Geostatistical Modelling and Simulation of Karst Systems

A thesis by

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Submitted in partial fulfilment of the requirements for the degree of

Master of Philosophy

The University of Adelaide

June 2016

Contents

List of Figures

List of Tables

List of Abbreviations

2D	two-dimensional
3D	three-dimensional
CPU	central processing unit
FILTERSIM	filter-based pattern simulation
FMA	fast marching algorithm
JSD	jensen shannon divergence
MDS	multi-dimensional scaling
MPS	multiple-point statistics
RAM	random-access memory
SGS	Sequential Gaussian Simulation
SIMPAT	Simulation of Patterns
SIS	Sequential Indicator Simulation
SNESIM	single normal equation simulation

Abstract

Groundwater is a significant water resource and in many parts of the world it occurs in karst aquifers. The modelling of karst systems is a critical component of groundwater resource assessment and flow. Geostatistical techniques have shown useful applications in the area of groundwater research because of their ability to quantify spatial variability, uncertainty and risk. Traditional geostatistical methods, based on variogram models, use only two-point statistics and thus are not capable of modelling the complex and, high-connectivity structures of karst networks. This has led to an increasing focus on spatial multiple-point statistics (MPS) to model these complex systems.

In this approach, a training image is used instead of a variogram. Patterns are obtained by scanning and sampling the training image and during the simulation they are reproduced using MPS. There are two implementations of MPS: (i) gridded and (ii) non-gridded. In gridded MPS, the training image, templates and simulations are based on rigid grids, whereas the spatially flexible non-gridded approach does not depend on rigidly specified grids. The non-gridded approach is relatively new (Erzeybek Balan 2012), and applications, especially in hydrogeology are few; however, the method has been used to simulate paleokarsts in petroleum applications. Non-gridded MPS has potential to improve the modelling of karst systems by replacing the fixed gridding procedure, used in the original form of MPS, by a more flexible grid adapted to each specific application. However, there are some weaknesses in the non-gridded approach reported in the literature. For example, the proposed template cannot properly represent the tortuous nature of a network, and the variation of the passage widths is not taken into account. In the case of a simple channelised system with a constant width, sampling

the central line of the passages is sufficient; however, most karst systems have networks with significantly varying widths. In addition, the variability among the realisations generated by non-gridded MPS is relatively small, indicating that the realisations do not cover the full space of uncertainty. In practical applications, it is not possible to know the exact extent of the full space of uncertainty, but the observed variability of the geology and geomorphology of similar structures would tell us when the variability among the simulations is too small (or too large). A lack of significant variability among simulated realisations makes the method inapplicable. This thesis presents a modified non-gridded MPS method that increases the variability among realisations and adequately captures the tortuosities of karst networks. To do this, it includes the width and constructs an optimal template based on a representative variety of directions adapted to each network instead of considering only a few major directions using a generic template as applied by Erzeybek Balan (2012).

The performance of Erzeybek Balan's (2012) non-gridded MPS method has only been visually demonstrated, which is not a sufficiently robust measure of performance. In this thesis, a systematic measure is developed to evaluate the variability among the realisations. This provides an objective way of comparing an important feature of the simulations generated by gridded MPS and the proposed modified non-gridded MPS.

The research starts with an investigation and modification of non-gridded MPS. A widely used demonstration image, which is based on a channelised system, is used to compare the performances of the original non-gridded MPS (Erzeybek Balan 2012) and the modified version proposed in this thesis. A distance-based measure is used to evaluate and compare pattern reproduction and the variability of the realisations generated by the modified non-gridded MPS and standard gridded MPS methods. This distance measure can be used to compare the multiple-point histograms of the realisations and training images. Gridded MPS and modified non-gridded MPS are then applied to two different karst systems—Olwolgin Cave and Tank Cave—and the realisations generated by each method are evaluated in terms of pattern reproduction and the extent of the uncertainty space.

The comparison examples demonstrate that the proposed modified non-gridded MPS generates a larger uncertainty space than that generated by gridded MPS. The results also confirm that modified non-gridded MPS performs significantly better than the original version of non-gridded MPS in terms of a larger (and more realistic) space of uncertainty and pattern reproduction when applied to a complex karst system.

Declaration of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma 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 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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Acknowledgements

I express my gratitude and appreciation to my supervisor, Professor Peter Dowd, and I am grateful for his contributions to my academic career. He introduced me to the great area of Geostatistics and I am thankful to him for sharing his knowledge and his expertise with me. His consistent support has allowed me to develop and has provided an optimal environment for research. I would like to thank *Elite Editing* for providing a professional editor to assist me in preparing my thesis. It was funded in part by the Walter and Dorothy Duncan trust. Last, I would like to thank Mohsen Hasanzadeh, my husband, Zohre Mazaheri, my dear mother-in-law, who passed away last year, Hooshang Hasanzadeh, my father-in-law, and Dariush and Mali Ghobadi, my parents, for their continued support for my goals.