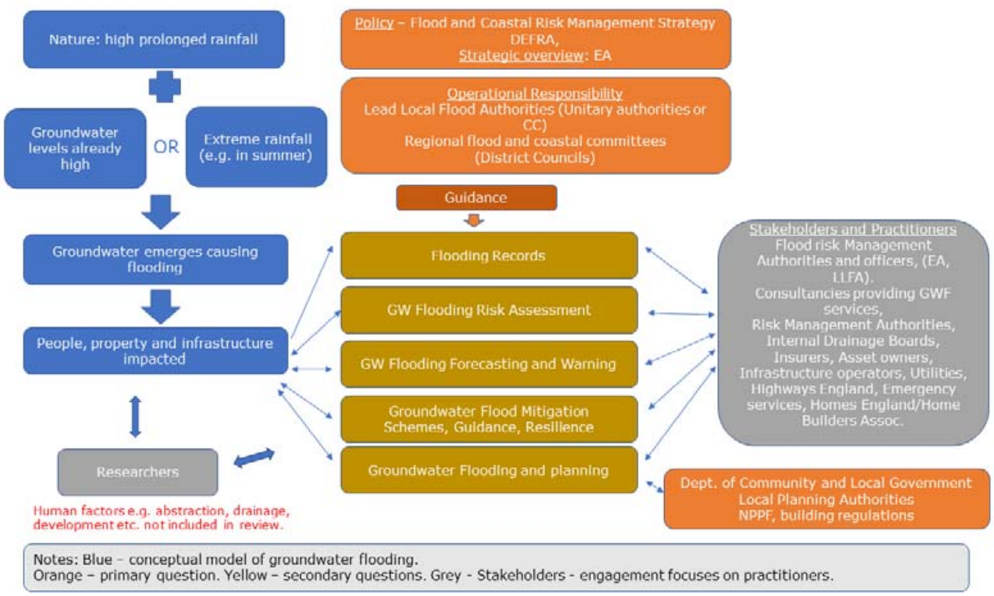

Figure A-1 Conceptual model used for the research basis

From the outset, it will be important to have a common definition of groundwater flooding to be used in this study. This definition will specify the mechanisms of groundwater flooding that will be included and to what depth.

Groundwater flooding may be defined here as the emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded (BGS website, 2019).

It is important that seasonally soggy or wet areas that are typically wet, for example in winter, following heavy rainfall, are excluded. Similarly, areas that are naturally (or as a result of development) poorly drained, should also be excluded.

There are 4 major settings in the UK where significant groundwater flooding can occur:

1. Unconfined major aquifers (also known as aquifer groundwater flooding or clear groundwater flooding). This relies on prolonged heavy rainfall in addition to initially high groundwater levels or very extreme rainfall intensity (for instance, in summer).
2. Shallow unconsolidated sedimentary aquifers (alluvial groundwater flooding) in river valleys near to large rivers. This relies on very high river levels for a prolonged time (a number of days) with initially fairly high aquifer groundwater levels.
3. Groundwater rebound following a reduction in pumping:
    a. in urban areas following reduction in industrial pumping
    b. in mining areas following reduction in mine dewatering.

In these situations, groundwater levels may have been lowered for many decades following high levels of groundwater abstraction. When the abstraction reduces or ceases, groundwater levels rebound. Rebound can result in higher groundwater levels which may intersect infrastructure (tunnels, foundations) and result in reactivating springs and discharges. Urban rebound has occurred in a number of cities: most notably London where groundwater levels were lowered during the Industrial Revolution and have subsequently rebounded, with considerable management of the rebound. Mine water rebound has occurred and is currently occurring in the north of England following cessation of coal mining.

4. Development linked groundwater flooding, this includes:

    a. thin aquifers where a large number of impermeable basements are constructed. These then have a reduction in storage, resulting in higher than previous groundwater levels. This can potentially be mitigated by building control measures to allow flow of groundwater around buildings, but the storage lost is harder to replace

    b. other underground structures, such as sewers, drainage networks, service trenches or pipes which allow rapid groundwater flow and facilitate emergence of groundwater where it is not normally found

The study will focus on the first 2 natural types of groundwater flooding. Although where evidence regarding rebound or development related groundwater flooding is available, this will be considered for including in the review. However, the review will not search specifically for industrial, mining or development related groundwater evidence. These are not natural groundwater flooding mechanisms and will not form the main focus of this study. However, it is recognised that sewer drainage and the sub-surface built-environment have important interactions with near surface groundwater, with the potential to both mitigate and exacerbate groundwater flooding.

A.6 Methods

The review will progress via the following methods (from JBA tender).

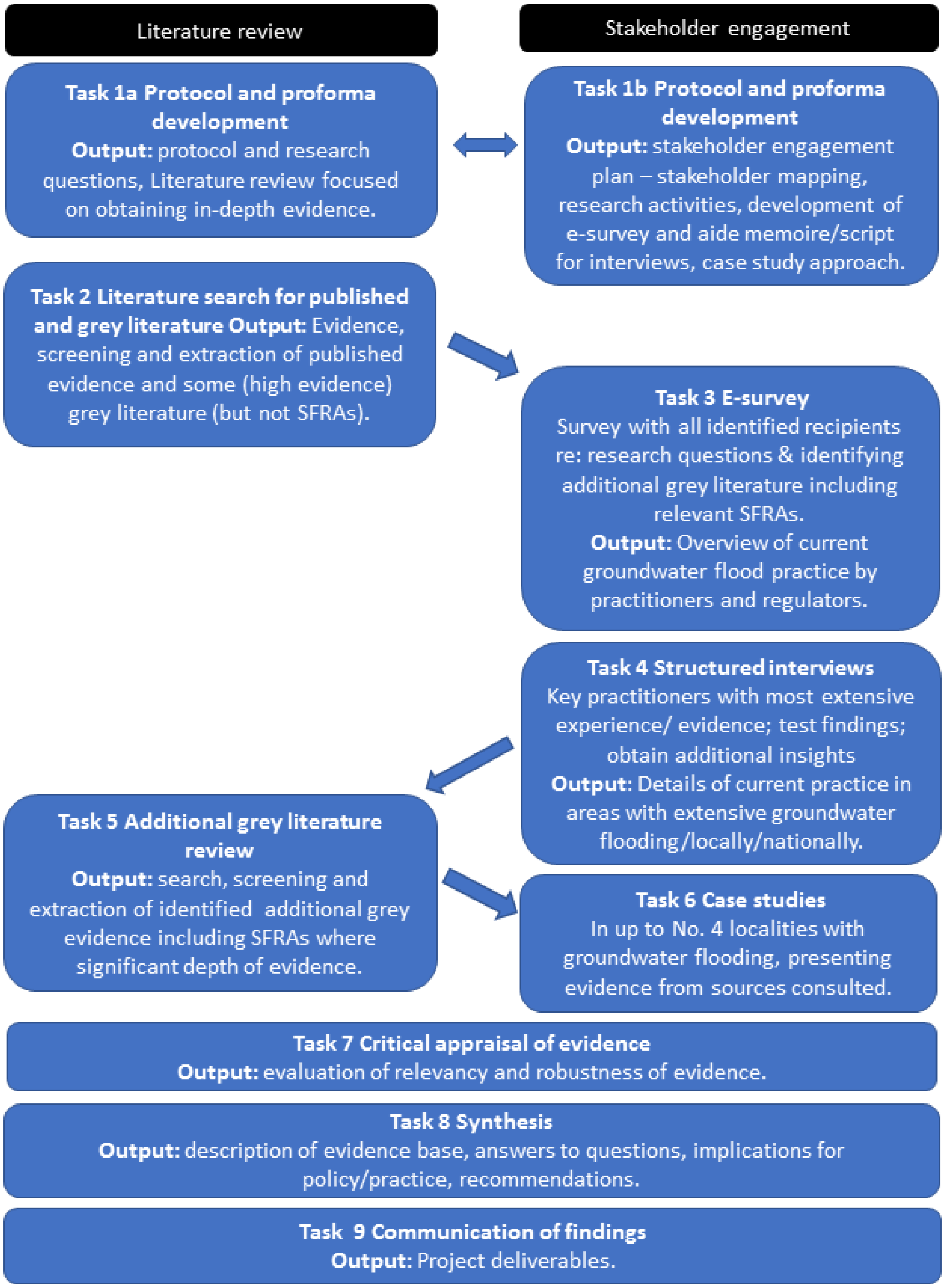

Figure A-2 Method

A.6.1 Search keyword

Following an initial trial search of literature, we would propose that the basic search string should be '**groundwater' AND 'flood***' in the title of the literature. This should yield data focused on groundwater flooding. Searching for 'groundwater flood*' in the abstract or whole text will yield a large number of responses that are not actually about groundwater flood risk, but which have only a passing mention of groundwater flooding.

This search will yield data regarding other locations than England and this will require screening. However, including England within the search term may exclude many groundwater flooding data sources based in England as many papers and reports do not mention England in either the abstract or title.

This search string will be regularly reviewed and extended if the literature search is excluding evidence relevant to the research questions.

Below is a list of additional keywords that can be incorporated into search strings when carrying a wider literature search.

- Approaches: approach*, manage*, method*, strateg*, application, propos*, proposition, procedur*, technique*, forecast*, system*, warning*
- Governance: governance, role*, responsibilit*
- Geographical location: England, country-wide, local
- Groundwater: groundwater, clear water, alluvial aquifer, chalk aquifer
- Flood: flood*, extreme event
- Risk reduction and resilience: mitigation, resilience, plan*

The final list of keywords will include synonyms so that evidence is not biased towards terminology. A set of articles from multiple sources relevant to the research questions will be screened for potential synonyms.

Wildcards will be used where possible to cover a range of keywords with the same root, for example the keyword 'strateg*' will include searches for 'strategies' and 'strategic'.

A.6.2 Strategy for evidence search

The final list of keywords will be used as the basis for constructing search strings to use in online academic databases and search engines. Boolean operators will be used where possible to broaden or narrow the search results. Previous REA experience suggests that vast amounts of non-relevant references may be obtained. In order to avoid this, we would have systematic search criteria. Our initial appreciation of the literature relevant to the primary question is that there is some (but limited) peer review published data. Most data available is in grey literature, but not all of this is on the web (this will be addressed via stakeholder engagement).

The search strings will be used to search through article titles initially. Search will be extended to abstracts and keywords as required. Initial approaches indicated that extending the search to abstracts yielded additional search hits, but that none of them had significant information relevant to the project questions.

Our approach will be to first search for '**groundwater' AND 'flood***'. This approach will be refined to combine: approaches, geographical location, groundwater, and flood and a word relating to governance, and risk reduction and resilience, for example.

(Approach* OR method* OR manage* OR…) AND (England OR local OR…) AND (groundwater) AND (flood* OR extreme event*) AND (governance OR role* OR responsibilit* OR…) OR (risk* OR resilience OR…).

Google Scholar will be considered since it is a useful source for grey literature and unpublished evidence, including conference presentations, technical reports and manuscripts on repositories that are in the review process and not yet published. By including this grey literature (that is, evidence not published in traditional academic peer-reviewed journals), we hope to overcome publication bias and conduct the most comprehensive search of the approaches of groundwater flood risk management which is often in the public domain or published on government and other regulator websites. In the interest of time, the search will be conducted on titles only, as the only alternative offered by Google Scholar is a full search term through the full text, which we believe will yield more results than is manageable.

The search will be an ongoing process. For each search, all search terms used, number of hits and date limits will be recorded in a database provided as an output of this project. Duplicates found across different searches will be removed.

The review team's previous work in the area opens up access to sources of grey literature and unpublished evidence. If during the search process it is found that there is an underrepresentation of studies including recent approaches, the review team will search for unpublished evidence through connections of the steering group, contacts with known experts in the field, and possibly, open calls for evidence. All such sources of evidence will be properly recorded for transparency. It is noted that there is generally a time lag in publishing peer reviewed academic literature (and some studies are never written up academically). Grey literature is likely to provide more up to data and focus on practical studies rather than theoretical approaches.

A.6.3 Outline inclusion and exclusion criteria

The review team will use their cross-disciplinary expertise to refine the list of searched evidence to a more relevant base of literature. This will be done in a systematic way using predefined inclusion criteria, which is determined with regard to the relevance of the evidence to the primary question. In line with the primary and guiding questions, the following inclusion criteria will be applied for articles:

- relevant to groundwater flooding
- focused on England
- written in the period from 2009 to the present
- relevant to approaches regarding groundwater flooding management/assessment
- investigating governance OR risk resilience and mitigation

The screening will be a 2-phase process. This first phase will involve a judgement of the headline or title of the source of evidence. It will be marked as clearly relevant, clearly not relevant or uncertain. Evidence marked as clearly not relevant will be removed at this stage. Some evidence may be easier to exclude than others, for example, evidence relating to marshes and wetlands (naturally wet areas).

The second-phase screening involves reading the abstract or first paragraph of the clearly relevant or uncertain pieces of evidence to identify those that meet the inclusion and will be retained for evidence extraction and synthesis. This 2-phase approach minimises the time spent screening irrelevant search results found by using a sensitive search string.

Databases of evidence after completing each step of the screening process will be provided as a project output. The review team will regularly liaise regarding search results. Members of the review team will screen sub-sections of the evidence found and compare results. This will ensure bias has been reduced and the inclusion/exclusion criteria are applied consistently.

A.6.4 Strategy for extracting information

The review team will extract relevant evidence from the screened database in a database capturing all pertinent information, referred to as the ‘systematic map’. As well as capturing information relevant to the primary question, evidence relating to the guiding 'secondary' questions will be retained and stored in the systematic map. For each piece of evidence, we will include information in the following categories, which are based on the secondary questions. It is noted that using closed questions should help classify data and enable gaps in data to be identified.

- geographical context (for mapping results) - location, for example, England-wide, local authority area
    - sub-classification zone of area of evidence: England, local authority area, Water Framework Directive (WFD) catchments, town/city, village, site specific. This will help identify the coverage of data regarding groundwater flooding activities
- type of evidence - peer-reviewed, unpublished (available or commercial/confidential), grey. This will highlight where most information is available and where studies are confidential and not available for public review/scrutiny
- topic of evidence - policy, governance, guidance, groundwater flood records, groundwater flood risk assessment, groundwater flood forecasting, groundwater flood warning, groundwater flood mitigation and resilience, planning and regulations. These topics relate to the project questions as illustrated in the conceptual model. For each of these topics further classification may be required:
    - groundwater flood risk assessments
        - methodologies used: observation of flooding, conceptual model, analytical assessment, numerical modelling of groundwater flood risk, mapping of risk
        - software used
        - model scenarios
        - resolution of results (for example 5m grid horizontally and vertically - how accurate are the groundwater levels)
        - use/applicability of results
        - availability of results (for example, commercial - data to be purchased, licenced, freely available)
        - is climate change considered?
        - validation of results (yes/no) and how?
- data used in study - analytical theory, modelling, observational
- definition of groundwater flooding used - for example, BGS definition
- type of groundwater flooding**:** principal aquifer (which?), alluvial aquifer, rebound, others
- severity/significance of flood risk (Data output) - for example, depth of water, extent of flooding, duration of flooding, frequency of flooding, number of properties affected
- data inputs - for example, rainfall, borehole water level data, geology, river levels, terrain, abstraction, weather forecasts

- timescale of approaches (recent or not) - for example, date of study, dates of groundwater flood risk management schemes, dates of risk assessments, current flood warnings (current date)
- organisations involved in governance - for example, government, the Environment Agency, local authority, other organisations
- organisations involved in groundwater flood risk management, for example, government, the Environment Agency, the local authority, the Fire Brigade, consultancies (which), other organisations
- organisations holding groundwater flood record data - for example, the Environment Agency, local authority, the Fire Brigade, consultancies (which), other organisations
    - where flood records are held (locally, nationally, individual records/reports for example S19, databases)
    - when flood records are recorded - for example, during flood, after floods), who records them, and who they are reported to
    - what data is recorded regarding groundwater flood events - for example, location, address, property, national grid reference (NGR), date, duration, depth of water, extent of flooding, and source of water)
    - is there a consistent approach for recording groundwater flooding? Yes/No/Don't know
- consideration of groundwater flooding in spatial planning
- the number of properties at risk of groundwater flooding now
- the number of properties at risk of groundwater flooding under climate change
- the management/mitigation/resilience measures used - for example, pumping, barriers for example, tanking and drainage
- gaps and limitations in the evidence acknowledged in the study (if applicable) for example, roles and responsibilities; lack of data, for example, regarding groundwater flooding occurrence (confusion with other types of flooding), mechanism, sources; over/under estimation of groundwater flood frequency; modelling study limitations, for example, not based upon observed flooding data; flooding study but mechanisms poorly understood

This categorisation of the data with regard to the project questions will highlight where data is available, how much is available, how recent the data is, and where there are gaps.

If it is found that the current template is not capturing all relevant information, then the template will be updated following consultation with the steering group.

The final systematic map will be provided as a project deliverable.

A.6.5 Strategy for critical appraisal

After the extraction stage, in a typical REA each piece of evidence is evaluated to consider both its relevance to the question posed by the REA and also the robustness of the quality of the method. Assessment of the evidence's relevancy and robustness is combined to give an overall evaluation. For this REA applying relevancy is fairly straightforward. However, following discussion at the SG1 meeting we would propose that robustness is replaced by 'level of information/understanding'. Using the criteria below, scores for each will be given and combined to give an overall assessment of the evidence.

The first step is to evaluate the relevancy of evidence in relation to the REA question. Criteria to consider will be:

- the relevancy of the method used to the primary question ('what are the current approaches to groundwater flood risk management in England?')
- the relevancy of the evidence to the target population: England
- relevance to the intervention assessed: is the data representative of the groundwater flooding mechanisms to be assessed?
- relevance to the outcome measured: does it relate to the secondary questions?

For evaluating relevancy an overall score of 0, 1, 2 or 3 will be given based on how well the evidence satisfies the criteria. That means a score of 3 will be given if the evidence satisfies most of the criteria, a score of 2 if it satisfies some of the criteria, and 1 if it satisfies few of the criteria. For example, a study investigating a single property groundwater flooding in England without addressing the question of groundwater flood risk management will be given a relevancy score of 1. If the data is not relevant to the study, score of 0, it will be excluded.

The second step is to evaluate the evidence's robustness. The Collins and others (2015) guidance offers criteria as a basis for evaluating robustness based on study design type (that is, quantitative experimental, observational, qualitative studies, economic studies, and reviews).

However, for this project the aim is to gather a good understanding of what activities are being carried out with regard to groundwater flood risk management. As such, it is useful to understand all the approaches to groundwater flood risk management across England. We would propose the following categorisation of the data with regard to 'level of information/understanding/management':

1. **No information**: don't know if groundwater flooding is a problem, but possibly isn't. No management of groundwater flooding, but possibly no flooding occurs.
2. **Low level** of management of groundwater flood risk: groundwater flooding poorly understood: there is groundwater flooding, but not much more is known.
3. **Moderate level** of management of groundwater flood risk: some involvement of authorities, some conceptual/numerical modelling, some data.
4. **High level** of management of groundwater flood risk: evidenced by engagement of regulatory authorities and stakeholders, good understanding conceptually, a calibrated model, considerable observational data.
5. **Comprehensive** management of groundwater flood risk: evidenced by full engagement of regulatory authorities and stakeholders, thorough understanding conceptually, a robust calibrated model, high level of observational data.

It is likely that all these levels of approach are present in some areas of groundwater flood risk management in England. The management approaches are likely to have developed in response to the level of groundwater flood risk and available resources. Depending on the level of risk the appropriate approach will vary; in other words, the level of management will be proportionate to the risk.

However, for the purposes of this study, while the level of information within the studies will be considered in the review process, this will not be a criterion to exclude evidence. It is acknowledged that data regarding all levels of groundwater flood risk management intervention are important in obtaining an overview.

A subset of evidence will be critically appraised by a second reviewer and compared against the lead reviewer's results to ensure the conclusions are fair and consistent.

A.7 How the evidence will be combined and summarised

The evidence that has been successfully screened and judged to be sufficiently relevant will be analysed to answer the primary and 'secondary' questions. Descriptions and summaries of the evidence base will be provided, as well as an overall summary of the critical appraisal stage.

The evidence will be summarised to answer the primary and 'secondary' questions. In combining and summarising the findings, we will be mindful of the dangers of 'vote counting' whereby each publication that supports a particular hypothesis is given one vote, regardless of factors such as sample size[5]. However, we are aware that as the review aims to document what approaches there are to groundwater flood risk management, all data is relevant to obtaining a full overview of the topic.

We will also provide a summary of the evidence gaps related to the primary and 'secondary' questions. In doing so, we hope that this information can be used to identify research areas of high priority for groundwater flooding.

Infographics and visualisations will be used where possible to communicate the review's findings to a wider audience, for example, a word cloud showing methods of assessing groundwater flood risk with their size relative to their frequency in the literature. Infographics of how groundwater flooding occurs and is managed will also be used.

The summary will help to assign a level of confidence the answers to the primary and 'secondary' questions, for example high, medium, low and contested. In assigning confidence, the review team will consider both the robustness and quantity of the evidence supporting the evidence statement.

A.8 Quality assurance

The review will undergo an internal quality assurance (QA) by Duncan Faulkner, Chief Hydrologist of JBA Group. The final technical report will be reviewed by the steering group, allowing for one revision by the review team.

A.9 Milestones and timeline

These are documented in the project programme and tender - to be updated following the project start-up meeting with the client.

A.10 Outputs

- Monthly progress reports
- Technical report detailing the review process and results, outlining evidence gaps and making recommendations of priority areas for flood risk management
- PowerPoint presentation summarising findings

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[5] Waddington, H. et al.,and others, 2012. How to do a good systematic review of effects in international development: a tool kit. Journal of Development Effectiveness, 4 (3), 359 to 387.

- Complete database of all search results
- database containing evidence after both phases of screening
- systematic map of evidence
- database of evidence used for synthesis
- infographics showing results of review
- 2-page science summary document

A.11 References

BGS. 2019 website: https://www.bgs.ac.uk/research/groundwater/flooding/home.html

Collins AM, Coughlin D, Miller J and Kirk S. 2015 'The production of quick scoping reviews and rapid evidence assessments: A How to Guide' (Defra, NERC, JWEG)

JBA. 2019 Tender: 'Rapid Evidence Assessment of groundwater flood risk management'

B Applying the REA

B.1 Literature search

B.1.1 Peer-reviewed literature search

Data was obtained from a literature search of peer-reviewed literature through online search tools Google Scholar (GS) and WorldWideScience (WWS). The search term was restricted to ‘Groundwater AND flood*”’ in the title of the publication to ensure the results were relevant to the study, with the term ‘flood*”’ giving some flexibility in the terminology used (that is, this would include flood, flooded, flooding). In addition to the text string, results were limited to a published date of 2010 onwards, and those based in England within the search engine. The restriction of published dates to 2010 and onwards is due to the increased emphasis on groundwater flooding since the Flood and Water Management Act 2010 and the 2018 revision of the National Planning Policy Framework (NPPF).

Following consultation with the steering group it was decided that additional literature published before 2010 but that was most relevant to the project would be reviewed. The main exception would be the Environment Agency’s ‘Making Space for Water’ (reference HA5) (Jacobs, 2007) report and Jacobs ‘Groundwater Emergence Maps’ (GEMs). Further refinement of the search term was not completed as suggested in the initial approach or protocol because the initial search resulted in a manageable number within the scope of the REA to be extracted.

The WorldWideScience search returned 1,184 hits using the search terms and specifying English sources only. However, a number of the references returned did not include groundwater and/or flood* and consequently, a manual search process within the 1,184 was completed in which 17 peer-reviewed articles were returned. The Google Scholar search returned 30 peer-reviewed articles.

B.1.2 Grey literature

Within Collins et al. (2015), grey literature is defined as “informally or non-commercially published information that can be difficult to search for using conventional searching techniques”. Grey literature often has more information regarding current practice. Given the applied nature of the REA questions regarding the approaches to groundwater flood risk management in England, more data was obtained via grey literature. Grey literature has been obtained from the following sources:

- Environment Agency supplied documents collated as part of the REA
- data obtained from the steering group
- internet search
- data obtained during the project from project consultees, including questionnaire respondents, semi-structured interviewees and other project contacts

From the sources listed above, a further 37 articles from grey literature were added to the systematic map (that is, a database of evidence meeting the screening criteria), further explained in section B.4.

B.1.3 Unpublished literature

Unpublished evidence has been defined as “information that has been produced but has not been published either formally or informally. This can help to “mitigate publication bias" (Collins and others, 2015) and enable the study to use other evidence. Unpublished literature has been included in the review where this has been specifically supplied to the project. This includes documents and data supplied by the Environment Agency and interviewees, including workshop findings and internal reports. 12 pieces of unpublished literature were included within the systematic map.

The occurrence of groundwater flooding in the winter of 2019 to 2020, during the project, has provided additional data sources and experience which this review has captured. Short notes have not been included in the systematic map but in the reporting narrative.

B.1.4 Screening

The peer-reviewed literature was screened for relevance.

The initial search term for the peer-reviewed literature produced a large number of results (1,184 for World Wide Science) and therefore required screening. The results were screened for relevance by assessing the literature title and abstract for relevance to the primary question and study area and data (England, 2010 onwards). Following screening of both the Google Scholar and World Wide Science results the final number of peer-reviewed articles to be extracted was 21.

However, given that the aim of the project was to collate evidence regarding groundwater flood risk management in England, nearly all the grey literature was included in the systematic map of evidence. Only evidence of very limited relevance was excluded. Given the large number of SFRAs available across the study area and the fact that many make limited reference to groundwater flooding, a decision was made to only include a selection of SFRAs where more detailed groundwater assessment was provided. The SFRAs screened originated from the questionnaire responses. The screening process was similar to that for the peer-reviewed literature.

Similarly, unpublished evidence specifically supplied to the review team was included in the review and systematic map unless of very limited relevance.

Table B-3 Number of literature types reviewed

Literature type	Number reviewed
Peer-reviewed	17
Unpublished	12
Grey	37

B.2 Stakeholder engagement

Given the applied nature of the REA questions it was important to obtain information from practitioners engaged in groundwater flood risk management, rather than from purely published literature. Additionally, stakeholders have been a significant source of grey literature where information is held more locally. This was carried out through an online questionnaire, semi-structured interviews and steering group engagement.

Within the REA approach stakeholder engagement is termed 'expert elicitation'. The questionnaire was designed so that the respondent answers mapped directly into columns within the systematic map of data.

B.2.1 Steering group

A steering group was established as part of this study to help guide the research and development of the project. Four steering group meetings were carried out at important stages of the project. The steering group represents a broad spectrum of groundwater flooding related sectors, including the Environment Agency, water industry, academia and lead local flood authorities.

The steering group meetings and review process highlighted additional literature (including literature before 2010 that the steering group felt was most relevant to the project) and data sources to be considered and provided feedback on the presentation of the results. Additionally, the steering group completed a review of the draft report.

B.2.2 Questionnaire

A detailed questionnaire was developed based closely on the REA questions to obtain information relevant to answering the REA questions in a structured way. A comprehensive list of stakeholders was developed together with the project steering group.

This included:

- Defra
- Environment Agency
- Lead local flood authorities
- National bodies involved in water and groundwater flood risk management
- Water companies
- Commercial organisations working with groundwater flooding

The questionnaire was disseminated via the regional flood and coastal committees (RFCCs), the project steering group networks and the lead local flood authorities, including ADEPT. Additionally, the survey questionnaire was publicised via social media (Twitter and LinkedIn) to provide wider access.

The data gathered through the questionnaire was incorporated into the systematic map for analysis in relation to the REA questions along with other data sources.

B.2.3 Semi-structured interviews

In order to obtain more in-depth information which was not readily available via the questionnaire JBA carried out a series of semi-structured interviews around the REA primary and secondary questions. These were generally focused on a sub-set of the questionnaire questions relevant to the expertise and experience of the interviewee and the findings map in general to the systematic map.

The semi-structured interviews were carried out with leading practitioners with most experience/evidence in groundwater flooding. The interview questions are provided in Appendix C.2.

These were used to augment the data in the systematic map. The evidence obtained from each interview (question responses and additional literature) has been captured in the systematic map.

Table B-4 Summary of semi-structured interviews

Organisation (role)	Main areas of discussion
Anglian Water (Strategic Flood Risk and Operational Managers)	Groundwater flood risk and management from a water industry perspective (strategic and operational). Impact of groundwater flooding in Lincolnshire during winter 2019 to 2020, gaps in knowledge and response strategy.

Organisation (role)	Main areas of discussion
Environment Agency (Flood Risk Resilience at Wessex)	Groundwater flood risk management in a chalk catchment (Wessex). Production and utilisation of a groundwater flood forecasting system.
JBA Consulting (Technical Director of Hydrology and Hydrometry)	JBA's national scale groundwater flood risk mapping.
GeoSmart Information Ltd. (Managing Director)	GeoSmart's national scale groundwater flood risk mapping and forecasting model.
British Geological Society (Principal Groundwater Modeller)	BGS's groundwater flooding susceptibility mapping. Clearwater chalk aquifer (Berkshire) groundwater flood model.
Environment Agency (Senior Technical Specialist for Groundwater Resources – Thames area)	Groundwater flood risk management in a chalk catchment (Thames). Managing flooding due to rebound around London.
Hampshire County Council (Flood Risk Manager)	Groundwater flood risk management in Hampshire from a local authority perspective.

B.3 Evidence extraction

B.3.1 Literature

The full text of the articles (peer review, grey and unpublished) remaining after the screening phase were assessed and information relevant to the primary and secondary questions extracted. Information was extracted from articles of relevance to the primary question and secondary questions using a set of pre-specified qualitative fields aimed at summarising the information of interest with regard to the secondary questions. The database of extracted information is referred to as a systematic map of the evidence (Collins and others, 2015).

The full systematic map, featuring the entire list of fields, was provided to the project as an output. The collated results features a restricted set of fields based upon the REA questions.

In a similar way all the stakeholder data, including questionnaire responses and semi-structured interviews, were included in the data extraction and analysis.

B.4 Critical appraisal

An essential part of an REA is to critically appraise the evidence found by the search. This ensures more relevant and reliable evidence is given greater consideration when summarising it. Critically appraising the evidence involves evaluating each piece of evidence to consider both its relevance to the REA question and also the robustness of the approach used. The assessments of both of these aspects are then combined to provide an overall evaluation for each piece of evidence returned by the review (Collins, 2015).

After the extraction stage, each item of literature screened and interview response was evaluated for its relevance to the research questions posed by the rapid evidence assessment and the robustness (thoroughness) of the approach used. Assessment of the evidence's relevance and robustness was combined to give an overall score for each piece of evidence. Relevance and robustness were judged using a set of criteria, giving scores for each and combining.

The critical appraisal stage was carried out by 3 reviewers from different disciplines, ensuring that expert knowledge was used effectively to inform the article's overall score. Cross-checks were carried out to ensure the appraisals were fair and consistent across reviewers. Inevitably, there is a degree of subjectivity with regard to this scoring system, but the reviewers completed their evaluation using the following guidelines.

B.4.1 Relevance

Evaluation of relevance was based upon the Collins and others' (2015) approach and scoring the evidence regarding:

- relevance of the method used for the primary question:
  'What are the current approaches to groundwater flood risk management in England?'.
- the relevance of the evidence to England
- relevance to the intervention assessed: is the data representative of the groundwater flooding mechanisms to be assessed?
- relevance to the outcome measured: does it relate to the secondary questions?

The scoring was as follows:

- 0 - not relevant to the study, exclude
- 1 - satisfies few criteria
- 2 - satisfies some criteria
- 3 - satisfies most criteria

The average score rounded to the nearest whole number was taken as the final relevance score.

Figure B-1 shows how the different types of evidence scored in terms of relevance. The graph identifies that the most common relevance score given to any document was 2. For the grey literature, of which there were the most documents (37), more documents were rated as 1 or 2 than of a higher relevance score. For the peer-reviewed and unpublished documents, very few were scored as 1, and none were deemed to be not relevant.

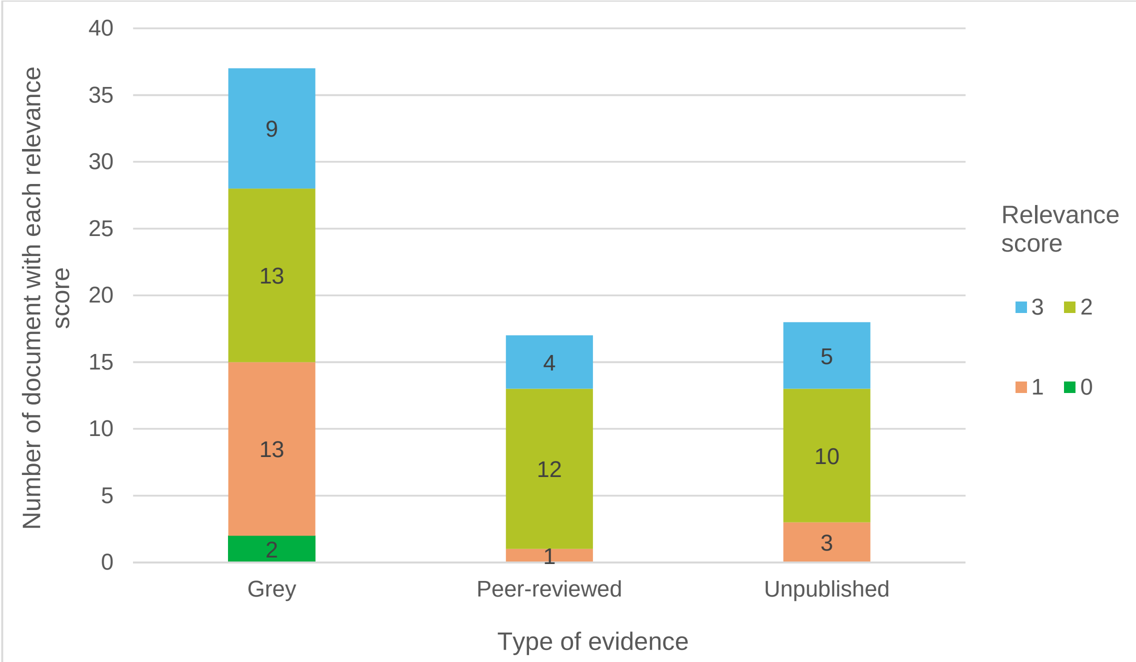


Figure B-1 Overview of the systematic map Evidence - Relevance of data

B.4.2 Robustness

The robustness fields within the systematic map were used to assess how in-depth the level of information/understanding and management of groundwater flooding was in the evidence source. While this approach cannot capture the subtle complexities of individual studies, these fields help to identify evidence that is likely to have wider usefulness. Data analysis can be used to quantify this and produce insights as to the main approaches to groundwater flooding, as well as gaps in the evidence.

The Collins and others' (2015) guidance offers criteria as a basis for evaluating robustness based on study design type (that is, quantitative experimental, observational, qualitative studies, economic studies, and reviews).

However, for this project, the aim is to gather a good understanding of what activities are being carried out with regard to groundwater flood risk management. As such, it is useful to understand all the approaches to groundwater flood risk management across England. Therefore, robustness was assessed in 2 methods.

The first included using the following questions, and each was scored, Yes/No.

1. Are the questions addressed by the study clearly identified?
2. Are related existing research or theories acknowledged?
3. Are funding sources and conflicts of interest declared?
4. Is the approach clearly and transparently presented?
   This was sometimes not the case in evidence regarding commercial groundwater flooding assessment.
5. Has the study used appropriate, up-to-date methods and are the conclusions supported by these methods?
6. Are any assumptions outlined clearly?
7. Is the context (time period/geography) of the study clear?

8. Have the study's conclusions been supported by empirical evidence with an appropriate data record length?
   It is noted that generally one of the main issues in groundwater flooding is the lack of a good widespread historical data set over a period sufficient to capture significant groundwater floods.

9. Are the links between hypothesis, data, analysis and conclusions clear and logical?

10. Have the limitations and validity of the study been addressed?

Taking into account the scoring on the above questions, the second method of assessment, including scoring each piece of evidence for robustness, within the context of groundwater flooding, in terms of:

I. Level of information (1-5)

II. Level of understanding (1-5)

III. Level of management (1-5)

For each robustness criteria above the scoring was as follows:

1. No information: do not know if groundwater flooding is a problem, but possibly is not. No management of groundwater flooding, but possibly no flooding occurs.

2. Low level: groundwater flooding poorly understood, there is groundwater flooding but not much more is known.

3. Moderate level: some involvement of authorities, some conceptual/numerical modelling, some data.

4. High level: evidenced by engagement of regulatory authorities and stakeholders, good understanding conceptually, a calibrated model, considerable observational data.

5. Comprehensive: evidenced by full engagement of regulatory authorities and stakeholders, thorough understanding conceptually, a robust calibrated model, high level of observational data.

An overall robustness score was obtained by averaging the 3 scores to the nearest whole number. The second method of assessment provides a robustness score in relation to groundwater flood risk management. However, it is acknowledged that the differing types of literature and evidence assessed mean that not all the description of the scores applies in each case. Evidence was not excluded on the basis of low robustness.

The overall robustness scores for the 75 documents reviewed can be seen in Figure B-2. This graph shows that the robustness of the groundwater flood risk management evidence within the different types of documents reviewed varied, with the most common scores being 2 (low level), 3 (moderate level) and 4 (high level). Both the peer-reviewed and unpublished data had fewer documents in the higher scores, meanwhile the peer-reviewed documents all had a robustness score over 3 or above.

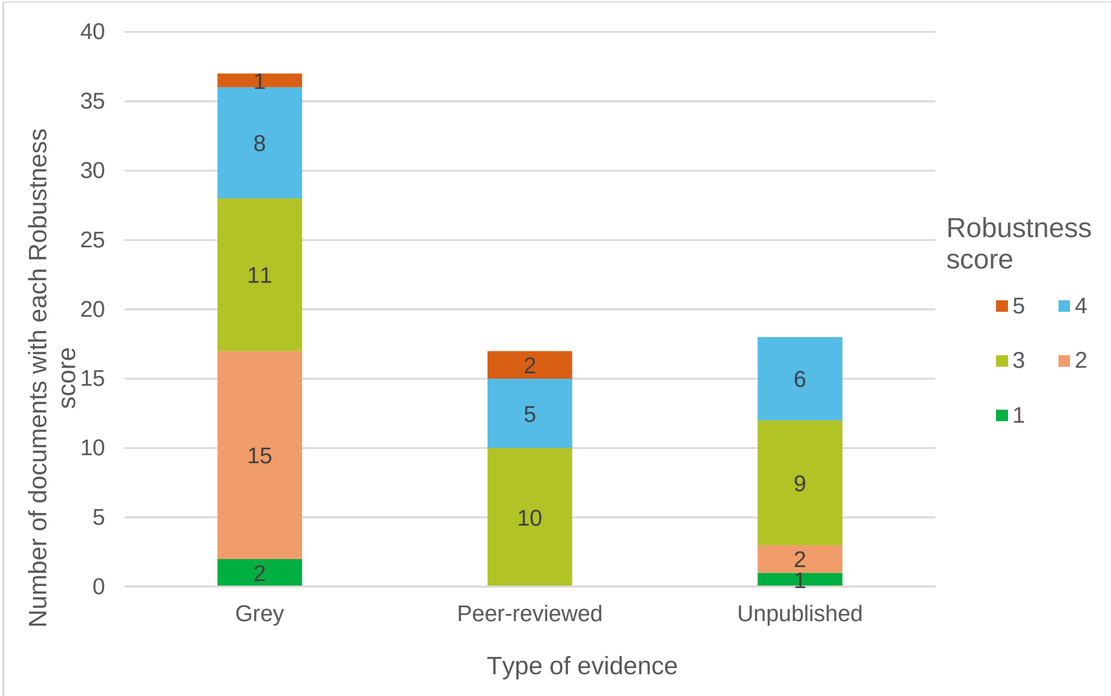


Figure B-2 Overview of the systematic map – Robustness of data

As the project included a high level of data gathering, in a number of cases evidence which was not very robust has been included in the review because it did provide some information regarding groundwater flood risk management and helped to provide an overall understanding. Additionally, where evidence was specifically provided to be included in the review, this was incorporated and retained in the systematic map even if it did not provide a high level of relevant information – this mostly applied to weblinks and short documents.

The overall robustness and relevance criteria were multiplied together to provide an overall grade of the evidence from 0 to 15.

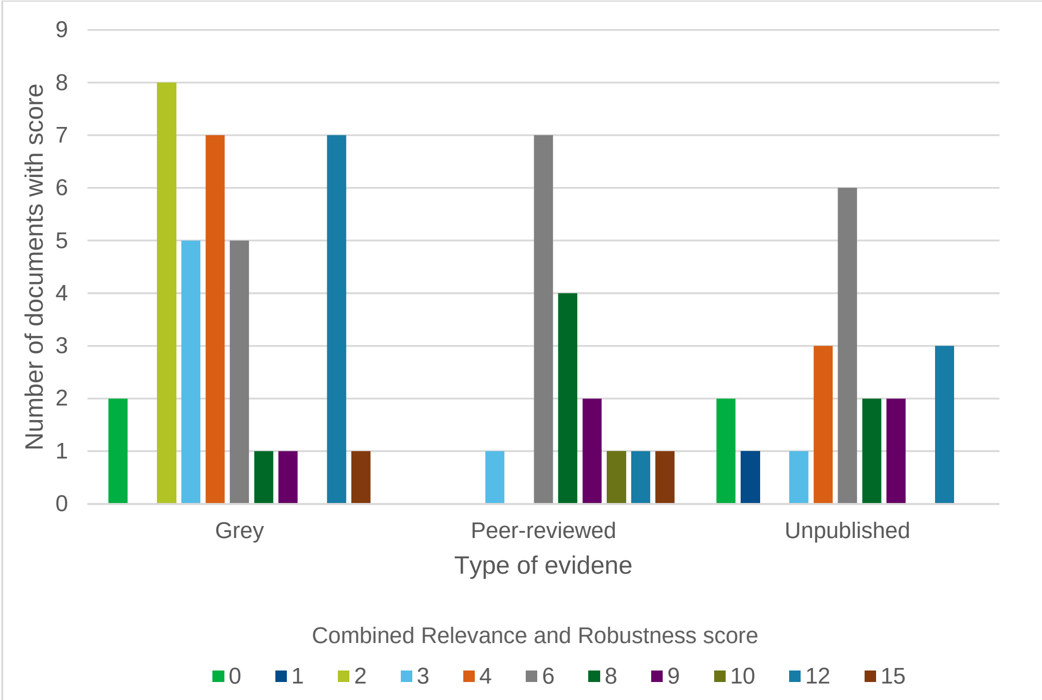


Figure B-3 Overview of the systematic map – combined robustness and relevance of data

The results of multiplying robustness and relevance can be seen in Figure B-3. The total scores vary across evidence type. The most common score for both the peer-reviewed and unpublished literature is shown as 6, while the most common score in the grey literature is 2.

In order to provide due weight to the more relevant and robust evidence, data with an overall score of 10 or more are included in the narrative reporting. All data with a grade above zero are included in figures, maps and summaries. In some cases, data with a grade of less than 10 have been included in the narrative where particularly relevant. In some aspects of the review there has been limited data available, for instance in some areas of the country or in some aspects of the secondary questions; in these cases, including of less robust/relevant data has provided some level of information.

B.5 Evidence summary

The evidence judged to be sufficiently relevant and robust was carried forward and used to generate summary findings to answer the primary and secondary questions. For this study, all data graded more than zero was included within the summary. This only excluded evidence that was not relevant to the study. Evidence that was less robust was given a lower grade but still included in the study as some evidence was viewed as better than no evidence in answering the questions.

These findings were derived from exploratory data analysis of the results of the systematic map, which identified, for example, particular evidence on which there is more consensus. This information was also used to identify gaps in the evidence and possible future directions for groundwater flood risk management activities.

B.6 Outputs

Table B-5 Deliverables

Document	Filename	Description
Search 1	Search results.csv	Full list of searched literature from academic database search and literature sourced internally.
Search 2	Search results removing duplicates and warning words.csv	Full list of searched literature after removing results duplicated between sources and screened using a list of warning words.
Screening	Screening.csv	Full list of literature remaining after manual screening phase, including the list of inaccessible sources and reviewers of each source.
Systematic map	Systematic map – final.xls	Full list of literature reviewed, including extracted evidence related to primary and secondary questions and critical appraisal scores.

C Information gathered through consultation

C.1 Steering group

Name	Organisation
Josie Bateman	Environment Agency
Hayley Bowman	Environment Agency
Mark Whiteman	Environment Agency
Geoff Parkin	Newcastle University
Ruth Burnham	Northamptonshire County Council
Jessica Fox	Hull City Council
David Martin	Wessex Water

C.2 Survey questions

Locality / organisation information

Q1 Please tell us which part of England you work in. If you are able to select one or more Lead Local Flood Authority location to describe the areas you cover this would be helpful to our research. We will ask questions later on that will refer back to the location(s) you select.

Q2 Please tell us the organisation or group you are responding on behalf of.

Q3 Do you have experience of groundwater flood risk management? (Y/N)

Q4 Have you had any specific training related to groundwater flooding or groundwater management? (Y.N)

Q5 Do you have access to or use others with specialist knowledge of groundwater flooding or groundwater management (Y/N)

Groundwater Governance

Q6 Do you or your organisation undertake work that relates to a statutory responsibility for groundwater flood risk management? (Y/N/DNK)

Q7 Do you work with other organisations to deliver groundwater flood risk management? (Y/N)

Q8 Which organisations do you work with to deliver groundwater flood risk management? Tick all that apply. Please provide more information on locality/function/team in the comment box.

Q9 Please leave a comment about any relevant documents you have that summarise current governance roles and responsibilities which we could access for our research, and web link if possible.

Groundwater flooding

Q10 Are there areas at risk of groundwater flooding? (Y/N/DNK)

Q11 What are the causes of groundwater flooding?

Q12 How much is groundwater flooding an issue?

Q13 If you'd like to leave a comment about the chance or mechanisms of groundwater in your area please do so here.

Groundwater monitoring

Q14 Do you want to answer questions about groundwater monitoring?

Q15 Do you or your organisation monitor groundwater levels for flood management purposes? (Y/N/DKN)

Q16 Do you use groundwater monitoring data (from your own organisation or others')? (Y/N/DKN)

Q17 What type of monitoring data do you use for groundwater flood risk management purposes?

Q18 In groundwater flood risk management what do you use this monitoring data for?

Q19 If you'd like to leave a comment about groundwater monitoring (processes, knowledge / skills) please do so here.

Groundwater flood records

Q20 Do you want to answer questions about groundwater flood incidents and records? (Y/N/DKN)

Q21 Do you (or your organisation) record groundwater flood incidents? (Y/N/DKN)

Q22 Please tell us where the data comes from and when it is recorded.

Q23 Which other organisations, that you know of, record incidents of groundwater flooding? Tick all that apply.

Q24 How are groundwater flood incidents recorded? Tick all that apply.

Q25 What information is recorded? Tick all that apply

Q26 How are the records used? Tick all that apply.

Q27 Have there been any incidents when groundwater flooding has occurred at the same time as flooding from other sources? (Y/N/DKN)

Q28 What are those other sources of flooding? Tick all that apply.

Q29 If you'd like to leave a comment about groundwater flood records (processes, knowledge / skills) please do so here.

Groundwater flood risk assessment

Q30 Do you want to answer questions on groundwater flood risk assessment? (Y/N)

Q31 How well do you think the chance of groundwater flooding and potential impacts are understood?

Q32 Can you estimate the number of properties susceptible to groundwater flooding? (Y/N)

Q33 If applicable, can you estimate the number of properties susceptible to groundwater rebound?(Y/N)

Q34 Can you estimate the number of properties susceptible to groundwater flooding in the future with climate change?

Q35 Do you or your organisation use maps / computer models / other products to determine the risk (chance and impact) of groundwater flooding? (Y/N/DKN)

Q36. Do you use national model/map products? (Y/N/DKN)

Q37. If you know which organisation produced the national model/map/product(s) you use, please tell us if you are happy to.

Q38 What level of accuracy do you perceive the national groundwater flood models and/or maps you use to have?

Q39. Do you produce your own groundwater flood models/maps? (Y/N)

Q40 What level of accuracy do you perceive your groundwater flood models/maps to have?

Q41 If you'd like to leave a comment about groundwater flood risk assessment (processes, knowledge / skills) please do so here.

<u>Groundwater Flood Forecasting</u>

Q42 Do you want to answer questions on groundwater flood forecasting? (Y/N)

Q43 Do you use the Joint Environment Agency/Met Office Flood Forecasting Centre's groundwater flood forecast?

Q44 What data is used in the groundwater flood forecasting system you use? Tick all that apply.

Q45 If you'd like to leave a comment about groundwater flood warning (data / systems / processes / knowledge / skills) please do so here.

<u>Groundwater flood warning</u>

Q46 Do you want to answer questions on groundwater flood warning? (Y/N)

Q47 Does your organisation issue groundwater flooding warnings?

Q48 Roughly what proportion of the areas susceptible to groundwater flooding can receive warnings?

Q49 Are groundwater flood warnings issued by the same systems used for warning about other types of flooding?

Q50 If you'd like to leave a comment about groundwater flood warning (data / systems / processes / knowledge / skills) please do so here.

<u>Groundwater flood mitigation, resilience and adaptation</u>

Q51 Do you want to answer questions on groundwater flood mitigation, resilience and adaptation? (Y/N)

Q52 In your opinion what level of action is taken for groundwater flood risk management?

Q53 Is groundwater flooding considered in spatial planning processes (e.g. through strategic flood risk assessments/local plans etc)?

Q54 Are you aware of any specific guidance for developing and delivering groundwater flood mitigation schemes? (Y/N)

Q55 Have any groundwater mitigation, resilience or adaptation schemes been delivered? (Y/N/DKN)

Q56 How many schemes have been delivered since 2010?

Q57 Please tell us about the types of mitigation measures that have been used for groundwater flooding. Tick all that apply

Q58 We would like to know more about these schemes. Please can you tell us the location(s) of them or where we could find out more about them (either online or direct contact with an organisation/team)?

Q59 Please provide further comments below if you would like to tell us your experience of planning and delivering groundwater flood mitigation or resilience measures in your locality.

<u>Opportunities and barriers to delivering groundwater flood risk management</u>

Q60 Please tell us your opinion of how well the following areas of groundwater flood risk management are understood (knowledge/skills) and implemented (processes/systems in place)

Q61 In your opinion generally what helps to deliver groundwater flood risk management?

Q62 In your opinion generally, what can hinder groundwater flood risk management?

C.3 Semi-structured interview questions

1. **Governance of groundwater flood risk management in England (for local authorities)**
    a. What are your roles and responsibilities for groundwater flood risk management in England?
    b. Have the current governance arrangements been appraised or reviewed?
    c. Which parties do you work together in groundwater flood risk management?
    d. How well do the relevant parties work together? Score 1 (no collaboration) - 5 (excellent collaboration)

2. **Recording groundwater flooding/access to historic records (for local authorities)**
    a. Do records of flooding get reported? (Where, when, how - for example, local/national databases?)
    b. Is there a consistent process for recording groundwater flooding? What is this process?

3. **Groundwater flood risk assessment (non-real time) (for modellers / software stakeholders, consultants)**
    a. Do you use/generate national scale risk assessment information? If so, what national scale risk assessment information do you use/generate?
    b. Do you use/generate local risk mapping techniques? If so, what local risk mapping techniques are used/generated?
    c. What are the current risk assessment (modelling and mapping) approaches do you use/generate?
    d. What are the methods of this risk assessment approach?
    e. What software, if any, do you use to complete your risk assessments?
    f. What are the data inputs required?
        i. Data origin type - Analytical theory, modelling, or observational?
        ii. Data inputs - rainfall, borehole water level data, geology, river levels, terrain, abstraction, weather forecasts
        iii. And what are the data outputs, model scenarios?
    g. What are the model scenarios and validation method used?

h. Where is it published? Who publishes it?

i. Can you estimate the number of properties at risk of groundwater flooding? How many and in what area/location

j. Is climate change considered?

k. What are the limitations to this method of risk assessment?

4. Groundwater flood forecasting and warning (real-time) (for modellers/software stakeholders, consultants, and local authorities)

a. Do you use/run a groundwater flood forecasting system? If so, what groundwater flood forecasting systems do you use or operate?

b. Is this at a national and/or local scale?

c. What data do these use/need?

    i. Borehole water levels, springs data, river data, rainfall data, flooding data, sewer data, do not know

    ii. And what are the data outputs/model scenarios?

d. What exists for warning of groundwater flooding?

e. How is the groundwater flood forecasting system integrated with systems for other types of flooding?

5. Groundwater flood mitigation (risk reduction and resilience) (for local authorities and the Environment Agency)

a. Have groundwater flood risk management schemes been implemented? If so, could you tell us more about these schemes? When did these take place? Where - local? national? What was the action and how did you measure its success?

b. Is there guidance on developing and implementing groundwater flood schemes?

c. Is there guidance on developing and implementing groundwater flood schemes?

d. What is the spatial scale of this guidance? National? District/local authority, organisation?

e. What practices are used for improving resilience (people and properties) to groundwater flooding?

    i. Property level resistance measures (designed to keep the water out of a property)

    ii. Property level resilience measures (to reduce any impact of flooding)

    iii. Community adaptation (through community flood groups or wardens)

iv. Engineering solution to control groundwater levels at the surface (for example, by channelling, diverting the flow or French drains)

v. Barriers to groundwater – Walls above ground

vi. Barriers to groundwater - Cutoffs - walls below ground surface

vii. Pumping groundwater from boreholes

viii. Pumping from sewers

ix. Pumping from basements/buildings

x. Pumping from other underground structures

xi. Other pumping

xii. Passive drainage measures to take the water away

xiii. Spatial and/or development planning

f. What are the requirements for considering groundwater in spatial planning?

6. Evidence and risk (for local authorities and the Environment Agency)

a. Can you identify the main gaps in evidence gaps in the processes for managing groundwater flood risk against statutory duties and the ambitions of the draft flood and coastal risk management strategy 2019?

D Analysis maps

Map 1 Lead local flood authority areas where groundwater flood incidents are reported

Map 2 Lead local flood authority areas where groundwater flood forecasting occurs

Map 3 Lead local flood authority areas where there is groundwater flood warning

Map 4 Lead local flood authority areas where there are groundwater flood risk management schemes

Map 5 Lead local flood authority areas where evidence data has been gathered against groundwater flood risk

Map 6 Groundwater flood risk in relation to lead local flood authority areas

E Case studies summary

Examples referenced in the report.

Topic	Reference
Conceptual understanding – prolonged heavy rainfall	GeoSmart reports to the Flood Forecasting Centre from South West England.
Conceptual understanding – anthropogenic changes	Mine water rebound risk assessment. MetroGreen, (Mott Macdonald, 2019).
Roles and responsibilities	Incident Management Handbook (Environment Agency, 2020).
Flood records	Flood Investigation Report for the Burton Fleming winter 2012/2013 section 19 report, (East Riding of Yorkshire, 2013).
Flood records	CEH/National River Flow Archive NRFA.
Flood records	BGS/National Groundwater Level Archive.
Flood records	Flood Online Reporting Tool (FORT) – see case study below.
Local risk assessment modelling	Northamptonshire groundwater risk assessment (ESI Ltd 2016b).
Local risk assessment modelling	Oxford, mapping and monitoring, (Macdonald and others, 2012).
Local risk assessment modelling	Mine water rebound risk modelling, MetroGreen development in Gateshead, (Mott Macdonald, 2019).
Local risk assessment modelling	Hampshire Local Flood Risk Management Strategy (Hampshire County Council, 2013).
Local risk assessment modelling	Portsmouth County Council and JBA, 2020.
Local risk assessment modelling	The West London Strategic Flood Risk Assessment, (Metis Consultants, 2018).
Local risk assessment modelling	Southern England (Buckinghamshire and West Berkshire), (Morris and others 2018).
Local risk assessment modelling	Environment Agency Wessex Area coupled MODFLOW-4R groundwater model, unpublished.
Local risk assessment modelling	London Potential for Elevated Groundwater (iPEG) maps – see case study below.
Flood forecasting	GeoSmart flood forecasting tool, (ESI 2016a).
Flood forecasting	Environment Agency CATCHMOD, (RAB 2016, Environment Agency 2005).
Flood forecasting	Thames Catchment Model/CATCHMOD, (Hyslop, 2012).
Flood forecasting	Groundwater flood forecasting model, using CATCHMOD, for Newmarket and Bury St Edmunds, (Williams, 2010).
Flood forecasting	AquiMOD and predecessor R-Groundwater developed by BGS for individual boreholes, (Upton and others 2011).
Flood forecasting	Environment Agency Patcham Brighton, (Adams and others 2010).
Flood forecasting	Hydro-JULES, (CEH, 2020).
Flood forecasting	Environment Agency National Groundwater Modelling System (NGMS), (RAB 2016).

Topic	Reference
Flood forecasting	BGS, GeoRise. (Mansour and others 2017).
Flood mitigation	Pumping in response to flooding, (East Riding of Yorkshire Council, 2013).
Flood mitigation	Compton in Berkshire after 2001; and Buckskin in Basingstoke after 2014 (Buss 2019).
Flood mitigation	Wessex infiltration reduction plans (Wessex Water, 2020). https://www.wessexwater.co.uk/environment/drainage-and-wastewater-management-plan/infiltration-reduction-plans
Flood mitigation	Hampshire County Council local flood risk management strategy action plan (Hampshire County Council, 2013).
Flood mitigation	SFRA for greater Norwich, (Norfolk County Council, 2015).
Flood mitigation	Mine water abstraction Gateshead (Mott Macdonald, 2019).
Flood mitigation	Buckskin Flood Alleviation Scheme – see case study below.
Flood mitigation	General Aquifer Research Development and Investigation Team (GARDIT) scheme for London, (Jones, 2020).

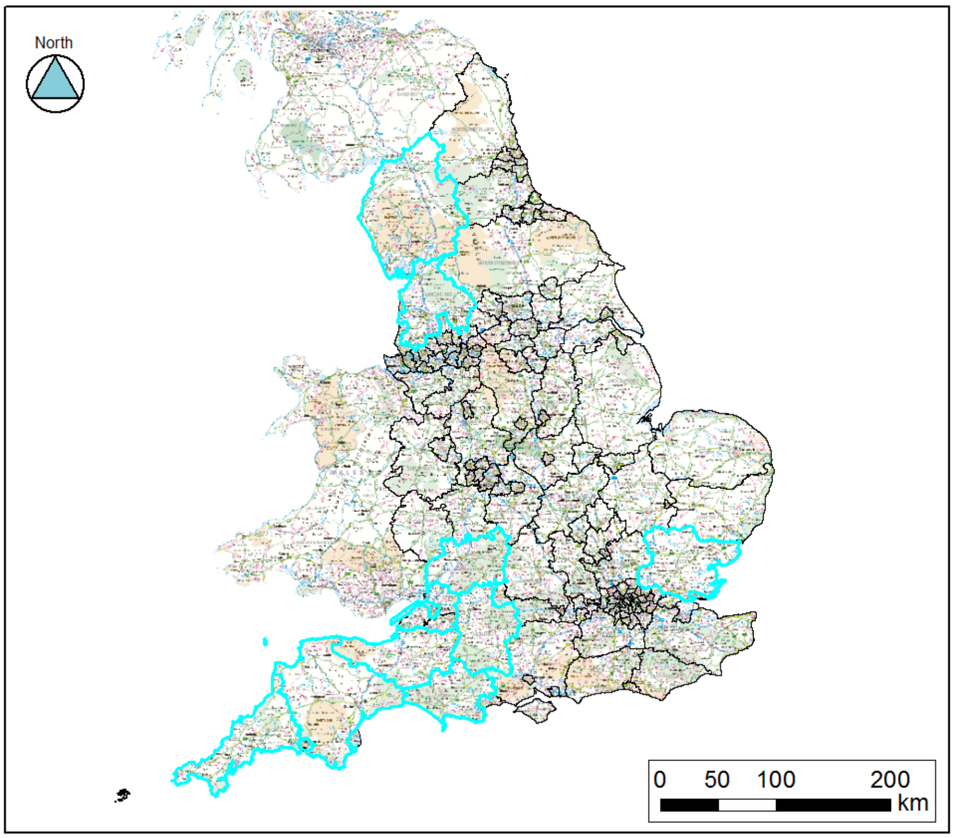
11 Flood Online Reporting Tool (FORT)

11.1 Secondary question: is there a consistent process for recording groundwater flooding incidents?

Organisation(s): Environment Agency with help from the Dorset County Council GIS team.

Date: 2013

Location: Wessex, Devon, Cornwall, Cumbria, Essex and Lancashire.



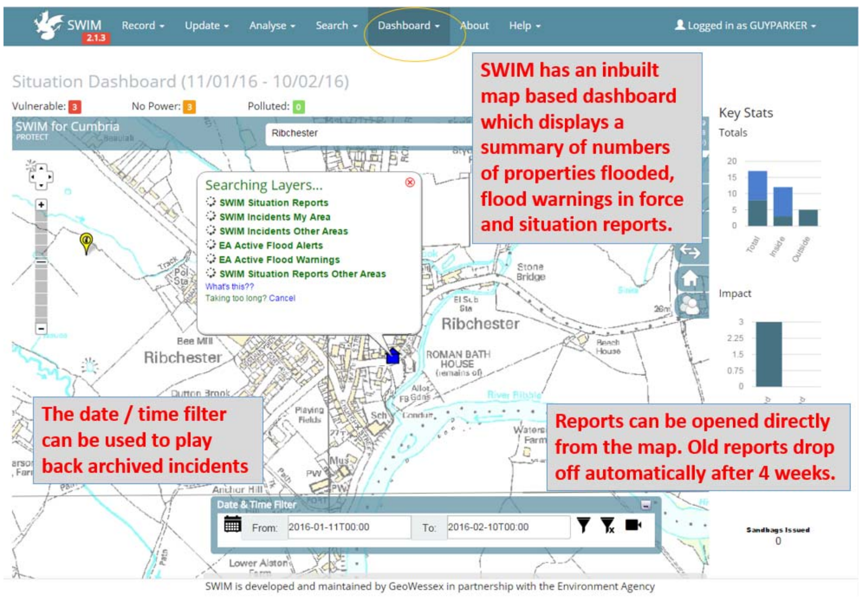
This tool was developed in 2000 and called SWIM (Severe Weather Information Management). It was updated in 2013 to Flood Online Reporting Tool (FORT).

It is an Oracle Geo database web platform, hosted by Dorset County Council (GeoWessex), used by local authorities and the Environment Agency across the south-west and also has been used in Cumbria and Lancashire. Work is ongoing to allow new areas access to this service whenever it is requested by the relevant flood risk management authorities (see hyperlink below for further details).

The FORT system has 5 goals:

1. **Report**: to allow members of the public, flood wardens and flood risk management authorities to enter details about property flooding in one place.

2. **Analyse**: allows flood risk authorities to quickly analyse flood data that can then be used in reports to help inform flood risk management strategies.
3. **Plan**: reports and analysis can be used when assessing new planning options and when assessing proposed flood alleviation schemes.
4. **Protect**: all records are spatially referenced allowing them to be used as a basis for localised protection schemes from community work down to individual property protection.
5. **Network**: the system can be used to help multiple agencies in their combined response to flooding both during an event and after. Data entered into the system is shared appropriately, providing an overall picture of what problems exist over a geographical area. This helps agencies better prioritise assistance both during and after an event. The system doesn't stop there, as it also includes tools to help flood risk authorities work closer with community and volunteer groups to tackle the causes of flooding at the local level.



Wardens are able to produce flood area reports, with specific details such as properties effects and types of flooding, while also being able to quickly share and use data such as searchable photographs and contacts. This can then be quickly disseminated to all partners, such as local authorities, fire services, water suppliers, with the portal having intelligent data forms which share information only to the relevant parties. This platform is the approved data collection tool across the South West Flood Risk Managers Area (Wessex and Devon, Cornwall & Isles of Scilly) and gets its funding from the South West and Wessex Regional Flood and Coastal Committee, with the amount determined by the number of participating local authorities. Although it has been used by other areas (for example, Cumbria) following periods of flooding, any funding from these has been on a one-off basis or use has been allowed on a voluntary basis.

Hyperlink to further detail: https://swim.geowessex.com/uk

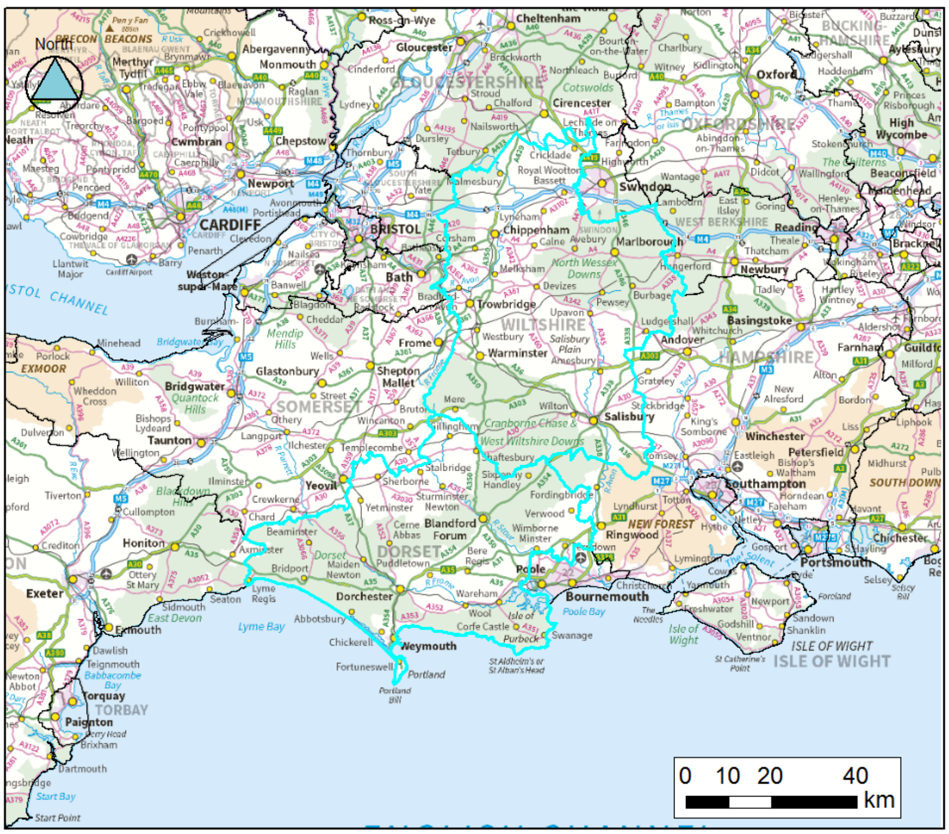
Source: Interview/literature

12 Groundwater flood forecasting and warning in Wessex

12.1 Secondary question: What groundwater flood forecasting systems exist?

Organisation: Environment Agency (Wessex)

Location: Wessex (Dorset and Wiltshire)



In the Wessex area, there has been an increasing need for good groundwater flood forecasting and warnings. There is a large amount of properties requiring groundwater abstraction pumps that need consistent management and maintenance over time. It is difficult to find ideal trigger levels for pumping, as pumping at the wrong time may unnecessarily dewater the aquifer and waste electricity. Ideally, the groundwater flood warning system should be consistent with the current fluvial warning service.

In Wessex, historic groundwater flooding events have shown that there are 3 distinct chalk areas, with different rainfall levels and groundwater responses. The older fractured chalk with greater rainfall has a much quicker emergence response time (2 to 3-week difference to other chalk areas). There is therefore a need to establish discrete geological warning areas based on response type, with separate warnings. To improve this there is a need for a more targeted network of monitoring boreholes, to better characterise the different response areas. Significant events in these areas should then be used for setting impact thresholds.

The Environment Agency (Wessex) investigated various options, including CATCHMOD, but, in the end, decided to use a more deterministic, spreadsheet-based solution. An empirical process model was developed in collaboration with Wood (previously Amec Foster Wheeler) consultants.

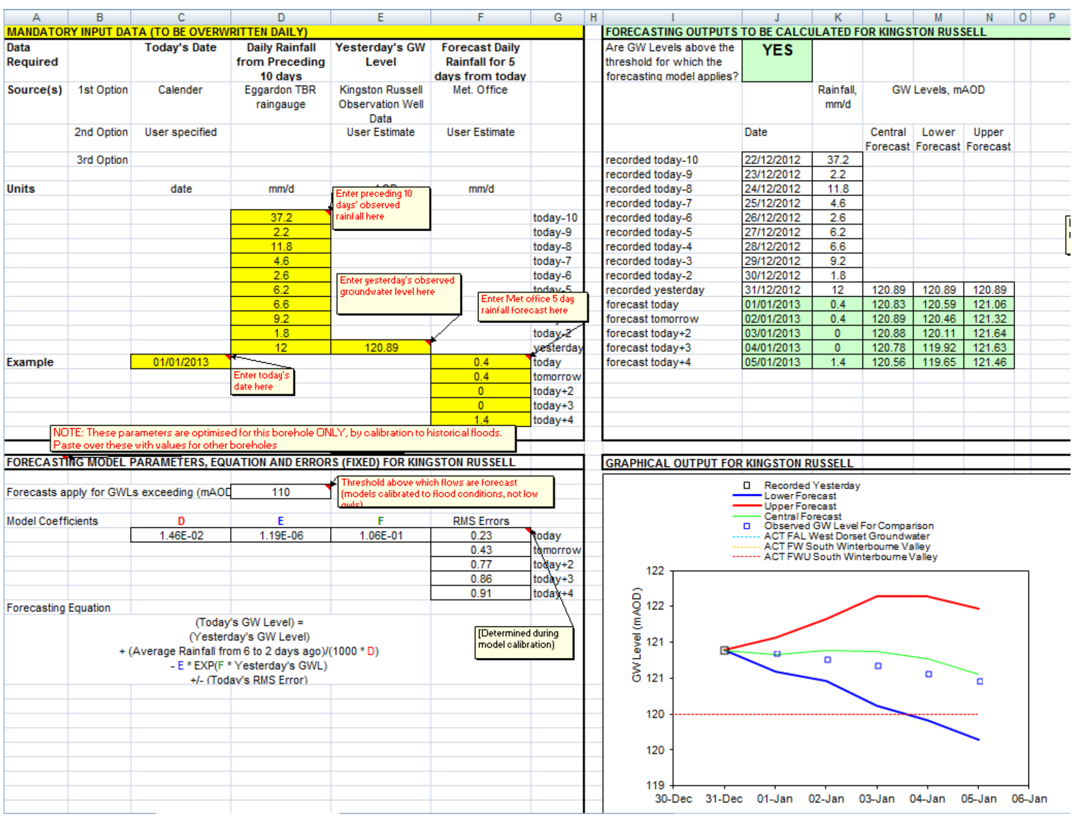
The model is mainly based on the following observed data:

- actual groundwater levels at a monitoring borehole
- latent rainfall at an in-catchment rain gauge
- forecast rainfall over the next 5 days
- local calibration factor.

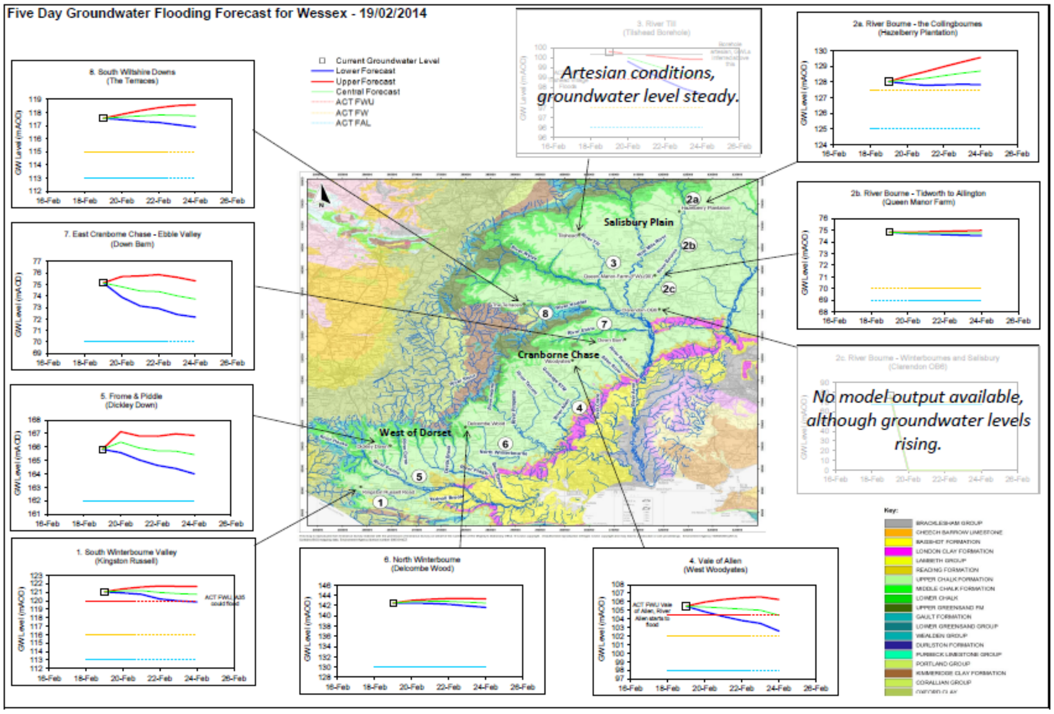
The model generates 3 outputs:

- reasonable best case
- reasonable worst case
- most probable

Outputs are compared to an impact threshold (for example, the onset of property flooding). Other thresholds could be developed in collaboration with the Environment Agency/LLFA partners such as Wessex Water, with indications such as groundwater infiltration in sewers, highway flooding and septic tanks failing.



Data is mostly generated from telemetry, with a summary of all locations sent to partners, and serves as a forecast tool for groundwater flood warnings. The thresholds for removing groundwater flood warnings may use local rivers as a proxy, as when the fluvial flooding peak has passed the groundwater table may remain high for some time afterwards without being an immediate flood risk.



Example 5-day groundwater flooding forecast for Wessex

Hyperlink to further detail: http://enquiries@environment-agency.gov.uk

Source: Interview/literature

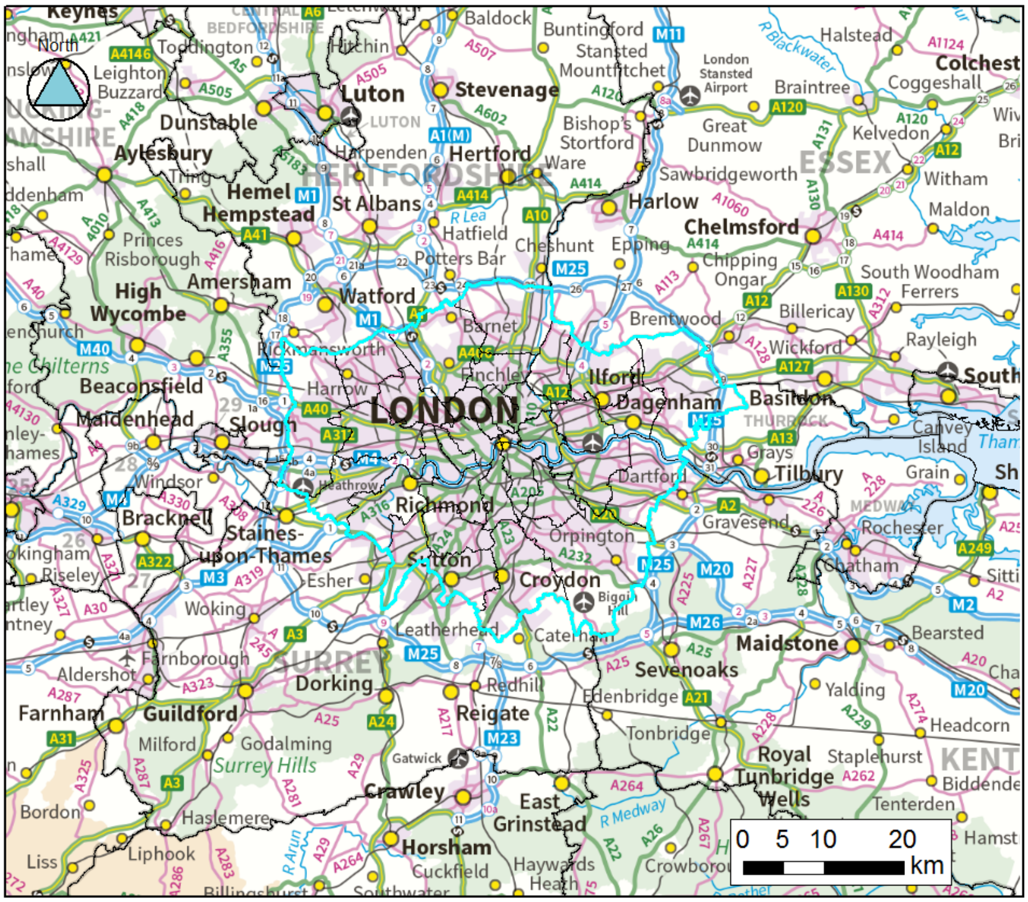
13 London Potential for Elevated Groundwater (iPEG) maps

13.1 Secondary question: What local risk mapping techniques are used?

Organisation(s): Greater London councils/JBA/Jacobs

Date: 2011

Location: Greater London



London councils have combined via the Drain London project to produce specific groundwater emergence maps, known as 'increased Potential for Elevated Groundwater' (iPEG) maps, to help determine the areas within Greater London that are possibly at risk of groundwater flooding (Capita Symonds, 2012).

The iPEG map shows those areas within the borough where there is an increased potential for groundwater to rise sufficiently to interact with the ground surface or be within 2m of the ground surface. The assessment was carried out at a Greater London scale. The 4 data sources listed below have been used to produce the 'Increased Potential for Elevated Groundwater' (iPEG) map:

- British Geological Survey (BGS) Groundwater Flood Susceptibility Map
- Jacobs Groundwater Emergence Maps (GEMs)
- Jeremy Benn Associates (JBA) Groundwater Flood Map
- Environment Agency/Jacobs Thames Estuary 2100 (TE2100) groundwater hazard maps

The iPEG has been combined with records of historic groundwater flooding. The discrepancy between recorded historic incidents and potential areas of future incidents may be attributed to the following:

- past incidents may be a result of localised flooding mechanisms (or other flooding mechanisms) which have not been assessed when producing the iPEG mapping
- the iPEG mapping does not represent local geological features and artificial influences (for example, structures or conduits) that have the potential to heavily influence the local rise of groundwater
- the iPEG map only shows areas that have the greatest potential for elevated groundwater and does not necessarily include all areas that are underlain with permeable geology
- the flood source attributed to some past incidents may not be accurate

Within the areas delineated, the local rise of groundwater will be heavily controlled by local geological features and artificial influences (for example, structures or conduits) which cannot currently be represented. This localised nature of groundwater flooding compared with, say, fluvial flooding suggests that interpretation of the map should similarly be different. The map shows the area within which groundwater has the potential to emerge, but it is unlikely to emerge uniformly or in sufficient volume to fill the topography to the implied level. Instead, groundwater emerging at the surface may simply runoff to pond in lower areas. For this reason, within iPEG areas, locations shown to be at risk of surface water flooding are also likely to be most at risk of run-off/ponding caused by groundwater flooding. Therefore, the iPEG map should not be used as a 'flood outline' within which properties at risk can be counted. Rather it is provided, together with the surface water mapping, to identify those areas where groundwater may emerge and, if so, what would be the major flow pathways that water would take.

Hyperlink to further detail: https://new.enfield.gov.uk/services/environment/flooding---information---surface-water-management-plan.pdf

Source: Literature

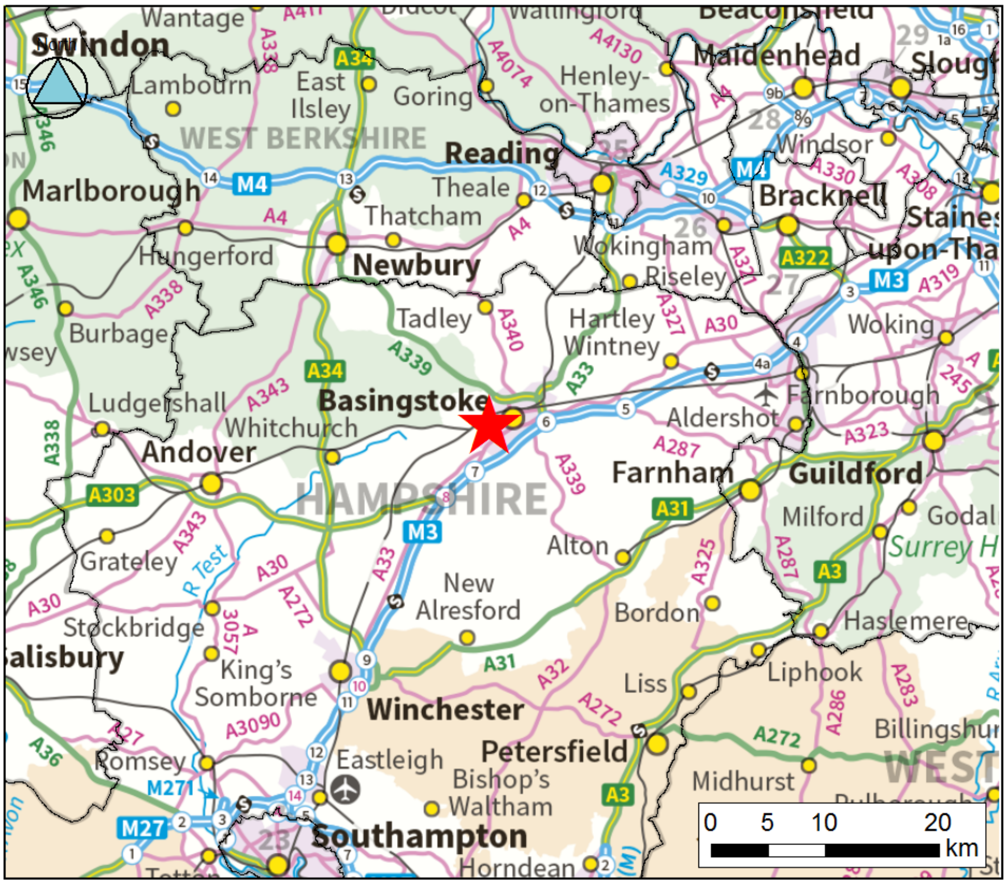
14 Buckskin Flood Alleviation Scheme

14.1 Secondary question: Have groundwater flood risk management schemes been implemented?

Organisations: Hampshire County Council, Basingstoke and Deane Borough Council, Environment Agency, Thames Water Utilities Limited, Sovereign Housing Association, South East Water Limited.

Date: 2018 to 2020

Location: Hampshire



In the winter of 2013 to 2014 Buckskin and the surrounding area was badly affected by flooding. A multi-agency group has been working together with local residents to understand the cause of the flooding and to develop solutions. The Buckskin multi-agency group is made up of:

- Hampshire County Council
- Basingstoke and Deane Borough Council
- Environment Agency

- Thames Water Utilities Limited
- Sovereign Housing Association
- South East Water Limited

In June 2017, the multi-agency group committed to work together to promote and develop the agreed scheme.

Section 19 report

Following the flooding incidents in Buckskin during February and March 2014, Hampshire County Council (HCC) as the lead local flood authority (LLFA) with Basingstoke and Deane Borough Council decided to carry out an investigation in line with section 19 of the Flood Water Management Act 2010 (FWMA). Hampshire County Council decided to contract out this work to a third-party consultant to maintain the objectiveness of this investigation. CH2M HILL (2014) were commissioned to carry out this investigation in March 2014. The flooding occurred between 7 February and the end of March 2014.

Investigation

This investigation focused on specific area of Buckskin that were affected by flooding, namely areas surrounding the Ridgeway Centre, Grampian Way and Basingstoke Golf Centre. Data for the investigation was obtained from the questionnaires circulated to residents, consultations with relevant risk management authorities and stakeholders and site visits.

Conclusions from investigation

Fluvial, surface water, foul water and groundwater flooding all affected the investigation area during the investigation period. 45 properties were reported as flooding (36 internally and 9 externally) by residents in the questionnaire responses. Using the flooding incident maps created for the investigation report, it is estimated that up to 88 properties could have been flooded.

The flooding appeared to be instigated by high groundwater levels which caused a dormant spring to become active and the surface water drainage, formed of soakaways, not to function. This, in turn, caused run-off to follow the historic river course north-east and to accumulate in low-lying areas.

There were 36 properties that reported foul flooding at their property, suggesting that the foul sewer network was unable to cope with the inundation from the groundwater and surface water flooding.

There could be a link between groundwater levels dropping due to increased abstraction from the West Ham Park West boreholes and the apparently fast flood subsidence in the north-east of the Buckskin estate. However, there is no conclusive evidence that this is the case.

Recommendations

Better monitoring of the groundwater, including setting up a threshold at which point actions should be taken, and a review of the multi-agency flood plan to make clear the actions required by RMAs during groundwater flooding.

The limitation of the drainage design and maintenance regime should be assessed to further understand the causes the flooding.

How does the flooding happen?

The main cause of flooding in Buckskin is a rise in the level of groundwater following long periods of heavy rainfall.

When the groundwater rises beyond a certain point, it stops the drainage from working, so any additional rainfall leads to water emerging from the ground and contributing to surface water flooding.

Flood water can enter the foul sewers through inundation (entry through gaps within the manhole covers) or infiltration (entry through cracks and defects in the pipe) causing them to be overwhelmed, which leads to contamination of flood water with sewage.

In future flood events surface water will be collected and removed by the new drainage system, therefore reducing the level of flooding.

Groundwater model

An initial feasibility study was carried out by Hampshire County Council which investigated further the causes of the flooding and assessed the flood mechanisms during the event. A number of possible mitigation options were then identified. The likely effectiveness of these options, as well as any potential adverse impacts on the surrounding areas, was considered. These options focus on managing the flood flows above ground during an event without groundwater assessment. On external review, the Environment Agency identified the need for some quantitative assessment of the groundwater flooding which was carried out by Atkins (2016).

This project aimed to understand the likely volumes of groundwater that the mitigation option would need to transmit, as well as carry out an assessment of the implications of this water being routed directly to the River Loddon.

To meet these aims, a bespoke groundwater model of the Buckskin area has been developed based on a number of existing models:

- regional groundwater model – Environment Agency Regional Mole model
- recharge model – Environment Agency CATCHMOD model
- existing fluvial model – Environment Agency 1D-2D flood model of the River Loddon (ISIS & TUFLOW)

Additionally, a bespoke, high level, 2D only, model of the area upstream of the current Environment Agency 1D-2D River Loddon model has been constructed to allow sufficient above ground analysis of groundwater flows in the Upper Loddon.

Three baseline scenarios were developed:

- 2014 event - 1 in 46 (2.2%) AEP baseline (historical)
- 5% event - 1 in 20 (5%) AEP baseline
- 1% event - 1 in 100 (1%) AEP baseline

The 2014 event historical groundwater model was calibrated against observed groundwater level and river level data as well as the Environment Agency regional Mole groundwater model. The groundwater model provides a good representation of flows in the River Loddon at Pyott's Bridge and groundwater levels at 142 Pack Lane.

The groundwater discharges were compared with peak flows within the original 2012 baseline scenario of the Environment Agency's 1D-2D model of the River Loddon (ISIS-TUFLOW). It was found that for most of the inflow points the groundwater component represents greater than 20% of the fluvial total for the 1 in 100 (1%) AEP. Although for the 5% AEP event, the groundwater flows are an average of 7% of the peak fluvial flow. The peak river levels have been assessed with the addition of the groundwater discharge and it was found that this had no impact on levels.

A number of mitigation options were assessed using the Buckskin model:

- carrier pipe option
- storage area option
- groundwater abstraction option

For the carrier pipe option, groundwater discharges at a number of main locations along the Upper Loddon through Buckskin were simulated and provided to Hampshire County Council to assess the carrier pipe design requirements for these flows.

For flood water storage areas, the simulated groundwater discharges were compared with the available storage area capacity. It was found that for the 2014 event and the 1% event, the available storage area would not be enough to store all the flood water, although it may be of some use in a 5% event (a flood water storage depth of 88cm was predicted).

Additional groundwater abstraction from the West Ham and West Ham Park groundwater abstractions was modelled using the Buckskin groundwater model and this was found to potentially reduce flood flows. However, although the abstraction simulates a significant impact downstream of West Ham Park, groundwater discharges are not reduced in Upper Buckskin. Furthermore, the abstraction rates used are very high and the practicalities of abstracting at these rates are considered to be significantly challenging to implement.

A high level economic appraisal was carried out to estimate the potential benefits of proposed mitigation option(s). Analysis showed that there are reasonable benefits available for a flood risk management scheme, with a minimum benefit value of £1.638 million.

The results from this work have been submitted to Hampshire County Council Engineering Consultancy, who have carried out a review and reassessment of the flood mitigation optioneering.

It is recommended that should any of the 3 mitigation options assessed as part of this study be taken forward to detailed design, more detailed modelling should be carried out. In particular, the calibration of the groundwater model would benefit from collecting spot flow data in the Upper Loddon, allowing the modelled distribution of the groundwater discharges along the Upper Loddon to be confirmed, and refined if necessary.

Aim of the scheme

The aim of the scheme is to better protect people, properties, businesses and infrastructure from the risk of flooding should there be a repeat of the events of 2013 to 2014.

The main objectives of the scheme are to:

- reduce the risk of flooding in a weather event similar to that of 2013 to 2014 without increasing the risk of flooding elsewhere
- reduce the impacts of flooding on the residents of Buckskin, their properties, businesses and infrastructure
- improve resilience to flooding

Project approval

A project appraisal of the scheme was approved by Councillor Humby, Executive Member of Environment and Transport on 24 April 2018. The report provides an overview of the scheme, estimated scheme costs of around £6 million and available funding from central government, the Thames regional flood and coastal committee and the multi-agency partners.

Questionnaire

Between summer 2017 and autumn 2018 a questionnaire for residents and businesses was delivered to over 500 properties in the affected area and an online version was made available to help us understand:

- where groundwater came up
- where water was pumped from
- what access requirements residents and businesses have

The responses to the questionnaire have informed the scheme design and will be used to facilitate access requirements during construction. The questionnaire is now closed.

Indicative programme

Proposed programme subject to consents and permits.

Milestone	**Timescale**
Phase 1 contract award	August 2018
Phase 1 construction starts	September 2018
Phase 1 construction ends	April 2019
Subway pipe construction starts	September 2019
Subway pipe construction ends	November 2019
Phase 2 contract award	October 2019
Phase 2 construction starts	November 2019
Phase 2 construction ends	Summer 2020

Design

The scheme will seek to reduce the risk of flooding by:

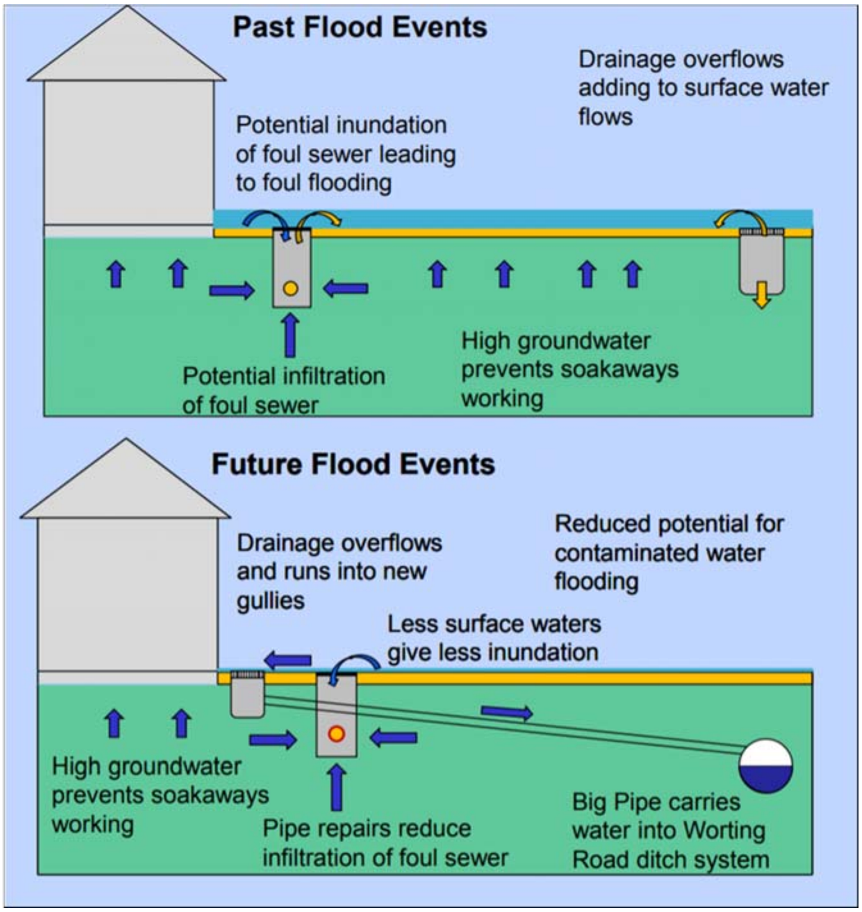
- diverting water away from the properties on the estate into a new large drainage pipe
- providing gullies and collection points along the flow path route in the Buckskin estate footpaths
- improving the connection to the ditches to the north of the Buckskin estate so that floodwater can be effectively drained away

The proposed scheme is being taken forward in 2 phases:

- phase 1 comprises improvements of ditches and upgrades to culverts along Churchill Way West and Worting Road, and improvements of ditches in Saunders Field to improve drainage of floodwater between Buckskin and the start of the River Loddon

- phase 2 comprises the installation of new lateral pipes to collect rising groundwater from between houses in the Buckskin area, and to direct floodwater to a new drainage pipe between the Ridgeway Centre and ditches to the north of Worting Road roundabout

A schematic conceptual diagram of the proposed scheme is shown below.



Hyperlink and contact details:
https://www.hants.gov.uk/landplanningandenvironment/environment/flooding/strategies/scheme-buckskin
Hampshire County Council, Email: buckskin.fas@hants.gov.uk

Source: Interview/literature