An adaptive multi-objective framework for the scheduling of environmental flow management alternatives using ant colony optimization

Joanna Margaret Szemis
BEng (Civil & Structural) Hons

Thesis submitted to The University of Adelaide
School of Civil, Environmental & Mining
Engineering in fulfilment of the requirements
for the degree of Doctor of Philosophy

Contents

Abstract

Rivers and their adjacent wetlands and floodplains worldwide have been altered or have vanished as a result of river regulation and development (such as dams, locks and weirs), as well as water over-allocation. In recent years, environmental flow management has been suggested as a means to mitigate these negative impacts. One approach in order to do this is through the scheduling of environmental flow management alternatives (EFMAs), such as reservoir releases and the operation of wetland regulators. However, this is not an easy task for the following reasons: (i) there are generally many wetlands and floodplains in any particular river system, all containing a wide range of biota that have different flow requirements; (ii) there is generally limited water allocated for environmental purposes, since there are multiple users (e.g. irrigation, domestic), all competing for the same water source; (iii) the schedules are generally developed over multiple years; and (iv) there are multiple competing objectives and constraints that need to be considered. This problem therefore lends itself to be formulated as an optimization problem, where the aim is to maximise the ecological integrity of the system, while also considering humans needs and the constraints of the system.

In this thesis, a generic adaptive multi-objective optimization framework for determining the optimal schedule of EFMAs for rivers and their associated wetlands and floodplains is developed and tested. In order to achieve this, ant colony optimization algorithms are selected, since they can take into account the conditional dependencies and sequential nature of the scheduling problem explicitly. This is possible, as the solution space can be represented by a graph structure that can be adjusted dynamically based on the choices made at

previous points in the decision graph, thereby reducing the size of the decision space and increasing the proportion of feasible solutions. This is not possible when most other metaheuristics are used. In addition to this, the framework is adaptive and able to incorporate forecasts of environmental water allocation, such that the environmental water can be used most efficiently in order to maximize ecological response.

The major research contributions are presented in three journal publications. Firstly, the initial single-objective formulation of the optimisation framework, which incorporates the temporal dependencies associated with the scheduling of EFMAs is presented and validated using a hypothetical case study. The framework is then extended to incorporate multiple objectives and applied to a river section in the South Australian River Murray, so that the trade-off between the ecological response and environmental water allocation can be examined. Finally the framework is further extended to incorporate adaptive features by using forecasts of environmental water allocation in the development of EFMA schedules, as well as an additional objective which aims to minimise the number of differences of EFMA schedules developed at subsequent time steps. Thus the framework provides valuable insight to managers into the EFMA scheduling problem, as it can be applied to investigate a wide variety of problems, such as investigating the likely ecological benefit gained from an increase in environmental allocation, the impact of system constraints on ecological response and the potential advantages of investment in additional infrastructure.

Statement of Originality

I certify that this work 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.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Signed:…………………………………. Date:……………..

Acknowledgements

Firstly, I would like to thank my supervisors, Prof Holger Maier and Prof Graeme Dandy, for their supervision, support and encouragement over the course of my PhD candidature. I would particularly like to thank Prof Holger Maier for his continual enthusiasm, vision and determination for my research to succeed. I am also grateful to Prof Graeme Dandy for his constant motivation and scientific insight into my research. Without their guidance, I would have never finished my PhD research. Thank You!

I would also like to thank Tumi Bjornsson and Richard Thompson, who went out of their way and happily provided the vital data for this PhD research. If it wasn't for these data, this research would have been very difficult to finish.

I very grateful to my fellow PhD students Fiona Paton, Jeffery Newman and Eva Beh for their friendship, encouragement, help and enjoyable discussions, which made the PhD experience less daunting than it would have been alone. Many thanks also to staff and other PhD students in the School of Civil, Environmental and Mining Engineering who have helped me throughout my PhD.

I would also like to thank my mother, Margaret, for her unwavering support through this rollercoaster ride, as well as my father, Olgierd, who every week would call and motivate me to press on. I would like to thank Andrew and Lizzie Szemis and Donna Krieg, who would be there to take my mind off things related to my research.

Finally, and most importantly, I like to thank God, who put me on this journey, which I would never have thought in million years I would be on. It has been definitely challenging and at times questionable, but in the end very rewarding.

List of Figures

List of Tables