EVALUATING THE BENEFITS OF SMART STORMWATER SYSTEMS

Summary of research outcomes

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Purpose of Study

This study assessed the potential benefits and costs of a range of stormwater storage options, including smart operation of storages, for urban stormwater systems. The benefits assessed include peak overland flow reduction, water re-use potential and water quality. The results are compared with more traditionally used pipe upgrades. This was undertaken for a catchment in the City of Unley, bounded by Fullarton Road, Glen Osmond Road and Wattle Street (Figure 1), located in Adelaide, South Australia.

This report presents a summary of the key research outcomes from this project and includes an overview of the options considered and analyses conducted. For further details and information about this project, including details of methodology, assessments, and costings please refer to the technical report, Thyer et al. (2019).

Options Investigated

The target peak overland flow reduction at the location of interest (Figure 1) was determined by the need to reduce flooding further north on Fullarton Road. The peak overland flow reduction options considered included:

Baseline Option – Equivalent Pipe Upgrade

The baseline was the equivalent pipe upgrade with diameter sized to produce approximately the same target peak overland flow reduction as the various storage options. For the cost comparison two different pipe lengths of 550m and 700m were used to show the sensitivity to this case study specific choice.

Option 1 - Passive End-of-System Storage

Option 1 was an underground, in-line, end-of-system detention storage retrofitted to the existing stormwater system, which represents a storage option used in some urban settings, is used for comparison purposes.

Option 2 - Passive Distributed Storage

Option 2 was an underground, in-line distributed storage option, where a number of smaller detention storages, retrofitted to the existing stormwater system, are distributed throughout the catchment to achieve approximately the same peak flow reduction as the baseline and Option 1. Distributing storages was expected to reduce the overall storage volume required to achieve the target compared with Option 1, as storages can be placed at strategic locations to delay flows further upstream, thereby reducing coincident flows from various sub-catchments at downstream locations. Machine learning optimisation methods were used to obtain the best possible configuration and sizing of these storages.

Option 3 - Smart Distributed Storage (before storm control only)

Option 3 added smart controls (before storm only) to the distributed storage option (i.e. to Option 2), which enables both retention and detention capability. This involves the use of a controllable orifice at the outlet of each distributed storage that remains closed the majority of time to retain water. This water resource can be used for urban greening and cooling, as well as providing water quality benefits. When a significant rainfall event is expected the controllable orifice is opened prior to the event (i.e. 'before storm' control), emptying retained water, thereby maximising available detention storage for flood control.

Option 4 - Smart Distributed Storage (before and during storm control)

Option 4 added smart real-time, 'during storm' event operation of controllable orifices fitted to the distributed storages in Option 3. In this option, the storages are also operated as systems, with the degree and timing of the orifice openings of each storage determined with the aid of machine learning optimisation algorithms based on knowledge of the hyetographs of the incoming rainfall events so as to maximise peak flow reduction at the location of interest. In this study these hyetographs are assumed to be known with certainty, providing an upper limit on the performance of this approach. Two variants are considered:

Option 4a

In Option 4a, the during storm real-time controls are used to maximise peak flow reduction using the same storage sizes as Option 3, hence maintaining water re-use and quality benefits.

Option 4b

In Option 4b, the during storm real-time controls are used to minimise the storages sizes providing a similar peak flow reduction as Options 1 to 3. This is expected to reduce system costs.

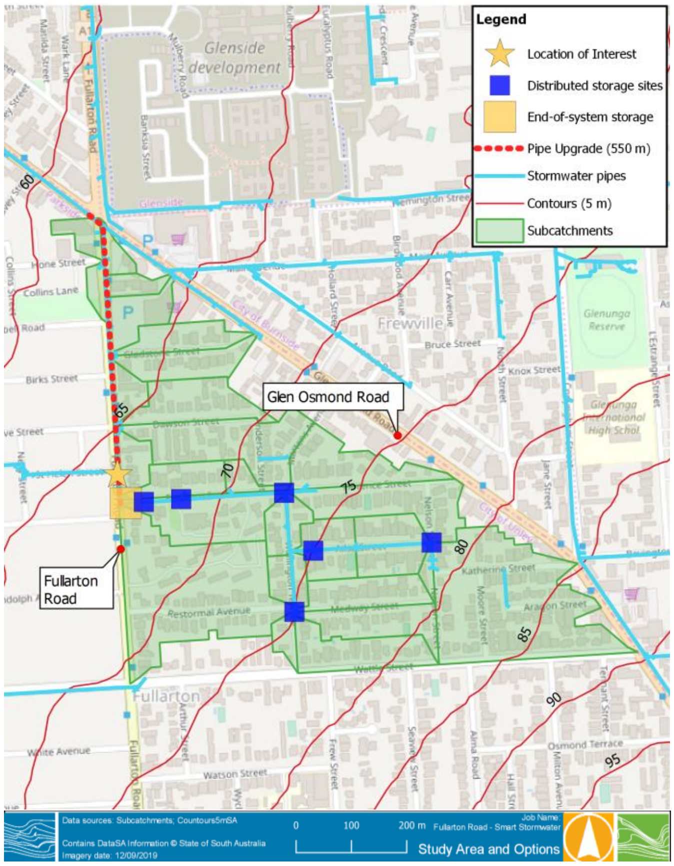

Figure 1 Study area showing approximate locations of overland peak flow reduction options investigated

Analysis Approach

The effectiveness of the different options was simulated using a hydraulic model to assess peak flow reduction impacts and an integrated stormwater model for determining water quality impacts and water re-use potential. Machine learning optimisation methods were used for determining the optimal location and sizes of the distributed storages and their orifice size (Options 2, 3 and 4), as well as the optimal real-time control strategies for operation of the outlets of the distributed storages (Option 4). Performance assessment was conducted for a 10% Annual Exceedance Probability (AEP) and system performances were averaged over 10 storm temporal patterns for design durations (20 to 45 mins). Results are summarised in Tables 1, 2 and Figures 2, 3.

Key Findings

Passive distributed storages optimised using machine learning achieves similar peak flow reduction as end-of-system storage with reduced storage size and cost and is easier to implement

Distributing six detention storages throughout the catchment (Option 2) would produce a similar peak flow reduction of 20% and reduce costs by 30-44% compared to the baseline pipe upgrade (Figure 2). Distributing storages has lower cost than an end-of-system storage (Option 1) because it reduces the total storage volume required to achieve the target peak flow. Distributing storages is easier to implement due to significantly reduced space requirements (i.e. each distributed storage varies between 50 and 97 kL, compared with 700 kL for the end-of-system storage) and because they are located on side streets rather than main road this reduces disruption to traffic and business.

This illustrates a key benefit of using machine learning methods to identify the optimal location and sizes of the distributed storages. A traditional trial and error design would be unlikely to find a similar outcome due to the high number of potential locations and sizes.

Smart distributed storage with 'before storm control' achieves a similar peak flow reduction at similar cost as pipe upgrade with additional water reuse and water quality benefits

Adding 'before storm controls', that empty tanks prior to large rainfall events, to the distributed storages (Option 3) provides similar peak flow reduction at similar cost to the baseline pipe upgrade. Figure 2 shows this outcome is dependent on the pipe length, this smart distributed storage Option 3 has a 10% lower cost than a 700m pipe length or a 15% higher cost than a 550m pipe length.

This smart distributed storage also has a number of additional benefits that are not provided by the baseline pipe upgrade, passive end-of-system storage (Option 1), or passive distributed storage (Option 2). These include approximately 3.1 ML/year of reliable supply of water re-use for urban greening and cooling and a number of water quality benefits (Table 2).

Table 1 Summary of key results for all options (adapted from Table 8-2 in Thyer et al. 2019)

Option No.	Description	Peak Overland Flow Reduction[1] (%)	Total Storage (kL)	Capital Cost[2] ($)	Capital Cost[3] (%) (relative to equiv. pipe upgrade)		Potential Reuse Volume (ML/year)	Water Quality Benefits
					550m pipe length	700m pipe length		
1	Passive end-of-system storage	22%	700	$494k	-1%	-21%	0	None
2	Passive distributed storage	20%	390	$350k	-29%	-44%	0	None
3	Smart distributed storage (before storm control only)	20%	390	$566k	15%	-9%	3.1	Medium
4	Smart distributed storage (before and during storm control)							
4a	*Maximising peak flow reduction (with same storages as Option 3)*	42%	390	$616k	25%	-1%	3.1	Medium
4b	*Minimising storage (with same peak flow reduction as Option 3)*	22%	50	$262k	-47%	-58%	0	Low

1. *Peak overland flow reduction is relative to peak overland flow of existing system of 1123 L/s.*
2. *Capital cost for smart distributed storage options is estimated as at 7/2019 and is subject to change (potentially decrease) as smart technology matures*
3. *Capital cost is relative to the equivalent pipe upgrade. Two pipe lengths are used to demonstrate the sensitivity to this case study specific variable.*

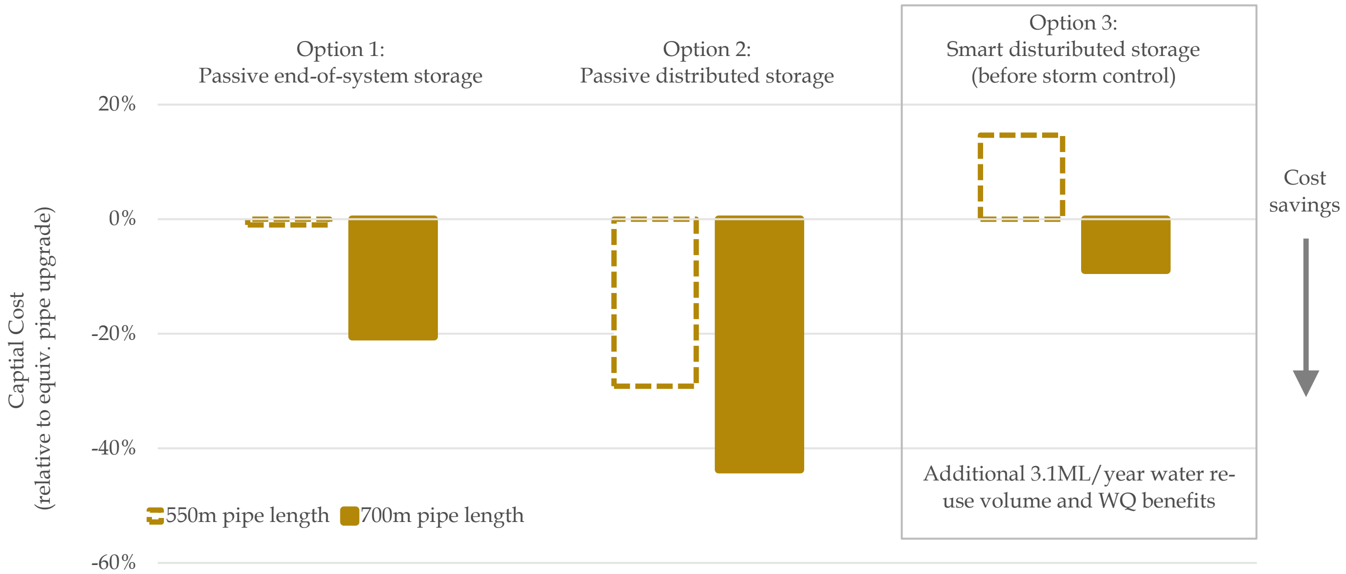

Figure 2: Comparison of cost for options 1-3 with similar peak overland flow reductions of 20%

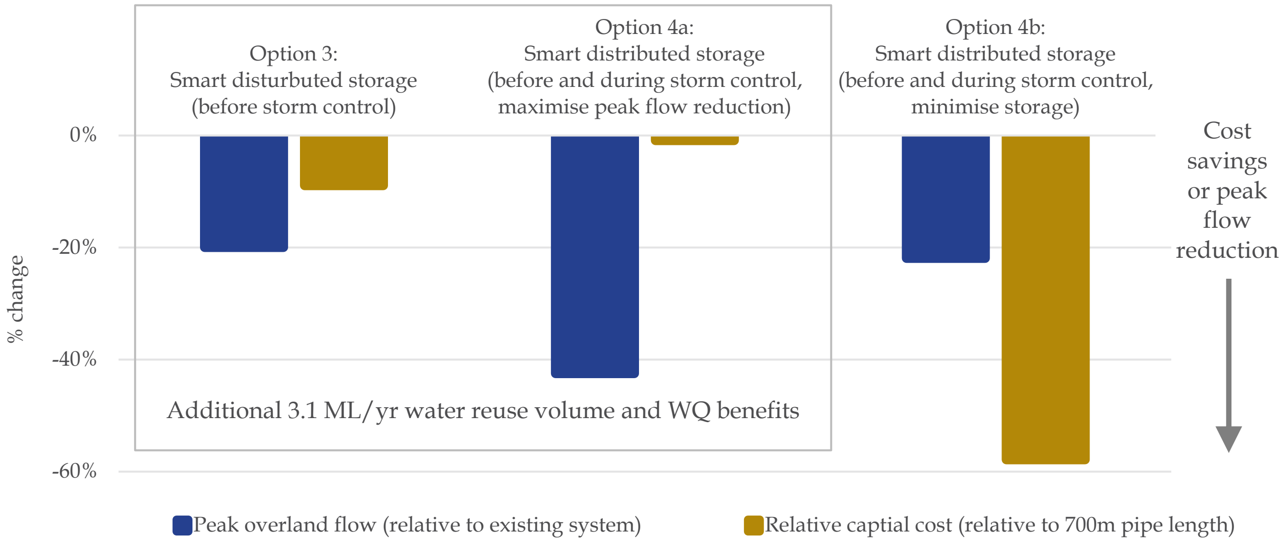

Figure 3: Comparison of performance for smart distributed storage options

Key Findings (cont'd)

Smart Distributed Storage with 'before and during storm control' achieves a far higher peak flow reduction or large reduction in system costs than all other options considered

Figure 3 compares the performance of the smart distributed storage options. A key outcomes is that by adding 'during storm' control (in addition to 'before storm' control) and operating the storages as a system leads to a 45% reduction in peak flows (Option 4a) which is higher than the ~20% peak flow reduction of Options 1-3. This is while maintaining the additional water re-use and water quality benefits. The cost of Option 4a is similar to the 700m equivalent pipe upgrade. However, it is the most expensive of the storage options.

Option 4b results in the largest cost saving of 58% (cf 700m pipe length) because the 'during storm' real-time controls are used to minimise the storage size while still achieving the same 20% peak flow reduction as Options 1-3. This cost saving is due to the much smaller storage size of 50 kL (Table 1). However, due to the smaller storage volume, there are minimal water reuse benefits and minimal water quality benefits.

It is important to note that the peak flow results for the smart distributed storage with 'during storm' control are best classified as a potential upper limit, as perfect knowledge of the incoming hyetograph is assumed, which will not be the case in practice. Consequently, the effectiveness of this approach is contingent on the development and use of appropriate rainfall forecasting methods. In addition, while the control technologies for Option 3 (Smart distribution storage (before control)) are reasonably well established, and could be implemented immediately, the control technologies underpinning this 'during storm' real-time operational approach require some development. As this 'during storm' real-time control constitutes a modification of the 'before storm' control rules, with no other required changes to the physical system, it can be implemented at minimal additional cost once the required technologies have been developed. This enables the distributed storage system to be adapted to increased future runoff resulting from further urban infill and/or the impacts of climate change.

Table 1 Summary of water quality benefits for Options 3 and 4a

Pollutant Constituent	Source	Residual Load	Reduction (%)
Flow (ML/year)	65	62	4.8
Total Suspended Solids (kg/year)	8,750	4,230	51.4
Total Phosphorus (kg/year)	17	13	27.2
Total Nitrogen (kg/year)	126	114	9.3

Conclusions

The conclusions of this evaluation of the benefits of a range of smart storage options are:

- Passive distributed storage provides similar peak overland flow reductions at substantial cost savings compared to an equivalent pipe upgrade (30%-44%) and the end-of-system storage.
- Smart controlled distributed storage options provide similar peak overland flow reductions and similar cost to an equivalent pipe upgrade of approx. 550m to 700m length with the additional benefits of potential water reuse volume of 3.1 ML/year and water quality benefits, in terms of reduced total suspended solids (51.4%), phosphorus (27.2%) and nitrogen (9.3%).
- Smart distributed storages with 'during storm' real-time control provide significant potential for additional peak flow reductions or cost savings through storage size reductions. Further development is needed for this technology to be used in practice.
- Machine learning / artificial intelligence optimisation methods played an essential role for identifying the optimal location, sizing and operating rules for the distributed storage options. Due to the high number of potential locations, sizes and operating rules a traditional trial and error design approach would be unlikely to achieve a similar outcome.

Future Opportunities

There is significant promise for the use of smart, distributed storage for addressing a range of challenges associated with integrated urban water management. These include flood control, urban greening and cooling and improving the quality of receiving waters. However, given that the results presented here were only obtained for a single catchment, the approaches used in this research need to be tested under a wider range of conditions (e.g. different catchments, different climates etc.) to confirm their generality. In addition, it would be prudent to conduct field trials to test the effectiveness of the various approaches under real-world conditions.

The water quality benefits and water re-use potential of distributed storages may be higher in cases where there is additional demand and where additional dedicated storage for harvesting is provided downstream (e.g. in a reserve). Through smart control, the distributed storages may also provide an opportunity for gravity-fed passive irrigation of verges, integration with biofilters for further treatment, and provide a water source for urban cooling. Total volume reduction and associated streamflow benefits may be increased by including opportunities for passive infiltration (e.g. within storages, feeding biofilters).

The 'during storm' control of storages in real-time during rainfall events has significant potential, however, more research and development is needed to be able to implement this in practice. This includes the development of the rainfall forecast technology required to optimise outlet flows and/or the development of control algorithms that are less reliant on such forecasts.

The effectiveness of the approaches to distributing storages at strategic locations throughout catchments and to controlling storage outlets in real-time during rainfall events is underpinned by a combination of the use of machine learning/artificial intelligence optimization techniques and the principle of delaying flows in different parts of catchments at different times so as to reduce the likelihood of coincident peak flows. Significant opportunities exist to apply these principles and techniques to other integrated water management problems (e.g. further upstream in catchments or using existing stormwater infrastructure components for storage).

References

Mark A. Thyer, Michael Di Matteo, Ruijie Liang, Holger R. Maier, Graeme C. Dandy (2019) *Evaluating Smart Storage Options for Drainage Rehabilitation to Provide Flooding, Reuse and Water Quality Benefits: Final Report*. Version 2. Prepared by University of Adelaide and Water Technology Pty. Ltd. for City of Unley.

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Howard Florey Reserve, Parkside, City of Unley (Photo Courtesy of Michael Di Matteo)