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Rainfall–streamflow–air temperature datasets (and catchment information) available internationally to assist with PUB Decade top-down modelling

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Abstract: One of the purposes of the Top-Down modelling Working Group (TDWG) within the Prediction in Ungauged Basins (PUB) Initiative of the International Association of Hydrological Sciences (IAHS) is to use available data (including new datasets – e.g. remote sensing products) to test existing rainfall-runoff models and develop new models. As such, effort has been made to collate data for a wide variety of catchments distributed over the globe. The first datasets obtained are for the UK, USA and Australia, yielding a total of 830 catchments. This paper describes the datasets, and presents an example of data analysis techniques that are being used to explore the behaviour of the different catchments represented in the datasets. Work will continue to expand the list of catchments with available data, and any additional datasets will be made available either directly or indirectly through the TDWG website (www.stars.net.au/tdwg).

Keywords: datasets; hydrology; Prediction in Ungauged Basins

1. INTRODUCTION

Datasets prepared from source databases for modelling often represent a substantial amount of effort. Whenever possible, it therefore makes sense for these 'frozen' datasets to be made available for re-use. Revised, or new, modelling techniques can then be applied using the frozen datasets, and results compared with previous work based on the same data. In this way, and in the spirit of the Prediction in Ungauged Basins (PUB) Decade (2003-2012), the hydrological research community can assess their different modelling techniques using the frozen datasets and report their findings in the context of reducing predictive uncertainty, which is one of the main objectives of PUB (e.g. Sivapalan *et al*., 2003; Post *et al*., 2005; and see "PUB Corner" at http://iahs.info). As a contribution to the PUB Decade from the PUB Top-Down modelling Working Group (TDWG, www.stars.net.au/tdwg/), the purpose of this paper is to provide details of some rainfall, streamflow and air temperature datasets that can be accessed internationally via the TDWG and other websites. Corresponding information about the catchments also available via websites (e.g. topography, land-use) is shown for some cases. Illustrative summary analyses of some of the data are presented. Where appropriate, the paper gives website addresses which, if the paper is being read on-screen, might be active hyperlinks.

2. DATASETS

2.1 United Kingdom hydrometric data

The National River Flow Archive (NRFA), maintained by the Natural Environment Research Council's Centre for Ecology and Hydrology (CEH), stores daily mean flows and much other relevant information for more than 1,200 catchments throughout the UK. The NRFA has a programme towards making its data, and information about the gauging stations and the catchments, increasingly available, free-of-charge, through its website (www.nerc-wallingford.ac.uk/ih/nrfa). Readers are strongly encouraged to browse this website. At the request of the TDWG, the NRFA has a webpage 'Predictions in Ungauged Basins (PUB) - UK data downloads' (www.nerc-wallingford.ac.uk/ih/nrfa/pub/index.html), from which (or elsewhere on the NRFA website) two datasets can be downloaded. These datasets will not satisfy all modellers' requirements, but they do provide a good starting point. For convenience, the two datasets are referred to here as Data60UK and Data200UK respectively. Some catchments are represented in both datasets.

2.1.1 Data60UK

Data60UK actually covers 61 catchments ranging from 12.4 to 1,480 km^2 (most of the catchments are less than 150 km^2) distributed throughout England and Wales (see Figure 1). Frozen datasets (1980-1990) of daily areal rainfall (mm) and streamflow (m^3s^{-1}) can be downloaded from www.nerc-wallingford.ac.uk/ih/nrfa/pub/data.html. The Data60UK dataset was prepared and used by Sefton and Howarth (1998) for a regionalisation study using the IHACRES rainfall-runoff model, first introduced by Jakeman *et al*. (1990). Seven of the Data60UK catchments, mostly in Wales, were used by Littlewood (2003) to demonstrate an enhanced IHACRES model parameter selection procedure and to discuss its implications for regionalisation studies. Figure 2 shows the distribution of Data60UK catchment area and Base Flow Index (BFI) estimated by the method of Gustard *et al*. (1992).

Figure 1. Location of the 61 gauges in the Data60UK dataset.

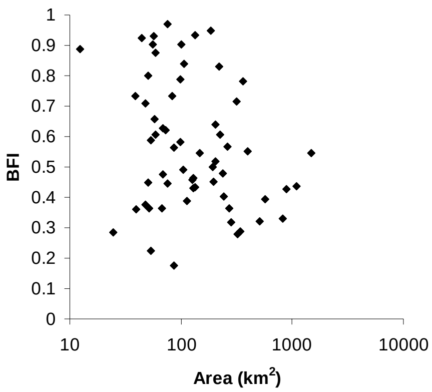

Figure 2. Distribution of area and BFI values derived for the 61 gauges in the Data60UK dataset.

2.1.2 Data200UK

At NRFA webpage www.nerc-wallingford.ac.uk/ih/nrfa/index.htm there is a link to 'River Flow Data: Time Series Downloads', from which daily mean flow data for about 200 sites can be downloaded. Currently, only monthly precipitation data are available for each catchment included in this dataset. However, the dataset can be used to explore the variation of flow statistics (e.g. BFI) across the UK. Also at www.nerc-wallingford.ac.uk/ih/nrfa/index.htm there is a link to 'Catchment Spatial Information' from which images of catchment topography, geology, land-use and average rainfall can be selected (see later).

2.2 MOPEX_USA dataset

The MOPEX (Model Parameter Estimation Experiment, Hogue *et al.*, 2004) working group has made available their dataset of 438 catchments in the USA (www.weather.gov/oh/mopex). These catchments are distributed across the USA (concentrated in the eastern US, see Figure 3) and range in area from about 70 to 10,000 km^2. For each gauge, time series of daily catchment areal precipitation, potential evaporation, flow and minimum and maximum temperature are available. In addition, catchment areal average values for a range of attributes are available (e.g. soils, vegetation, monthly mean greenness fraction), as well as catchment boundaries.

Figure 3. Location of the 438 gauges in the MOPEX dataset.

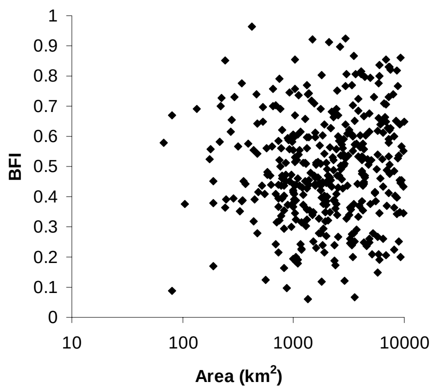

Figure 4. Distribution of area and BFI values derived for the gauges in the MOPEX dataset (2 gauges not included: 8085500, 10,329 km^2, BFI=0.21; and 6480000, 10,096 km^2, BFI=0.65).

The majority of the catchments in the MOPEX_USA dataset have mid-range BFI values (see Figure 4), and considerably larger catchment areas than the UK dataset.

2.3 Australian dataset

This dataset (Peel *et al*., 2000) consists of daily catchment areal precipitation, streamflow data, plus mean monthly potential evapotranspiration for 331 unimpaired catchments (not affected by large flow control structures) between 50 and 2,000 km^2, located mostly in New South Wales and Victoria (and to a lesser extent Tasmania), with relatively few gauges over the rest of Australia (see Figure 5). Precipitation data from the SILO gridded daily dataset were used (www.nrm.qld.gov.au/silo/), and cover the period from 1901 to 1998. Streamflow data has a variable coverage (at least 10 years, not including any gaps in the data) depending on data availability. Additional spatial datasets are available through the Australian National Resources Atlas (audit.ea.gov.au/ANRA).

Figure 5. Location of the 331 gauges in the Australian dataset (taken from Peel *et al*., 2000)

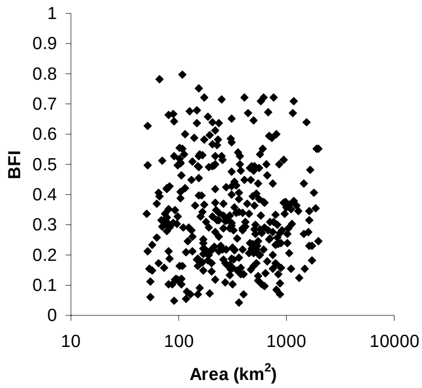

Figure 6. Distribution of area and BFI values derived for the 331 gauges in the Australian dataset.

The catchments included in the Australian dataset typically have a lower BFI than the Data60UK and MOPEX datasets, and intermediate catchment areas (Figure 6).

3. EXAMPLES

The catchment details in Section 3 were downloaded from the NRFA website.

3.1 Example 1: a high BFI catchment in the UK

Gauge 42008 (Cheriton Stream at Sewards Bridge) is a 75.1 km^2, very permeable (Upper Chalk), catchment located in the south of England (see Figures 7 to 9). Its contributing area differs considerably from the topographical catchment. The average annual rainfall is 889 mm, generating a mean flow of 0.66 m^{3}s^{-1}. The land use in the catchment is predominantly rural, with 50.2% arable and horticulture, 29.6% grassland, 13.3% woodland, 3.7% mountain, heath or bog, and 3.3% of the catchment urbanised. The Base Flow Index (BFI) for this catchment is 0.97 (the highest value in Data60UK). Laize (2004) shows how the spatial datasets from which Figs 7 to 9 were derived can be combined to give a Representative Catchment Index to assist with hydrometric network appraisals.

The results of the cross-correlation analysis (Croke, 2005) is shown in Figure 10. The top panel shows the seasonal influences, while the bottom plot, the influence of events. The baseline is a cosine function fitted to the negative lag values of the cross-correlation function. The top panel shows almost no seasonal variation in the rainfall autocorrelation function (amplitude 0.007), but very strong variation in the streamflow-rainfall cross-correlation function (amplitude 0.073). The phase lag in the cross-correlation function is 96 days. This lag indicates there is a strong buffering of the rainfall which may be due to wetting up of the catchment and/or a delay in the aquifer response to recharge. The cross-correlation function shows a small peak near a lag of zero, corresponding to a quick response to rainfall. However, the main signal is a slow response component with a peak delayed by more than 1 month. This is likely to be due to the characteristics of the regional aquifer discharging to the stream, particularly the distance between effective recharge location and the discharge sites.

Figure 7. Location of gauge 42008 (Cheriton Stream, images from the UK NRFA website).

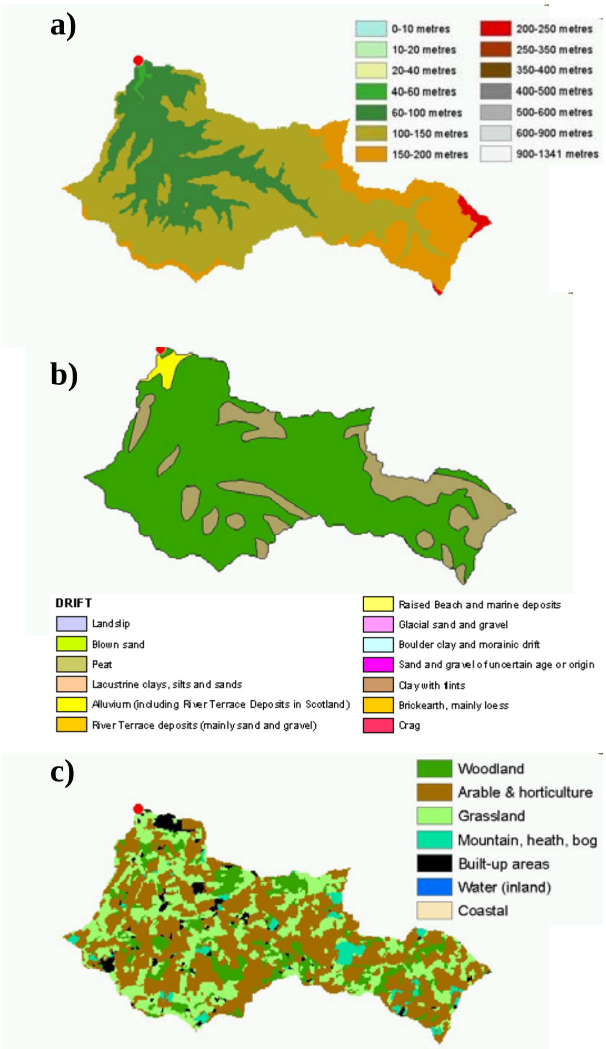

Figure 8. Catchment 42008 (Cheriton Stream): images from the UK NRFA website) (a) topography, (b) drift geology on Upper Chalk covering most of the area and (c) land use.

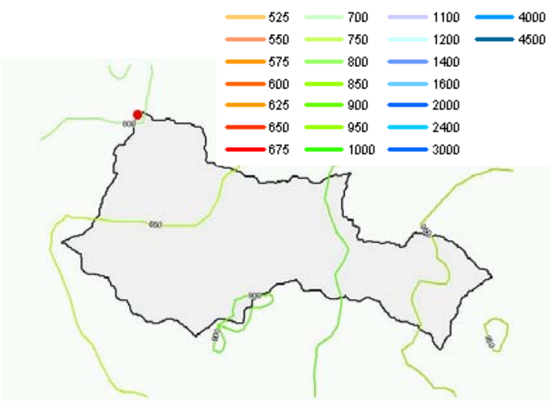

Figure 9. Mean annual distribution of rainfall for gauge 42008 (Cheriton Stream, images from the UK NRFA website).

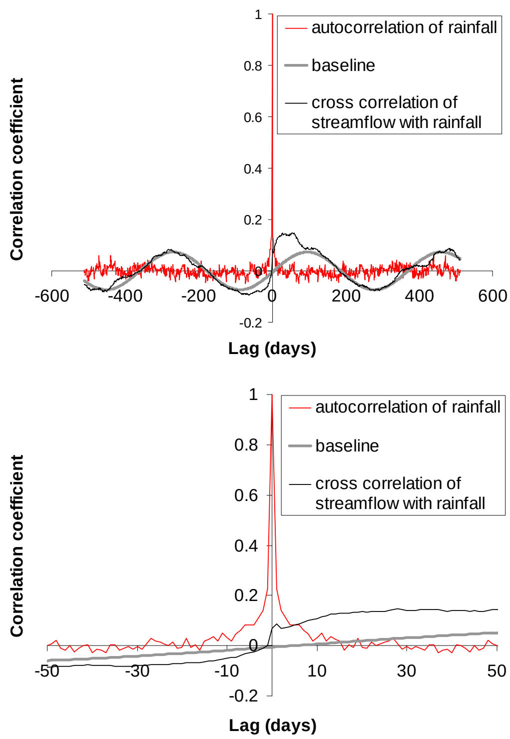

Figure 10. Cross-correlation analysis for gauge 42008 (Cheriton Stream).

3.2 Example 2: a low BFI catchment in the UK

Gauge 25006 (Greta at Rutherford Bridge) is an eastward draining Pennine catchment of 86.1 km^2 located in northeast England (see Figure 11). The catchment is underlain by a moderate permeability fissured aquifer, with 57.7% peat and 34.4% boulder clay and morainic drift. The land use is predominantly natural, with 63.6% mountain, heath or bog, 34.1% grassland, 1.2% woodland, 0.7% arable and horticulture and 0.4% urban. There is a strong rainfall gradient across the catchment, with a mean annual rainfall of greater than 1400 mm in the upper catchment, decreasing to approximately 850mm in the east. The mean annual rainfall for the catchment is 1128mm, and the mean flow is 2.26 m^3s^{-1}, corresponding to a runoff coefficient of 73%.

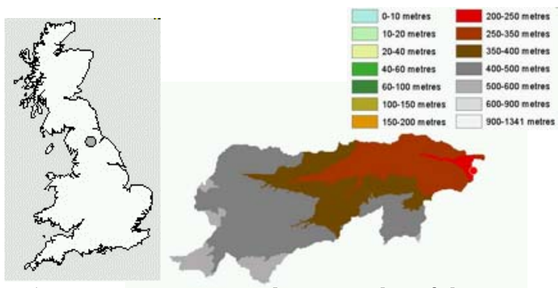

Figure 11. Location and topography of the Greta at Rutherford Bridge catchment (gauge 25006, images from the UK NRFA website).

4. COMMENT ON DEVELOPMENT OF TOP-DOWN MODELS

Top-down models are developed based on information contained within available datasets. This may be constrained by an understanding of the processes, or an understanding of the processes may be drawn from the analysis of the data. Fourier analysis can yield insights into the mean catchment response characteristics (particularly near the peak) without assumptions regarding the functional form of those characteristics (e.g. Croke *et al.*, 2000). While there are often difficulties in using Fourier analysis on rainfall and streamflow time series (particularly concerning stationarity), the cross-correlation functions avoid many of these problems by producing a single response peak averaged over a large number of events (Croke, 2005). The underlying assumption of this approach is that the effective rainfall sequence is sufficiently similar to the rainfall sequence. While this is not always the case, the approach can be used to develop an understanding of the characteristics of different catchments, as well as providing a further test of model performance.

The IHACRES rainfall–runoff model (Jakeman *et al.*, 1990) represents the catchment response as two components: a non-linear module that converts precipitation (*p*) into effective rainfall (*u*); and a linear module that convolves effective rainfall with a unit hydrograph (*h*) consisting of two exponentially decaying stores. This can be represented as:

$$q = u * h = (s \bullet p) * h \tag{1}$$

where *s* is a catchment wetness index time series generated by IHACRES, * is the convolution operator and $\bullet$ is the multiplication operator. Representing the cross-correlation of *x* and *y* as $c_{x,y}$, and the Fourier transform of *x* as *X* gives the ratio (*r*) of the cross-correlation of rainfall and streamflow with the autocorrelation of rainfall as:

$$R = \frac{C_{p,q}}{C_{p,p}} = \frac{U}{P} \bullet H \tag{2}$$

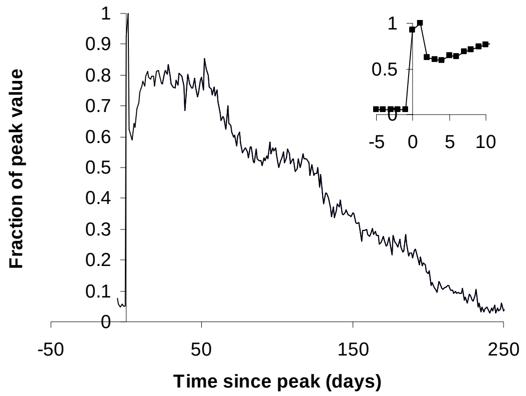

Figure 12. Modulus of r for gauge 42008 (Cheriton Stream at Sewards Bridge, Area=75.1 km^2 Data60UK dataset).

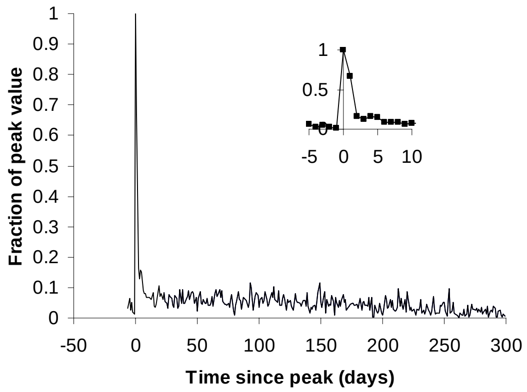

Figure 13. Modulus of *r* for gauge 25006 (Greta at Rutherford Bridge, Area = 86.1 km^2, Data60UK dataset).

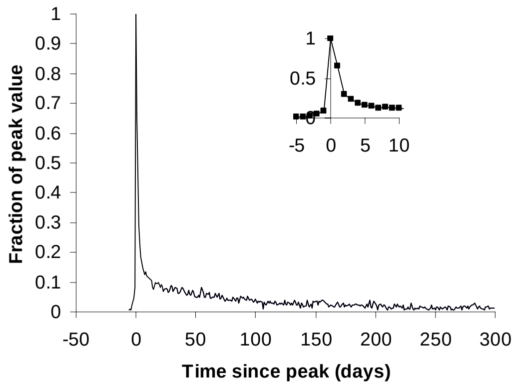

Figure 14. Modulus of *r* for gauge 405205 (Murrindindi River, Area=105km^2, Australian dataset).

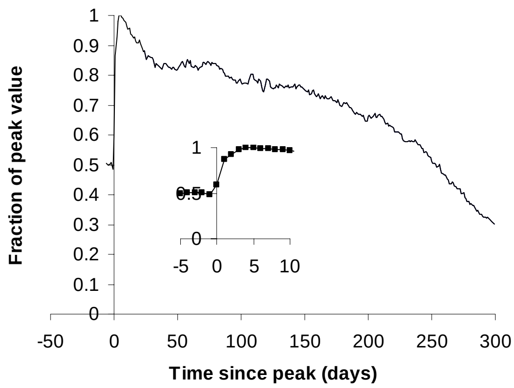

Figure 15. Modulus of r for gauge 02273000 (Kissimmee River, Florida, Area =7474.7 km^2, MOPEX_USA dataset).

Thus the ratio *r* represents a combination of the influence of the non-linear module and the unit hydrograph. While this cannot be used to uniquely define the appropriate model structure, it does yield an additional test of the adopted model structure. Examples of these functions derived for catchments included in the datasets discussed here are given in Figures 12 to 15 and show the range of *r* functions that may need to be represented in a model or group of models. In some cases, a simple model structure with one or two exponential terms may be appropriate (e.g. Figures 13 and 14). In others, more complicated unit hydrograph modules are warranted (e.g. Figures 12 and 15).

5. CONCLUSIONS

This paper describes datasets that have been made available through the TDWG and other websites. Researchers are strongly encouraged to collaborate with the contributors of the datasets. Contact details for the contributors are available through the datasets page of the TDWG website.

Using Fourier analysis, it is possible to obtain an indication of the response characteristics of a catchment without *a priori* assumptions regarding the functional form of the response. While only examples are shown here, the derived response characteristics for all catchments will be made available through the TDWG website.

6. ACKNOWLEDGMENTS

Land use, geology and elevation depicted in Figs. 8 and 11 are © NERC based on © Crown Copyright, licence 100017897 (2005). Rainfall in Fig. 9 is based on data from the UK Met Office.

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