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Estimating numbers of properties susceptible to groundwater flooding in England

Groundwater Science Directorate

Open Report OR/15/016

BRITISH GEOLOGICAL SURVEY

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Keywords

Groundwater Flood; England.

Bibliographical reference

MCKENZIE A A & WARD R S. 2015. Estimating numbers of properties susceptible to groundwater flooding in England *British Geological Survey Open Report*, OR/15/016. 16pp.

Keyworth, Nottingham British Geological Survey 2015

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Foreword

A number of different processes can cause flooding that affects properties and infrastructure. The risk of flooding from rivers and the sea has been studied in detail, and assessments and counts of properties in areas at risk have been published. Flooding from intense rainfall and flooding from groundwater are relatively rare occurrences, and less data is available to assess risk.

During early 2014 there was widespread flooding across southern England, some from rivers and the sea, but also groundwater played an important role, either as a primary cause of flooding, or exacerbating flooding from rivers.

During the 2014 flooding the Environment Agency and the British Geological Survey (BGS) worked together to provide advice to government, through the 'Scientific Advisory Group for Emergencies' (SAGE) committee. The committee noted that widely reported estimates of the number of properties that might be affected by groundwater flooding, at a national level, had been produced in 2004, but had not been recently revised or updated.

BGS and the Environment Agency worked together to review and update the existing estimates of the total number of properties in areas that are potentially affected by groundwater flooding. Data from the 2014 flooding was used to refine the property count, recognising that only a small percentage of properties within an area of potential groundwater emergence will actually be impacted by flooding.

Acknowledgements

Data on the extent of flooding from rivers and sea, and reports from Environment Agency staff of incidents of groundwater flooding were provided by the Environment Agency.

Shirley Greenwood and Mark Whiteman of the Environment Agency advised on data sources and methodologies.

Colleagues from the British Geological Survey provided advice and further data on the extent of flooding and the numbers of properties affected.

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Summary

In the wake of widespread groundwater flooding that affected properties and infrastructure in southern England during 2014, a review has been undertaken of the number of properties in England that might be vulnerable during episodes of high groundwater levels, and an estimate made of how many properties might be affected in susceptible areas.

Groundwater flooding can happen in many geological environments, but is a particular problem on Chalk and Limestone aquifers, where around 920,000 properties are in areas where groundwater emergence could occur. This represents fewer properties than previously estimated for these areas. However, a further 3,800,000 properties are in areas underlain by other aquifer types that could be affected by groundwater flooding or shallow water tables.

The actual impact of groundwater flooding on properties is often mitigated by building design or natural/artificial drainage systems which act to lower water tables and move emergent water to rivers. As a result only a small percentage of properties identified above are likely to be impacted by groundwater flooding. Although there is limited observational data, we believe that up to 138,000 properties might be impacted in chalk and limestone areas and up to 151,600 in other areas.

This means the revised estimate of the number of properties in areas at risk of groundwater flooding is between 122,000 and 290,000.

Groundwater may play a role in the flooding of a further 980,000 properties in areas that are also at risk from river and/or coastal flooding. In addition, groundwater flooding is a significant issue for subsurface infrastructure. Note that this latter issue has not been assessed in this report.

1 Introduction

Groundwater flooding is flooding where the pathway for water reaching a receptor, whether a building or other infrastructure, is through flow in the subsurface. Under extreme conditions groundwater recharge from rainfall, or from infiltrating streams and drains, raises groundwater levels in the lower parts of catchments to such an extent that groundwater either impacts buried infrastructure such as sewers and basements, or spills out onto the surface where it can cause problems in-situ, or further down gradient as water flows overland.

Groundwater flooding has only been explicitly recognised as an issue distinct from pluvial and surface water flooding over the last two decades, with the major floods of 2000/2001 giving an impetus to studying and mapping groundwater floods and flooding susceptibility.

A DEFRA sponsored study[1] in 2004 estimated that 1.6 Million households in England were in areas potentially vulnerable to groundwater flooding during an extreme event. This figure has been widely quoted as representative of the scale of groundwater flood risk, although the many caveats within the report are often marginalised.

Following a renewed and extended episode of groundwater flooding in Southern England in the spring of 2014, the Environment Agency and BGS have revisited the estimates of the number of properties that are in areas with a groundwater flood hazard, with the aim of providing better estimates in a similar way to those prepared for flooding from rivers, the sea and surface water.

[1] Strategy for Flood & Coastal Erosion Risk Management: Groundwater Flooding Scoping Study (LDS 23) – Final Report, Jacobs GIBB Ltd, May 2004

2 Previous Estimate

The DEFRA report calculated the number of properties at risk from a count of properties lying within zones defined on Groundwater Emergence Maps (GEMS) that were prepared as part of the study. The GEMS maps are composites, with a geological base, using information on aquifer properties, groundwater levels and reported flood incidents to define areas where groundwater may reach the surface or impact on infrastructure. The coverage of the GEMS maps was limited to major aquifers (as defined by hydrogeological mapping – not the former Environment Agency definition of major aquifers). 6.4 million properties (from OS Address point data, which can underestimate the true number of properties in an area) were located on these major aquifer units. Of these, 1.7 million were located in the GEMS zones, the majority on Chalk.

This value was refined by removing 100,000 properties that fell within the areas at risk of flooding from rivers and sea in a flood with a 1 in 100 chance of occurring in any year, and so were considered more likely to be at risk from surface water flooding. Of the remaining 1.6 million properties 380,000 were on the Chalk in the areas of Southern England considered most at risk from groundwater flooding.

The report recognised that far fewer than 1.6 million properties were affected in the 2000/2001 event - because the actual emergence of groundwater is affected by local factors and geological heterogeneity, and also because in the topographically lower portions of the GEMS zones, drainage systems and construction methodologies will mitigate the actual impact of a flooding event.

The report also considered the impact of groundwater level rebound in areas where, because of urban water abstractions or mining, groundwater levels were historically artificially depressed. No separate estimates of the number of properties that may be affected were given. The interrelationship between river flooding and permeable superficial deposits (see below) was also not part of the DEFRA study.

3 Review methodology

3.1 BACKGROUND

The Environment Agency have flood risk mapping for three different types of flooding; flooding from rivers, the sea and surface water. These maps are used in conjunction with the National Receptor Database (NRD), a GIS of properties and infrastructure, to calculate the number of properties that lie within areas with a 1 in 100 and 1 in 1000 chance of occurring in any year[2]. Comprehensive records of households and other properties affected by groundwater flooding are not available, for England and Wales. Some of the reasons for this are discussed below.

3.2 DATA ON POTENTIAL OCCURRENCE

BGS has prepared GB-wide groundwater flood susceptibility maps[3] – on a 50 metre grid, with a nominal resolution of 1:50k. The maps are effectively an amalgamation of datasets on permeability and on groundwater level (either observed or estimated) to identify shallow groundwater.

The dataset recognises two modes of groundwater flooding – 'Clearwater' when groundwater levels rise in an unconfined aquifer in response to recharge higher in the catchment (which can be further subdivided into flooding from Chalk and Limestones, and flooding from other aquifers) and 'Permeable Superficial Deposits' (PSD) where surface water can move through sands and gravels and cause flooding adjacent to a watercourse.

Four classes of groundwater flood susceptibility are defined:

C: Potential for groundwater flooding to occur at surface, emergent

B: Potential for groundwater flooding of properties situated below ground level, affecting infrastructure

A: Limited potential for groundwater flooding to occur

D: Not considered to be prone to groundwater flooding

Assumptions:

Susceptibility doesn't mean that flooding will occur, and ignores anthropogenic factors that might reduce risk – e.g. drains, cut-off walls or elevation of infrastructure above ground level.

3.3 DATA ON ACTUAL OCCURRENCE

Data on actual occurrences of groundwater flooding comes from 3 sources.

- Recorded information. This includes incidents logged by the Environment Agency at household level. Some data may also be collected by Department for Transport (for roads), water companies (for sewers), the fire service, local authorities and insurance companies. At local level this may be complemented by reports from flood wardens and other local groups. With the exception of the Environment Agency data, these reports are not centrally collated.
- Systematic survey. This may include mapping during flood events, either on the ground or using remote sensing/aerial photography.
- Reports. Published and unpublished reports and literature on groundwater flooding and local hydrogeological conditions.

[2] Flooding in England: A National Assessment of Flood Risk, Environment Agency, 2009.
[3] http://www.bgs.ac.uk/research/groundwater/datainfo/GFSD.html

Assumptions:

Logged incidents may fail to distinguish between flooding from rivers, surface water and groundwater incidents, and incidents may have multiple causes.

Groundwater flooding incidents are relatively rare, and were not systematically recorded before 2000/01. Each episode of flooding is driven by unique spatial distributions of rainfall, and it is likely that there are areas where flooding may occur, but where it hasn't occurred since detailed records began.

Logs of incidents represent reports, rather than occurrences. Households may not report for a variety of reasons, including familiarity, where incidents are common, assumption that authorities are already aware or perceptions that reporting won't make any difference.

Aerial survey is likely to be limited to groundwater flooding at the surface, and is unlikely to detect shallow groundwater, sewer surcharge and flooded basements.

3.4 INITIAL APPROACH

To estimate the number of properties that may be affected by groundwater flooding groundwater susceptibility mapping has been used, supplemented by data from the Environment Agency on reported incidents during the 2013/14 flooding event.

a) BGS groundwater flood susceptibility has been used to highlight the areas where groundwater flooding might occur, distinguishing the source of flooding, the geological environment and whether water is likely to reach the surface or affect buried infrastructure. The classes used were:
   i) Clearwater flood susceptibility on Chalk and limestone aquifers, emergent or affecting infrastructure
   ii) Clearwater flooding on other bedrock aquifers, emergent only
   iii) Permeable superficial flooding, emergent only

b) Properties within the different areas have been summed. This was carried out using counts of residential properties from the NRD, coupled with an allowance for non-residential properties of a further 33% (NRD estimates of properties are more accurate than postcode based estimates, which may be 40% smaller).

c) Results were compared to the area that is considered to have at least a 1:1000 chance of flooding in any year from river or sea.

d) The number of properties in a susceptible community was compared to reported incidents where data were available to calculate the percentage of properties vulnerable to flooding.

Assumptions:

This approach works well on outcrop Chalk where the flooding process is straightforward, and good observations are available, on other geologies there will be greater uncertainty.

Estimating the total number of properties affected from reported incidents requires expert judgement.

No account is taken of differences in occurrence and reporting between urban and rural areas. This may lead to an over estimate of affected properties in urban areas where more developed drainage and sewer systems are expected to reduce receptor vulnerability.

It is assumed that groundwater flooding processes are similar across a geological unit, so estimates of susceptibility and vulnerability based on recent events are applicable in areas outside the footprint of the 2013/14 event.

It needs to be emphasised that this approach is designed to estimate the number of properties that might be affected in a statistical manner, not to identify individual properties at risk.

4 Results

4.1 COUNTS OF SUSCEPTIBLE PROPERTIES

The table below summarises the result of the estimate of properties that are in areas susceptible to groundwater flooding. On chalk and limestone aquifers 1,060,000 properties were identified as being in areas susceptible to Clearwater flooding. If properties that are also at risk from river and coastal flooding are eliminated from the count this is reduced to 920,000 properties.

For other aquifer types, 650,000 properties, or 580,000 when those also at risk from river and coastal flooding are eliminated, are in areas susceptible to Clearwater flooding.

4,000,000 properties, or 3,210,000 when those also at risk from river and coastal flooding are eliminated, are in areas susceptible to Permeable Superficial Deposit flooding.

Table 1: Properties in areas susceptible to groundwater flooding

	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**

4.2 ESTIMATES OF THE NUMBER OF PROPERTIES AFFECTED

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.

To assess the relationship between properties in flood susceptible areas and properties affected we examined reports of flooding received by the Environment Agency during the 2013/14 flood, which focussed strongly on the Clearwater Chalk flooding in Oxfordshire, Berkshire and along the South Downs. The ratio of properties in susceptible areas to reports of flooding is highly variable within individual affected communities, but across the counties an overall figure of between 5% and 15% of susceptible properties appear to have been impacted.

Assuming that vulnerability to hazard is similar across areas of the Chalk and Limestone aquifers where reports were not analysed, and outside South East England where the 2014 groundwater flood event was focussed, this implies 46,000 to 138,000 properties might be affected.

Estimating the number of properties that may be affected in other aquifers is hampered by lack of systematic observations. Large numbers of properties have been affected in susceptible areas, e.g. on Humberside in 2007, and in 2014 on the lower Thames, but the majority of affected properties have been in areas also at risk of flooding from river and sea as well.

Assuming that the lack of systematic observation is largely driven by the rarity of impact, we estimate that perhaps 2% to 4% of properties may be affected in other aquifers susceptible to Clearwater flooding, i.e. 11,600 to 23,200 properties. If similar vulnerability exists for areas affected by permeable superficial deposit flooding, it implies that between 64,000 to 128,000 properties may be affected. In addition there are 214,000 properties in areas of clearwater groundwater emergence and a further 770,000 on permeable superficial deposits where groundwater may exacerbate a flood from river or sea with a 1 in 1000 chance of occurring in any year.

Table 2: Estimate of properties affected.

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

5 Discussion

The methodologies used in the 2004 Defra report that estimated that 1.6 million properties were located in areas where groundwater flooding could occur used a relatively simple model of groundwater levels, and a relatively narrow range of geological and hydrogeological conditions. We have calculated a revised estimate from BGS groundwater flood susceptibility mapping. The DEFRA estimate was focussed on major aquifers, and in particular the Chalk, and so should be compared to the new estimate of the number of properties in areas where clearwater flood emergence on Chalk and Limestone is possible - 920,000 properties. This smaller estimate of properties in areas where groundwater emergence might occur results from the use of a more detailed model of groundwater level, and a more conservative estimate of potential rise in groundwater levels than was used in the 2004 DEFRA report. If account is taken of the difference in accuracy of an NRD property count and the earlier postcode estimates, the difference is even larger.

Flooding from groundwater on other aquifers and in permeable superficial deposits was not quantified previously. We estimate that there are 580,000 properties on other aquifers, and 3,210,000 on superficial deposits.

The estimates of the number of properties in zones where groundwater emergence is possible need to be qualified by the fact that only a small percentage of these properties may be vulnerable and directly affected by an event (although secondary effects such as sewer surcharge and flooding of roads may also be a factor). Local topography, and adaption, for instance the construction of land drainage and sewers, reduce the number of vulnerable properties. Based on the analysis of flooding observed during early 2014, and taking a mid-range value for the numbers of properties at a similar level of risk, we would estimate that around 205,700 properties are actually at risk in the event of groundwater flooding of similar severity.

The total number of properties in areas at risk from groundwater flooding is now estimated to be between 122,000 and 290,000.

Our estimate is focussed on flooding with a direct impact on properties. Groundwater flooding may have secondary impacts, for instance disruption to transport, sewer surcharging and damage to agricultural productivity.

Improved estimates of both groundwater flood susceptibility and receptor vulnerability are possible, at least on the Chalk where a combination of higher resolution groundwater level mapping, an inventory of historically flooded properties and modelling of where emergent groundwater runs off the landscape would all be valuable. On other aquifers the priority should be to improve the understanding of when shallow water tables give rise to flooding events.