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# Dynamic rating curve assessment for hydrometric stations and computation of the associated uncertainties: Quality and station management indicators

Thomas Morlot [a,c,*], Christian Perret [a], Anne-Catherine Favre [b,c], Jonathan Jalbert [c,d]

[a] Électricité de France, Division Technique Générale (EDF-DTG), 21 Avenue de l'Europe, BP 41, 38040 Grenoble Cedex 9, France
[b] Université de Grenoble Alpes (UGA), Institut National Polytechnique de Grenoble (GINP), École Nationale Supérieure de l'Énergie, l'Eau et l'Environnement (ENSE3), France
[c] Laboratoire d'Étude des Transferts en Hydrologie et Environnement (LTHE), BP 53, 38041 Grenoble Cedex 9, France
[d] Département de mathématiques et de statistique, Université Laval, 1045 avenue de la Médecine, Québec G1V 0A6, Canada

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SUMMARY

A rating curve is used to indirectly estimate the discharge in rivers based on water level measurements. The discharge values obtained from a rating curve include uncertainties related to the direct stage–discharge measurements (gaugings) used to build the curves, the quality of fit of the curve to these measurements and the constant changes in the river bed morphology. Moreover, the uncertainty of discharges estimated from a rating curve increases with the "age" of the rating curve. The level of uncertainty at a given point in time is therefore particularly difficult to assess.

A "dynamic" method has been developed to compute rating curves while calculating associated uncertainties, thus making it possible to regenerate streamflow data with uncertainty estimates. The method is based on historical gaugings at hydrometric stations. A rating curve is computed for each gauging and a model of the uncertainty is fitted for each of them. The model of uncertainty takes into account the uncertainties in the measurement of the water level, the quality of fit of the curve, the uncertainty of gaugings and the increase of the uncertainty of discharge estimates with the age of the rating curve computed with a variographic analysis (Jalbert et al., 2011). The presented dynamic method can answer important questions in the field of hydrometry such as "How many gaugings a year are required to produce streamflow data with an average uncertainty of X%?" and "When and in what range of water flow rates should these gaugings be carried out?".

The Rocherousse hydrometric station (France, Haute-Durance watershed, 946 [$km^2$]) is used as an example throughout the paper. Others stations are used to illustrate certain points.



## 1. Introduction

Direct measurements of discharges in rivers are still too time consuming and expensive for continuous monitoring of streamflows. In most cases, streamflows can be deduced from continuous measurements of water levels using stage–discharge relationships (called rating curves in the field of hydrometry) based on discrete measurements of water levels and discharges, referred to as gaugings. Water level measurements, discharge measurements and rating curves thus constitute an indirect way of estimating the discharge in rivers. However, given the growing importance of environmental questions and resulting regulatory requirements, it is also necessary to know the uncertainty of such estimates. Data users, modellers, forecasters and engineers all agree on this point. Knowledge of uncertainties can also be used to improve the operational management of hydrometric stations. However, quantifying the uncertainty of streamflow data is a relatively new objective for data producers (Herschy, 2002). In France, the first attempts date back 30 years (Masson et al., 1987), but operational applications have not yet seen the day. In other countries, researchers have realized that the uncertainty associated with stream discharge measurements or estimates is necessary for many questions related to water resources such as flood flow estimations (Clarke, 1999; Petersen-Øverleir and Reitan, 2005, 2009; Moyeed and Clarke, 2005; Pappenberger et al., 2006), rainfall–runoff model calibration (Blazkova and Beven, 2009; McMillan et al., 2010) and hydraulic model calibration (Domeneghetti

* Corresponding author at: Électricité de France, Division Technique Générale (EDF-DTG), 21 Avenue de l'Europe, BP 41, 38040 Grenoble Cedex 9, France. Tel.: +33 476 20 25 90.

*E-mail address:* thomas.morlot@edf.fr (T. Morlot).

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et al., 2012). A comprehensive literature review of methods for estimating the uncertainty associated with stage–discharge relationships has already been published (Le Coz, 2012). Most modellers presently ignore the often high uncertainty associated with streamflow data in the calibration of hydrological models and use these data as if they were totally accurate. The calibration of such models could change drastically if uncertainty were taken into account. This could have an impact on flood forecasting and the design and operation of infrastructures that directly concern the safety of life and property. Major errors and damage can occur if the estimation of streamflow uncertainty is neglected (McMillan et al., 2010). Thus the quantification of streamflow data uncertainties is an extremely important issue in hydrology.

Frequent changes in the stage–discharge relationship often make real time streamflow monitoring quite difficult while the need for continuous (short-time step) high reliability data is obvious. The historical method used to produce rating curves based on a sufficient number of chronologically contiguous gaugings well distributed over the widest possible range of discharges is poorly adapted to fast or cyclical changes of the stage–discharge relationship (Di Baldassarre and Montanari, 2009). Thus this method is not well suited to hydrometric stations subject to frequent changes, in particular those located in mountainous regions or impacted by vegetation. The classical method does not sufficiently take into account erosion and sedimentation processes or seasonal vegetation growth (Reitan and Petersen-Øverleir, 2011). Moreover, gauging conditions in mountainous regions complicate the task of measurement technicians. All papers quoted in the literature review of methods for estimating the uncertainty associated with stage–discharge relationships (Le Coz, 2012) deal with this historical method. Few studies discuss the use of rating curves in the case of unstable channel sections. ISO (1998); Herschy (2009); Rantz (1982) have attempted to deal with this problem by segmenting the gaugings into time periods during which hydraulic control is assumed to be stable. Guerrero et al. (2012); Reitan and Petersen-Øverleir (2011) have explored more dynamic methods to build rating curves, taking into account stage–discharge relationship variability. However the problem has not been completely solved in the literature.

This study develops an original dynamic and operational method to compute rating curves and their associated uncertainties in order to obtain more accurate and more reliable streamflow data. The method computes a rating curve for each gauging performed at the considered hydrometric station. Then, an uncertainty model is fitted for each of the computed rating curves. The uncertainty model takes into account the uncertainties in the measurement of the water level, the quality of fit of the rating curve to the gaugings, the uncertainty of gaugings and the aging of the rating curves assessed through a variographic analysis (Jalbert et al., 2011). We will show that this dynamic rating curve assessment improves the methodology developed by Jalbert et al. (2011). Moreover such an approach can be used to classify hydrometric stations according to a typology derived from their past behaviour. The interpretation of the last gauging can be used to make an objective decision that can range from a simple conservation of the rating curve to the proposal of a new curve that can be used directly on an operational base. This original dynamic method takes into account the variability of flow conditions and the lifetime of a rating curve. It can thus be used to regenerate streamflow data series with confidence intervals that take into account the aging of the rating curves. Finally, the proposed method can be used to significantly improve real time management of hydrometric stations.

The French hydrometric station of Rocherousse located on the Ubaye river (Haute-Durance watershed, 946 [km$^2$]) will be used as an example throughout the paper. This station measures the natural Ubaye flow entering the reservoir behind Serre-Ponçon dam. The hydraulic control of this hydrometric station is a channel control section. Others French hydrometric stations are also used as illustrations.

## 2. Inventory: stability of hydraulic controls in the hydrometric station network under study

### 2.1. Channel and section controls

Classical hydrometric stations rely on an assumption of an objective function between water level and discharge. This condition is clearly met when a hydraulic control exists. The physical characteristics of the channel that govern the relationship between stage and discharge represent the hydraulic control parameters at a given cross section. In hydrometry, two kinds of hydraulic control can be distinguished: channel controls and section controls, also referred to as critical flow controls. Channel controls exist far from singularities where flow geometries are regular and the hydraulic control is governed by a Manning–Strickler law. In such a case, the flow is controlled mainly by the slope and roughness of the river bed. Section controls exist at natural or artificial singularities (sills, rocks, weirs) where the flow becomes critical due to an overfall and the hydraulic control is governed by a threshold law. In this case, the flow is mainly controlled by the geometry and the surface state of a cross-section. In both cases the stage–discharge relationship can be modelled hydraulically by a power function (ISO, 1998; Schmidt, 2002; Rantz, 1982) defined in Eq. (1) as:

$$Q = a(H - H_0)^b, \tag{1}$$

where $H_0$ is a parameter modelling the cease-to-flow reference level and $a$ and $b$ are parameters that must be estimated. The exponent $b$ has typical theoretical values of 5/3 (Manning–Strickler), 5/2 (triangular weir) or 3/2 (rectangular weir).

The least squares method is generally used to estimate the three parameters $a, b$ and $H_0$ . The first step to apply this method consists in linearizing Eq. (1) as $\log(Q) = \log(a) + b\log(H - H_0)$. Then different values are set for $H_0$ and the intercept $\log(a)$ and slope $b$ of the regression parameters are estimated for each of them. Minimization of the sum of the squared residuals gives the final value of $H_0$. The corresponding regression line directly gives estimates of the remaining two parameters $b$ and $\log(a)$. Most rating curves can be modelled by the power law defined in Eq. (1). Sometimes sums or piecewise combinations of such power functions may be suitable to model the stage–discharge relationship taking into account changes in the hydraulic control and in the river bed morphology. All these different cases can be accounted for in the present study. For the case of changing river bed morphology, the break-point in the curve can be deduced from the shape of the sample of gaugings or from knowledge of the physical structure of the hydraulic control.

### 2.2. From stable to unstable hydraulic controls

The *shape Division Technique Générale* (DTG) of Électricité de France (EDF) operates a hydrometric network focused on the mountainous regions of France (Alps, Pyrenees and Massif Central). It includes around 300 hydrometric stations. Half are located at an altitude higher than 600 [m] and half have upstream catchment areas smaller than 330 [km$^2$] (Fig. 1). The data collected are used for real time monitoring of rivers as well as hydrological studies and the design of structures.

Hydrometric stations may be classified into three families: stable (when the rating curve is stable), moderately stable (when the rating curve sometimes needs to be modified) or unstable