#120 - Optimising an integrated stormwater system for a biodiversity corridor

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Highlights

- Integrated stormwater management case study using an evolutionary optimisation approach.
- Optimal detention storage retrofits for daylighting drains.
- Storages used for multiple benefits including passive irrigation, harvesting and flooding.
- Insights and lessons learned from an industry application of stormwater design optimisation.

Introduction

Stormwater management has long been recognised as providing unique ways to achieve multiple urban liveability benefits including urban greening and cooling, water quality improvement, and flood resilience (Mitchell, V. G. et al., 2006). More recently, optimisation-based design approaches for stormwater management systems were developed to identify cost-effective design solutions with respect to multiple objectives (Di Matteo et al., 2017; Dandy et al., 2019). However, there have been limited industry applications of optimisation approaches to multi-objective stormwater management design.

This paper describes a stormwater detention basin optimisation and option shopping approach used as part of an integrated stormwater management concept design. The concept design features flood mitigation, urban greening via passive irrigation, and stormwater harvesting at a site in Adelaide, Australia.

Methodology

Case study

The case study application of optimal stormwater conceptual design was a multi-function stormwater system for a new Biodiversity Corridor within the City of Mitcham in the Adelaide foothills, South Australia, Australia (median annual rainfall 774 mm p.a.). The stormwater system diverts runoff for passive irrigation by daylighting existing stormwater drains into a number of basins to be located in the reserves.

There were six potential locations identified for the basins online of the existing drainage network. The basins needed to improve upon the current system's peak stormwater flow capacity to allow a future pipe capacity reduction downstream. This detention basin network design is the subject of this paper.

In addition, low flow offtakes from the basins were to be incorporated to feed a series of swales and soakage trenches to support new tree plantings in the otherwise barren reserves. Stormwater harvesting opportunities were also evaluated for the basins for irrigation of the reserves and export off-site.

Identify design objectives, decision variables and constraints

The detention basin size and layout design approach was formulated into a formal optimisation problem (Dandy et al., 2019; Yazdi, 2018). The optimisation problem had two objectives: minimise peak flow at the downstream location and minimise total storage volume within the reserves. The decision variables (design parameters) were the size and locations of the storages, and the outlet orifice size of the storages. The constraints were the maximum and minimum size of the design parameters and the peak flow performance of the design should not exceed the existing flow rate for a 10% annual exceedance probability (AEP) design storm event.

Optimisation and simulation approach

In order to select from the large number of possible design solutions (combinations of detention basin size, location and orifice sizes) an evolutionary optimisation algorithm (Dandy et al., 2019) was used. The optimisation algorithm selected the decision variables for each design solution based on the objective function performance of prior solutions and random operators to encourage search of diverse combinations of design parameters. Each design solution was modelled using a 1-D hydraulic model (PySWMM version 0.5) to evaluate the peak flow performance objective function.

The optimisation approach was applied for three scenarios (a 300 mm, 600 mm pipe, and 900 mm pipe capacity downstream of the network). Each scenario was run for 10,000 simulations. This enabled identification of near Pareto-optimal design solutions for each scenario (solutions for which there is almost no additional decrease in total storage volume possible to achieve a peak flow rate).

Visualisation and option shopping of stormwater designs

Following the concept design phase for the project, the large number of solutions generated through the optimisation runs were plotted on a dashboard with multiple linked visuals to enable retrospective “option shopping” capability (Di Matteo et al., 2019). The data visualised included the objective function performance (peak flow and total storage volume), design parameters (size and location of each basin), and other design parameter data. The option shopping enables solutions to be filtered based on performance or design characteristics (e.g. location or size of basins). Multiple designs were isolated and compared to identify acceptable solutions based on engineering judgment and that would satisfy the flood and non-flood mitigation objectives (e.g. total available volumes for passive irrigation, stormwater harvesting capacity).

Results and discussion

The optimisation results are shown on the option shopping dashboard in Figure 1. The figure shows the linked visuals that facilitated the retrospective selection of concept designs. Importantly, the near-Pareto optimal options are included in the visualisation. This allowed options that provided benefits not included in the optimisation formulation to be evaluated in other modelling software manually (e.g. eWater MUSIC to evaluate the stormwater harvesting and passive irrigation performance of networks of basins).

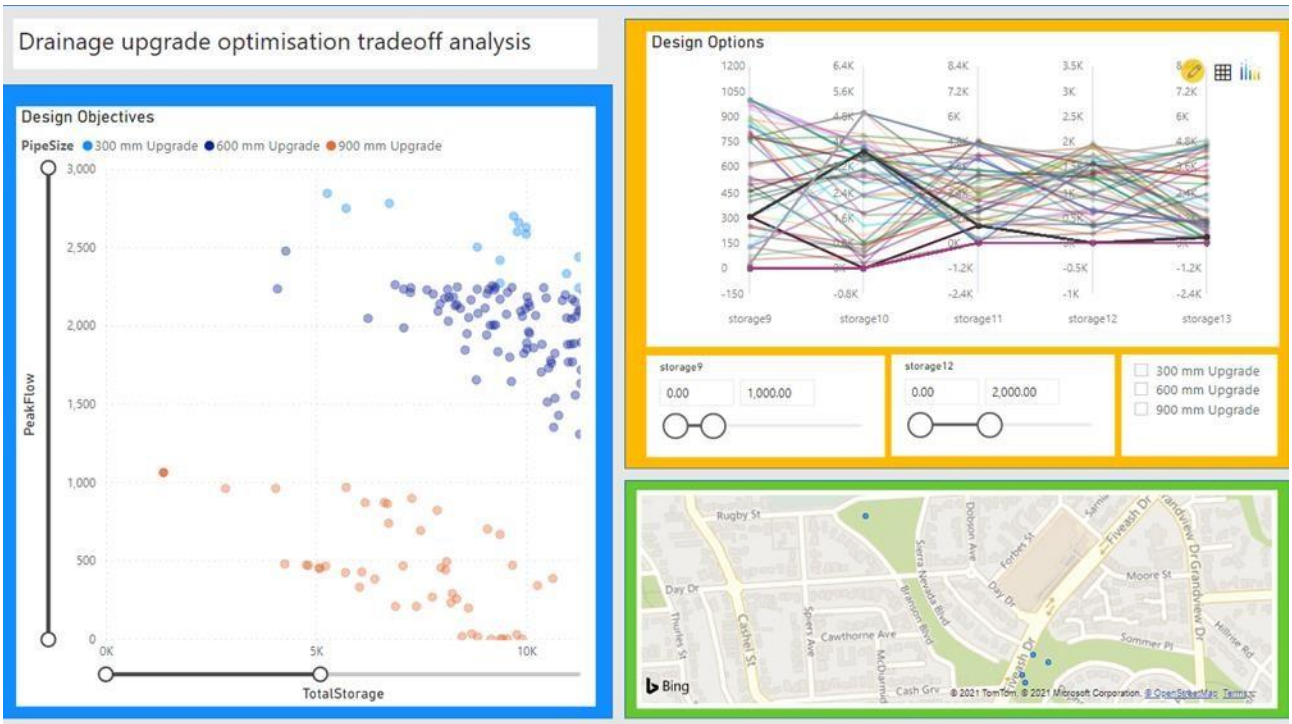

Figure 1. Design trade-off and option shopping dashboard.

These options, that were inferior to the formal objectives trade-off frontier (peak flow and total storage volume), but were nonetheless feasible and performed well in other objectives, were assessed and compared with the optimal solutions. For example, several detention basin configurations near the Pareto-front were suitable for delivering future stormwater harvesting and passive irrigation outcomes as storages were located at sites within the reserves near demand for irrigation (assuming future retrofit of the storages with controlled outlets would be possible to enable a dual detention and retention function).

The findings were consistent with Di Matteo et al., (2019), which showed that options that performed well in many-objective (>3 objective) formulations of the design problem (e.g. considering cost, water quality, stormwater harvesting, and amenity) are inferior to but found near the Pareto-optimal frontier of a two-objective formulation of the system's objectives (e.g. considering cost and water quality only).

Conclusions and future work

This study presented an industry case study application of an evolutionary optimisation approach to designing the size and layout of retrofitted stormwater detention storages for daylighting stormwater flows as part of a biodiversity corridor concept design. Through robust and transparent optimisation of the size and layout of storages, efficiencies and opportunities that delivered multiple benefits could be identified.

Option shopping through near-Pareto optimal as well as non-optimal solutions was facilitated through a dashboard with linked visuals. This enabled solutions to be identified from the optimisation results that had desirable performance and design configurations for stormwater harvesting and passive irrigation and that met flood mitigation targets.

Key lessons learned as part of this study included:

- Identify opportunities to refine constraints on the basin size taking into account amenity values at the concept design phase (e.g. maximum wall height)
- Consider relaxing or eliminating constraints for peak flow performance to enable a wider search near the Pareto optimal solutions.

Future work could link the optimisation engine to a continuous simulation model as well as the 1-D hydraulic model within the optimisation framework to optimise for multiple objectives (e.g. volume reduction via passive irrigation, stormwater harvesting, as well as flood detention using real-time controlled operation (Di Matteo et al., 2017; Xu et al., 2018)).

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