A virtual hydrological calibration procedure for stochastic rainfall model

# Abstract

# Introduction

* **focus of the paper: stochastic rainfall models and their streamflow-based application. Brief statement for gaps and objectives.**

Stochastic rainfall modelling involves the generation of sequences of rainfall at a scale of interest (e.g., sub-daily, daily, monthly, annual, multi-annual) that is statistically similar to observed rainfall timeseries, typically measured at rain gauges. Simulated rainfall is a primary input to hydrological model, for simulating streamflow. The simulated streamflow is then used to assess risks such as floods (ref) and droughts (ref). *Stochastic rainfall models are commonly fitted to observed rainfall data. However, it is possible that the simulated rainfall will not be translated to realisation of streamflow that is statistically similar to the observed one. For example, due to the incapability of stochastic rainfall model to capture important rainfall attributes or limited understanding of the rainfall-runoff process.* This paper introduces a new hydrological calibration procedure that allows stochastic rainfall models to be calibrated with streamflow statistics.

* **literature review: (1) influence of rainfall input on simulated streamflow stochastic rainfall model development (with observed rainfall statistics), (2) stochastic rainfall model development (with observed rainfall statistics)**

In catchment hydrology, the term continuous simulation is the simulation of the wet and dry condition of a catchment by estimating the loss in rainfall and generating streamflow at daily, hourly, and sub-hourly time scales. **Generally, the process of continuous simulation requires a sequence of rainfall time series and a rainfall-runoff model and different types of meteorological data such as potential evapotranspiration or temperature depending on the specification of the model. The rainfall time series can be (1) the observed rainfall data collected at a rain-gauge or a network of rain-gauges or (2) generated from a rainfall model (e.g. a stochastic rainfall model). While the rainfall-runoff model can be a lumped conceptual model, a semi-distributed model, or a distributed model (Boughton and Droop, 2003).** Continuous simulation allows the generation of long sequences of streamflow from which important flood or drought statistics can be extracted for the establishment of appropriate mitigation strategies, early warning, or long-term projection. Boughton and Hill (1997) used continuous simulation to generate 1 million years of streamflow to assess streamflow annual maxima for a catchment in Victoria, Australia. Viviroli et al. (2009) evaluated a continuous simulation framework for ungauged catchments is Switzerland and shown that the framework is suitable for flood estimation in ungauged catchment compared to the standard empirical and stochastic methods.

**However, a challenge to the continuous simulation approach is to assess the impact of uncertainties in rainfall data on rainfall-runoff models response.** Poor understanding of the effect of rainfall variability or rainfall data uncertainties on the output of rainfall-runoff models will hamper the capability of continuous simulation in providing reliable hydrological assessment (Michaud and Sorooshian, 1994, Faurès et al., 1995, Andréassian et al., 2001, Cristiano et al., 2017). The sensitivity of rainfall-runoff models to input rainfall has become attention to researchers. Michaud and Sorooshian (1994) examined the effect of rainfall sampling errors on peak-flow estimations on a 150 km2 semi-arid catchment and concluded that poor spatial representation of rainfall (inadequate rain-gauges network in point sampling) accounts for 58% underestimation in observed peak-flow. Similarly, Wilson et al. (1979) emphasized the spatial distribution of rainfall input through an experiment on a small-size catchment (68.6 km2). However, Nicótina et al. (2008) pointed out mixed conclusions in the effect of rainfall spatial variability on rainfall-runoff models response from multiple mesoscale catchments, where some catchments tend to dampen the effect of spatial distributions while others tend to amplify it and concluded that the sensitivity of runoff response to the spatial distribution of rainfall is also affected by catchment characteristics such as hillslope and routing time distribution. Recently, Bennett et al. (2019) introduced a formalised hydrological evaluation framework to assess stochastic rainfall models and found that “good” simulated rainfall can create “poor” streamflow estimations while “poor” simulated rainfall can create “good” streamflow estimations. The highly seasonal catchment process within the rainfall-runoff model was argued to be the cause of such findings (Bennett et al., 2019). There is clear evidence that the varying nature of rainfall and the uncertainties in rainfall data sampling affect the response of rainfall-runoff models which depends on the representation of catchment characteristics within rainfall-runoff models. Therefore, there is a need to further explore the rainfall and runoff relationship and to develop new procedures and frameworks to address this relationship for a better assessment of hydrological impacts.

Mitigation strategies, early warning and long-term projection of floods and droughts require robust prediction, frequency estimation and projection techniques (Lamb et al., 2016, Brunner et al., 2021). The idea of continuous simulation is a promising solution for those techniques (Brunner et al., 2021). The concept of continuous simulations were proposed in the 1970s (Linsley and Crawford, 1974). However, due to significant computational cost and high demand for data, the concept has not been widely adopted in practice (Lamb et al., 2016, Berk et al., 2017). Over the past two decades the fact that rapid technological development has allowed a vast majority of data to become available digitally and of adequate quality, and computers begin to handle them efficiently has encouraged the application of continuous simulation (Viviroli et al., 2009a). Continuous simulation is the simulation of the wet and dry condition of a catchment by estimating the loss in rainfall and generating streamflow at daily, hourly and sub-hourly time scales (Boughton and Droop, 2003). Hence, the process of continuous simulation would generally require a sequence of rainfall time series and a rainfall-runoff model and other types of meteorological data such as potential evapotranspiration or temperature depending on the specification of the model. The rainfall time series can be (1) the observed rainfall data collected at a rain-gauge or a network of rain-gauges or (2) generated from a rainfall model (e.g. a stochastic rainfall model). While the rainfall-runoff model can be a lumped conceptual model, a semi-distributed model or a distributed model (Boughton and Droop, 2003). With increasing developments in stochastic rainfall modelling and rainfall-runoff modelling, the application of continuous simulation can further be extended to catchments where there are limited or no rainfall gauges (Blazkova and Beven, 2002, Viviroli et al., 2009a, Viviroli et al., 2009b).

* **gap and motivations:** (1) the qualities and defects of simulated streamflow are rarely a consideration in development of rainfall model. (2) representation of “good” rainfall to “bad” streamflow

The key objective of this paper are:

1. Present the virtual hydrological calibration procedure for SRMs
2. Demonstrate the calibration procedure with a single site rainfall model and a conceptual rainfall runoff model
3. Evaluate the virtual hydrological calibration procedure

# Virtual hydrological calibration

## Overview

A typical calibration procedure for a stochastic rainfall model involves matching some rainfall statistics with the observed data by adjusting rainfall model’s parameters. Figure 4.2 illustrates the calibration procedure of stochastic rainfall models with observed rainfall data.



Calibrating with observed rainfall data allows stochastic rainfall models to preserve identified rainfall statistics. The simulated rainfall time series can be used as input for hydrological models to produce streamflow time series for hydrological assessment. However, it is not necessarily given that simulated rainfall time series will translate to streamflow time series that preserve the properties of observed streamflow data. Therefore, the first objective of this project is to assess the feasibility of calibrating stochastic rainfall models that are able to preserve streamflow statistics. Figure 4.3 illustrates a schematic of the hydrological calibration procedure for stochastic rainfall models.



## Step 1 – rainfall simulation

**Estimating stochastic rainfall model and rainfall model parameters**: To initiate the experiment, the stochastic rainfall model will be calibrated with at-site observed rainfall data; while the rainfall-runoff model will be calibrated with at-site observed runoff data. This procedure will allow the stochastic rainfall model to simulate rainfall data that are similar to the condition at the site which could avoid potential divergence to the hydrological calibration procedure at later stages. While the set of parameters for the rainfall-runoff model will be fixed throughout the process after they are calibrated and evaluated with the observed runoff.

## Step 2 – streamflow simulation

**Simulating streamflow with simulated rainfall input:** the sequences of simulated rainfall will be used as input to the (already calibrated) rainfall-runoff model to generate sequences of simulated streamflow. Note that a separate aim will investigate the influence of the hydrological model on the overall method.

**Simulating virtual-observed streamflow with observed rainfall input**: A sequence of observed rainfall data will be used as input to the same rainfall-runoff model to generate a sequence of virtual-observed streamflow. This approach removes the possibility of errors from observed streamflow influencing the comparison

## Step 3 – objective function

* Sum of square errors
* Relative errors

## Step 4 – optimization

**Comparing simulated streamflow and virtual-observed streamflow**: The flow duration curve (FDC) will be the subject of the comparison. The FDC is computed from the streamflow sequences produced in the previous stage. The simulated FDC and the virtual observed FDC will be compared against each other forming an objective function using the sum of squares error (SSE) metric. The value of the objective function will be used to inform the calibration of the stochastic rainfall model parameters (i.e. minimizing the SSE by changing stochastic rainfall model parameters).

**Evaluating stochastic rainfall model performance**: To ensure the performance of the stochastic rainfall model in simulating rainfall input that preserves streamflow characteristics, the model will be verified with a virtual-observed FDC at a different time period (split-sample validation)

# Case study

# Results

# Discussion

* Rainfall attributes

# Limitations and opportunities

* Rainfall runoff models
* Objective function
* Feasibility – runtime

# Conclusions

* Limitation and future opportunities

*Data availability.* All the data used in this study can be requested by contacting the corresponding author Thien Nguyen at truonghuythien.nguyen@adelaide.edu.au.

*Author contributions.*

*Competing interest.* The authors declare that they have no conflict of interest.

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# Reference