



# A hybrid artificial intelligence model for river flow forecasting



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## ABSTRACT

A hybrid hydrologic estimation model is presented with the aim of performing accurate river flow forecasts without the need of using prior knowledge from the experts in the field. The problem of predicting stream flows is a non-trivial task because the various physical mechanisms governing the river flow dynamics act on a wide range of temporal and spatial scales and almost all the mechanisms involved in the river flow process present some degree of nonlinearity. The proposed system incorporates both statistical and artificial intelligence techniques used at different stages of the reasoning cycle in order to calculate the mean daily water volume forecast of the Salvajina reservoir inflow located at the Department of Cauca, Colombia. The accuracy of the proposed model is compared against other well-known artificial intelligence techniques and several statistical tools previously applied in time series forecasting. The results obtained from the experiments carried out using real data from years 1950 to 2006 demonstrate the superiority of the hybrid system.

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## 1. Introduction

River flow modelling and prediction is one of the earliest forecasting problems to have attracted the interest of a good number of scientists. Given the importance of estimating flows for the livelihoods of inhabitants located near rivers, it has been necessary to record and study the flow data from early historical times. In fact, the ancient Egyptians established several mechanisms to measure river flows, even using this knowledge to predict floods [1].

Nowadays, the availability of an accurate river flow forecasting method can help in the resolution of relevant tasks such as (i) the optimal design of water storage and drainage networks, (ii) the management of extreme events such as floods and droughts, (iii) the planning of future expansion or reduction of reservoir capacities, (iv) improving the efficiency of power generation and (v) aiding in the prevention and comprehension of hydrologic hazards like the change of hydro-climatic regime, erosion and sediment movement, mud flows or environmental pollutants [2,3].

In the context of time series studies, prediction methods are usually based on the analysis, representation and projection of existing

time series data [4]. In this situation, obtaining an accurate forecast is particularly difficult when the target system is governed by dynamic processes under chaotic and stochastic conditions. To deal with this scenario in our problem domain, traditional approaches like statistical tools and specific hydrological models have been previously applied with different levels of success [5,6]. Nevertheless, relatively recent works apply artificial intelligence (AI) methods like artificial neural networks (ANNs) and hybrid systems to the problem of river flow forecasting in order to generate more accurate models [7–9].

Based on our previous experience developing hybrid forecasting systems [10,11], here we present the definition of a novel hybrid AI model able to predict the behaviour of a reservoir flow influx located in the Department of Cauca (Colombia). The aims for developing the proposed system are twofold: it should allow a precise estimation of the electricity production as well as provide adequate flood control in the zone.

The implemented system uses a case-based reasoning (CBR) model that incorporates a hierarchical clustering technique and a Fourier frequency analysis method to perform the initial selection and filter of similar data values, an Elman and a Modular ANN to generate a primitive forecast, and a final auto configurable weighting schema able to adjust the definitive prediction.

The structure of the paper is as follows: first, we present a brief overview of past efforts and recent approaches related with river flow forecasting; then the hybrid forecasting system is explained and the results obtained with the proposed model are discussed and analyzed; finally, the main conclusions are summarized and future work is outlined.

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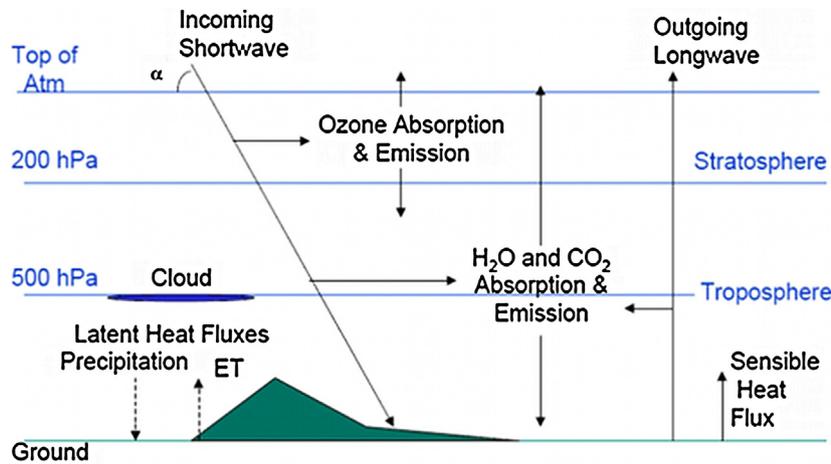


Fig. 1. Simplified hydro climate model (physically based).

## 2. River flow forecasting: past efforts and recent approaches

In hydrology, river flow forecasting is one of the most frequently analyzed problems. For this reason, different predictive models coming from several areas of knowledge under different approaches and with specific goals have been developed resulting in various levels of success. Although many of them are variations of ANN architectures and neuro-fuzzy approaches, numerous hydrological models and black-box alternatives are also available. This section presents a general overview of existing approaches previously used in hydrology that are related to the problem of river flow forecasting.

### 2.1. Classical forecasting methods: hydrological and black-box models

During the last decades, a large number of papers focused on modelling and forecasting of river flow dynamics have been published [12–18]. This is because, previous to the development and general application of AI tools in the field, hydrologists and researchers had to appeal to some expert-based forecasting methods or to develop new models according to the intrinsic characteristics of the problem domain. Many techniques currently used in both approaches assume linear relationships amongst the variables. These techniques can be classified into two main groups: (i) hydrological models and (ii) black-box approaches.

Hydrological models can be understood from three different perspectives: (i) based on spatial representation [19], (ii) based on a representation of the hydrological processes [20] and (iii) based on the temporal extension in which the model can be applied [12].

The classification based on spatial representation considers three types of models: (i) aggregated (ii) semi-distributed and (iii) distributed models. In the first type, a uniform spatial rain distribution is assumed and all the hydrological variables are considered global and constant in time for the whole basin. The second type allows some variability in both the spatial distribution of rain and the hydrological variables. The last type permits variability in the parameters and the spatial distribution of rain, dividing the basin into cells and simulating hydrological processes for each one.

Taking into account the classification based on the representation of hydrological processes, there are three main categories: (i) physically based models [13,14], (ii) conceptual models [15] and (iii) metric models [16,17]. The first one is specifically designed to mathematically simulate or approximate the general internal sub-processes and physical mechanisms that govern the river flow

process. The input is represented by the precipitation values that are partitioned into components and routed through the sub-processes to the watershed outlet as stream flow, to the surface and deep storages or to the atmosphere as evaporation [13]. Fig. 1 shows a simplified hydrological model that incorporates five physical variables (incoming shortwave and outgoing longwave; ozone absorption and emission; H<sub>2</sub>O and CO<sub>2</sub> absorption and emission; latent and sensible heat fluxes; precipitation) together with their interactions.

In the case of conceptual models, parameters must be estimated from fitting the model to historical rainfall-runoff data. Fig. 2 shows a typical structure of a conceptual watershed hydrological model adapted from [21]. Therefore, a conceptual model can not be used in engaged watersheds where historical rainfall-runoff data are not available.

Finally, metric models are those that, after performing a search on the observed data are able to characterize the system response. The characterization is performed by an information extraction method applied over the existing data. These models are built with minimal or no consideration of the physical processes that occur in the hydrological system, and they use the simplest watershed representation. Their main advantage is that they require minimum data, but their utilization is limited because of both the variability of the observed data and their inability to consider watershed changes.

The classification based on temporal extension distinguishes two main categories: (i) event-driven models, developed for short time simulations with a unique rain episode, and (ii) continuous models, which allows daily, monthly and seasonal runoff simulations.

While physically based models are very useful to understand the physical mechanisms involved in river flow dynamics or any other hydrological process, they are difficult to apply. The main drawbacks originate from the fact that they require a large number of parameters to model the complexity of river flow dynamics and the difficulties associated with the extension of a particular model to even slightly different situations.

In contrast to hydrological models, black-box approaches are designed to identify the connection between inputs and outputs without analyzing the internal structure of the physical process [18]. In this approach, stochastic models are fitted to historical records in order to forecast the short and long term behaviour of hydrological variables that represent the states of the hydrological phenomena. In this sense, black-box models may not necessarily lead to a better understanding of the river flow process, but they do have the advantage of being easy to apply even under different

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