Optimal Water Allocation and Scheduling for Irrigation Using Ant Colony Algorithms

by

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Thesis submitted to The University of Adelaide,
Faculty of Engineering, Computer and Mathematical Sciences,
School of Civil, Environmental and Mining Engineering
in fulfilment of the requirements
for the degree of Doctor of Philosophy

Contents

Abstract

In most regions of the world, irrigation is vital for food production. However, under increased water demands due to population growth, economic development, and climate change in recent decades, there is likely to be a significant reduction in the amount of water available for irrigation. Therefore, it is imperative to make the best use of water that is available for irrigation. This applies to: 1) the optimal allocation of land and water resources for irrigation management to achieve maximum net return, subject to constraints on area and water allocations at the district or regional scale; and 2) the optimal irrigation scheduling of available water, as well as fertilizer, in order to maximise net return at the farm scale. In order to rigorously address these problems, metaheuristic optimization algorithms have been used extensively due to their abilities in terms of finding globally optimal or near-globally optimal solutions and relative ease of linkage with complex simulation models. However, the application of these algorithms to real-world problems has been challenging due to the generally large size of the search space and the computational effort associated with realistic long-term simulation of crop growth and associated soil-water processes.

In this thesis, general simulation-optimization frameworks for optimal irrigation management (including optimal crop and water allocation, and optimal irrigation water and fertilizer application scheduling) have been developed in order to make the application of metaheuristic optimization methods to the above problems more computationally efficient. As part of this approach the problems are represented in the form of decision graphs which are solved using ant colony optimization (ACO) as the optimization engine. The frameworks enable dynamic reduction of the size of the search space by using dynamic decision variable option (DDVO) adjustment during solution construction. This also ensures only feasible solutions are obtained as part of the stepwise solution generation process. In addition, the computational efficiency of the ACO algorithms within the framework for optimal crop and water allocation has been increased by biasing the options at each node in the decision-tree graph based on domain knowledge

(represented by a visibility factor, VF). Furthermore, the framework for optimal irrigation scheduling was linked with a process-based crop growth model to enable optimal or near-optimal irrigation water and fertilizer application schedules to be identified.

This thesis is arranged as a series of three publications that present the main research contributions. The first paper introduces a generic simulation-optimization framework for optimal crop and water allocation at the regional or district scale using decision-tree graphs, ACO and the search space reduction technique based on dynamically adjusting decision variable options during stepwise solution construction. The performance of this technique in terms of finding feasible solutions, solution quality, computational efficiency and convergence speed was compared with that of linear programming (LP) and a “standard” ACO approach using static decision variable options (SDVO) on a benchmark case study from the literature. The second paper extends the ACO formulation for optimal crop selection and irrigation water allocation in the first paper by incorporating domain knowledge through VFs to bias the search towards selecting crops that maximize net returns and water allocations that result in the largest net return for the selected crop, given a fixed total volume of water. This improvement enables locally optimal solutions related to the factors (i.e., crops and water) affecting net return to be identified, and enables promising regions of the search space to be explored. The benefits of this improved formulation were tested on the benchmark case study used in the first paper and a real-world case study based on an irrigation district located in Loxton, South Australia near the River Murray. In the final paper, the formulation for detailed optimal irrigation water and fertilizer application scheduling at the farm scale is introduced and applied to a case study considering corn production under center pivot irrigation in Colorado, USA. The Root Zone Water Quality Model 2 (RZWQM2) was used for this case study to simulate the detailed impacts of irrigation water and fertilizer application scheduling on crop growth at a fixed time step. The utility of the proposed framework was demonstrated in terms of finding better net returns while using less fertilizer and similar amounts of water, or similar net returns while using less water and fertilizer, compared with the Microsoft Excel spreadsheet-based Colorado Irrigation Scheduler (CIS) tool for annual crops.

Statement of Originality

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Nguyen, D.C.H., Maier, H.R., Dandy, G.C. & Ascough II, J.C., 2016. Framework for computationally efficient optimal crop and water allocation using ant colony optimization. Environmental Modelling & Software, 76, 37-53.

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Acknowledgements

First of all, I would like to thank my supervisors, Prof. Holger Maier and Prof. Graeme Dandy, for their supervision, support, and dedication during my PhD research. I am particularly grateful to Prof. Holger Maier for his guidance, determination and enthusiasm in helping me to finish the thesis and improve my research skills (including presentation, writing, and publication). I would also like to thank Prof. Graeme Dandy for his encouragement, constant motivation and inspiration to keep my morale positive for the four years of my PhD candidature.

I would like to thank Dr James C. Ascough II (Research Hydrologic Engineer, USDA-ARS-PA, Agricultural Systems Research Unit, Fort Collins, Colorado, USA) and Associate Prof. Allan A. Andales (Department of Soil and Crop Sciences, Colorado State University, Fort Collins, Colorado, USA) for their support and supervision involving the provision of data, crop growth models and technical assistance for the success of my PhD research.

I am grateful to Darran King (CSIRO Ecosystem Sciences) for providing the data of the River Murray case study. I am also grateful to the staff of eResearch South Australia for the kind assistance to run the models using supercomputers.

I acknowledge my PhD peer, Joanna Szemis, for her support in developing the initial model. I also acknowledge all the staff and other postgraduate students in the School of Civil, Environmental and Mining Engineering who have helped me enjoy my PhD life.

I am grateful to my friends for their encouragement.

I would like to thank my parents (Nguyen Duc Ngoc and Nguyen Thi Huong), my sister (Hong Chau), my brother (Cong Song), and my family for their encouragement, love and trust. Finally, I would like to thank my wife, Hai Duong, for her love and support. She has accompanied me over the journey of my PhD candidature.

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