British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

HYDROLOGICAL OUTLOOK

Outlook based on modelled groundwater levels and seasonal climate forecast

2013

NATURAL ENVIRONMENT RESEARCH COUNCIL

Funding

The research described in this publication has been funded by the Natural Environment Research Council.

Authors

Christopher Jackson, Magdalena Pachocka, Jonathan Mackay

Publication Address

British Geological Survey
Environmental Science Centre
Keyworth
Nottingham
NG12 5BB
UK

General and business enquiries: +44 (0)115 936 3100
E-mail: enquiries@bgs.ac.uk

Report number

British Geological Survey Open Report OR/13/046 (Revision date: 21 October 2013)

Contents

1 Foreword

This document describes the use of Met Office seasonal climate forecasts to produce the one and three month ahead groundwater level forecasts that form part of the UK Hydrological Outlook.

2 General methodology

To forecast groundwater levels we use models that simulate fluctuations in groundwater level at 25 sites across the UK. Each of these models is driven by rainfall and evaporation time-series and has been calibrated against past observations of groundwater level. To forecast the change in groundwater level at a site over the coming one and three months we make use of 1 and 3-month ahead climate forecasts produced by a Met Office climate model. These two climate forecasts are probabilistic. Each consists of an ensemble of up to 42 members, and each member provides a projection of rainfall and temperature into the future. Each member of the two climate forecast ensembles is run through each groundwater model. Consequently, a probabilistic groundwater level forecast is produced for each site. We produce forecasts at sites located in most of the principal aquifers of the UK but currently not all; sites in some aquifers, where groundwater abstraction has significantly modified the observed groundwater level hydrograph, have not been modelled yet.

3 Technical details

The groundwater level forecasts are based on models of groundwater level hydrographs at 25 observation boreholes across the UK (Figure 1). Monitoring at most of these sites started towards the beginning of the 1970s and measurements have generally been made at approximately monthly intervals. All but one of these models were developed as part of a previous collaborative project: Future Flows and Groundwater Levels (BGS, 2013). This project assessed the impact of climate change on the water resources of Great Britain and provides additional information about the sites. The model sites were selected through consultation with the Environment Agency, Scottish Environment Protection Agency and water companies, and based on the following criteria:

- they cover the range of principal aquifer types across the UK.
- the groundwater level time-series is indicative of bulk aquifer storage.
- there is a reasonable length of record (preferably greater than 20 years).
- groundwater abstraction impacts are minimal.
- they are not significantly controlled by surface water levels.

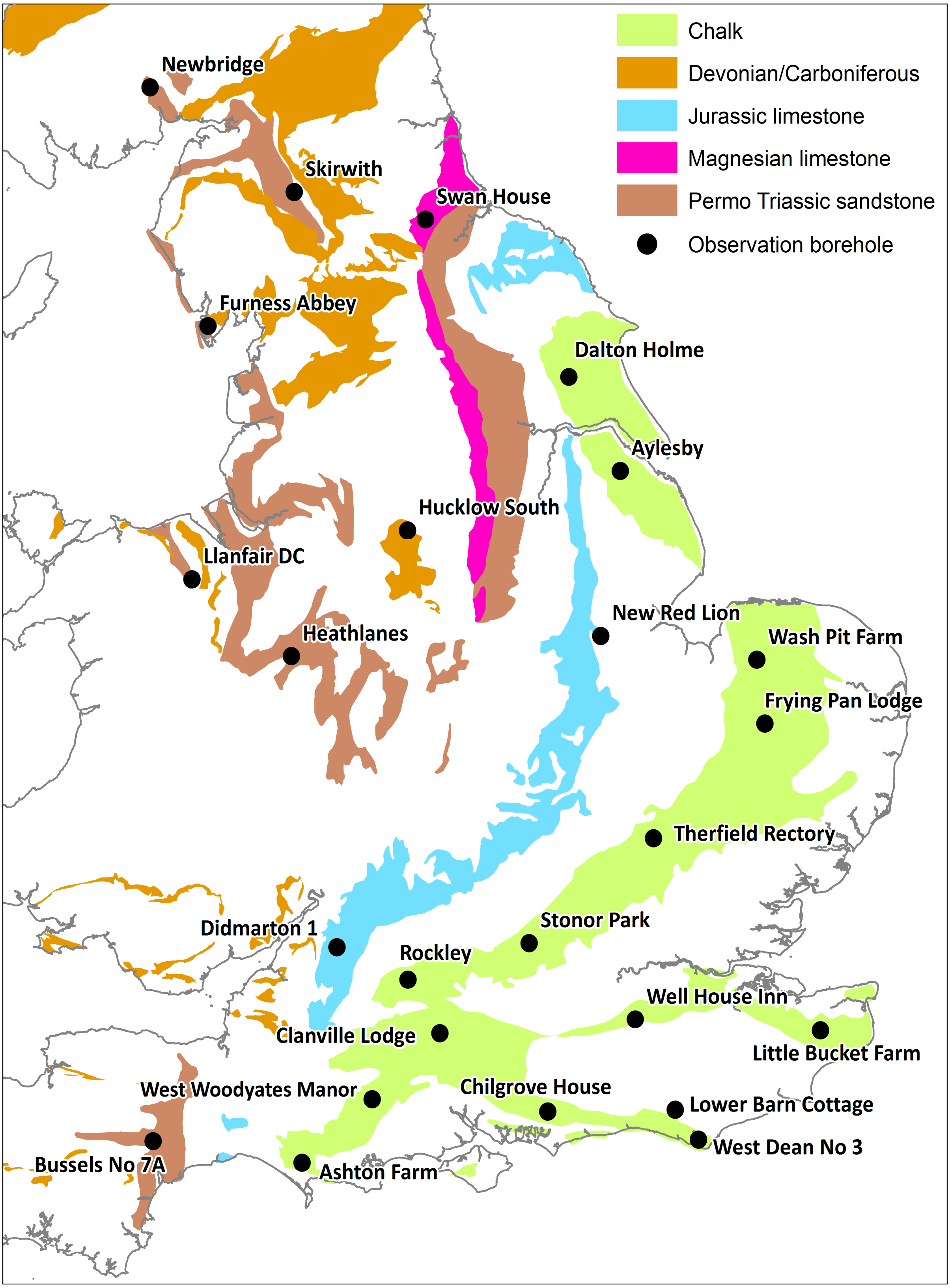

Figure 1 Principal UK aquifers and location of modelled observation boreholes

Of the 25 sites modelled, 14 are located on the Chalk, six on the Permo-Triassic sandstone, four on limestone, and one on the Lower Greensand (Lower Barn Cottage). Due to data limitations and abstraction impacts, currently, there is only one site in Scotland (Newbridge) and one in Wales (Llanfair Dyffryn Clwyd).

To make the forecasts it is necessary to be able to simulate the changes in the historic groundwater level time-series in response to changes in rainfall and evaporation. To do this we use the R-Groundwater model (Jackson, 2012). This conceptualised lumped groundwater catchment model simulates the transfer of rainfall into soil water, and its drainage to the water table over time, which drives fluctuations in the groundwater level. The model is composed of three simple components:

1. a soil water balance model that partitions rainfall between evaporation, surface runoff and potential recharge (or soil drainage),
2. an unsaturated zone transfer function that can delay and spread the arrival of potential recharge to the water table, and
3. a saturated groundwater flow module that simulates flow through, and changes in groundwater head within, a representative aquifer block.

We use a Monte Carlo approach to calibrate each R-Groundwater model against historic observations. Many sets of model parameters are generated by randomly sampling from user defined ranges of values, which have been defined based on hydrogeological knowledge of the aquifers (e.g. the effective porosity, or specific yield, of Chalk aquifers is typically between 0.5 and 2%). Each of these parameter sets is used to run the model and a measure of the goodness-of-fit (Nash Sutcliffe Efficiency) of the simulated groundwater levels to the observations is calculated. The best model is selected by examining the ensemble of historic simulations. Currently only this best model is then used to produce the forecast.

To forecast groundwater levels, equivalent forecasts of rainfall and potential evapotranspiration (PET) are required to drive R-Groundwater. Rainfall and temperate are taken from the 1-month and 3-month ahead climate forecast produced by the Met Office GloSea5 model (Met Office, 2013). This forecast consists of a 42-member ensemble of lumped rainfall and temperature values for the whole of the UK. Due to the spatial variability of rainfall and temperature over the UK, these data are then downscaled for each of the 25 sites. Rainfall is downscaled based on a prior linear regression analysis between historic observed lumped UK and catchment-specific rainfall totals. The temperature forecasts are translated into PET forecasts using the Blaney-Criddle equation (Allen, 1986). Forecast lumped UK temperature values are first converted to PET and then these values are downscaled to each site based on a prior linear regression analysis between historic observed lumped UK and catchment-specific PET values. Observed catchment PET values are based on those produced by the Met Office Rainfall and Evaporation Calculation System (MORECS; Hough and Jones, 1997) on a 40 km grid.

The Met Office forecast ensemble members are iteratively fed through each model producing an equivalent ensemble of groundwater level projections at each site. In summary the procedure for producing the ensemble groundwater level forecasts at a site is:

1. Run the R-Groundwater model for the period of groundwater level observations up to the present using historic observed rainfall and potential evaporation.

2. Update the model groundwater level state with the most recently observed groundwater level.
3. Downscale each member of the GloSea5 climate rainfall forecast to the site. Downscale each member of the GloSea5 climate rainfall forecast to the site.
4. Convert the GloSea5 climate temperature forecast to PET and then downscale this to each site.
5. Run R-Groundwater for the upcoming 1 and 3-month periods, for each paired rainfall and PET ensemble member.

4 Presentation of the results

The analysis of the ensemble forecasts for the 25 sites across the UK consists of an assessment of the forecast at each observation borehole. Each member of the groundwater level ensemble forecast at a site is categorised according to the following scale:

	Category	Percentile range of historic observed values for relevant month
Black	Exceptionally high levels	> 95
Dark blue	Notably high levels	87-95
Light blue	Above normal	72-87
Green	Normal	28-72
Yellow	Below normal	13-28
Orange	Notably low levels	5-13
Red	Exceptionally low levels	< 5

These categories are based on the distribution of values simulated *within the related month of the year*. Consequently, there are 12 such scales: one for each month of the year. For example, forecasts for January are categorised using the distribution of groundwater levels that have been simulated in January, over the full period of the historic record. Therefore, “Exceptionally high levels” should be read as “Exceptionally high levels [for the month of the forecast]”.

Forecast maps, such as those shown in Figure 2 are presented for five members of the 1-month and 3-month ahead ensemble climate forecast. These include the ensemble members with the lowest (Min) and highest (Max) rainfall totals, and the ensembles members nearest to the 25th, 50th and 75th percentiles of the distribution of forecasted rainfall.

5 Example monthly information sheet

The information generated is summarised on a single information sheet. The summary sheet contains two set of maps, one for the one-month ahead outlook and the other for a three month period. Key points of note are marked on the annotated figure below.

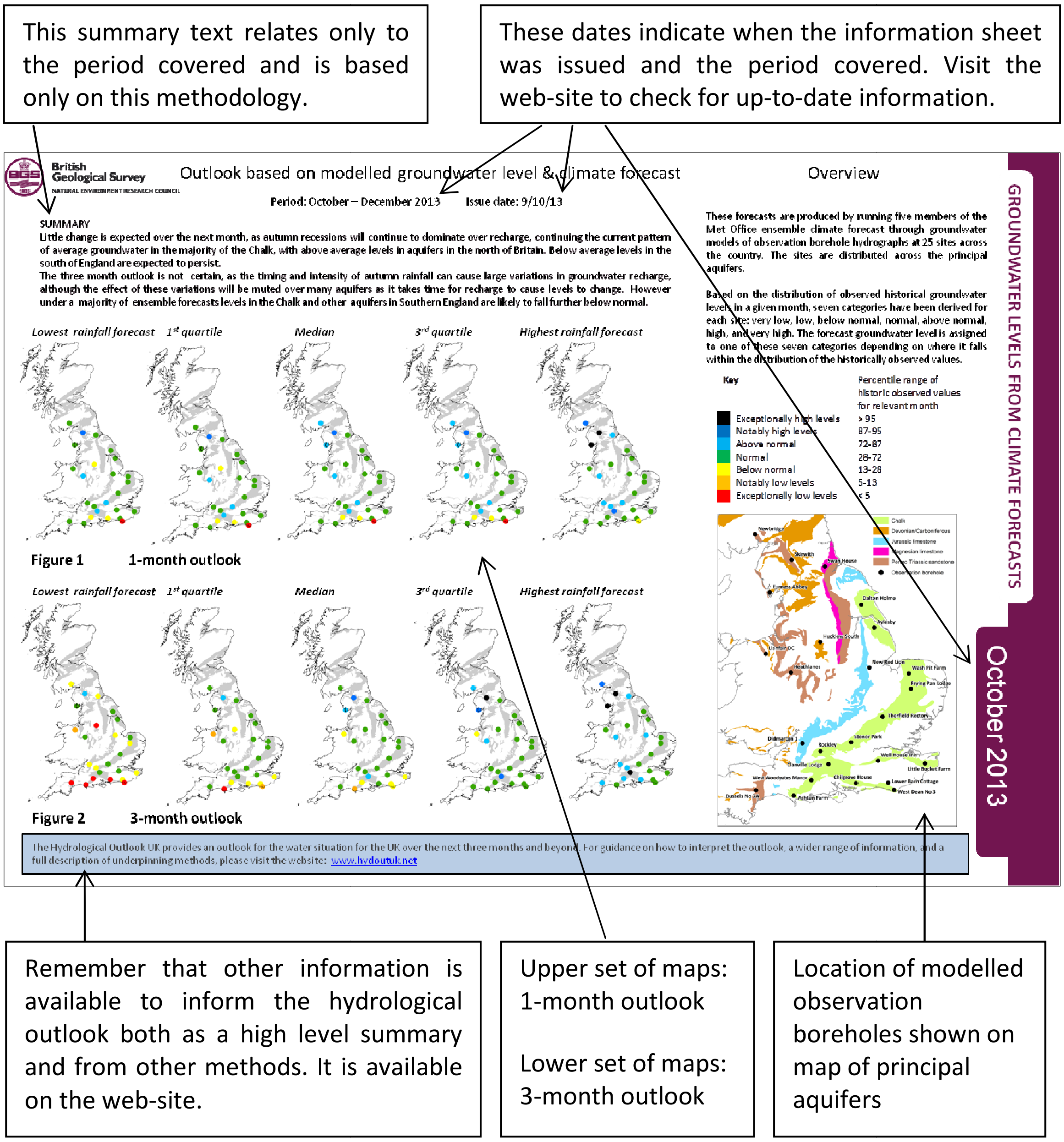

Figure 2. *Overview groundwater level information sheet for the outlook based on the Met Office seasonal climate forecast.*

6 References

Allen, R.G. (1986). Rational Use of the FAO Blaney-Criddle Formula. Journal of Irrigation and Drainage Engineering, 112(2), 139-155.

BGS (2103). British Geological Survey web page (Accessed 21/10/2103): http://www.bgs.ac.uk/research/groundwater/change/FutureFlows/home.html

Hough, M.N., and Jones, R.J.A. (1997). The United Kingdon Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0 – an overview. Hydrology and Earth System Science, 1(2), 227-239.

Jackson, C.R. (2012). Future Flows and Groundwater Levels: R-Groundwater model summary. British Geological Survey Commissioned Report CR/12/105.

Met Office (2103). Met Office web page (Accessed 21/10/2103): http://www.metoffice.gov.uk/publicsector/contingency-planners