Journal of Hydrology 393 (2010) 163–173

Contents lists available at ScienceDirect

Journal of Hydrology

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

Generating synthetic high resolution rainfall time series at sites with only daily rainfall using a master–target scaling approach

Shane Anthony Jennings [a], Martin F. Lambert [a,*], George Kuczera [b]

[a] School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide, SA 5005, Australia
[b] School of Engineering, University of Newcastle, Newcastle, NSW 2308, Australia

ARTICLE INFO

Article history:
Received 29 September 2009
Received in revised form 3 June 2010
Accepted 21 August 2010

This manuscript was handled by A. Bardossy, Editor-in-Chief, with the assistance of Ezio Todini, Associate Editor

Keywords:
Rainfall
Rainfall simulation
Stochastic hydrology
Point rainfall

SUMMARY

Australia is typical of many countries in that it has an extensive network of rainfall recording stations which record rainfall data in various forms ranging from a daily time step down to 6-min resolution. However, while the length of historical daily records is often large, there are very few 6-min (pluviograph) records available of significant length. Not only does this lack of significant short time scale data impose a major obstacle in the application of a Monte Carlo approach to risk estimation, it also inhibits the application of rainfall simulation models that use this data for direct calibration. While the advent of numerous stochastic rainfall models provides methods for extending historical rainfall records, without adequate historical rainfall data available for calibration their accuracy is questionable.

This paper describes the development of a new technique which significantly extends the applicability of stochastic point rainfall models that require historical data for calibration. The technique uses a new 'master–target' scaling relationship. A model calibration is undertaken at a 'master' site with a long pluviograph record, which is then scaled to the 'target' site using the information from the target site in form of either a short pluviograph or a daily rainfall record. This approach removes the need for significant pluviograph data at the 'target' site and enables the stochastic rainfall model to be applied at sites with either short pluviograph or daily rainfall records. The master–target scaling technique is demonstrated using an existing high-resolution point rainfall model based on wet-dry alternating storm events. Extensive testing using numerous pairs of Australian sites demonstrates its validity.

1. Introduction

The design and analysis of complex hydraulic engineering systems is typically risk-based. Underground urban pipe networks, bridges, culverts, channels and wetlands are all designed to cope with natural stormwater flows of a certain flood magnitude. The estimation of how often these systems will fail (or the probability of observing an event that exceeds an assumed design level – flood risk) is fundamental to the risk analysis process.

The problem of estimating flood risk can be solved empirically using a Monte Carlo continuous simulation model which requires simulating the flood response due to a long rainfall record and empirically deriving the resultant flood probability distributions. This technique works on the basis that a sufficiently long simulation will eventually sample almost all possible joint probability interactions (i.e. all combinations of rainfall input and possible runoff conditions). If this can be achieved successfully, the derived flood probability distribution can be viewed as an accurate inference of the true flood probability distribution.

A significant issue is the availability and length of historical rainfall records available for use in Monte Carlo applications. This is particularly important if we consider the tails of the flood probability distribution where it is unlikely that, say, a 15-year historical record can provide accurate estimates of a 100-year flood event. While the advent of numerous rainfall models can provide a method for extending historical rainfall records, without adequate historical rainfall data available for calibration, their accuracy is questionable. In particular, models which attempt to produce synthetic rainfall at the sub-hourly resolution are often susceptible to insufficient calibration data to adequately simulate the complex processes at shorter time scales. This is particularly relevant for analysis of systems where initial catchment conditions or storage volumes are important (i.e. flood analysis or when investigating Water Sensitive Urban Design components in new or existing stormwater systems). Without the local availability of significant high resolution data for calibration or a technique to use alternate additional data sources (i.e. daily), these models will continue to remain restricted in their application and usefulness as an engineering tool.

* Corresponding author. Tel.: +61 883035838; fax: +61 883034359.
E-mail address: mlambert@civeng.adelaide.edu.au (M.F. Lambert).

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doi:10.1016/j.jhydrol.2010.08.013

To highlight this point we consider the availability of high resolution data in Australia. The Australian Bureau of Meteorology presently administers about 940 pluviograph rainfall sites across Australia. Further analysis into the extent of this data reveals significant inadequacies. Of the 940 pluviograph sites in Australia, the combined average length is only approximately 15 years. Even if this value is slightly biased by a number of sites that are relatively new (or were installed for a specific purpose and contain only a few years of record), more alarming is the fact that of all sites that are still active, less than 40 have a record length greater than 40 years. Fig. 1 displays the sparse nature of these pluviograph sites in Australia. Complicating issues further is that these historical records often contain sections of missing or erroneous data (faulty gauges, time aggregated rainfall totals), which present another obstacle (and a potential reduction in data length) in using this data to successfully calibrate high resolution rainfall models.

Further analysis of Fig. 1 shows that while sparse in number, the long term pluviograph records across Australia are located at the major Australian centres and are distributed throughout the major climatic regions. In addition to the network of pluviograph stations, the Bureau of Meteorology administers approximately 18,000 daily recording stations. With the assumption of a 40-year calibration record being adequate, then there are in excess of 7300 daily sites which contain a sufficient data record and just over 4400 of these are still active. For models that are able to utilise daily data for calibration, the Australian data set provides a comprehensive number of sites to choose from with a distribution across the nation that almost guarantees an adequate calibration site can be found within close proximity as shown in Fig. 2. At locations where no data are available, techniques also exist which provide interpolated daily data records at the site of interest based on neighbouring data sites (i.e. via the SILO Australian Bureau of Meteorology process). These in turn can be used for model calibration.

It is clear that any high resolution rainfall model relying completely on significant historical pluviograph data for calibration is severely limited in its application in Australia in contrast to models capable of using daily data records. We believe this conclusion applies to many countries. This study presents a continuous rainfall simulation model with adequate complexity to capture the subdaily rainfall characteristics that is structured in a manner to utilise the limited information available from sites with short pluviograph or daily rainfall records. This provides a valuable hydrological tool capable of widespread application across Australia and other countries with similar data constraints.

2. Selection of stochastic rainfall model

Point rainfall models have been developed to reproduce the statistical structure of rainfall using various techniques. Earlier models were often based on the theory of Markov chains with their explicit dependence structure. More recently event based alternating renewal models and Poisson cluster models have received coverage in the literature. One problem with Poisson cluster models is that their structure ensures that the conditional relationship between intensity and duration cannot be modelled explicitly even though it is generally accepted that this dependency exists (Grace and Eagleson, 1966, 1967; Acreman, 1990; Heneker et al., 2001). Another serious concern for the application of these models arises when the historical record contains missing or erroneous data periods.

Numerous authors state that Bartlett-Lewis and Neyman-Scott based models are able to reproduce a variety of rainfall statistics over different levels of aggregation but they are not always able to replicate statistics not used during the calibration process. The application of these models to historical data sets with missing or erroneous data periods is also a concern. While techniques have been suggested to circumvent this problem (Cowpertwait, 1991a,b; Gyasi-Agyei, 1999) questions remain as to the influence and effectiveness of these techniques given the quality of historical records. In addition to this, many researchers have indicated that parameters for the cluster models are difficult to estimate. This is partly because they are not intuitive or easily observed from the historical data. Foufoula-Georgiou and Guttorp (1986) suggested that since the N–S model does not provide an adequate description of the underlying rainfall generating process, no physical meaning should be attached to the parameters. Even though

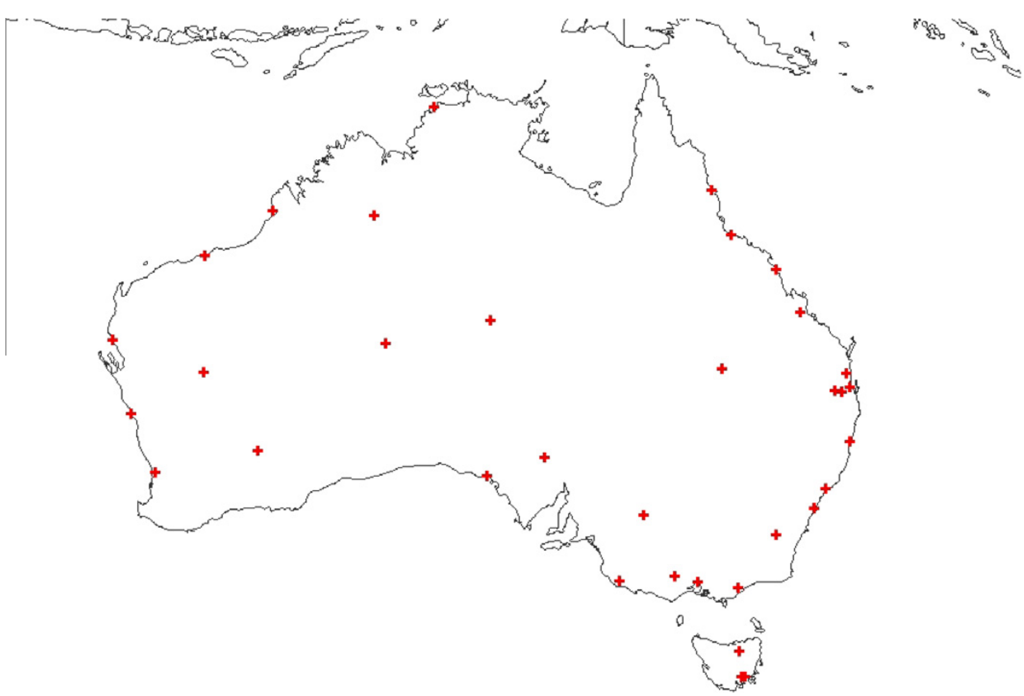

Fig. 1. Australian bureau of meteorology: pluviograph recording stations with a historical record greater than 40 years.