Regionalization methods in rainfall–runoff modelling using large catchment samples

RALF MERZ, GÜNTER BLÖSCHL & JURAJ PARAJKA
Institute for Hydraulic and Water Resources Engineering, Vienna University of Technology, Vienna, Austria
merz@hydro.tuwien.ac.at

Abstract In ungauged catchments, model parameters are usually transposed from gauged catchments as no runoff data are available for calibrating them. Parameters can be either transposed from nearby catchments or, alternatively, functional relationships between model parameters and available catchment attributes can be derived from gauged catchments that may be further away. This article summarizes the most important methods and recent findings from the literature with a focus on the relative performance of the regionalization methods. As performance is strongly influenced by the local conditions, general findings on the suitability of regionalization methods for a given climate region can only be obtained by analysing a large number of catchments at the same time. Even with large catchment samples, the differences between the regionalization methods tend to be small. Suggestions for improving current regionalization methods are given.

Key words rainfall–runoff modelling; regionalization; similarity; ungauged catchments

INTRODUCTION

Modelling the rainfall–runoff behaviour of ungauged catchments is of interest both for understanding systems behaviour and as a basis of sustainable water resources management. The main challenge with rainfall–runoff modelling in ungauged catchments is the lack of local runoff data to calibrate the model parameters. Parameter calibration is important because most model equations are empirical in nature, model output depends on the initial and boundary conditions that are poorly known and, probably most importantly, because most of the flow processes take place in the subsurface where media characteristics are heterogeneous and unknown. Soil properties can change dramatically in space but change very little in time, so parameter calibration can significantly enhance model performance.

In ungauged catchments, model parameters have to be estimated from other sources of information. An appealing way to estimate model parameters in ungauged catchments is to glean the model parameters from hydrologically similar catchments. The concept of hydrological similarity assumes that the runoff response to a given rainfall input in two different catchments will be similar if similar rainfall–runoff processes occur.

These processes are not known in full detail and thus different similarity concepts have been proposed in the literature. The process of transferring parameters from hydrologically similar catchments to a catchment of interest is generally referred to as regionalization (Blöschl & Sivapalan, 1995). The two most widely used concepts for regionalizing model parameters are hydrological similarity as a function of spatial proximity and similarity as a function of catchment attributes.

Regionalization based on spatial proximity

The rationale of this group of methods is that catchments that are close to each other will have a similar response as the climate and catchment conditions will only vary smoothly in space. The notion of spatial proximity is by no means trivial as it can be defined in a number of ways and the choice of method in any particular case is usually not obvious. An example of this group is the delineation of spatially contiguous regions with approximately homogeneous model parameters. The regions are found from an analysis of a number of gauged catchments and available hydrological information using statistical tools such as cluster analysis, principal component analysis and multiple regression (Nathan & McMahon, 1990). Hydrological information to assist in delineating homogeneous regions may consist of hydrogeological maps, climate maps, soil and vegetation maps and process indicators such as the seasonality of hydrological processes (Merz *et al*., 1999). Yu & Yang (2000) propose to establish regional flow duration curves, which comprise a family of regression equations relating the flow of various exceedence percentages with catchment area. The regional flow duration curves can then be used to calibrate model parameters in ungauged catchments.

An alternative to homogeneous regions are geostatistical methods, such as kriging. The main strength of kriging is that it is a best linear unbiased estimator (BLUE); best meaning that the mean squared error is a minimum, linear meaning that the estimate is a weighted mean of the data in the area, and unbiased meaning that the mean expected error is zero (Merz & Blöschl, 2004).

Regionalization based on catchment attributes

The analysis of observed hydrological behaviour often reveals small scale variability but catchments that are far apart may still be hydrologically similar (e.g. Pilgrim, 1983), so alternatives to the spatial proximity concepts have been proposed. These concepts are often based on similarity of catchment attributes that are available in both gauged and ungauged catchments. Runoff is not considered as a catchment attribute that will make this group of methods applicable to the ungauged catchment case. Catchment attributes include catchment size, information on topography, land use, geology, elevation, soil characteristics, as well as climate variables such as mean annual precipitation, and are thought of as surrogates of the hydrological processes within a catchment. The rationale of this approach is that catchments with similar attributes may also behave hydrologically similarly (Acreman & Sinclair, 1986). The catchment attributes can be used in regionalization methods of various structures.

The first type of methods use a distance measure of hydrological similarity which is a function of the differences in catchment attributes of two catchments. The distance measure is zero if the catchment attributes are identical and increases as the attributes get more dissimilar. The distance measure can be used in statistical methods such as cluster analysis, principal component analysis, and classification trees (Breiman *et al.*, 1984; Nathan & McMahon, 1990; Bates, 1994) to group the catchments. Once the groups are identified, the model parameters can be transferred from an analogue gauged catchment within the same group to the ungauged catchment of interest. A particular variant is the Region of Influence approach (Burn & Boorman, 1993), where for each catchment of interest a separate pooling group is formed.

The second way of using catchment attributes are regression analyses between model parameters and catchment attributes. Regression relationships are black-box models, although some degree of process reasoning can come in. Due to the availability of catchment attributes in geographic information systems, correlations between model parameters and catchment attributes are widely used in regionalization (e.g. Sefton & Howarth, 1998, Seibert, 1999; Kokkonen *et al.*, 2003; Merz & Blöschl, 2004). In multiple regressions, one may encounter the problem of multicollinearity, i.e. when at least one of the attributes is highly correlated with another attribute or with some linear combination of them. If multicollinearity is present, the regression coefficient can be highly unstable and unreliable (Hirsch *et al.*, 1992). One therefore limits the number of catchment attributes used in the regression, sometimes combining a number of attributes into an index, which is assumed to be representative of one aspect of the rainfall–runoff relationship (such as the base flow index, IH, 1999). Sequential regression may assist in identifying robust parameter estimates (Lamb & Kay, 2004). Sometimes the delineation of homogeneous regions and regression analyses are combined (e.g. Burn & Boorman, 1993). A formal way of combining regression analyses and the delineation of homogeneous regions are Classification And Regression Tree (CART) models (Breiman *et al.*, 1984; Laaha & Blöschl, 2006).

ANALYSES USING LARGE SAMPLE SIZES

Testing the performance of various parameter regionalization methods is usually done by withholding the runoff data in a catchment of interest, transferring the model parameters from neighbouring gauged catchments, simulating runoff in the catchment of interest and, finally, comparing the simulation performance in the catchment of interest against the observed runoff data in that catchment. This type of test is useful as it fully emulates the ungauged catchment case and one can analyse the relationship between model parameters and catchment attributes in a subjective way. However, the performance of the regionalization methods is strongly influenced by the local conditions and it is hence very difficult to arrive at general conclusions. Only if a large number of catchments is analysed at the same time can more general conclusions be inferred on the suitability of regionalization methods in a given climate region. It is therefore very important to use a large number of samples in comparative regionalization analyses. Although numerous regionalization studies are reported in the literature, only a few of them use large catchment samples. Clearly, it is difficult to obtain reliable data sets containing many catchments that are not affected by human intervention. A number of studies of this type are summarized below.

Sefton & Howarth (1998) compared calibrated parameters of the IHACRES model with catchment attributes of 60 catchments in England and Wales. The best correlations they obtained were R^2 = 0.59 between a routing parameter and percentage of aquifers, and R^2 = 0.69 between an evaporation parameter and mean annual precipitation. For the storage parameters, no significant correlations were obtained. Peel *et al*. (2000) related, separately, the calibrated parameters of the SYMHID model to four indices that were to reflect climate, terrain and soil characteristics in 331 Australian catchments. They used the ratio of mean annual rainfall to the mean annual areal potential evaporation as an index for climate and the difference of the 90th percentile and the 10th percentile elevation in a catchment as an index of topographical relief. Soil depth and plant available water holding capacity were used as soil indices to reflect the relationship of model parameters and soil characteristics. The highest coefficient of determination, R^2 = 0.2, was found for the correlation of one parameter to the climate index. The correlations of model parameters to other indices were smaller and not statistically significant at the 0.05 level. As climate was suggested to be the main driving factor, the data set was subdivided into three climate regions but this did not increase the correlations much.

Young (2006) regionalized the model parameter of the PDM water balance model based on a data set of 260 catchments in the UK. The model parameters of 179 catchments were calibrated against 10 years of observed daily runoff and 81 catchments were retained as an independent evaluation catchment data set in a split sample test. Two regionalization methods, based on the similarity of catchment attributes, were tested. First, in a regression analysis, each of the six model parameters was related individually to the available catchment attributes in a way to maximize the explained variance. In the second regionalization method, termed nearest neighbour approach, the complete set of model parameters was transposed from a number of donor catchments that were most similar in terms of catchment attributes. Runoff time series were simulated using the transposed parameters and the final time series was taken as the arithmetic mean of the individual series. Thus, the nearest neighbour approach retains the structure of the donor catchment parameters. For both methods, the similarity between the catchments was mainly based on catchment attributes derived from a hydrological response classification of soils (Hydrology of Soil types, HOST, Boorman *et al*., 1995). The median Nash-Sutcliffe model efficiency using regression-based model parameters was ME = 0.70 as compared to ME = 0.71 for locally calibrated simulations. For the nearest neighbour method the efficiencies were slightly lower.

Beldring *et al*. (2002) used 141 catchments in Norway for calibrating a version of the HBV model. They then treated 43 additional catchments as ungauged and regionalized the model parameters as a function of land-use classes. For both sets of catchments they found median Nash-Sutcliffe efficiencies of 0.68 and concluded that the regionalization method represented the main features of the landscape well. However, for 20% of the second set of stations the efficiencies were less than 0.3.

Vandewiele & Elias (1995) derived the parameters of a monthly water balance model for 75 catchments in Belgium from neighbouring catchments. For a case where they regionalized parameters using kriging, their model performed well for 72% of the catchments while it was only 44% when transferring parameters from the nearest catchment.

Hundecha & Bárdossy (2004) applied the HBV model to 95 catchments in the Rhine basin to analyse the effect of land-use change on runoff. Instead of regionalizing the model parameters directly, the regionalization was carried out by initially assuming a functional form of the relationship of model parameters and catchment attributes and then calibrating the parameters of the functional form for many catchments simultaneously. The Nash-Sutcliffe model efficiency was between 0.79 and 0.9 for 30 calibration catchments and between 0.76 and 0.92 for the validation catchments. The established functional form of model parameters and catchment attributes could be used to estimated model parameters in ungauged catchments.

Parajka *et al*. (2005a), which is an extension of Merz & Blöschl (2004), examined the relative performance of a range of parameter regionalization methods. They simulated the daily water balance dynamics of 320 Austrian catchments using a semi-distributed conceptual catchment model, following the structure of HBV. They evaluated the predictive accuracy of the regionalization methods by jack-knife cross-validation against observed daily runoff and snow cover data. They compared nearest neighbours, inverse distance weighting and kriging as variants of spatial proximity-based methods and multiple regressions and the transposition of a set of model parameters from a donor catchment as variants of catchment attribute-based methods (Fig. 1). Two methods performed best. The first was a kriging approach where the model parameters were regionalized independently from each other. The second was a similarity approach where the complete set of model parameters was transposed from the donor catchment that was most similar in terms of a number of catchment attributes. For both methods, the median Nash-Sutcliffe model efficiency of daily runoff for the 11 year calibration period was ME = 0.67 as compared to ME = 0.72 for locally calibrated simulations. For the verification period, the corresponding efficiencies were 0.62 and 0.66. The regionalization of model parameters based on multiple regression performed poorer with the corresponding efficiencies of 0.65 and 0.60 for the calibration and verification periods, respectively.

An overview of studies on regionalization of rainfall–runoff model parameters using large catchment samples is given in Table 1.

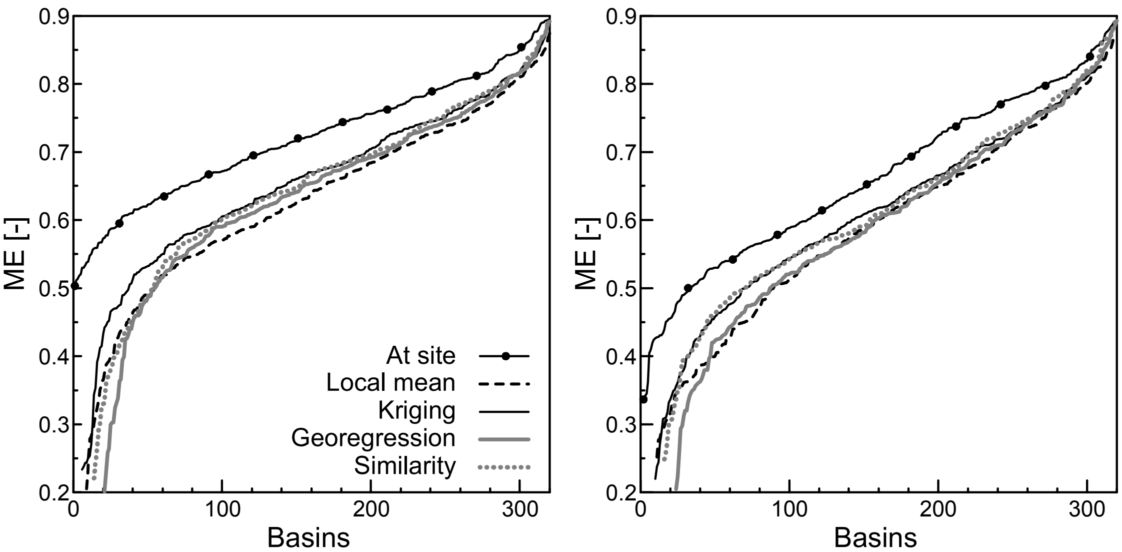

Fig. 1 Cumulative distribution functions of Nash-Sutcliffe runoff model efficiencies (ME) using different regionalization methods in 320 Austrian catchments. Calibration (left) and verification (right) periods. From Parajka *et al*. (2005a).

Table 1 Overview of rainfall–runoff regionalization studies using large catchment samples.

Reference	Country	Model	Number of catchments used	Time step	Methods
Sefton & Howarth (1998)	UK	IHACRES	60	Daily	Regression with catchment attributes
Peel *et al*. (2000)	Australia	SIMHYD	331	Monthly	Regression with catchment attributes
Beldring *et al*. (2002)	Norway	HBV	186	Daily	Regression with catchment attributes
Parajka *et al*. (2005a)	Austria	HBV (semi lumped)	320	Daily	Regression with catchment attribute Similarity concepts Spatial proximity methods (Kriging, nearest neighbour)
Merz & Blöschl (2004)	Austria	HBV (lumped)	308	Daily	Regression with catchment attributes Spatial proximity methods (Kriging, nearest neighbour)
Young (2006)	UK	PDM	260	Daily	Regression with catchment attributes Nearest neighbour approach based on similarity in catchment attributes
Hundecha & Bárdossy (2004)	Rhine basin	HBV	95	Daily	Regional calibration of parameter of regression function of model parameters and catchment attributes
Vandewiele & Elias (1995)	Belgium	3 parameter water balance model	60	Monthly	Spatial proximity methods (Kriging, nearest neighbour)

DISCUSSION AND CONCLUSIONS

All the studies examined here reported relatively low correlations between model parameters and catchment attributes. One explanation for the low correlations is that the measurable catchment attributes may not be relevant for the dominant processes. Most of the rainfall–runoff processes take place in the subsurface while most of the catchment attributes (such as topographic characteristics and vegetation) are available at the land surface only and contain very little information about the subsurface. Soil type or geological characteristics as available in regional studies, often, are not representative of subsurface flow processes that can be dominated by peds and cracks. Also, pieces of information such as geology and soils are static indicators of hydrological response as they do not vary much over hydrological time scales. What would be more valuable are indicators that better capture the dynamics of hydrological processes. An attempt at obtaining more hydrologically justifiable catchment attributes is the classification of soil types in the UK (Boorman *et al*., 1995). Certainly, the successful application of regression analyses hinges on a sensible parameterization of subsurface processes. In the Austrian case study (Parajka *et al*., 2005a), for example, where information on soil hydrology was unavailable, the regression performed poorer than in the UK study where such information was available (Young, 2006). It would also seem possible to choose catchment attributes by hydrological reasoning based on the dominant hydrological processes. The process typology of regional floods of Merz & Blöschl (2003), for example, could be used to guide selection of catchment attributes to be used in statistical regionalization methods.

If no hydrologically justifiable catchment attributes are available, spatial proximity may be a better measure of catchment similarity (e.g. Parajka *et al.*, 2005a). The delineation of spatially contiguous regions according to climate is often a first step in a regionalization approach or can be combined with regression analyses between model parameters and catchment attributes (Peel *et al.*, 2000). However, it may be difficult to assign ungauged catchments to one of the delineated homogeneous regions, particularly for ungauged catchments close to the region boundaries. An alternative to the homogeneous region approach are geostatistical methods. Although these methods tend to exhibit little bias, random errors can be large (Parajka *et al.*, 2005a).

One of the problems with the use of geostatistical methods in hydrology is that they have evolved in the mining industry, where one is interested in cubic blocks. Unlike mining blocks, catchments are nested and water follows a stream network. It is therefore clear that upstream and downstream catchments would have to be treated differently from neighbouring catchments that do not share a subcatchment. Based on ideas of Sauquet *et al.* (2000), Skøien *et al.* (2005) proposed the TOP-KRIGING approach of geostatistical regionalization that takes into account the organization of the landscape into nested catchments. They showed that the proposed method outperformed the traditional Euclidian framework when regionalizing flood frequencies to ungauged catchments and they were able to assign uncertainty bounds to the regionalized values. More work along the lines of hydrologically justified spatial statistics seems to be warranted to contribute to improved parameter regionalization.

Another problem in regionalizing model parameters is the significant uncertainty of the calibrated parameters in the gauged catchments *per se*. There are methods of accounting for parameter uncertainty in the regionalization of model parameters (see, e.g. Campell & Bates, 2001). To better constrain model parameters, additional data on state variables can be used in the calibration procedure (Mroczkowski *et al.*, 1997; Gupta *et al.*, 1998). Parajka *et al.* (2005a) used observed snow depths to constrain model parameters and Parajka *et al.* (2005b) used soil moisture information from scatterometer satellite data. An alternative to the use of observed state variables is regional calibration in which the model parameters of a number of catchments are calibrated simultaneously (e.g. Fernandez *et al.*, 2000; Szolgay *et al.*, 2003). The idea of regional calibration is to obtain more robust parameters which may reduce regionalization uncertainty but the potential of this approach has not yet been fully evaluated.

In terms of the overall runoff simulation performance, the comparisons of the different regionalization studies based on many catchments suggest that there is no single best regionalization method. Results of some of the studies are seemingly conflicting. In Young (2006), the best regionalization method was a regression of individual model parameters to catchment attributes, while the transposition of the complete data set using a nearest neighbour approach based on catchment similarity performed slightly poorer. In contrast, the results of Parajka *et al.* (2005a) indicated that the transposition of a complete set of model parameters performed better than the regression method. It should be noted, however, that the differences between the methods were small and may be related to the particularities of the data sets used. The crucial point, perhaps, is not the statistical method to be used but the measures of similarity. Traditional catchment attributes such as catchment size, land use, geology, topographic elevation, soil characteristics, as well as climate variables such as mean annual precipitation, are perhaps less representative of the driving hydrological processes than is usually thought. It may, therefore, be worthwhile to focus future work on hydrologically meaningful catchment attributes (such as Boorman *et al.*, 1995) and hydrological distance measures (Skøien *et al.*, 2005). Analyses such as Merz & Blöschl (2003) may assist in understanding processes at the regional scale and help derive such attributes. Although scientific regionalization studies are usually directed towards formalized regionalization methods, as discussed above, it is important to remember that the quantity and quality of expert judgement included in any regionalization approach, be it through delineating regions, selecting catchment attributes or other avenues, play a very significant role in maximizing regionalization performance.

Acknowledgements We would like to thank the Austrian Academy of Sciences (project no. HÖ31 and APART [Austrian Programme for Advanced Research and Technology] – fellowship) for financial support.

REFERENCES

Acreman, M. C. & Sinclair, C. D. (1986) Classification of drainage basins according to their physical characteristics; an application for flood frequency analysis in Scotland. *J. Hydrol.* **84**, 365–380.

Bates, B. C. (1994) Regionalization of hydrologic data: a review. Cooperative Research Centre for Catchment Hydrology, Monash University, Victoria, Australia.

Beldring, S., Roald, L. A. & Voksø, A. (2002) Avrenningskart for Norge (Runoff map for Norway, in Norwegian), Norwegian Water and Energy Directorate, Report No. 2, Oslo, Norway.

Blöschl, G. & Sivapalan, M. (1995) Scale issues in hydrological modelling—a review. *Hydrol. Processes* **9**, 251–290.

Boorman, D. B., Hollis, J. M. & Lilly, A. (1995) Hydrology of Soil Types: A Hydrologically Based Classification of the Soils of the United Kingdom. *IH Report No. 126.* Institute of Hydrology, Wallingford, UK.

Breiman, L., Friedman, J. H., Olshen, R. & Stone, C. J. (1984) *Classification and Regression Trees*. Wadsworth International Group, Belmont, California, USA.

Burn, D. H. & Boorman, D. B. (1993) Estimation of hydrological parameters at ungauged catchments. *J. Hydrol*. **143**, 429–454.

Campbell, E. P. & Bates, B. C. (2001) Regionalization of rainfall–runoff model parameters using Markov Chain Monte Carlo samples. *Water Resour. Res.* **37**(3), 731–739.

Fernandez, W., Vogel, R. M. & Sankarasubramanian, A. (2000) Regional calibration of a watershed model. *Hydro. Sci. J.* **45**(5), 689–707.

Gupta, H. V., Sorooshian, S. & Yapo, P. O. (1998) Toward improved calibration of hydrologic models: multiple and noncommensurable measures of information. *Water Resour. Res*. **34**(4), 751–763.

Hirsch, R. M., Helsel, D. R., Cohn, T. A. & Gilroy, E. J. (1992) Statistical analysis of hydrological data. In: *Handbook of Hydrology* (ed. by R. Maidment), 17.1–17.55. McGraw-Hill, New York, USA.

Hundecha, Y. & Bárdossy, A. (2004) Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model. *J. Hydrol.* **292**, 281–295.

Institute of Hydrology (IH) (1999) *Flood Estimation Handbook*. Institute of Hydrology, Wallingford, UK.

Kokkonen, T. S., Jakeman, A. J., Young, P. C. & Koivusalo, H. J. (2003) Predicting daily flows in ungauged catchments: model regionalization from catchment descriptors at the Coweeta Hydrologic Laboratory, North Carolina. *Hydrol. Processes* **17**, 2219–2238.

Laaha, G. & Blöschl G. (2006) A comparison of low flow regionalization methods—catchment grouping. *J. Hydrol*. (in press).

Lamb, R. & Kay, A. L. (2004) Confidence intervals for a spatially generalized, continuous simulation flood frequency model for Great Britain. *Water Resour. Res*. **40**, W07501, doi:10.1029/2003WR002428.

Merz, R. & Blöschl, G. (2003) A process typology of regional floods. *Water Resour. Res.* **39**(12), 1340, doi:10.1029/2002WR001952.

Merz, R. & Blöschl, G. (2004) Regionalization of catchment model parameters. *J. Hydrol*. **287**, 95–123.

Merz, R., Piock-Ellena, U., Blöschl, G. & Gutknecht, D. (1999) Seasonality of flood processes in Austria. In: *Hydrological Extremes: Understanding, Predicting, Mitigating* (ed. by L. Gottschalk, J. C. Olivry, D. Reed & D. Rosbjerg) (Proc. Birmingham Symp., July 1990), 273–278. IAHS Publ. 255. IAHS Press, Wallingford, UK.

Merz, R. & G. Blöschl (2005) Flood frequency regionalization—spatial proximity vs. catchment attributes. *J. Hydrol.* **302**(1–4), 283–306.

Mroczkowski, M., Raper, G. P. & Kuczera, G. (1997) The quest for more powerful validation of conceptual catchment models. *Water Resour. Res*. **33**(10), 2325–2335.

Nathan, R. J. & McMahon, T. A. (1990) Identification of homogeneous regions for the purpose of regionalization. *J. Hydrol*. **121**, 217–238.

Parajka, J., Merz, R. & Blöschl, G. (2005a) A comparison of regionalization methods for catchment model parameters, *Hydrol. Earth System Sci*. (HESS) **9**, 157–171.

Parajka, J., Naeimi, V., Blöschl, G., Wagner, W., Merz, R. & Scipal, K. (2005b) Assimilating scatterometer soil moisture data into conceptual hydrologic models at the regional scale. *Hydrol. Earth System Sci*. (HESS) Discussion, SRef-ID: 1812-2116/hessd/2005-2-2739.

Peel, M. C., Chiew, F. H. S., Western, A. W. & McMahon, T. A. (2000) Extension of unimpaired monthly streamflow data and regionalization of parameter values to estimate streamflow in ungauged catchments. Report prepared for the National Land and Water Resources Audit, in: Australian Natural Resources Atlas website: http://audit.ea.gov.au/anra/water/docs/national/Streamflow/Streamflow.pdf.

Pilgrim, D. H. (1983) Some problems in transferring hydrological relationships between small and large drainage basins and between regions. *J. Hydrol*. **65**, 49–72.

Sauquet, E., Gottschalk, L. & Leblois, E. (2000) Mapping average annual runoff: a hierarchical approach applying a stochastic interpolation scheme. *Hydrol. Sci. J.* **45**, 799–815.

Sefton, C. E. M. & Howarth, S. M. (1998) Relationships between dynamic response characteristics and physical descriptors of catchments in England and Wales. *J. Hydrol*. **211**, 1–16.

Seibert J. (1999) Regionalization of parameters for a conceptual rainfall–runoff model. *Agric. Forest Meteorol*. **98–99**, 279–293.

Skøien, J., Merz, R. & Blöschl, G. (2005) Top-Kriging—geostatistics on stream networks. *Hydrol. Earth System Sci.* Discussions **2**, 2253–2286. SRef-ID: 1812-2116/hessd/2005-2-2253.

Szolgay, J., Hlavčová, K., Kohnová, S. & Danihlik, R. (2003) Estimating regional parameters of a monthly balance model. *J. Hydrol. Hydromech*. **51**(4), 256–273.

Vandewiele, G. L. & Elias, A. (1995) Monthly water balance of ungauged catchments obtained by geographical regionalization. *J. Hydrol.* **170**, 277–291.

Young, A. (2006) Stream flow simulation within UK ungauged catchments using a daily rainfall–runoff model. *J. Hydrol.* (in press).

Yu, P. S. & Yang, T. C. (2000) Using synthetic flow duration curves for rainfall–runoff model calibration at ungauged sites. *Hydrol. Processes* **14**(1), 117–133.