

APPENDIX D: GROUNDWATER ANALYSIS

Contents

D.1	Groundwater flooding susceptibility.....	2
D.2	Approach to assessing the impact of climate change on groundwater	2
D.3	Climate change indicator: frequency of high groundwater levels for clearwater flooding ...	4
D.4	Climate change indicator: frequency of high groundwater levels for permeable superficial deposits flooding	6
D.5	References.....	6

D.1 Groundwater flooding susceptibility

Groundwater flooding is a response to changing groundwater levels in the discharge zone of an aquifer. These levels are governed by the amount and timing of groundwater recharge, which is in turn a function of rainfall and evapotranspiration. The relationship between rainfall and groundwater recharge is non-linear – soil moisture deficits need to be satisfied before recharge can take place, and the properties of soil and rock constrain the volume of water that can recharge in a given period. This non-linearity, and the seasonal nature of groundwater recharge, which generally happens in the winter months when evapotranspiration is low, means that projections of groundwater's response to climate change need data on seasonal changes. Projections of future change in groundwater recharge are quite variable, both in magnitude and direction of change. Several projections suggest a short term reduction in recharge, with substantial increases in recharge in 50 to 75 years time. In the Thames catchment, representative of an area of England where significant groundwater flooding has occurred in the past, the probability of future increases in long term recharge is lower.

Note:

Groundwater recharge is very sensitive to changes in land use, and this may well be an additional driver of change. This interaction is excluded here.

It is assumed that climate change will largely affect the frequency of flooding, rather than its spatial distribution at national level. This is reasonable because groundwater discharges are generally constrained by geological and hydrogeological factors, for instance the presence of fractures enhancing local permeability, or lithological variation constraining the location of a spring.

D.2 Approach to assessing the impact of climate change on groundwater

Geological units across Great Britain have been classified in relation to a susceptibility to groundwater flooding, derived from their geological characteristics and observations and models of groundwater depth (Macdonald et al, 2008). The methodology has been extended to Northern Ireland for this analysis, albeit using lower resolution mapping.

Groundwater flood susceptibility identifies relatively large areas where groundwater may be found at shallow depths and where increased recharge may result in flooding. Within these Groundwater Flood Zones (GFZ) groundwater flooding is likely to impact only a small proportion of properties and infrastructure, and the zones are not at a sufficiently detailed scale to recognize individual property susceptibility. The maps do not address the frequency and hence flood risk directly.

Three forms of groundwater flooding are mapped:

- *Clearwater flooding* (from Chalk or Limestone aquifers).
- *Clearwater flooding* (from other aquifers).
- *Permeable superficial deposit flooding* - where groundwater and fluvial systems are well linked.

For each of these the BGS dataset has four classes of *groundwater flood susceptibility*¹:

- **A:** Potential for groundwater flooding to occur at surface (in this class the geology is such that groundwater flooding is possible but considered highly unlikely)
- **B:** Potential for groundwater flooding of property situated below ground level
- **C:** Limited potential for groundwater flooding to occur (but groundwater levels may be near the surface)
- **D:** Not considered to be prone to groundwater flooding (in this class the geology is such that groundwater flows are unlikely to be possible)

¹ Class C represents the highest susceptibility to flooding.

The above are standard BGS and not modified here, however slightly different approaches have been taken across the UK in how the data are used, reflecting differences in geology and rainfall and the observational record of groundwater flooding.

In England and Wales all 3 forms of groundwater flooding are incorporated into the assessment.

In Scotland SEPA have noted that there is a low risk of groundwater flooding in Scotland (as an independent source) but recognize that it could influence the duration of flooding as a result (and in combination with) flooding from other sources. Thus only permeable superficial deposit flooding has been factored into the FFE.

In Northern Ireland the published preliminary flood risk assessment (Rivers Agency, 2011) considers that there is no 'significant risk' of groundwater flooding. We have identified some areas where the geological and hydrogeological conditions for groundwater flood occurrence are present, and have incorporated them in our analysis. In practice distinguishing between groundwater flooding, surface water flooding, fluvial flooding and wetlands can be problematic. Because of the lower resolution of the data, and the lack of observed events, only permeable superficial deposit flooding has been factored into the FFE.

For all areas only those areas prone to groundwater flooding at the surface, susceptibility Class C, have been considered in this analysis.

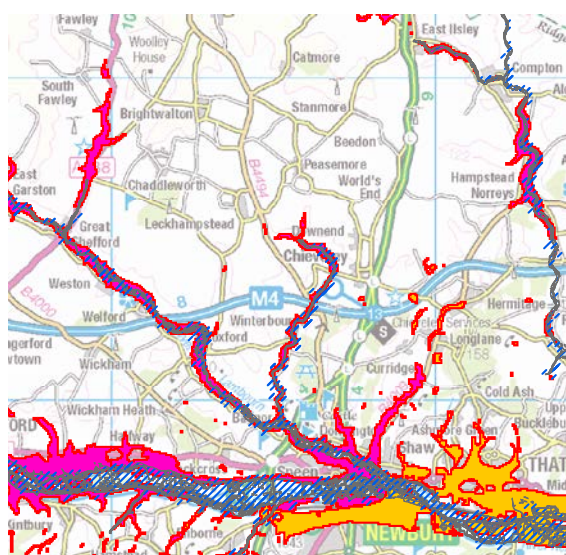


Figure D1 Example of groundwater flood susceptibility mapping.

Note: Purple areas represent Clearwater groundwater flood areas, yellow areas of permeable superficial deposit flooding. Both susceptibility Class C. Blue hatching represents areas at risk of flooding from rivers. (Map derived from BGS Susceptibility data).

The probability of groundwater flooding within an area of susceptibility is not formally defined, as observational data on recurrence is limited, and the frequency of flooding will vary across a susceptible aquifer. For Clearwater flooding, baseline flood frequencies were set using reports of historical flooding and hydrograph analysis for 10 distinct geographic areas within the Chalk and Jurassic aquifers in England. Outside these aquifers, where Clearwater flooding may occur in non-Chalk or limestone aquifers in England and Wales a baseline recurrence interval of 50 years is assumed. For flooding in permeable superficial deposits it is assumed the flood frequency is equivalent to the median flood frequency of the closest fluvial flood area.

Table D1 Baseline frequency for Clearwater groundwater flooding.

Region	Flood recurrence, years
Chalk North Downs + Kent	30
Chalk South Downs	20
Chalk Wessex	15
Chalk Berks/Bucks	25
Chalk East Anglia	50
Jurassic Yorkshire	25
Jurassic South	25
Chalk Yorkshire	30
Chalk Lincolnshire	40
Chalk Hampshire	20
Other aquifers	50

Groundwater flooding does not impact all properties within the area identified as susceptibility to groundwater: Factors for the percentage of properties that will be directly affected by each type of groundwater flood have been generated for different geological situations from historical reports, principally data collected during the 2001 and 2014 events in Southern England, from flooding in England in the summer of 2007, and in North East Scotland in 1997 and 2001. For example, within 1 ha of Clearwater flooding on Chalk it expected that fewer than 10% of the properties within the area will actually experience impacts from flooding (McKenzie and Ward, 2015) and in North East Scotland in 1997 and 2001 (MacDonald et al 2008). It must be recognized that the evidence base for estimating groundwater flooding off Chalk and limestone Clearwater flooding is more credible than on other lithologies, and hence the estimation of 3% of properties in susceptible areas being affected is highly uncertain.

Table D2 Structure for the indicative probability of groundwater flooding

Groundwater flooding	Baseline	Probability and climate
Clearwater flooding, Chalk and Limestone	10% of receptors on groundwater flood susceptibility	Changes in flood frequency from analysis of representative hydrographs.
Clearwater flooding, other aquifers	3% of receptors on groundwater flood susceptibility	
PSD flooding outside flood plains	3% of receptors on groundwater flood susceptibility	Linked to changes in fluvial flood probability
PSD flooding on floodplains	Linked to fluvial flood model	

D.3 Climate change indicator: frequency of high groundwater levels for Clearwater flooding

The spatial extent of areas where groundwater flooding may occur will remain unaltered as the climate changes, only the frequency of flooding changes: As the spatial extent of groundwater is primarily governed by the geology it is reasonable to assume that the areas prone to groundwater flooding remain unaltered.

The Futureflows project has run groundwater models for several different climate scenarios (Jackson et al 2011). Simulations of the groundwater level were prepared for 24 observation boreholes across

major UK aquifers. Models were run for the period 1950 to 2099 for an ensemble of 11 variants of the HadRM3-PPE climate model, each variant corresponding to a different Climate sensitivity, as well as probabilistic predictions of change from a medium and high emission scenario in the 2050s, and a high emission scenario in the 2080s. For use within the FFE we have selected 3 of the models, with a range of climate sensitivities.

For each epoch the change in probability of exceeding 90% of the range of modelled levels is calculated, using the 90% level for 1980-2010 as a baseline.

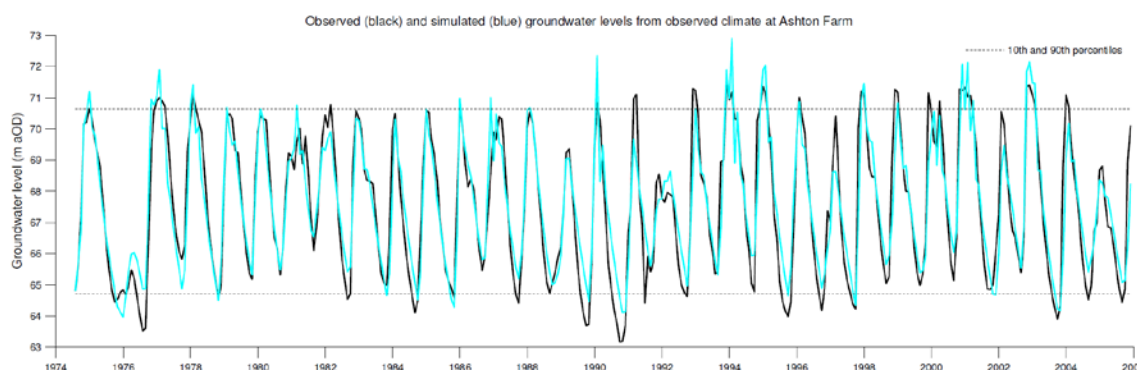


Figure D2 Modelled (and observed) groundwater levels for an observation well, assuming that groundwater flood events occur when levels exceed 90th percentile.

The likelihood of extreme groundwater events is a complex function of climate change, reflecting not only changes in annual rainfall and evapotranspiration, but the seasonality of rainfall, rainfall intensity and temperature, as well as aquifer characteristics and land cover. To assess these changes under the climate change scenarios of relevance to the CCRA the following model runs have been used:

- **For the scenario based on a 2° change in Global Mean Temperature** – The HADRM3-PPEUK-afixa model; which corresponds to a 2.58°K Climate sensitivity was used.
- **For the scenario based on a 4° change in Global Mean Temperature** – The HADRM3-PPEUK-afixk model; which corresponds to a 3.90°K Climate sensitivity was used.
- **For the H++ scenario** – The HADRM3-PPEUK-afixq model; which corresponds to a 7.11°K Climate sensitivity was used.

Based on a comparison between these results and the baseline frequency analysis the following table of change factors has been derived.

Table D3 Change factors for frequency of groundwater flooding.

Region	Baseline recurrence	2020			2050			2080		
		2°C	4 °C	H++	2 °C	4 °C	H++	2 °C	4 °C	H++
Chalk North Downs + Kent	30	1	1	0.7	1.2	0.3	0.7	1.3	0.5	0.5
Chalk South Downs	20	0.8	1.1	0.5	1.8	1	1.5	2	1.9	1.5
Chalk Wessex	15	1	1	1	1.5	0.9	1.3	1.6	1.5	1.6
Chalk Berks/Bucks	25	0.9	0.8	0.9	1.2	0.6	0.7	1.2	0.7	1.1
Chalk East Anglia	50	0.5	0.6	0.7	0.6	0.2	0.3	1.3	0.3	0.4
Jurassic Yorkshire	25	0.7	1	0.8	0.8	0.8	0.8	1	0.4	0.9
Jurassic South	25	0.7	0.7	1	1.2	1	1.2	1.5	1.1	1.2
Chalk Yorkshire	30	0.6	0.9	0.8	0.7	0.5	0.7	1	0.5	0.5
Chalk Lincolnshire	40	0.6	0.9	0.9	0.7	0.6	0.6	1.2	0.5	0.4
Chalk Hampshire	20	0.8	0.7	0.9	1.2	0.7	1.4	1.5	1.2	1.5
Non Chalk/Lst CWF	50	1.2	0.8	1.5	1.2	1	1.7	1.5	0.9	2

*Note: The future frequency is calculated as the baseline frequency * the change factor*

D.4 Climate change indicator: frequency of high groundwater levels for permeable superficial deposits flooding

PSDs are associated with fluvial processes and highly connected with the hydrological processes, reacting to rainfall in similar time frame to the watercourse. Groundwater flooding on permeable superficial deposits is therefore be linked to the frequency of fluvial flood events in the same catchment, and we have used the Ordnance Survey Terrain 50 DTM to link the 1km grid of PSD groundwater flooding to the relevant fluvial flood cell. If a property is affected by groundwater, flooding can be expected to be prolonged increasing the associated damages by 1.2 at the equivalent return period.

D.5 References

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