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Stochastic Spatial Rainfall Modelling for
Hydrological Design: Development of a
Parsimonious Simulation Approach and Virtual
Hydrological Evaluation Framework

Bree Sarah Bennett

B. Eng Civil & Structural Engineering (Hons)

B. Laws (Hons)

Thesis submitted in fulfilment of the requirements for the degree of Doctor of
Philosophy

The University of Adelaide
Faculty of Engineering, Computer and Mathematical Sciences
School of Civil, Environmental and Mining Engineering

-June 2016-

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Abstract

The management of water, viewed either as a natural hazard or a vital resource, is critical for the safety and prosperity of communities. The risks associated with managing water availability, whether in scarcity or excess, are critical concerns for the design and operation of infrastructure as well as the implementation of public policy. The spatial variability of rainfall is a known driving force of catchment dynamics and water availability, but despite this, it is often poorly represented in hydrologic studies and designs.

This thesis focuses on improvements to the estimation, simulation and evaluation of spatial rainfall. Specifically these developments include: (i) the development of a generalised approach for spatial extreme rainfall estimation; (ii) the development of a flexible, continuous, and spatial stochastic model of rainfall and its corresponding evaluation; and (iii) an innovative framework for critically evaluating the performance of stochastic rainfall models via the assessment of simulated streamflow. Australian case study locations, with varying climates, are used to present and investigate these approaches.

A new approach for estimating extreme spatial rainfall intensities and a critical evaluation of current approaches for estimation are presented. Current techniques for estimating extreme spatial rainfall are reliant on areal reduction factors (ARF) to convert intensity estimates of extreme point rainfall to extreme spatial rainfall. It is common practice to ignore spatial variation in rainfall intensity and assume a constant ARF over a large region. Approaches using ARFs for estimating extreme spatial rainfall were demonstrated to be in error by 5% to 15%. A new approach that explicitly incorporates the variation of spatial rainfall over an area, referred to as Intensity Frequency Duration Area (IFDA) was developed to address this issue. IFDAs use spatially interpolated rainfall grids to directly estimate how extreme rainfall intensity varies with frequency, duration and area for a given location. The IFDA approach overcomes the shortcomings of existing approaches by avoiding the need to assume a fixed regional ARF value. IFDA provide direct and unbiased estimates of extreme spatial rainfall.

An alternative approach to spatially interpolated observations of extremes is to use data generated by a stochastic spatial rainfall model. A new model for continuously simulating fields of daily spatial rainfall in a parsimonious manner is developed in this thesis. A Gaussian latent variable approach is used because it is able to simultaneously generate rainfall occurrences as well as amounts. Parameter surfaces are produced via kriging which enables the model to produce stochastic replicates for any location of interest in the catchment. Additional benefits of the model are that it removes the need for interpolation to construct catchment average rainfall estimates, preserves the rainfall's volumetric properties and can be used with distributed hydrologic models. A comprehensive evaluation approach was developed to identify model strengths and weaknesses. This included a performance classification system that provided a systematic, succinct and transparent method to assess and summarize model performance over a range of statistics, sites and scales. The model showed many strengths in reproducing observed rainfall characteristics with the majority of statistics classified as either statistically indistinguishable from the observed or within 5% of the observed across the majority of sites and seasons.

A significant challenge when evaluating rainfall models is that the key variable of interest is resultant streamflow, not generated rainfall. Typical evaluation methods use a variety of rainfall statistics, but they provide limited understanding on (i) how rainfall influences streamflow generation; (ii) which rainfall characteristics are most important; and (iii) the trade-offs made when one or more features of rainfall are poorly reproduced. An innovative virtual hydrological evaluation framework is developed to evaluate whether deficiencies in simulated rainfall lead to deficiencies in resultant streamflow. The key feature of the framework is the use of a hydrological model to compare streamflow derived from observed and simulated rainfall at the same location. The framework allows the impact of an influencing month of simulated rainfall on streamflow in an evaluated month of interest to be isolated. Application of the virtual hydrological evaluation framework identified the importance of transition months May and June (late autumn/early winter) in the 'wetting-up' phase of the catchment cycle. Despite their low monthly flow volumes, the transition months contributed significantly to error in the annual total flow.

With improved representation and evaluation of spatial rainfall, this thesis ultimately demonstrates more realistic and accurate methods for hydrological estimation.

Statement of Originality

I, Bree Sarah Bennett, certify that this thesis contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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Date

Acknowledgements

'Far and away the best prize that life has to offer is the chance to work hard at work worth doing.'

– Theodore Roosevelt 1903

I feel honoured and privileged to have been able to experience the pleasure of research. For this my most sincere gratitude goes to my supervisory team, Professor Martin Lambert, Associate Professor Mark Thyer, Professor Bryson Bates and Dr Michael Leonard, who have provided me with great support, inspiration and guidance throughout my candidature. Your combined skill, expertise and passion for research have been invaluable.

I would like to thank my family, friends and colleagues who have shown interest in my research. Particular thanks go to Nicole Arbon who has been especially steadfast in her support and encouragement.

Finally, thanks go to my husband, Phil, for his unwavering encouragement and understanding.

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