Journal of Hydrology 538 (2016) 487–499

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Sources of variation in hydrological classifications: Time scale, flow series origin and classification procedure

Francisco J. Peñas *, José Barquín, César Álvarez

Environmental Hydraulics Institute, Universidad de Cantabria - Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

ARTICLE INFO

Article history:
Received 9 March 2016
Received in revised form 22 April 2016
Accepted 23 April 2016
Available online 30 April 2016
This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Flow classification
Inductive
Expert-driven
Time scale
Simulated flow series
Northern Iberian Peninsula

SUMMARY

Classification of flow regimes in water management and hydroecological research has grown significantly in recent years. However, depending on available data and the procedures applied, there may be several credible classifications for a specific catchment. In this study, three inductive classifications derived from different initial flow data and one expert-driven classification were defined. The hydrological interpretation, statistical performance and spatial correspondence of these classifications were compared. Daily Gauged Classification (DC) was derived from daily flow data while Monthly Gauged Classification (MC) and Monthly Modeled Classification (MMC) were derived from monthly flow series, using gauged and modeled flow data, respectively. Expert-Driven Classification (EDC) was based on a Spanish nationwide hydrological classification, which is being used in the current River Basin Management Plans. The results showed that MC accounted for much of the critical hydrological information variability comprised within the DC. However, it also presented limitations regarding the inability to represent important hydroecological attributes, especially those related to droughts and high flow events. In addition, DC and MC presented an equivalent performance more than 60% of the time and obtained a mean ARI value of 0.4, indicating a similar classification structure. DC and MC outperformed MMC 100% and more than 50% of the times when they were compared by means of the classification strength and ANOVA, respectively. MMC also showed low correspondence with these classifications (ARI = 0.20). Thus, the use of modeled flow series should be limited to poorly gauged areas. Finally, the significantly reduced performance and the uneven distribution of classes found in EDC questions its application for different management objectives. This study shows that the selection of the most suitable approach according to the available data has significant implications for the classification uses. Therefore, caution is recommended, especially if classifications are to be use in a normative manner.

1. Introduction

Hydrological classifications group river reaches according to their similarity with respect to their natural flow regime (Snelder et al., 2009). This is now regarded as one of the first steps in hydroecological research (Olden et al., 2012). The ultimate aim of hydrological classifications is diverse. For instance, they have been employed to describe stream flow variability across landscapes (Baeza and Garcia de Jalón, 2005; Poff, 1996; Solans and Poff, 2013), to determine catchment functions and processes (Reidy Liermann et al., 2012; Snelder et al., 2009; Yaeger et al., 2012), to analyze the hydrological changes produced by human pressures (Pegg and Pierce, 2002; Wang et al., 2011; Peñas et al., 2016) and to unravel the influence of stream flow on river ecology (Chinnayakanahalli et al., 2011; Jowett and Duncan, 1990; Monk et al., 2011). Therefore, hydrological classifications play a key role in guiding water resource planning and management (Olden et al., 2012) and are especially valuable for the determination of environmental flows (Kennard et al., 2010; Poff et al., 2010; Reidy Liermann et al., 2012).

The classification of flow regimes has gone through an important development in the last few decades, and hydrological classifications have been performed in almost every corner of the world using available data and a wide diversity of statistical procedures (Olden et al., 2012). Many classifications available in the literature share a series of common steps (see Olden et al., 2012; Snelder and Booker, 2013). Each of the steps can be conducted following the collection of different scientifically defensible methods depending on the rationale, objectives and available data, and many of the

* Corresponding author.
E-mail address: penasfj@unican.es (F.J. Peñas).

http://dx.doi.org/10.1016/j.jhydrol.2016.04.049
0022-1694/

classifications have been demonstrated to be defensible and statistically robust.

Regarding the type of data used in hydrological classifications, it is generally accepted that daily hydrologic data provide the appropriate temporal resolution for understanding stream ecology and guiding hydroecological research (Archfield et al., 2014). Many of the hydrologic attributes related to daily information (frequency, magnitude and duration of short-term high flow events, the timing of annual extremes, or the rate and frequency of hydrograph changes) influence a wide range of ecosystem functions and processes (Bunn and Arthington, 2002; Richter et al., 1998). Hence, their omission may lead to an inaccurate or incomplete vision of the ecologically relevant hydrology. Although Poff (1996) demonstrated that monthly flow data produced a high error rate in capturing several critical features, it may still adequately gather much of the hydro-ecologically relevant information (Harris et al., 2000; Solans and Poff, 2013; Valipour et al., 2013). Moreover, Poff (1996) postulated that monthly flow data would be useful for the analysis of low flow events as they generally present a longer duration.

There are basins and regions where gauging stations representing unaltered hydrological regimes are very rare (Carlisle et al., 2010; Poff et al., 2010). This is especially true for those areas that are subjected an intense hydrologic regulation, as is the case of the Mediterranean area of Spain (Bejarano et al., 2010; Belmar et al., 2011). In most cases, the utility of classifications rests on the ability to collect spatially explicit data and develop predictive tools (McManamay et al., 2012b), i.e., classification of complete fluvial networks including all the ungauged rivers. The classification of fluvial networks in these situations can follow two approaches: (i) a deductive, or *a priori* classification can be applied, which postulates the organization of patterns in flow regimes in terms of environmental factors (Coopersmith et al., 2012; Snelder and Biggs, 2002), or (ii) flow time-series provided by hydrologic rainfall–runoff simulation models can be generated to develop an inductive classification system. The classifications of rivers through deductive procedures are widely accepted (Snelder and Biggs, 2002; Wolock et al., 2004), but Belmar et al. (2012) and Snelder and Booker (2013) demonstrated that inductive classifications outperformed deductive classifications. In this regard, the reliability of the modeled series may be constrained due to the complexity associated with the determination of model parameters (Duan et al., 2006) and conceptual errors in the models (Kirchner, 2006). This may pose an important degree of uncertainty in classifications obtained from the modeled series. The comparison of inductive hydrologic classifications based on gauged and modeled flow series has not been addressed to date.

A third type of classification is the expert-driven. This type of classification does not rely on the multivariate statistical analysis most commonly used in hydrological classifications to define class boundaries, but rather on experts' rules. There are few examples of this method (but see CEDEX, 2009; Hughes and Hannart, 2003; Kachroo et al., 2000; Krasovskaia et al., 1994). Expert-driven classifications lack, in general, the desirable qualities of objectivity, transparency, interpretability and repeatability. Indeed, depending on the expert, results may differ greatly from one classification to another. Therefore, although it has not been quantified to date, expert-driven classifications may have a lower performance than inductive classification.

In summary, there are still gaps within the field of hydrological classifications that have not been investigated to date. Three critical weaknesses that may greatly influence the reliability and interpretability of a specific classification have been identified: (1) the flow series time scale (daily versus monthly), (2) the flow series origin (gauged versus modeled) and (3) the classification procedure (inductive versus expert). Hence, the main objective of this study is identifying the main drawbacks of using a simplified dataset or procedure for developing a hydrological classification. This will allow for the framing of the further use of hydrological classifications in those areas where the appropriate data (i.e., daily gauged flows) are not available.

To achieve this, the authors developed three inductive classifications and one expert-driven classification covering the northern third of the Iberian Peninsula. The first inductive classification was based on daily gauged series and was used as the best possible classification approach, because it is able to account for the maximum hydro-ecological information possible. The other two inductive classifications used monthly flow series. One used monthly flow series derived from the daily flow series while the other was based on flow series obtained from a nationwide rainfall–runoff model. The four classifications are compared in terms of their performance (classification strength and discrimination ability), interpretability (most influential hydrological indices) and spatial arrangement (spatial configuration of classes). It is hypothesized that daily flow series would outperform the classifications based on monthly flow series. Moreover, the authors expected that the classification based on monthly gauged series would perform better than the classification based on simulated flow series and that it would produce a more similar spatial arrangement to the classification based on daily flow series. Nonetheless, regarding the interpretation of the classifications based on monthly flow series (gauged or modeled), it cannot been know *a priori* whether or not they would differ considerably from daily flow classifications, given that monthly series still account for critical hydrological information. Finally, authors expected that expert-driven classifications would present the lowest performance and would be the most difficult to interpret. Finally, implications for river management are discussed on the basis of these differences.

2. Methods

2.1. Study area

The study area comprises the northern third of the Iberian Peninsula (Fig. 1) covering a total area greater than 124,000 km^2. It represents heterogeneous environmental conditions and can be broadly segregated into three main zones. Detailed information about climatic and catchment characteristics of the study area can be found in Peñas et al. (2014).

2.2. Initial hydrologic data

2.2.1. Gauged flow series

Different Spanish water agencies and regional governments provided series of daily mean flow measured at 428 gauging stations. Only gauges unaffected by impoundments or important abstractions upstream and with available data for the period 1976–2010 were selected for analyses. The analyzed the quality of the series was analyzed according to Peñas et al. (2014). Ultimately, 156 gauges were selected, which accounted for an average length of 17 years of data.

Daily time series were aggregated into monthly flow series in order to analyze the effect of reducing the detail of the time scale of the flow series. Both daily and monthly series were normalized to eliminate the influence of flow magnitude (Snelder et al., 2009). Normalization was obtained by dividing all daily or monthly flow values by the mean annual flow (Poff et al., 2006). Normalization of flow series by the mean flow was chosen because of its widespread application in the hydro-classification literature (e.g. Kennard et al., 2010; e.g. McManamay et al., 2012a; Snelder and Booker, 2013), although it is not necessarily the most unique and best approach (Milligan and Cooper, 1988).