Stormwater harvesting: assessing operational system performance

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Abstract

Recently, it has become apparent that stormwater harvesting has the potential to play a significant role in the sustainable management of water resources. However, it has been recognized that uncertainties concerning the operational performance of existing stormwater harvesting systems and also the lack of appropriate design standards are barriers to the widespread adoption and utilization of stormwater harvesting. In this study, we gathered design and operational information regarding three stormwater harvesting systems located in Melbourne as well as undertook water quality and quantity monitoring. It was found that the design objectives of each system were developed in order to meet a range of environmental, social and economic outcomes, and while most of these objectives were met, some were rather qualitative and so are difficult to assess. The design of each harvesting system did not represent what was built and this is likely limiting operational performance. The ongoing drought has severely impacted on the volume of stormwater harvested from the two smaller systems, However recent winter/spring rainfall has increased the volume of stormwater in storage. In comparison, the larger Royal Park system has been able to provide significant amounts of stormwater during the very dry summer of 2007 and throughout the year. Preliminary water quality monitoring indicated that systems featuring WSUD devices are able to improve the water quality (in terms of TSS, TN and TP) of incoming stormwater. Importantly, it appears that systems which do not have disinfection will more frequently have *e. Coli* levels which exceed 10 orgs/100 mL.

Introduction

Victorian and Australian water resources are approaching the limits of sustainability due to population growth (increased demand), a prolonged drought and aging infrastructure. Furthermore, it has been recognised that the current 'traditional' management of water supply, wastewater and stormwater as separate components of the urban water cycle, have various negative environmental, social and economic impacts. In order to address the above issues, there has been a recent emergence of the paradigm of 'Integrated Urban Water Management (IUWM)' (Marsalek et al. 2001). IUWM attempts to consider the urban water cycle as a whole system, which integrates water supply, wastewater and stormwater. IUWM facilitates innovative engineering solutions such as stormwater harvesting which were not previously prevalent.

Recently, there has been a significant increase in the use of stormwater for non-potable end uses such as irrigation and toilet flushing (Hatt el. 2006). Widespread recognition that stormwater harvesting can provide a range of environmental benefits (Mitchell et al. 2005) and good community acceptance of the use of stormwater for non-personal end uses (ARCWIS, 1999) have been some of the key drivers for the increase in stormwater recycling projects throughout Victoria.

Surprisingly, stormwater harvesting systems have been established despite significant knowledge gaps, particularly concerning the lack of appropriate design standards and water quality guidelines specifically related to stormwater harvesting (Hatt et. 2004). Consequently, there are uncertainties in regard to how appropriately existing stormwater harvesting systems have been designed and how these systems perform in relation to end use water quality requirements and operator objectives.

This study's aim was to review the design objectives of three stormwater harvesting systems located in Melbourne, quantify if these objectives were met and investigate how closely the "as built" system reflects the design of each stormwater harvesting system. This study is a component of a larger, two year long Smart Water Fund project entitled "Quantifying Stormwater Recycling Risks and Benefits" (http://iswr.eng.monash.edu.au/research/projects/stormwater_recycling).

Method

Design information regarding each stormwater harvesting system was gathered through obtaining relevant design documentation, interviewing operators/designers and site visits. Preliminary water quality monitoring was undertaken through the collection of grab water samples. Also, initial readings from the flow monitoring program were collected so that an assessment of the amount of stormwater used for each systems could be quantified.

Results

Monash University

The Monash University stormwater harvesting system is located in Clayton, Victoria. Runoff is collected from a small catchment that consists of 2.1 ha of sports oval, 0.7 ha of car park and 0.0225 ha of roof. The mean rainfall is 770 mm/y while potential evapotranspiration is some 1450 mm/y (BOM, 2007a). Irrigation excess from a large sports oval (2.1 hectares) is colleted via a subsurface drainage system. Stormwater runoff from a portion of the car park (0.3 hectares) is collected and, along with the irrigation runoff, is conveyed directly to a storage pond. In comparison, runoff collected from the large multi-level car park (0.4 hectares) undergoes treatment before entering the storage pond (detailed below). Finally, a small amount of roof runoff is collected from a near by building (0.0225 hectares) and flows directly into a storage pond.

Stormwater runoff from the multi-story car park flows into two 18 m^3 sedimentation tanks in series. This pre-treated stormwater than enters a biofilter which provides further treatment before stormwater enters the storage pond. Treated stormwater is retained in an open storage pond. Treated stormwater is pumped from the storage pond into a series of balancing tanks (145 m^3 in total storage) which dampen daily fluctuations. Potable water (estimated to be around 30% under typical climate conditions) is mixed with the treated stormwater in the balancing tanks. Water from the balancing tanks is than used to irrigate the sports oval.

The design objectives of the Monash University harvesting system were:

1 Reduce potable water usage within Monash University's Clayton Campus;
2 Support Monash University's water conservation strategy; and
3 Meet Melbourne Water's stormwater discharge requirements.

The system was not designed with a specific potable water reduction target. Operators were content with the system being able to meet as much of the irrigation demand as possible (i.e. reliability was not a concern). Operators claim that they expected the system not to be able to fully meet demand because the storage pond did not appear 'clean' and the level of the storage pond can at times appear 'low.'

At the conceptual design stage, the operators determined that the irrigation demand would be in the range of 5.4 to 7.2 ML/year. Following the designers intention to use a 70% and 30% mix of treated stormwater and potable water respectively, the demand for treated stormwater would be in the range of 3.8 to 5.0 ML/year.

It is evident that since construction, the Monash University harvesting system has met the design objectives, although only a preliminary assessment of the water quality of the stormwater discharge has been made (see Table 2). The lack of a well defined stormwater harvesting target is surprising as it makes assessment of a level of service difficult. However, the operators must be rightfully acknowledged for their enthusiasm to establish the Monash University harvesting system at a time when stormwater harvesting was not necessary popular and design standards not available.

Altona Green

The Altona Green site is located in Altona Meadows, Victoria. The catchment contains 20 residential blocks, a local road and 4.4 ha of sports oval. The mean annual rainfall is 557 mm/y (BOM, 2007b). Roof runoff is colleted via the guttering of 20 unit blocks along two streets which than proceeds to drain into a piped system that crosses under the street. Stormwater runoff colleted by street gutters and directed through chute openings in the kerb. Irrigation runoff from the sports oval also drains into collection system.

Runoff is collected via a large grassed swale which surrounds the southern sports oval. After treatment, flow is directed from the swale into a pit where it is than pumped into a 400 m^3 Alantis™ underground storage tank. Treated stormwater from the storage tank flows into a pit where a low pressure pump and automatic sprinkler system is used to irrigate the sports oval. Within the outlet pit is a potable mains connection which provides back up in drier months.

The design objectives of the Altona Green harvesting system were:

1 Reduce potable water usage within the Hobsons Bay area;
2 Compliance with Melbourne Water's best practice guidelines for pollutant removal targets;
3 Improved access to economical supplies of water leading to more sustainable landscaping and maintenance of sporting fields (Charlton, 2006);
4 Improved habitat for Altona Skipper Butterfly, which is classed as a vulnerable species and is found only in Altona (Charlton, 2006);
5 Reduced volume of stormwater discharge from the site which minimises impacts on downstream waterways;
6 Provide a area for public recreation;
7 Promote Hobsons Bay City Council as environmentally sensitive;
8 Ensure that there is no pollutant accumulation (nitrogen and phosphorus) within the bioretention trench as a result of recycling the stormwater runoff (Hyder Consulting, 2003); and
9 Provide flood protection.

Based on a preliminary options report (Hyder Consulting, 2002), the intended use of treated stormwater would be approximately 3.5 ML/year. Operators were aware based on the conceptual design and their subsequent choice of a 400 m^3 storage facility that there would be short falls in the drier months and a back up supply of potable would be needed. Ultimately, operators were content with the system being able to provide as much potable substitution as possible. The sites total irrigation was determined to be 4.0 ML/year based on an external consultant's opinion (Hyder Consulting, 2002). In terms of stormwater quality management, the design intentions were to ensure that Melbourne Water's stormwater quality discharge requirements were met.

The design objectives of the Altona Green harvesting system reflect broadly, a range of environmental, social and economic expectations. While it is inherently difficult to ascertain whether or not some objectives have been met (i.e. pollutant removal targets), it is clear that following establishment of the harvesting system, potable water use and stormwater discharge have decreased within the municipality, albeit modestly.

Royal Park

The Royal Park site is located in the suburb of Parkville in Melbourne. Runoff is collected from a 187 ha mixed urban land use catchment. The mean rainfall is 653 mm/y (BOM, 2007c). Stormwater runoff from the catchment is collected using the traditional minor drainage network and is conveyed to a silt trap and diversion weir. The collected stormwater is allowed to pool directly upstream of the diversion weir in the silt trap. Flow is directed from the silt trap into a wetland with well established vegetation. Treated stormwater from the wetland is stored in a large open pond with 12 ML of active storage. Next, the treated stormwater is pumped from the storage pond through a UV disinfection unit uphill to a series of balancing stores which account for daily fluctuations in pumping capacity. Treated stormwater is distributed from the balancing stores to a range of end uses of irrigation end uses which include: a golf course (fairways and greens), three ovals and, during the summer of 2006/2007, numerous trees located across the City of Melbourne municipality (water tankers are used to carry water from the balancing stores to the trees). The system is fitted with potable water backup via the balancing stores.

The broad objectives of the Royal Park harvesting system were:

1 Reduce potable water usage within the City of Melbourne;
2 Improve the quality of stormwater entering the Moonee Ponds Creek;
3 Increase biodiversity in the surrounding area;
4 Provide a focal point for visitors;
5 Provide educational opportunities for local schools; and
6 Implement one of the key objectives of the Royal Park Master Plan.

The above objectives were intended to compliment some of the City of Melbourne's broad strategic policies such as:

- Councils commitment under its Total Watermark strategy to reduce potable water consumption in parks by 40% by 2020;
- Councils commitment under its Total Watermark strategy to improve stormwater quality; and
- The Royal Park Master Plan which identified that a native wetland should be established in the area.

The intended end use of recycled stormwater was for irrigation of three north ovals, golf course and also for watering of some trees. A preliminary assessment revealed that the demand for the use end use would be approximately 95 ML/y. During the conceptual design process it was estimated that the amount of water supplied would be constrained by the area available for the wetland treatment train and the storage, resulting in an expected annual supply of 74 ML/y for irrigation. The operators were content with the system being able to meet as much of the demand as possible – system reliability was not a critical factor in the systems development.

This study concluded that it is likely that all the design objectives has been fulfilled (although, this will be confirmed through the future analysis of the water quality and flow monitoring of the system). Such is the success of the system, that operators are currently exploring further possible end uses. This system is a great example of how good partnerships and strong financial support can deliver a highly successful project. The design objectives of this system highlight specifically, the types of outcomes that can be achieved by stormwater harvesting complimented with water sensitive urban design principles.

Comparing as-built systems with the design

The design of a stormwater harvesting system does not necessarily reflect what is actually 'on the ground' Alterations between the initial design and current 'as-built" system occurred at each site (Table 1).

Table 1 – Alterations from in design intentions and the current system.

Altona Green	• It was envisaged that macrophytes would be established within the grassed swale to promote further treatment, however to date none have been established. • Failure of operators to conduct routine water quality monitoring.
Monash	• The multi-story car park and smaller section of roofing were not part of the systems initial catchment. They have been added on to the system in order to increase the supply of stormwater. • The use of sedimentation tanks rather than a sedimentation basin due to simplicity of construction.
Royal Park	• The UV disinfection unit was planned to be placed in the north-west corner of the storage basin however it was placed in the south-west corner. Consequently, the suction outlet has been placed closer to the inlet than intended, reducing the effective time of detention before harvesting.

Preliminary Performance Monitoring

Monitoring of the three stormwater harvesting sites commenced in December of 2006 and will continue for at least twelve months. The ongoing drought conditions which prevail in Melbourne have impacted on the performance of the stormwater systems as would be expected.

Flow metering data collected from the Monash University system shows that during the summer irrigation season of 2006/2007, minimal stormwater was used for irrigation of the main sports oval. For example during the period 7th December 2007 and 20th March 2007, some 80 kL of stormwater was used compared to 3400 kL of potable water. Very low rainfall during the summer of 2006/2007 caused the storage pond to fall below an acceptable drawdown level for stormwater harvesting. Thus, operators have had to rely on the potable water backup to irrigate the sports oval, which received a dispensation from the Stage 3 water restrictions due to its use in senior competition cricket. Over the winter months of 2007 the storage pond refilled and as a result the operators have recommenced harvesting stormwater from the storage pond.

Since monitoring commenced at the beginning of January at Altona Green, stormwater has provided some 15% of the irrigation water used at the Altona Green site. Again, this low level of stormwater harvesting is due to the prevailing drought conditions drastically reducing the stormwater available to harvest. Continuous flow monitoring at the Altona site particularly highlights the absence of storm events required to fill the storage tank. Like at the Monash University system, the underground store at the Altona Green site refilled over the winter months and has begun to be drawn upon as the 2007/2008 summer irrigation season commences.

In comparison, stormwater has provided all the of the irrigation and tree water tank requirements at the Royal Park site since it was commissioned in late December 2006, resulting in some 41 ML of stormwater being harvesting in the nine month period up until September 2007. This amount is below the design estimate of 74 ML/y although this will have occurred because (i) the irrigation season commenced before the stormwater harvesting system was commissioned so this monitoring month period does not represent a full irrigation season, and (ii) the area to be irrigated was scaled back by the operators due to concerns about there being insufficient stormwater runoff entering the system during the drought period. As it has turned out though, the monitoring of the system has shown that substantially more stormwater could have been harvested from the system.

In comparison to the two other systems, the Royal Park site continued to harvest water throughout the winter of 2007, albeit at modest levels, primarily for street tree watering (Figure 1).

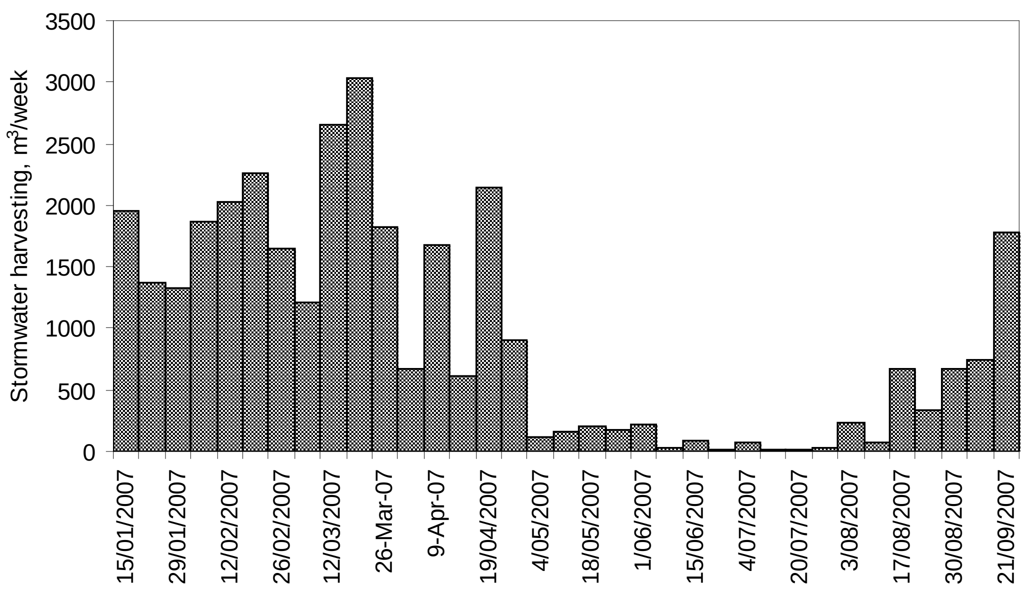

Figure 1 – Royal Park weekly stormwater harvesting volumes

As noted earlier, extensive wet and dry period water quality monitoring throughout each of the stormwater harvesting systems, is occurring as part of the larger project. The below tables (Tables 2 to 4) present a preliminary indication of the water quality at the end of each systems treatment train based on grab samples taken during dry weather periods. Note that several of these values are based on as few as one grab sample so are indicative only.

Table 2 - Preliminary Royal Park post UV unit water quality monitoring results

	pH	Turbidity, NTU	EC, mS/m	TSS, mg/L	TP, mg/L P	TN, mg/L N	*E. coli*, MNP Colilert orgs/100mL	*Clostridium perfringens*, orgs/100mL	Somatic coliphage, orgs/100mL
Mean	7.2	9	70	3.2	0.04	0.5	6	11	<1
Maximum	8.6	64	100	17.0	0.40	0.9	43	46	2
Minimum	6.4	0	45	0.5	0.01	0.3	0	0	<1
No. of samples	30	30	21	19	22	26	27	6	6

Table 3 - Preliminary Altona Green post storage water quality monitoring results

	pH	Turbidity, NTU	EC, mS/m	TSS, mg/L	TP, mg/L P	TN, mg/L N	*E. coli* , MNP Colilert orgs/100mL	*Clostridium perfringens* , orgs/100mL	Somatic coliphage, orgs/100mL
Mean	7.3	25	30.4	2.3	0.09	0.6	41	0	<1
Maximum	8.0	68	47.5	8.1	0.20	2.0	240		
Minimum	6.3	7	21.0	0.5	0.01	0.2	0		
No. of samples	8	9	9	8	4	9	11	1	1

Table 4 - Preliminary Monash University storage water quality monitoring results

	pH	Turbidity, NTU	EC, mS/m	TSS, mg/L	TP, mg/L P	TN, mg/L N	*E. coli* , MNP Colilert orgs/100mL
Mean	7.7	18	38.2	0.2	0.27	0.4	99
Maximum	8.8	90	55.1	0.2		2.1	300
Minimum	7.3	1	32.3	0.2		0.0	4
No. of samples	5	6	6	5	1	6	5

Economics of each system

A full assessment of the economics of each system is beyond the scope of this summer studentship project. Therefore only brief comment is provided. The financial cost of implementing each stormwater harvesting system varied significantly (Table 5). Data is not available on the operating costs of each system, limiting the ability to conduct life cycle costing analysis over the full life of each system.

Table 5 – Construction costs of each stormwater harvesting system

Site	Cost (Australian dollars)
Altona Green	$250,000 (Year 2003)[1]
Monash University	$70,000 (Year 2002)[2]
Royal Park	$5,000,000 (Year 2005)[3]

[1]Hatt, et al (2004)., [2]Nick Aldous, pers. comm., [3]Tony Moussa, pers. comm.

In the authors' view, it is likely that the owners of each system will experience short to medium term economic losses due to the relatively high capital costs relative to the stormwater yield. However in the longer term, once the pay-back-period has passed, the owners will experience economic gains. The length of this pay-back-period will be influenced by a range of factors including the cost of potable water (an avoided cost), which is anticipated to rise significantly in the short to medium term.

Discussion

Stormwater harvesting systems which collect water from a permanent waterway, such as Royal Park, appear to be significantly less susceptible to the sort of below average rainfall conditions experienced during the summer of 2006/2007, still operating well and providing substantial amounts of stormwater for harvesting. Also, it could be argued that the catchment of the Royal Park system is relatively large relative to the amount of stormwater being harvested. In contrast, systems such as those at Altona Green and Monash University are more sensitive to changes in rainfall.

When operators are not overly concerned with the amount of potable water substitution achieved by each system, it is likely that the desire to take an active role in water conservation and environmental protection is a major driver in establishing these systems. With many organizations and individuals striving towards improved environmental outcomes, this driver is well justified.

Mismatches in design intent and what is actually ‘on the ground’ can have implications on the performance of stormwater harvesting systems and more broadly, design objectives. It is very important that good communication (two way feedback and reporting) occurs between all project partners so that how a stormwater harvesting system is built, accurately reflects the design. Furthermore, as the establishment of a stormwater harvesting system is an evolving process with the potential to encounter many unforeseen circumstances, it is critical that all decision making is appropriately justified in consultation with project partners.

Conclusion

A recognized need and potential for stormwater harvesting have been key drivers in its widespread adoption across Australia. Currently, stormwater harvesting systems are being established with design objectives, which are intended to deliver broad environmental, social and economic benefits. While operators expectations of system performance have been meet, they lack an in-depth understanding of the systems behavior, largely due to minimal resources being allocated to ongoing monitoring of the systems.

The three systems assessing in this study have all been affected by the low rainfall experienced since monitoring commenced in November 2006, although the Royal Park system has been able to provide sufficient amounts of stormwater to maintain the condition of the sports ovals without the use of any potable water. Further monitoring of water quality and quantity will progressively provide a fuller picture of each systems performance.

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