URBAN POTABLE WATER HARVESTING

Rainwater and stormwater harvesting for potable use in an existing suburb in Melbourne

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ABSTRACT

This project was initiated to fill a perceived knowledge gap regarding the potential viability of harvesting roof and/or stormwater from existing, highly urbanised catchments for direct potable use through the water supply grid.

Short time-step water balance modelling was used to assess the potential water yield from urban harvesting, taking into account the vagaries of calculating roof catchment areas in established developments, local climate data, uncertainty regarding runoff co-efficients, and the likely capacity of key infrastructure components. The direct benefits of these schemes are the volume of water made available for local use, and the equivalent saving in water purchases not required from the grid.

Investigations also looked in some detail at the indirect benefits from urban water harvesting to assess whether the economic value of these benefits helped offset the costs. Water harvesting has indirect benefits by lowering demand on the regional water supply system, reducing pollutant discharge to the environment, and a lower frequency of nuisance flooding.

The project highlighted that in this area, while harvesting roofwater and/or stormwater is relatively expensive compared to the existing reticulated water supply system, there are many parameter values that can significantly change the economics at certain locations. These include catchment size (larger natural catchments provide more efficient harvesting), the availability of natural storages, and prior ownership of the land required for infrastructure by the key proponent.

In this study roofwater harvesting, on-lot and collection system costs represented over half the total cost. The cost of roofwater harvesting can be reduced by up to 20% if storage and land costs can be avoided, for example, if a natural storage site exists, such as a lake, and if land is donated. However, even with reduced costs, the unit levelised financial cost (capital and recurrent) of water remains high at roughly $27,000 to $38,000 per ML.

For stormwater harvesting, without on-lot and collection systems, the cost could be reduced by up to 85% if favourable conditions can be found to reduce storage and land acquisition costs. With higher yield, and low storage and land costs, stormwater harvesting begins to look cost-competitive, as the unit levelised cost of water drops to between $2,500 and $4,400 per ML.

The economic value of the indirect benefits was found to be around $2,000 per ML, which is significant, but not sufficiently large to offset the high costs.

The analysis suggests that the 'optimum' scale for urban water harvesting in established highly urbanised catchments for potable use is around 1,500 to 2,000 lots.

INTRODUCTION

Yarra Valley Water and City West Water have completed numerous studies into alternative water supplies for greenfield development that consider sourcing non-potable water from sewer mining, stormwater harvesting or roofwater harvesting.

Yarra Valley Water also has a greenfield project at Kalkallo, a development area 35km north of Melbourne CBD, which will harvest stormwater from a 160-ha catchment (approximately 1 ML/day) and treat it to potable standard. The treatment plant, already constructed but not yet in service, uses an advanced treatment train incorporating activated carbon, dissolved air flotation, microfiltration and advanced oxidation.

Against this background, however, there is very little information available for networked, or cluster scale, rainwater harvesting schemes in existing urban development for potable use. The hypothesis is that water collected in a separate system would be of higher quality, requiring less treatment, thereby enhancing the viability of such an option. This study focused on this aspect.

When harvesting rainwater was considered, the option of harvesting stormwater also arose. The hypothesis is that the additional cost of more complex water treatment can be offset by the improved catchment efficiency, and avoidance of the need for a separate collection system. So why not just use the one pipe system, particularly when the proximity of each pipe puts the rainwater collection network at risk of cross-contamination by stormwater? If the collected roofwater has to be treated to nearly the same extent as stormwater, then it may be simpler to use the existing drainage system to harvest the full catchment runoff.

OBJECTIVE

The objective of this study was to determine if it was possible to deliver a technically and commercially viable rainwater- or stormwater-harvesting scheme for potable use in an existing suburb. The project proponent also sought to understand the unique parameters that would make a project viable, so that the study knowledge would have transferrable value to other sites.

STUDY AREAS

Two study areas in established suburbs of Melbourne were selected for investigation – one in Fitzroy North and the other in Northcote. The Fitzroy North site is bound by Park St, Bennet St, Scotchmer St and St Georges Rd. Developed in the late 19th century, it is approximately 7.9 ha with a high population density (45 dwellings per ha) and lot sizes ranging from 55m^2 to 440m^2. Figure 1 shows a typical cluster of dwellings. The site is located within City West Water's area of responsibility.

Figure 1. Representative high-density housing in a Fitzroy North street.

Figure 2. These decorated timber ballards in a Northcote street reflect a community that is socially and environmentally aware.

The Northcote site is bounded by Arthurton Rd, St Georges Rd, Sumner Ave, Winfred St and Merri Creek. Developed during the 1920s, it is approximately 21 ha with a moderate population density of 17 dwellings per ha, and lot sizes averaging 465m^2. It is an environmentally and socially aware community (see Figure 2) and is located within Yarra Valley Water's area of responsibility.

The two sites are located approximately 1.5km apart.

HARVESTING OPTIONS

For each site, four generic options were identified. In all cases, harvested water was to be treated to potable quality and then injected directly into the mains water supply.

Option 1: Roofwater harvesting into household tanks with water then draining slowly by gravity to a central pumping station delivering into a storage tank.

Option 2: Roofwater harvesting into household tanks followed by low-rate pumping into a central storage tank.

Option 3: Roofwater and connected lot area stormwater harvesting into a high rate gravity main delivering to a central pumping station and then into a storage tank.

Option 4: All stormwater runoff, surface and piped, is collected from the catchment into a central pumping station delivering into a bio-retention filter or raingarden for preliminary treatment before flowing into a storage tank.

There were various sub-options within the four broad conceptual options above, based on site-specific constraints and opportunities such as the size of catchment areas, the size of household tanks, diversion points, storage location and treatment plant locations. Six of the most promising sub-options were eventually selected with characteristics as below:

- **Option 1a:** Roofwater only, household tanks, low rate gravity collection, optimistic catchment area;
- **Option 2a:** Roofwater only, household tanks, low rate pumped collection, optimistic catchment area;
- **Option 3a:** Roofwater only, high rate gravity collection, optimistic catchment area;
- **Option 3c:** Roofwater plus area drainage, high rate gravity collection, optimistic catchment area;
- **Option 4a:** All stormwater with raingarden, optimistic allowance for impervious fraction;
- **Option 4c:** All stormwater, no raingarden, optimistic allowance for impervious fraction.

The indicative process train required to achieve potable quality would be as follows (note that, apart from pre-treatment systems, the unit processes required for either roofwater or stormwater are likely to be substantially the same to ensure water of potable quality):

- Trash racks/gross pollutant removal;
- Oil and sediment trap (stormwater only);
- Autostrainer/pre-filter;
- Membrane ultrafiltration (<0.1 µm) as the main filtration stage;

Table 1. Basic characteristics of roofwater and stormwater catchments in each study area.		
Characteristic	Fitzroy North	Northcote
Gross study area (ha)	7.9	21
Development density (Dwelling/ha)	45	17
Rainfall (mm/yr)	678	678
Roofwater catchment area (ha)	2.7	12.2
Number of houses in roofwater catchment	124	206
Household tank size (kL)	1	1
Total roof area (ha)	1.5	4.7
Total roofwater runoff (ML/yr)	10.2	31.9
Potential roofwater capture (ML/yr) Note 1	6.0	19.1
Stormwater catchment area (ha)	3.4	17
Percent impervious area	82%	67%
Stormwater catchment runoff (ML/yr)	16.8	67.6

Note 1: Allows for losses and the fact that not all roof areas and downpipes can be accessed for harvesting.

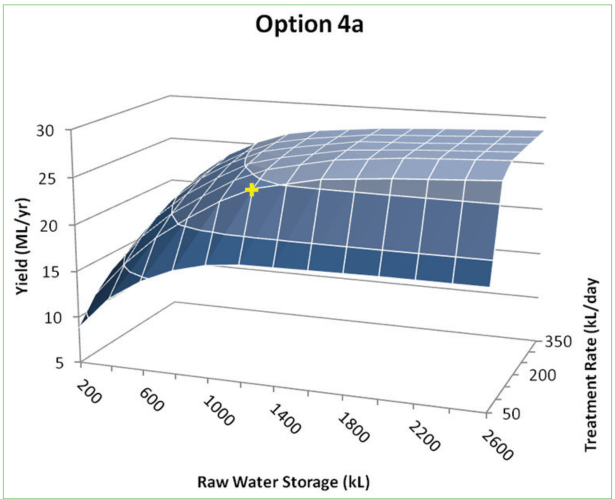

Figure 3. Sample water balance output – stormwater harvesting from the Northcote catchment.

- Advanced oxidation to remove organics and pathogens;
- UV (up to 186 mJ/cm^2 for 4 log virus inactivation based on the USEPA);
- Residual chlorination (0.5–1 mg/L);
- Fluoridation (if required).

Basic characteristics of the roofwater and stormwater catchments adopted for the study are outlined in Table 1.

METHODOLOGY

The potential water yield from the connected catchment was estimated using a 30-minute time-step water balance for the representative rainfall year (1996) in accordance with Melbourne Water's MUSIC Guidelines (Melbourne Water, 2010). The Water Balance was undertaken using Visual Basic within an Excel spreadsheet model with catchment runoff derived from the MUSIC Model. Inputs to the model included assessments of the available catchment area, the percentage of roof area that might practically be connected to the collection system and the assessed range of runoff co-efficients. A range of infrastructure capacities (tank sizes, transfer rates, diversion rates, treatment capacities) were investigated to optimise the system design.

Longer time-scale water balancing was also undertaken to check the yield results derived from the representative rainfall year. The longer time-scale modelling used 14 years of one-minute data (2000–2013). It was found that the yield for the representative year 1996 was high relative to that for the 14-year average data. It was also found that the rainfall for the 2000–2013 period was drier than the long-term average. Yields from the representative year were, therefore, scaled back to provide a better estimate of long-term average yields. To illustrate the output generated, an example of the water balance results is shown in Figure 3. This shows, for the Northcote catchment, the potential stormwater harvesting yield for a range of water storage volumes and treatment plant capacities. The yellow cross indicates the 'optimum' yield point adopted for further assessment and pricing.

An evaluation framework was developed incorporating relatively standard assessment methods such as the use of an NPV (Net Present Value) financial model consistent with the Victorian Department of Treasury and Finance

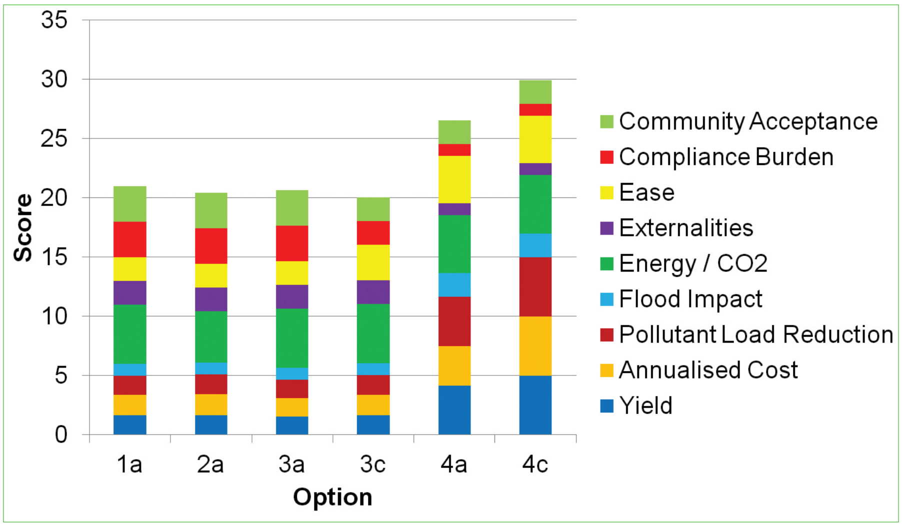

Figure 4. Example of multi-criteria analysis – Northcote (Options 1, 2 & 3 roofwater; Option 4 stormwater).

Table 2. Summarised results for roofwater and stormwater.		
Parameter	Roofwater	Stormwater
Water yield (kL/lot/yr)	30 to 40	45 to 90
Minimum capital cost ($ per lot)	$15,000 to $20,000	$20,000 to $25,000
Minimum O&M cost ($ per ML)	$6,000 to $10,000	$2,000 to $6,000
Minimum levelised cost ($ per ML)	$20,000 to $40,000	$12,000 to $20,000
Approximate levelised economic benefit ($ per ML)	$2,000	$2,000
Benefit-cost ratio	< 0.2	< 0.3

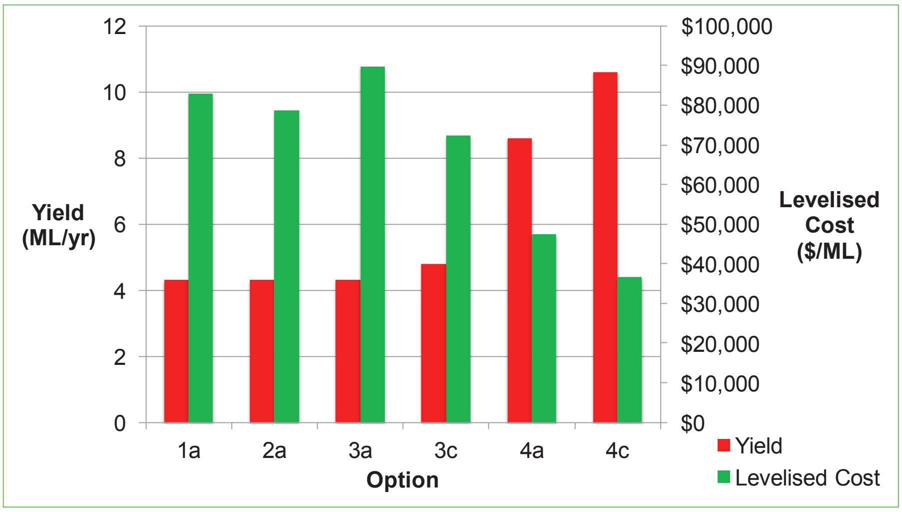

Figure 5. Yield and levelised cost in the Fitzroy North catchment of 7.9ha for a range of roofwater and stormwater harvesting options.

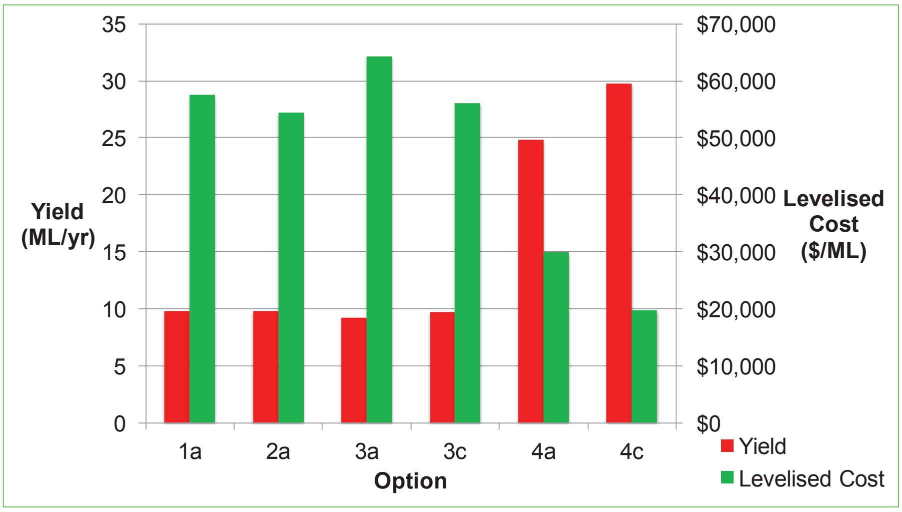

Figure 6. Yield and levelised cost in the Northcote catchment of 21ha for a range of roofwater and stormwater harvesting options.

(2008) guidelines and the assessment of a range of evaluation criteria via a simplified multi-criteria approach. The quantitative evaluation criteria were: scheme yield (ML/yr), savings on variable bulk water charges ($/ML), pollutant load reduction (kg of N removed), energy use (kWh/ML), and local flood reduction (refer to further comments following). The qualitative evaluation criteria were: ease of implementation, compliance burden, community acceptance, construction impacts and economic impact.

A colour-coded approach to displaying the results of the multi-criteria analysis (Figure 4) was found to be a useful communication tool for stakeholders. The image combines quantitative data (eg yield, cost and pollutant reduction) with qualitative information (eg compliance burden and community acceptance). In all cases the data was expressed on a scale of 1 (poor performance) to 5 (good performance); the qualitative information was assessed subjectively.

The indirect benefits of harvesting were investigated to understand their economic value to the community. Decentralised water supplies reduce the demand on regional systems and allow the potential to defer major infrastructure investment; this was valued in terms of a reduction in the fixed component of bulk water charges. Pollutant (TN) load reduction can be valued in terms of the avoided cost of stormwater treatment systems.

Flooding benefits were evaluated using the Water Balance model to assess the significance of the harvested water volume relative to the rainfall hydrograph during an event, particularly in the more frequent intensity events. The analysis considered 60-minute rainfall for the 18% AEP (Annual Exceedance Probability)/ 5-year ARI and the 5% AEP/20-year ARI events. Rainfall and captured water volumes were compared at five-minute intervals over the 60-minute event.

The small-scale results were then scaled up using each study area as the basic catchment unit. Yield was assumed to be linearly related to catchment size or number of lots. Each enlarged catchment delivers water into a common pressure collection system connected to centralised facilities, i.e. a single storage and treatment plant located at some suitable central location. The scales considered were 1x, 8x, 24x and 48x. This system design was conceptual only, and did not represent actual catchment areas.

For each scaled-up option, a levelised cost ($/ML) was derived based on estimated capital and operating costs, and scheme yield. Capital costs were calculated from first principles, or derived from construction databases and recent construction experience. Annual operational and maintenance costs were calculated as a percentage of capital costs plus an estimate of the power consumption. Treatment plant and pumping stations were assumed to be replaced at the end of a 20-year life.

Direct benefits were valued based on the fixed and variable bulk water supply charges by Melbourne Water to water retailers ($ per ML). The forecast demand for bulk water, and Melbourne Water's bulk charges in 2013/14, were considered to be representative for a typical year. This gives a benefit, in terms of avoided cost, of $1,655 per ML for Yarra Valley Water and $1,555 per ML for City West Water. In Victoria, additional charges apply if desalinated seawater is required; this was allowed for by assuming it would be required once every three to five years, contributing between 20% to 40% of the bulk water supplied. This results in additional costs in the range $30 to $98 per ML.

The total net economic value of indirect benefits was around $2,000 per ML, mainly due to deferral of major infrastructure ($400–$800 per ML of yield based on work undertaken on headworks savings due to rainwater tanks – MJA (2012)), pollutant (TN) reduction ($300–$600 per kg based on the Victorian stormwater offset charge (Alluvium, 2014)), and a subjective assessment of community willingness to pay for the scheme ($10–$20 per household). Offset against this is the assessment that local harvesting will use more energy and, therefore, produce more greenhouse gases; local harvesting is estimated to require around 800–900 kWhr/ML of water produced compared with the Melbourne average of 375 kWhr/ML (valued at 1.18kgCO_2-e per kWhr and between $8-23/t CO_2-e). No value was placed on flooding reduction due to a lack of any data, eg insurance payouts, reflecting the actual costs of nuisance flooding.

The benefit-cost ratio was calculated as the present value of all benefits divided by the present value of all costs.

RESULTS

The yield and levelised cost for the Fitzroy North and Northcote sites is shown in Figure 5 and Figure 6 respectively. For both these chosen areas the stormwater yield was in the order of three times larger than the rainwater yield. The levelised cost was equally inversely correlated to yield, with the cost for the largest yields being in the order of one-third of the lower yields.

The lowest levelised cost that could be obtained with these options was in the order of $20,000 per ML. This was obtained in the Northcote catchment. Recognising that having a larger area reduced the cost, further work was done at both sites to determine the scale at which the lowest cost could be obtained.

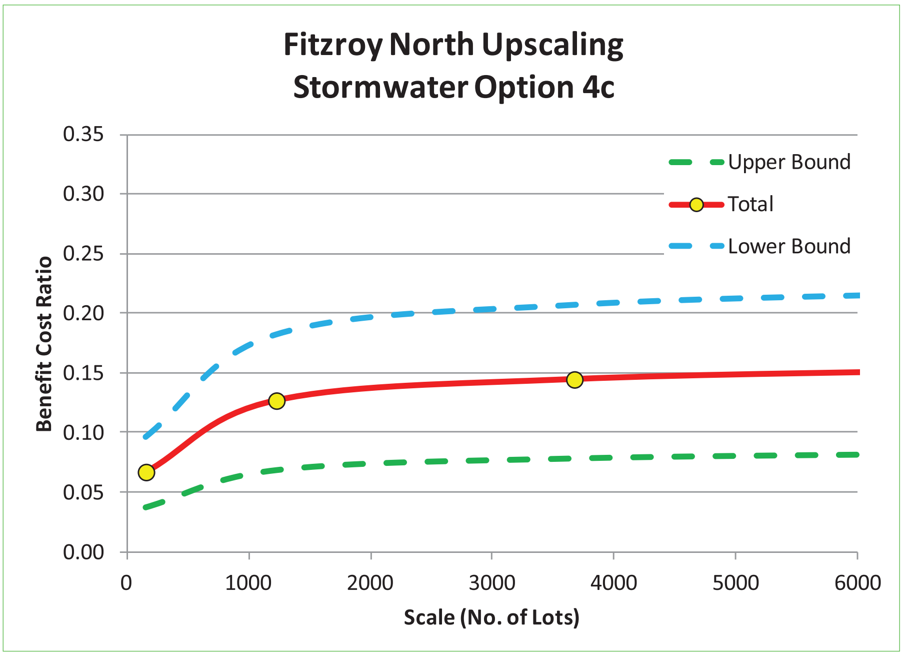

Figure 7. The stormwater benefit-cost ratios for upscaled catchments in the Fitzroy North catchment, harvesting rainwater and stormwater (the upper and lower bounds reflect the range of uncertainty in capital and operating costs, and the value of benefits arising).

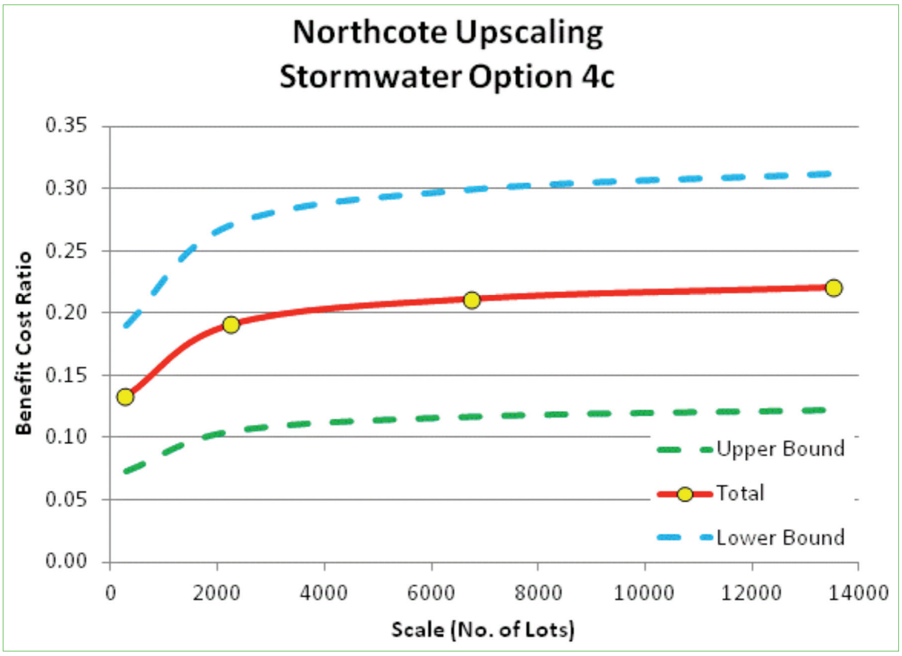

Figure 8. The benefit-cost ratios for upscaled catchments in the Northcote catchment, harvesting rainwater and stormwater (the upper and lower bounds reflect the range of uncertainty in capital and operating costs, and the value of benefits arising).

Not only will yield change with varying areas, so too will capital and operating costs. To capture varying capital and operating costs and benefits, a benefit cost ratio has been used. The effect of varying areas in both Fitzroy North and Northcote for Option 4c is shown in Figures 7 and Figures 8 respectively. This shows that the optimal scale for a development with the density of Fitzroy North and Northcote is in the order of 1,500 to 2,000 lots.

A summary of the range of capital and operating costs for all of the roofwater and stormwater options at both development densities studied is listed in Table 2. This shows that in the higher density development areas in an existing development, the lowest levelised cost that could be obtained was in the order of $12,000 per ML.

DISCUSSION

The study shows that a substantial portion of connected catchment runoff can be effectively harvested with greater yield from stormwater harvesting than for roofwater due to the larger effective catchment area. Roofwater harvesting in existing urban areas is difficult because of the uncertain and varying nature of roof designs, roof drainage systems, external connections and system condition. It is, therefore, difficult to estimate the effective roof catchment that can be used.

Stormwater pollutant reduction is essentially proportional to runoff reduction, so stormwater harvesting provides greater benefits in this regard because it removes a larger proportion of catchment runoff. Local water harvesting has the greatest impact on minor flooding events, reducing as the severity of the event increases. From an energy and greenhouse gas perspective, all options appear to be similar, with the analysis suggesting that the specific energy (kWh per ML) could be about 2.5 times the average specific energy for the Melbourne water supply system.

The cost of all options is very high. Stormwater has a lower unit cost ($10,000 to $25,000 per ML) because of the higher yield compared to roofwater ($20,000 to $40,000 per ML) and the use of existing conveyance infrastructure. The value of bulk potable water supply offset (about $1600 per ML) is much lower than the cost of producing water from these schemes.

For roofwater harvesting, on-lot systems and retrofitted, dedicated communal collection systems account for over half the total cost. The cost of roofwater harvesting can be reduced by up to 20% if the central storage and land cost can be removed, as could occur when a natural storage site such as a lake exists and the land is owned by the water authority. However, unit costs remain high at roughly $27,000 to $38,000 per ML. With stormwater harvesting, which does not require on-lot and retrofitted collection systems, the cost could be reduced by up to 85% if favourable conditions can be found to remove storage and land acquisition costs (more likely to be feasible in a greenfield development rather than an inner city suburb). With lower storage and land acquisition costs, and higher yield, stormwater harvesting begins to look cost competitive, with levelised costs as low as $2,500–$4,400 per ML.

The indirect economic benefits of urban water harvesting, presently valued at around $2,000 per ML, are significant, but not great enough to offset costs to the extent that any of the rainwater schemes become economically feasible.

While all potable reuse options are expected to have high compliance requirements in terms of process validation, water quality verification, reporting and regulatory oversight, roofwater harvesting may have fewer obligations because it is perceived as a lower risk source. On the other hand, stormwater harvesting may be easier to implement because it uses existing draiange infrastructure within the catchments.

The optimal scale for either rainwater or stormwater harvesting appears to be around 1500 to 2000 lots, beyond which there is little increase in the benefit-cost ratio. That is, there is a lack of economy of scale beyond the optimal catchment size.

CONCLUSION

The study shows that while harvesting rain and stormwater from existing urban catchments is technically feasible, it is very costly, which consequently makes it unlikely to be adopted. The evaluation suggests that stormwater harvesting is preferred over rainwater harvesting because it provides a larger source of water at a lower unit cost, with less community disruption.

While care needs to be taken with the estimates, the overall conclusion is that, with a larger catchment, and the availability of a natural storage and no land acquisition costs, it could be theoretically possible to develop cost-effective stormwater harvesting schemes in existing urban areas in Melbourne. Local networked roofwater harvesting schemes were not cost-effective when compared with the existing centralised water supply system, because of the smaller effective catchment area (and, therefore, yield) and the high on-lot and collection system costs.

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