
# Water Distribution System Optimization using Metamodels

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# Contents

# Abstract

Evolutionary Algorithms (EAs) have been shown to apply well to optimizing the design and operations of water distribution systems (WDS). Recent research in the field has focussed on improving existing EAs and developing new ones so as to obtain better solutions (closer to the global optimum) and/or find solutions more efficiently.

The primary aim of this research, however, has been to broaden the scope of optimization to include a number of the many factors that planning engineers need to consider when designing or planning the operations of WDS. Those factors considered here are (1) water quality criteria, (2) real-world, complex systems, and (3) the incorporation of data uncertainty.

Incorporating each of these factors independently increases computational run-time of EA-based optimization of an algorithm that is already computationally intensive compared to other (inferior) algorithms that have been used in WDS optimization. Water quality models tend to run slower than hydraulic models due to the shorter timestep that is required to ensure sufficient accuracy, and the need for extended period simulations thereby increasing the simulation duration. Real-world models run slower due to their size. Data uncertainty is typically accounted for through the use of Monte Carlo simulations, that add several orders of magnitude to the computational requirements of optimization.

Considering each of these factors together compounds the computational requirements to a point where it is impossible to optimize WDS using EAs in a reasonable amount of time. In this research metamodels have been used in place of simulation models within an EA to reduce this computational burden. A metamodel is a model of a model that runs much faster than the said model, but is still a high-fidelity approximation of it. The particular type of metamodel used in this research is an Artificial Neural Network (ANN) due to its theoretical capabilities and demonstrated effectiveness in water resources applications.

The use of metamodels to act as surrogates for complex simulation models is not a trivial task. Therefore, guidelines have been developed on how best to incorporate them into the WDS optimization process.

The overall metamodel-empowered, EA-based optimization algorithm developed in this research was applied to several case studies. Two small case studies, both variations of the New York Tunnels problem were studied for proof-of-concept purposes. They demonstrated that near globally-optimal solutions could still

be found using the metamodel-based approach, i.e. there was minimal compromise in the effectiveness of the EA-based approach. Two larger, real-world problems were also studied: Wallan (operations planning) and Pacific City (system augmentation). These last two case studies were key to demonstrating the power of using metamodels in that they enabled a computational speed-up of up to 1375 times (137,500%) compared to a non-metamodel approach. This speed-up includes factoring in the computational overheads of using metamodels, i.e. time to generate calibration data and calibrate the metamodels.

# Declaration

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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# List of Publications

The following is a list of the publications related to the research presented in this thesis:

***Journal Papers:***

Broad, D. R., Dandy, G. C., and Maier, H. R. (2005). "Water Distribution System Optimization Using Metamodels." *Journal of Water Resources Planning and Management - ASCE*, 131(3), 172-180.

Broad, D. R., Maier, H. R., and Dandy, G. C. (2010). "Optimal Operation of Complex Water Distribution Systems Using Metamodels." *Journal of Water Resources Planning and Management - ASCE*, 136(4), 433-443.

Broad, D. R., Dandy, G. C., and Maier, H. R., (2014). "Systematic approach to determining metamodel scope for risk-based optimization and its application to water distribution system design", *Environmental Modelling & Software,* Submitted.

***Refereed Conference Paper:***

Broad, D. R., Dandy, G. C., Maier, H. R., and Nixon, J. B. (2006). "Improving Metamodel-based Optimization of Water Distribution Systems with Local Search." *IEEE World Congress on Computational Intelligence, 16-21 July 2006*, Vancouver, BC, Canada, on CD-ROM.

***Unrefereed Conference Papers:***

Broad, D. R. (2004). "Incorporating Water Quality and Reliability into the Optimisation of Water Distribution Systems." *Fourth Postgraduate Student Conference of the CRC for Water Quality and Treatment, 14-16 April 2004*, Noosa, Queensland, 181-187.

Broad, D. R., Dandy, G. C., and Maier, H. R. (2004). "A Metamodeling Approach to Water Distribution System Optimization." *EWRI World Water and Environmental Resources Congress, 27 June - 1 July 2004*, Salt Lake City, Utah, USA, on CD-ROM.

Broad, D. R., Maier, H. R., Dandy, G. C., and Nixon, J. B. (2005). "Estimating Risk Measures for Water Distribution Systems using Metamodels." *EWRI World Water and Environmental Resources Congress, 15 - 19 May 2005*, Anchorage, Alaska, USA.

Broad, D. R. (2006). "Optimising Water Distribution Systems using Metamodels." *Fifth Postgraduate Student Conference of the CRC for Water Quality and Treatment, 10-13 July 2006*, Melbourne, Victoria.

Broad, D. R., Maier, H. R., Dandy, G. C., and Nixon, J. B. (2006). "Optimal Design of Water Distribution Systems including Water Quality and System Uncertainty." *8th Annual International Symposium on Water Distribution Systems Analysis, 27-30 August 2006*, Cincinnati, Ohio, USA, on CD-ROM.

***Report:***

Gibbs, M., Broad, D. R., Dandy, G. C., and Maier, H. R. (2010). "Decision Support Systems for Water Quality Optimisation." Water Quality Research Australia.

***Presentation:***

Broad, D. R. (2005). "Improving Water Distribution System Optimisation through the use of Metamodels", AWA Computer Modelling Special Interest Group.

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*Soli Deo gloria*