Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
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Environment Agency

# HYDROLOGICAL OUTLOOK

## Outlooks based on modelled river flow and groundwater levels from historical climate

2013

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# 1 Foreword

This document describes the use of historical sequences of observed climate to generate seasonal river flow and groundwater level outlooks that form part of the UK Hydrological Outlook. This is based upon the Environment Agency methodology used within their Water Situation Reports.

# 2 General methodology

The outlook based on modelled surface water and groundwater from historical climate is issued every month, and provides outlooks from 3 to 12 months ahead for key river basins and groundwater observation boreholes across Great Britain. These outlooks are based on ensembles of historical sequences of observed climate (rainfall and potential evapotranspiration) that form input to surface water or groundwater models. The outputs are probabilistic simulations of river flows and groundwater levels over the forecast horizon (up to 12 months ahead), at each location.

# 3 Technical details

To manage water resources effectively, we need to anticipate episodes of anomalously high or low water availability both in our rivers and aquifers a few months ahead. However, current weather forecasts are not yet available at seasonal (more than 3 months ahead) to inter-annual scales with enough accuracy to be used for water resource management, and alternatives techniques need to be developed that provide useful information for water managers.

Hydrological processes are dependent on climate (primarily water inputs from rainfall and water losses through evaporation and transpiration) but also on soil and geology, as they determine the water storage capacity in the catchment. Conceptual river flow and groundwater level models are useful tools for representing the hydrological processes of a catchment. When run continuously over a time period they provide time-series of flow and groundwater levels expected from the given climate input.

By creating climate sequences, which combine observations to date with sequences sampled from the historic record, an ensemble of possible climate scenarios can be generated. We combine historic observations for the past 24-month period up to the current time, with an ensemble of constructed ‘future’ sequences. The future ensemble is generated by extracting each of the 24-month periods from the historic record (1961-2007) that begin in the month corresponding to the start of the current outlook (i.e. the current month). The surface water and groundwater storage states simulated at the start of the outlook at a given location are the same for all the members of the ensemble.

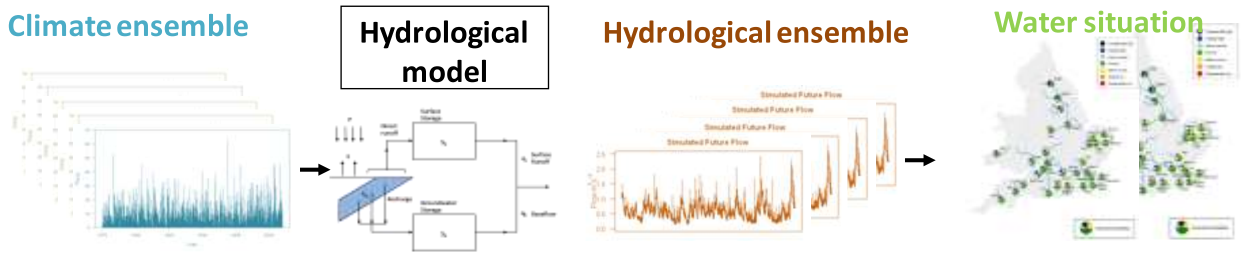


***Figure 1.*** *The Water Situation Long Term Outlook: hydrological modelling from historical climate envelope.*

Four hydrological models are used to produce the river flow and groundwater level outlooks from historical climate. For smaller surface water catchments the two lumped surface water models, PDM and Catchmod, are used to simulate river flow. For larger catchments the semi-distributed model CLASSIC is used to simulate river flow. The R-Groundwater and Catchmod models are used to simulate groundwater levels at observation boreholes. PDM, CLASSIC and R-groundwater were used for the Future Flows and Groundwater Levels project (CEH, 2013). Because this approach is based on simulated river flows and groundwater levels, it is associated with hydrological modelling uncertainties.

The outlooks based on modelled river flow and groundwater levels from historical climate are a set of ensembles describing their possible evolution for 3- to 12-months ahead based on all historic sequences from 1961. Consequently, the resulting simulated response of the catchments can be compared with their historical probability. Because all historical climate sequences are used to generate the outlook probability distributions, any difference with the historical probability distributions can be attributed to the antecedent condition of the catchment which depends on the near past (last 24-months) climate. The outlook, therefore, highlights catchments which are more likely to get wetter / drier than normal because of their modelled antecedent conditions.

The outlooks rely entirely on historical sequences and therefore, they are not *forecasts*. Using past climate as possible analogue of future climate is a simple way to generate long-term outlooks but it does not contain any knowledge of the state of the atmosphere and ocean. It is important to remember that it is possible that some of the historical sequences used might be inconsistent with current large-scale atmospheric conditions and would therefore be unlikely to occur in the next few months.

To help with the interpretation of the results, the outlooks are compared with the reference sample for each location, time of the year and forecast horizon (from 3 to 12 months). For groundwater the reference distribution is derived from historic observed levels. For river flows, to avoid possible biases in the hydrological modelling influencing the interpretation of the results, the reference sample is derived from simulated (and not gauged) flows using observed historical climate as input data. This is performed for each start date and lead time.

Due to the long hydrological memory of groundwater-fed catchments, any deviations from normal in the current conditions are likely to continue for a few months ahead. However, because the outlook is based on ensembles of historical climate sequences, with time the outlook will slowly revert towards the distribution of river flows and groundwater levels expected from climatology.

## 4 Interpretation of the outlooks based on modelled river flow or groundwater levels from historical climate results and graphs

Following the methodology used in the Environment Agency's Water Situation Reports [www.envrionment-agency.gov.uk/watersituation] the outlooks based on modelled river flow from historical climate are shown as an ensemble of N-month ahead averages of river flows. The outlooks based on groundwater levels from historical climate are shown as an ensemble of groundwater levels for each month of the outlook period.

The categories used to plot these ensembles are defined from the reference sample based on the rank of the data within the sample and given in Table 1. Up to seven categories are used (Figure 2), but because the extreme categories have a relatively low probability of occurrence they could be aggregated with the adjoining categories.

The categories of Table 1 are defined according to the Cunnane plotting position, where the probability for any value of a distribution to be lower than x is given by: $\mathrm{P(x)} = \frac{\mathrm{r}-0.4}{\mathrm{Y}+(1-0.8)}$

| Category | Probability of value being surpassed by a lower value P(x) | Probability of occurence | Colour coding |
|---|---|---|---|
| Exceptionally high | >0.95 | 0.05 (5%) | Black |
| Notably high | 0.87-0.95 | 0.08 (8%) | Dark blue |
| Above normal | 0.721-0.869 | 0.15 (15%) | Light blue |
| Normal | 0.28-0.72 | 0.44 (44%) | Green |
| Below Normal | 0.131-0.279 | 0.15 (15%) | Yellow |
| Notably low | 0.05-0.13 | 0.08 (8%) | Orange |
| Exceptionally low | <0.05 | 0.05 (5%) | Red |

***Table 1.*** *Definition of categories and associated probabilities used to classify the outlook probabilistic ensembles of river flow averages or groundwater levels at the forecast horizon (Environment Agency 2011).*

Graphically, the reference sample can be compared to the outlook sample by plotting the empirical cumulative distribution functions associated with each forecast horizon (N in month) as a stacked diagram using the colours according to the reference categories for that time of year and location. See an example in Figure 2. The reference empirical cumulative distribution (shown as Clim on the x-axis) is assumed to represent the expected distribution and by definition consists of the following categories, described in percent of the total height of the diagram and from bottom to top: 5% red (exceptionally low), 8% orange (notably low), 15% yellow (below normal), 44% green (normal), 15% light blue (above normal), 8% dark blue (notably high) and 5% black (exceptionally high).

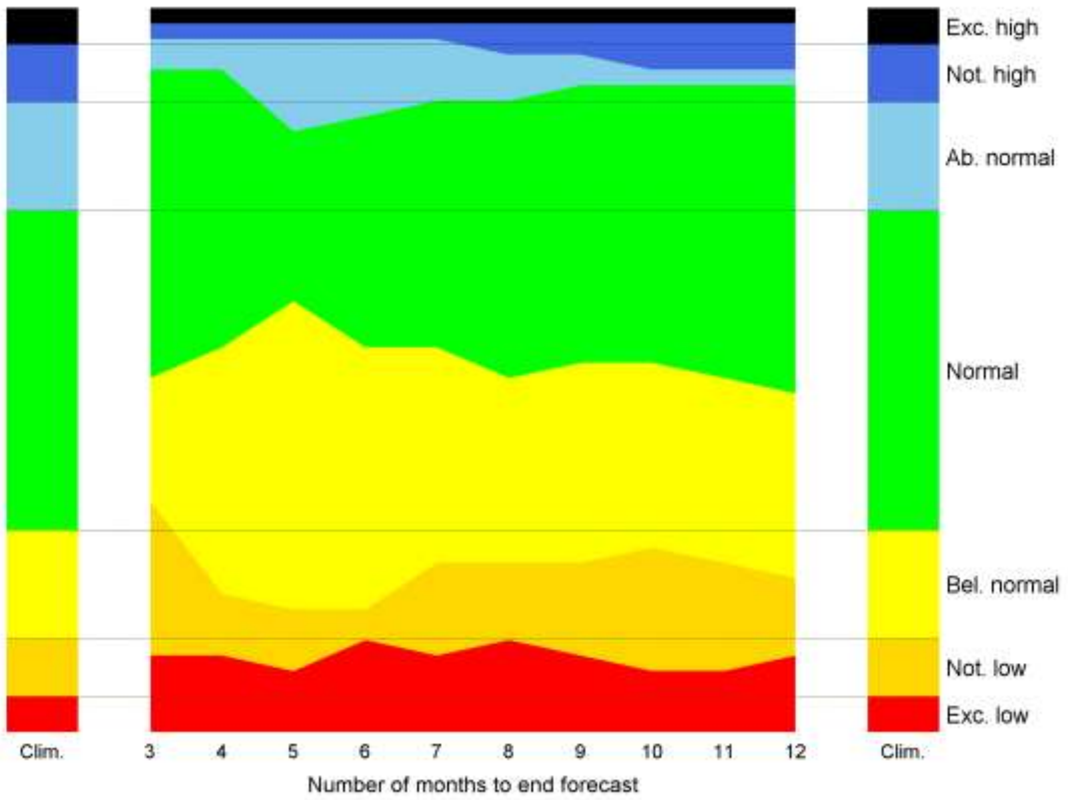


***Figure 2.*** *Example of outlook based on modelled river flow and groundwater levels from historical climate, shown as stack diagrams of the empirical cumulative distribution for forecast horizons from 3 to 12 months (x-axis). The height of each colour band for a given x-axis represents the proportion of the sample within a given flow category. Seven categories are considered; they are defined using the reference empirical cumulative distribution (shown as 'Clim' in the graph) and from bottom to top are associated with the following percent of the total height: 5% exceptionally dry (red), 8% notably dry (orange), 15% below normal (yellow), 44% normal (green), 15% above normal (light blue), 8% notably wet (dark blue) and 8% exceptionally wet (black).*

## 5 Example monthly information sheets

The information generated is summarised on two summary information sheets, one for surface water (river flow) and one for ground water levels.

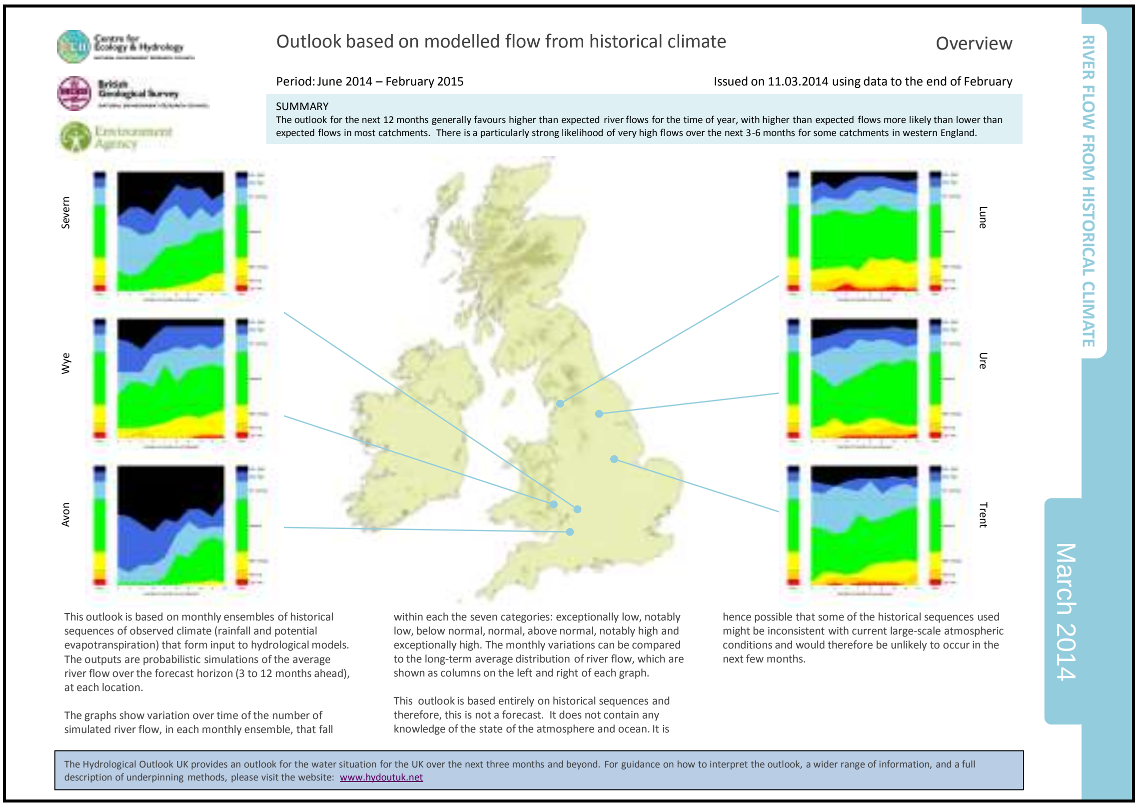


***Figure 3**. Information sheet for the outlook based on modelled river flow from historical climate*

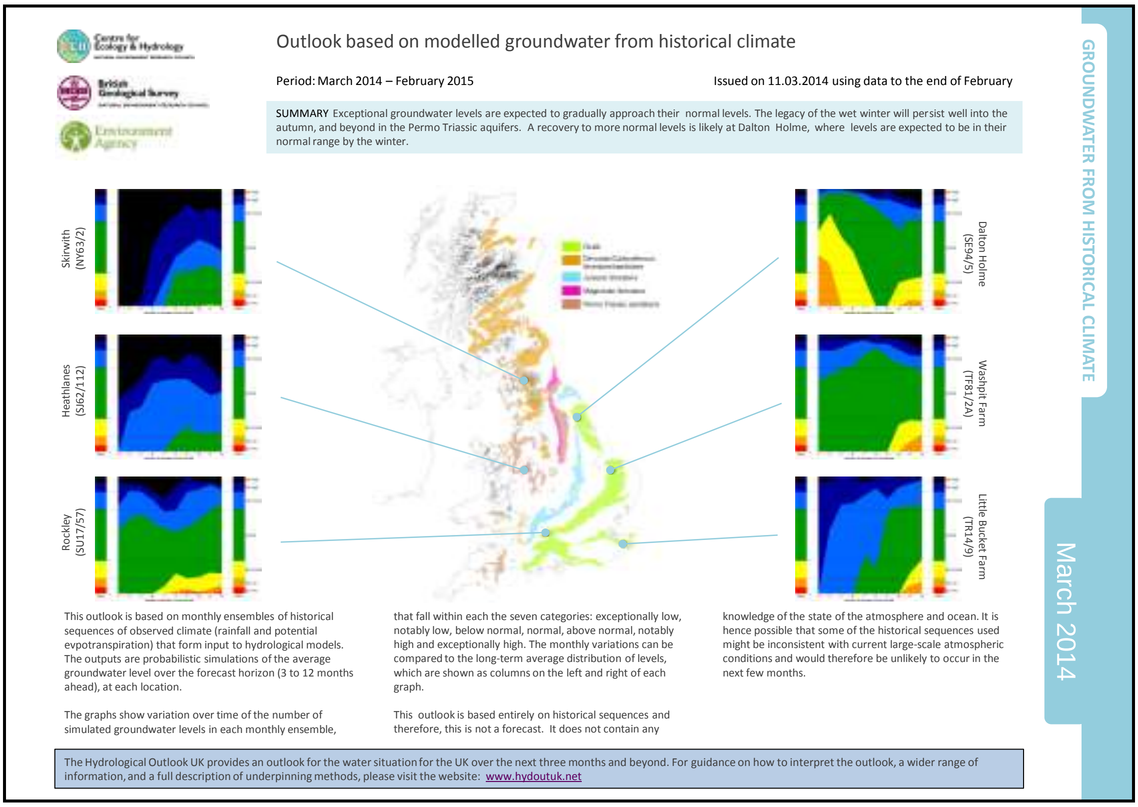


***Figure 4**. Information sheet for the outlook based on modelled groundwater level from historical climate*

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