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Low flow estimation in Austria

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Abstract This paper gives an overview of river low flow processes and low flow estimation methods in Austria. Streamflow data from 325 sub-catchments in Austria, ranging in catchment area from 7 to 963 km^2, are used for the analyses. The performance of a number of regionalization methods for q95 low flows is assessed by leave-one-out cross-validation which emulates the case of ungauged catchments. A regional regression model based on a catchment grouping according to low flow seasonality performs best, but low flow estimates from short (one year) streamflow records outperform the best regionalization method when using an appropriate climate adjustment method. A q95 low flow map for all of Austria is compiled that combines local stream flow data with the regionalization estimates. It is argued that a combination of different sources of information—various types of regionalization models and streamflow records of various lengths—provides a wealth of information that should be exploited for low flow estimation.

Key words catchment grouping; cross validation; low flow; prediction at ungauged sites; PUB; regionalization; regional regression; seasonality

INTRODUCTION

Estimation of environmental flows generally requires long streamflow records that represent natural flow regimes. In a practical context, for instance when specifying minimum flows for hydropower operation or other water uses, estimates are usually required for sites where the natural river flow regime has been altered in recent years and/or no streamflow records are available. Regionalization techniques can be used to infer environmental flows from neighbouring, undisturbed catchments where streamflow data have been collected. These regionalization methods should take into account the main processes driving low flows as this will likely improve the estimates over purely statistical methods.

This paper gives a synopsis of several low flow studies in Austria which have been carried out in the general context of developing a national low flow regionalization procedure. Runoff data in a standard period, 1977–1996, from 325 sub-catchments in Austria ranging in catchment area from 7 to 963 km^2 are used. The low flow measure chosen is the q95 flow quantile (P[Q > q95] = 95%) which is used for numerous purposes in water resources management, including the specification of residual flows in water abstraction licenses. The analyses in this paper focus on specific low flows, q95 (L s^{-1} km^{-2}), i.e. q95 divided by the catchment area.

SEASONALITY OF LOW FLOWS

Summer and winter low flows are subject to important differences in the underlying hydrological processes. Thus one would expect that summer and winter low flows exhibit different spatial patterns caused by the variability of physical catchment properties and climate forcing. The seasonality of low flows was investigated by using the circular seasonality index (Laaha, 2002). The index consists of two parameters, the mean day of occurrence and the strength of seasonality. A vector map of the seasonality index is presented in Fig. 1. The clear patterns of low flow seasonality indicate that river low flows in the different parts of Austria are produced by vastly different processes. In the lowland east of Austria, river low flows mainly occur in the summer and are a result of evaporation exceeding precipitation, which depletes the soil moisture stores of the catchments. In the Alpine areas of the west of Austria, in contrast, river low flows mainly occur in the winter and are a result of snow storage and frost processes. The link between seasonality patterns and dominant processes suggests that regionalization of low flows should take seasonality patterns into account as they reflect the main processes driving low flows.

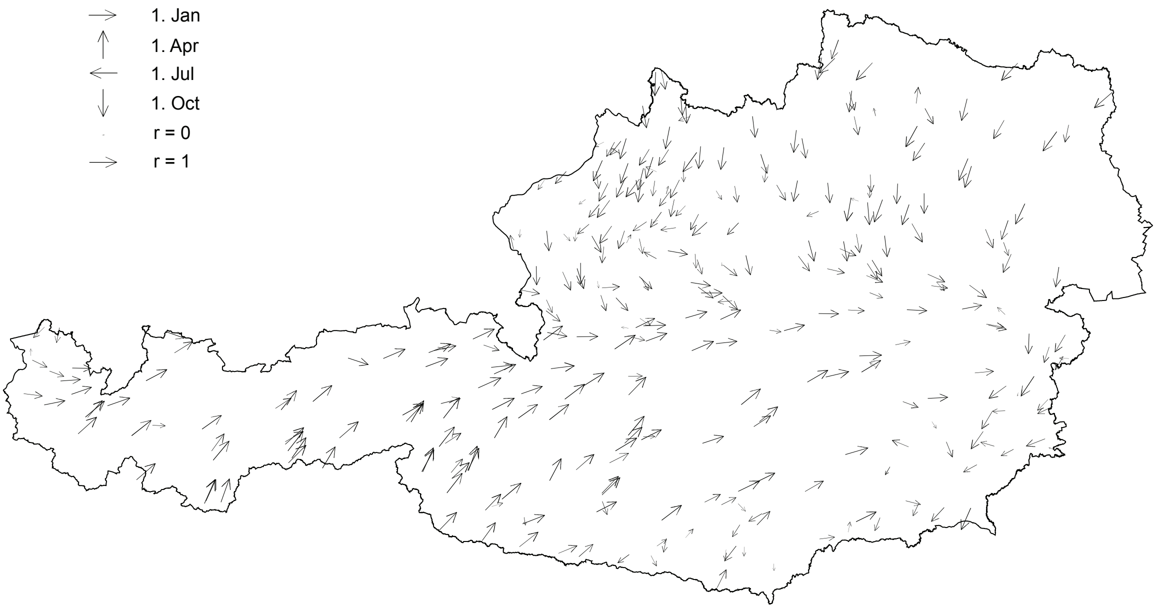

Fig. 1 Low flow seasonality index of 325 sub-catchments in Austria. Long arrows indicate strong seasonality and their direction represents the mean day of occurrence of specific low flow discharges less than q95.

REGIONALIZATION

To put the predictive power of the seasonality indices into context and to find the best grouping method for low flow regionalization, four catchment grouping methods were compared in terms of their performance in predicting specific low flows q95 for ungauged catchments (Laaha & Blöschl, 2006a). These grouping methods are the residual pattern approach (e.g. Hayes, 1992; Aschwanden & Kan, 1999), weighted cluster analysis (Nathan & McMahon, 1990), regression trees (Breiman *et al*., 1984; Laaha, 2002), and regions of similar low flow seasonality (Laaha & Blöschl, 2003). All of these methods use low flow data and most of them use catchment characteristics as well. For each group, a regression model between q95 and catchment characteristics, representing catchment topography, precipitation, geology, land cover and stream network density, has been fitted independently, using a stepwise regression approach. For the purpose of regionalization of low flows to ungauged sites, each site of interest needs to be allocated to one of the regions. For groupings that form contiguous regions, the ungauged site has been allocated by its geographical location. For groupings that are not contiguous in space, a classification tree fitted between group membership and catchment characteristics was used.

The performance of the methods was assessed by leave-one-out cross-validation of the regression estimates, which emulates the case of ungauged catchments. The allocation rules were integrated in the procedure, in order to give a full emulation of the prediction at ungauged sites. The results (Fig. 2) indicate that the grouping based on seasonality regions performs best. It explains 70% of the spatial variance of q95. The favourable performance of this grouping method is likely related to the striking differences in seasonal low flow processes in the study domain. Winter low flows are associated with the retention of solid precipitation in the seasonal snow pack while summer low flows are related to the relatively large moisture deficits in the lowland catchments during summer. The regression tree grouping performs second best (explained variance of 64%) and the performance of the residual pattern approach is similar (explained variance of 63%). The weighted cluster analysis only explains 59% of the spatial variance of q95 which is only a minor improvement over the global regression model, i.e. without using any grouping (explained variance of 57%).

An analysis of the sample characteristics of all methods suggests that, again, the grouping method based on the seasonality regions has the most favourable characteristics although all methods tend to underestimate specific low flow discharges in the very wet catchments. It appears that the seasonality characteristics as illustrated in Fig. 1 contain a lot of information highly relevant to low flow regionalization.

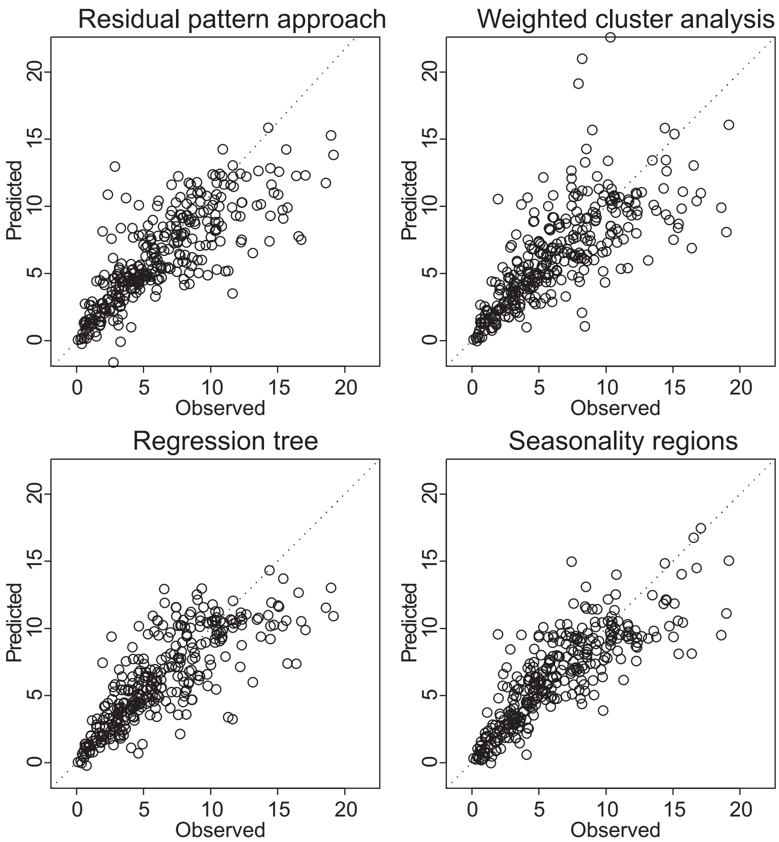

Fig. 2 Scatter plots of predicted *vs* observed specific low flow discharges q95 (L s^{-1} km^{-2}) for ungauged sites in the cross-validation mode. Each panel corresponds to one regional regression model and each point corresponds to one catchment.

SHORT RECORDS

Runoff data from the standard period are available in 325 catchments but short records and spot gaugings are available in a much larger number of catchments. It is, however, not obvious how they can be best used for low flow estimation. Due to climatic variability and other sources of variability that occur over short time scales, low flow characteristics estimated from a few years of streamflow data may deviate from the long-term average. Hence, some adjustment is necessary to make low flow estimates from short records consistent with low flow characteristics of the 20-year standard period. A number of methods of adjusting q95 specific low flow estimates from short streamflow records for climate variability were compared for the study area (Laaha & Blöschl, 2005). The climate adjustment methods consist of two steps, donor site selection and record augmentation using information from nearby sites with longer stream flow records. The accuracy of the methods is assessed here by comparing the adjusted estimates from hypothetically shortened records with estimates from the full 20-year record at the same site. The results (Fig. 3) indicate that the downstream donor selection method, which uses an adjacent gauge on the same river as donor, performs best on all scores. Alternative methods, which are based on catchment similarity and correlation of annual minimum flows, do not perform as well. The coefficient of determination of q95 specific low flows increases from 63 to 89% for one-year records, and from 86 to 93% for three-year records when adjusting the estimates by the downstream site method. For five years or more, the value of the climate adjustment methods is much lower, and low flow estimates from records longer than five years are less sensitive to the availability of suitable donors. A method that uses spot gaugings of streamflow during a low flow period only performs slightly better than a simple regionalization procedure in terms of predicting q95 at an otherwise ungauged site. Comparisons with more sophisticated regionalization procedures suggest that, on average over the study region, one year of continuous stream flow data clearly outperforms the more sophisticated regionalization method while the spot gauging method provides less accurate low flow estimates than the sophisticated regionalization method.

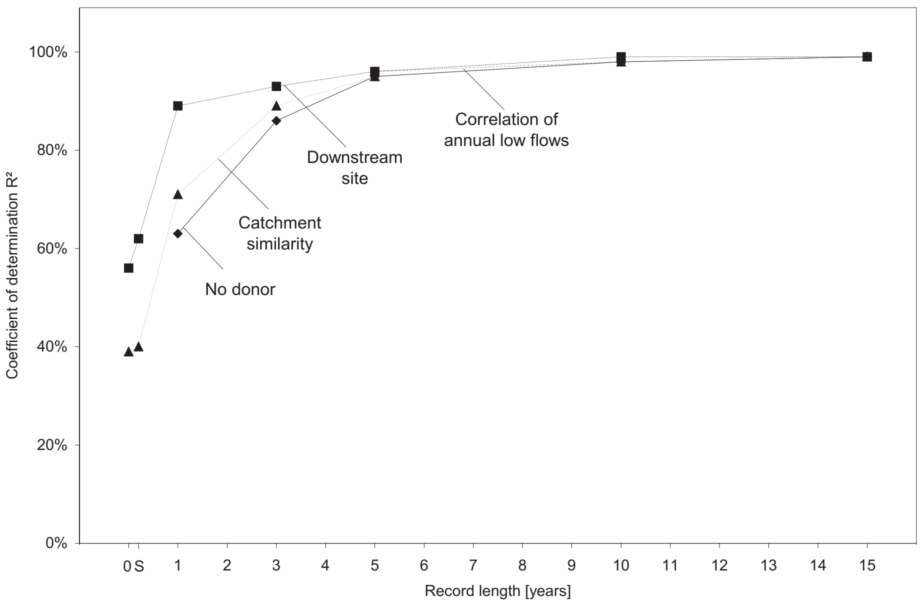

Fig. 3 Coefficient of determination R^2 (%) of specific low flow discharge q95 estimated from records of less than 20 years as compared to 20-year records. Various climate adjustment techniques are used. 0, no local streamflow data; S, spot gaugings.

LOW FLOW MAPPING

Estimates of low flows for all streams in Austria will be most accurate if regionalization methods and local information from both long- and short-record sites are combined. The mapping procedure for Austria combines these sources of information. As a starting point, the regional regression model is applied to small sub-areas of catchments. To this end, catchment characteristics of sub-areas need to be calculated, and each of them needs to be allocated to one region by geographic location or based on catchment characteristics. The regression model assigned to the region is then used to predict the specific low flow value.

Regression models are always associated with residual errors, so the observations will not be exactly reproduced by the predictions. To match the observed low flows, for consistency, the initial low flow estimates for river sub-basins are therefore calibrated to the observed low flows using water balance constraints for the low flow situation (Laaha & Blöschl, 2006b). Gauges with at least five years of continuous streamflow data are used for local calibration. The low flow characteristics calculated from the short records are adjusted for climatic variability using the downstream site method in order to make them compatible with low flow characteristics of the standard observation period.

Although the proposed mapping procedure makes maximum use of the available data, significant uncertainty due to the regional variability of low flow processes remains. This uncertainty can be quantified by error propagation methods. This is the subject of ongoing research that will be presented in the near future.

CONCLUSIONS

A seasonality analysis of low flows has been presented which suggests that river low flows in different parts of Austria are produced by vastly different processes. In the lowland east of Austria river low flows mainly occur in the summer and are a result of evaporation exceeding precipitation, which depletes the soil moisture stores of the catchments. In the Alpine areas of Austria, river low flows mainly occur in the winter and are a result of snow storage and frost processes. The relative accuracy of different approaches to catchment grouping for low flow regionalization has been examined by cross-validation. A regional regression model that is based on a catchment grouping according to the seasonality of low flows explains 70% of the total variance of specific low flows and performs better than regional regressions based on alternative grouping techniques. The information from short streamflow records for estimating Q95 has been examined by an analysis of hypothetically shortened records to evaluate the performance of different climate adjustment methods. A method that uses the adjacent downstream gauge on the same river as the donor site performs best. One year of continuous streamflow data outperforms the best regionalization method, although estimates from less then five years of streamflow data are sensitive to the presence of an adequate donor site. A mapping procedure is proposed which combines regionalization estimates and low flow measurements. The initial estimates of the regional regression model are adjusted to observed specific low flows of the sub-catchment of all available gauges that exhibit at least five years of continuous streamflow records. It appears that a combination of different sources of information—various types of regionalization models and stream flow records of various lengths—provides a wealth of information that should be exploited for low flow estimation. The analyses of the regional low flow processes and the comparisons of the regionalization methods suggest that process understanding can indeed assist in regionalizing low flow characteristics to provide more accurate estimates than existing standard methods.

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REFERENCES

Aschwanden, H. & Kan, C. (1999) *Le débit d'étiage Q347—Etat de la question*. Communications hydrologiques 27. Service Hydrol. et Géol. National, Berne, Switzerland.

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

Hayes, D. C. (1992) Low flow characteristics of streams in Virginia. *US Geological Survey, Water Supply Paper 2374.*

Laaha, G. (2002) Modelling summer and winter droughts as a basis for estimating river low flows. In: *FRIEND 2002 - Regional Hydrology: Bridging the Gap between Research and Practice* (ed. by H. A. J. van Laanen & S. Demuth), 289–295. IAHS Publ. 274. IAHS press, Wallingford, UK.

Laaha, G. & Blöschl, G. (2003) Saisonalität von Niederwasserspenden in Österreich. *Mitteilungsblatt des Hydrographischen Dienstes in Österreich* **82**, 59–68. Bundesministerium für Land- und Forstwirtschaft, Wien, Austria.

Laaha, G. & Blöschl, G. (2005) Low flow estimates from short stream flow records—a comparison of methods. *J. Hydrol*. **306**, 264–286.

Laaha, G. & Blöschl, G. (2006a) A comparison of low flow regionalization methods—catchment grouping. *J. Hydrol.* **323**(1–4), 193–214.

Laaha, G. & Blöschl, G. (2006b) Niederwasserspende (Specific low flow). In: *Hydrologischer Atlas Österreichs*, Karte 5.8. Österreichischer Kunst- und Kulturverlag, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW), Wien, Austria.

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