Restoration of stormwater retention capacity at the allotment-scale through a novel economic instrument
Tim D. Fletcher, Christopher J. Walsh, Darren Bos, Veronika Nemes, Sharyn RossRakesh, Toby Prosser, Belinda Hatt and Rhiannon Birch

ABSTRACT

Urbanisation results in changes to runoff behaviour which, if not addressed, inevitably degrade receiving waters. To date, most stormwater management has focussed on the streetscape and public open space. Given that much of the catchment imperviousness is located on private land, we developed and tested a novel economic instrument (a uniform price auction) for encouraging allotment-scale stormwater retention. We evaluated bids using an integrated environmental benefit index (EBI), based on the ability of the proposed works to reduce runoff frequency, pollutant loads and to reduce potable water demand. The uniform price auction resulted in 1.4 ha of impervious areas being effectively ‘disconnected’ from the stormwater system. The EBI provided an objective and transparent method of comparing bids, which varied in the type of works proposed (e.g. rainwater tank, rain-garden), the cost and the resulting environmental benefit. Whilst the pilot auction was a success, the public subsidy of works undertaken was around 85%, meaning that property owners a relatively small private benefit in the works. Future auction rounds will be revised to (i) test an EBI which is more focussed on the protection of streams (assessing changes to runoff frequency, baseflow volumes and water quality) and (ii) provide an auction process which is simpler to understand, and provides greater practical support for landholders who wish to undertake works.

Key words | stormwater retrofit, environmental benefit index, stormwater auction

INTRODUCTION

Impacts of urban stormwater runoff on aquatic ecosystems are well documented (e.g. Walsh et al. 2005b), with water quality pollution (Hatt et al. 2004) and flow disturbance (Leopold 1968) both considered as important drivers of the resultant degradation of receiving waters (Booth & Jackson 1997). Despite many studies often focussing on one or the other exclusively, the general consensus in the literature is that degradation results from the interactive (confounded) effects of changes in both hydrology and water quality (Walsh et al. 2004b, 2009; Roy et al. 2008).

The hydrological impacts of urbanisation are also well documented, with increases in peak flows and runoff volumes (Holman-Dodds et al. 2005). However, urbanisation in fact impacts on nearly every component of the urban water cycle (Figure 1), with reduced infiltration (due to increased impervious area) and evapotranspiration (due both to diminished vegetation cover and lower soil moisture). Baseflows are commonly reduced.

Perturbations to the urban water cycle thus result not only in changes in magnitude of fluxes, but also in the frequency of events. In the pre-development situation, surface runoff to receiving waters would occur infrequently (Walsh et al. 2004a), only when the rainfall intensity or depth exceeded the soil’s infiltration capacity. In the urban context, with impervious areas connected directly to receiving waters, even a small rainfall event (> 1 mm) is enough to generate runoff. The frequency of disturbance to waterways thus increases dramatically, even for a relatively small change in impervious cover (Figure 2), with direct consequences for ecosystem health (Roy et al. 2005; Walsh et al. 2009).

As well as receiving waters being degraded by urbanisation, towns and cities in many parts of the world are
facing increasing shortages of potable water (Coombes & Mitchell 2006; Hatt et al. 2006). Stormwater represents an alternative water resource (readily used for non-potable purposes, and with appropriate treatment, for potable uses), which has the advantage of being generated close to where it is needed. Stormwater harvesting thus represents an opportunity to both reduce the impacts of urbanisation on waterways, and reduce demand on existing potable water resources. In addition to stormwater harvesting, a range of more sustainable stormwater management technologies have been developed, including vegetated swales and biofiltration systems.

Whilst these techniques have significant water quality and flow management benefits (Fletcher et al. 2007), there are two problems which limit their potential impact on the health of receiving waters (which is after all a primary goal of ‘water sensitive’ stormwater management):

1. Since the frequency of runoff will increase even when there are very small levels of imperviousness in a catchment, there is a need to apply these ‘water sensitive’ techniques to almost all impervious areas. Walsh & Kunapo (2006) showed degradation of stream health with as little as 1% directly connected imperviousness. Over the last decade, implementation of stormwater treatments on public land (streetscape, precinct and regional scale) has become common, but to date, little progress has been made in engaging private landowners in installing stormwater management systems. Given the lack of available public land, ignoring private land will often result in efforts falling short of the level of stormwater treatment necessary to achieve tangible stream health outcomes.

2. Targets for stormwater management are often ‘incomplete’, considering only some of the mechanisms by which stormwater runoff impacts on receiving waters. For example, throughout much of Australia, stormwater targets focus primarily on reducing long term pollutant loads. Whilst a flow management objective may be specified (e.g. maintain the 1.5 year average recurrent interval flow at pre-development level), it is rarely enforced. No attention is paid to restoring the frequency of ‘disturbance events’ to receiving waters back to its pre-development level.
This project thus aims to address these two limitations:
1. It tests a novel ‘Stormwater Tender’ for encouraging the implementation of stormwater management systems aimed at retaining stormwater onsite, on private land. The method uses a ‘reverse auction’, where private landholders bid for the level of subsidy they require in order to install systems.
2. It develops a new Environmental Benefit Index (EBI), which assesses the degree to which a proposed stormwater project will (i) reduce runoff frequency to receiving waters, (ii) reduce pollutant loads to receiving waters and (iii) reduce potable water usage.

We describe here the implementation of the Stormwater Tender, along with the use of the EBI to rank the bids received. We document lessons from the pilot application of the tender. The project aims to test the hypothesis that the widespread application of water sensitive stormwater systems will result in a tangible improvement in ecosystem health of the Little Stringybark Creek.

METHODS

The stormwater tender

Incentives for the installation of rainwater tanks are widespread in Australia. They are commonly structured according to the size of tank to be installed, and the nature of uses to which the water will be put (with regular uses such as toilet flushing receiving greater rebates, due to the greater volume of potable water saved). Despite the attractive simplicity of ‘fixed rebates’, they provide no opportunity for ‘negotiation’ between the property owner and the funder. Given that each person will have their own willingness to pay (i.e. their own level of altruism), a fixed rebate may result in a greater price being paid than necessary, or worse, in less people installing systems.

The Stormwater Tender (see www.urbanstreams.unimelb.edu.au for a detailed description) is thus aimed at encouraging private land owners to increase the amount of stormwater captured or retained and treated on their land. The aim of the tender is to purchase environmental benefits. The tender thus provides flexibility in the actions undertaken by landholders, but primarily funds installation of rainwater tanks, rain-garden infiltration systems, or other simple ‘stormwater disconnection’ systems (such as downpipe diversions to gardens).

Before conducting the tender, we undertook a survey of community awareness and attitudes, both within the study catchment and within a nearby control catchment. This allowed us to test target the messages used to encourage community participation. We followed up with a similar survey after the Stormwater Tender, to determine its effect.

Most environment-purpose auctions tend to use a discriminatory price auction (Nemes et al. 2010), where bidders are paid what they bid. In this project, a reverse uniform price auction was instead used, with bids ranked according to their cost per unit of environmental benefit (EB) provided (see Section ‘The stormwater tender’). That is, we invited landholders to submit bids describing the systems they proposed to install, and the minimum price at which they would be prepared to undertake the works. In a uniform price auction, bids are ranked according to their ‘value for money’ (i.e. lowest to highest dollar requested per unit of EB). Starting with the most cost-efficient, bids are accepted until the budget is committed or a reserve price is reached. The first tender to be excluded sets the price that all successful bidders receive for the EB units they supply (Table 1). This price is expressed as dollars for 1 unit of environmental benefit ($/EB). The theory of this approach is that it removes profit-seeking behaviour by bidders (Bower & Bunn 2001), because they know that if they bid at the lowest ‘acceptable’ price, they will get at least that price and likely more.

The EBI

The EBI considers three measures: (i) reduction in runoff frequency, (ii) reduction in total nitrogen loads discharged

<table>
<thead>
<tr>
<th>Tender ranking</th>
<th>EB</th>
<th>Bid</th>
<th>‘Value for money’</th>
<th>Tender successful</th>
<th>Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>$1,050</td>
<td>$700 per unit of EB</td>
<td>Yes</td>
<td>$1,650</td>
</tr>
<tr>
<td>2</td>
<td>2.2</td>
<td>$1,936</td>
<td>$880 per unit of EB</td>
<td>Yes</td>
<td>$2,420</td>
</tr>
<tr>
<td>3</td>
<td>3.4</td>
<td>$3,100</td>
<td>$912 per unit of EB</td>
<td>Yes</td>
<td>$3,740</td>
</tr>
<tr>
<td>4</td>
<td>1.7</td>
<td>$1,870</td>
<td>$1,100 per unit of EB</td>
<td>No</td>
<td>$0</td>
</tr>
<tr>
<td>5</td>
<td>2.1</td>
<td>$2,730</td>
<td>$1,300 per unit of EB</td>
<td>No</td>
<td>$0</td>
</tr>
</tbody>
</table>

Given a funding pool of $10,000, the price for all tenders is set at $1,100/unit of EB provided. Hence, only the top three tenders are successful (payment highlighted in bold). The payment they receive is calculated as their Environmental Benefit × $1,100 (the price/EB of the first unsuccessful bid, highlighted in bold in ‘Value for Money’ column) (Source: Nemes et al. 2010).
The runoff frequency measure is used to predict the direct benefit to Little Stringybark Creek, because there is substantial evidence that the frequency of stormwater discharge is a strong predictor of the ecological condition of small streams (Walsh et al. 2005a, 2009). The runoff frequency is calculated on a daily basis, based on a comparison of the runoff frequency from the impervious area in comparison to the frequency of runoff which would have occurred in the natural (pre-developed state) (Equation (1)). The pre-developed frequency was established using a MUSIC model (Cooperative Research Centre for Catchment Hydrology 2005) developed for the site. The runoff frequency index was calculated as retention capacity (RC; Walsh et al. 2009):

\[
RC = 1 - \max \left( \frac{R_t - R_u}{R_u - R_r} \right)
\]

where \( R_C \) = retention capacity, \( R_t \) = number of days of runoff per year from the impervious area following treatment; \( R_u \) = frequency of runoff from the same area in pre-urban state (modelled as being 12 days per year); \( R_r \) = frequency of runoff from the impervious area before treatment (modelled as being 121 days per year).

We also took into account the degree to which a proposed project would help protect downstream waterways from nitrogen loads (Harris et al. 1996). Nevertheless, our primary motivation for funding works within the catchment was the restoration of Little Stringybark Creek. We thus gave a higher weighting (0.5) to that sub-index.

The EB index (weighted mean of the three indices, Table 2) was standardised by impervious catchment area by multiplying by

\[
A/100 \text{ m}^2
\]

where \( A \) = area (m\(^2\)) of currently connected impervious area to drain to the proposed system, and 100 m\(^2\) is the standard unit for evaluation of the environmental benefit. The result is that each bid provides a calculated number of EB units. A property with 200 m\(^2\) of roof and 100 m\(^2\) of paving (300 m\(^2\) in total), connected to the stormwater drainage system, has the potential to earn 3 EB units.

To assist landholders to prepare their bid, we developed a web-based tool (Figure 3) which allowed them to calculate the number of EB units for their proposed project and to optimise its design to maximise the number of EB units provided. For example, a 5,000 L tank installed and used only for garden watering would produce significantly less benefit than the same tank connected to the house for internal uses (e.g. toilet flushing, hot water) as well as garden watering. Water demands distributed evenly throughout the year have a better match between supply and demand, resulting in a greater water savings and stormwater runoff reductions (Mitchell et al. 2008).

### Table 2 | Summary of sub-indices comprising the EBI

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Weighting</th>
<th>Measure</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in runoff frequency</td>
<td>0.5</td>
<td>Proportional reduction in the number of days of runoff.</td>
<td>Increased frequency of runoff has a major impact on urban streams.</td>
</tr>
<tr>
<td>Reduction in total nitrogen load</td>
<td>0.3</td>
<td>Proportional reduction in annual N load exported.</td>
<td>Port Phillip Bay is threatened by increases in nitrogen levels.</td>
</tr>
<tr>
<td>Water conservation/volume reduction</td>
<td>0.2</td>
<td>Proportion of harvestable water that is captured for use.</td>
<td>Public benefit to conserve water/ improved performance of future downslope treatments.</td>
</tr>
</tbody>
</table>

from the site and (iii) savings of potable water (Table 2). The runoff frequency measure is used to predict the direct benefit to Little Stringybark Creek, because there is substantial evidence that the frequency of stormwater discharge is a strong predictor of the ecological condition of small streams (Walsh et al. 2005a, 2009). The runoff frequency is calculated on a daily basis, based on a comparison of the runoff frequency from the impervious area in comparison to the frequency of runoff which would have occurred in the natural (pre-developed state) (Equation (1)). The pre-developed frequency was established using a MUSIC model (Cooperative Research Centre for Catchment Hydrology 2005) developed for the site. The runoff frequency index was calculated as retention capacity (RC; Walsh et al. 2009):

\[
RC = 1 - \max \left( \frac{R_t - R_u}{R_u - R_r} \right)
\]

where \( R_C \) = retention capacity, \( R_t \) = number of days of runoff per year from the impervious area following treatment; \( R_u \) = frequency of runoff from the same area in pre-urban state (modelled as being 12 days per year); \( R_r \) = frequency of runoff from the impervious area before treatment (modelled as being 121 days per year).

We also took into account the degree to which a proposed project would help protect downstream waterways from nitrogen loads (Harris et al. 1996). Nevertheless, our primary motivation for funding works within the catchment was the restoration of Little Stringybark Creek. We thus gave a higher weighting (0.5) to that sub-index.

The EB index (weighted mean of the three indices, Table 2) was standardised by impervious catchment area by multiplying by

\[
A/100 \text{ m}^2
\]

where \( A \) = area (m\(^2\)) of currently connected impervious area to drain to the proposed system, and 100 m\(^2\) is the standard unit for evaluation of the environmental benefit. The result is that each bid provides a calculated number of EB units. A property with 200 m\(^2\) of roof and 100 m\(^2\) of paving (300 m\(^2\) in total), connected to the stormwater drainage system, has the potential to earn 3 EB units.

To assist landholders to prepare their bid, we developed a web-based tool (Figure 3) which allowed them to calculate the number of EB units for their proposed project and to optimise its design to maximise the number of EB units provided. For example, a 5,000 L tank installed and used only for garden watering would produce significantly less benefit than the same tank connected to the house for internal uses (e.g. toilet flushing, hot water) as well as garden watering. Water demands distributed evenly throughout the year have a better match between supply and demand, resulting in a greater water savings and stormwater runoff reductions (Mitchell et al. 2008).
telephone calls. The shortlist of providers (plumbers and landscape gardeners) was also available to bidders to help in estimating costs of proposed works.

Given that 50% of the connected impervious area in the catchment is public land, we also needed to take into account the potential cost of undertaking works on public land as an ‘alternative’ to the bids being received from private landholders. To do this, we calculated the number of EB units that would be delivered by each of the 10 public land projects for which conceptual designs had already been prepared. We divided the cost by the number of EB units, arriving at a figure of $2,839 per EB unit. We made the decision to use this as a ‘cut-off figure’ in the evaluation of bids from private landholders, because to spend more than this would mean that the auction fund is paying more than necessary to achieve the same level of environmental benefit.

RESULTS

Stormwater tender outcomes

Of the 740 households in the catchment directly connected to the stormwater drainage system, 303 submitted an Expression of Interest. Of these, 101 submitted full bids. The evaluation of bids according to their cost ($/EB unit) was undertaken. Figure 4 shows the cumulative number of EB units provided by the bids and the resulting cumulative cost. The bids varied widely, with the cheapest being $100/EB unit and the dearest being $22,700 per unit. Thirty two bids were submitted at a price/EB unit cheaper than that which could be delivered by works on public land with the same budget ($2,389/EB). These bids delivered a total of 63 EB units. As a result of ‘cutting off’ the auction at this point, we were left with unspent funds. We thus offered a ‘second chance’ to unsuccessful bidders, suspecting that some bidders had engaged in profit-seeking behaviour. Indeed, when these bidders were offered the chance to ‘re-bid’ at a fixed price of $2,839/EB (i.e. lower than their original bid), 23 landholders agreed, delivering another 38 units of environmental benefit (and saving at least $43,000 compared with what we would have paid if we’d accepted their original bids). The majority of works on private land have now been undertaken. As part of the claim process, landholders submitted to us receipts for the work. We were thus able to compare the actual cost with the amount they are paid. On average, private landholders only contributed 15% of the actual cost of the works.

Figure 3 | Web-based EB calculator tool.
The 54 properties who undertook works (Table 3) were able to effectively ‘disconnect’ 74% of their collective impervious surfaces of 1.92 ha. This equates to ∼1% of the total connected impervious area of the catchment (around 50% of which is made up of private allotments, with the rest made up of public space impervious surfaces, such as roads and carparks, etc.).

Effects on community awareness and attitudes

The purpose of the stormwater tender was not just to directly engage ‘bidders’ in undertaking stormwater management works on their properties, but to increase the awareness of all landholders within the catchment. Using the results of the pre- and post-tender survey, we found that after the tender had been implemented:

- 64% of respondents believed that rainwater harvesting may play a vital role in the protection of urban streams (in comparison to 35% in the control catchment).
- The proportion of landholders who recognised that they had a role to play in managing stormwater increased by 29% in the study catchment (c.f. 19% in the control catchment).

Survey respondents also reported a much greater awareness of their local creek and its ecological condition following the stormwater tender.

Table 3 | Summary of results from stormwater tender

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of properties treated</td>
<td>54</td>
</tr>
<tr>
<td>Impervious area treated (m²)</td>
<td>13,740</td>
</tr>
<tr>
<td>Nitrogen retained (kg/year)</td>
<td>14.5</td>
</tr>
<tr>
<td>Potable water savings (ML/year)</td>
<td>5.96</td>
</tr>
<tr>
<td>EB Units</td>
<td>137</td>
</tr>
<tr>
<td>Average rebate per property ($)</td>
<td>6,000</td>
</tr>
<tr>
<td>Percentage of project cost paid by auction (%)</td>
<td>90</td>
</tr>
</tbody>
</table>
overcome several significant barriers to participation. The most common reason given for not submitting a bid by householders who had expressed interest was a lack of time (50% of survey respondents), followed by confusion about the process (41%) and an inability to make the upfront payments to plumbers/installers, prior to a reimbursement being provided (39%).

These lessons will be vital in determining how the next round of the Stormwater Tender is run. Our intended approach is to run the next round as a ‘uniform price ascending clock’ auction, whereby a price per EB unit will be set and the community will be asked to submit bids at that price. After a pre-determined period (e.g. one month), if there are funds still available, the price will be increased (by a pre-determined amount), and so on. All bidders will be paid the final reserve price (as per the standard uniform price method used in the pilot round). In addition, a number of providers of the required services (installation of tanks and rain-gardens) will be put on a preferred supplier panel of providers of the required services (installation of tanks). In addition, a number of providers of the required services (installation of tanks and rain-gardens) will be put on a preferred supplier panel of providers of the required services (installation of tanks).

Ongoing development of an integrated index for stormwater management

In the next round of the auction, we are aiming to refine the EBI to take into account a range of indicators which are better focussed on the needs of receiving waters (Table 4). The EB index will now consider not just the frequency of surface runoff, but will also be based on the provision of filtered flow at appropriate rates. Our aim is to encourage stormwater management systems which are most effective in restoring the post-development hydrology (measured by runoff volumes, frequency and contribution to baseflow) as close as possible to the pre-development levels. For example, one option may be to install a rainwater tank, one proportion of which is used for storage and rainwater harvesting, and the other part of which has a ‘trickle outlet’ of filtered water to pervious land which discharges water at a rate equivalent to that which would have infiltrated into groundwater in the pre-development state. This ‘baseflow rate’ can be derived relatively simply, by using a nearby similar catchment to identify a baseflow rate, and standardising this rate by area. Our hypothesis is that achieving close to pre-developed flow regimes will allow aquatic ecosystems to be successfully restored (through additional works such as instream modifications and riparian revegetation). Whilst flows remain significantly disturbed, such restoration remains difficult.

Table 4 | Proposed components for a revised EBI

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in mean annual runoff volume back to natural volume.</td>
<td>Excess runoff volume is a primary cause of degradation to receiving waters.</td>
</tr>
<tr>
<td>Similarity between the pre-developed volume of baseflow and the volume of stormwater released as filtered flows.</td>
<td>Protection of downstream lentic receiving waters by ensuring baseflow hydrology maintained.</td>
</tr>
<tr>
<td>Reduction of days in which filtered flow exceeds ‘pre-developed baseflow’ or drops to zero back to natural frequency.</td>
<td>Encourage systems which (i) retain storm runoff but (ii) maintain baseflow up to the natural pre-development level.</td>
</tr>
<tr>
<td>Water quality concentrations (e.g. 75%ile).</td>
<td>Protection of small lotic receiving waters (small streams), which are sensitive to spikes in concentration.</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Application of a novel economic instrument – a Stormwater Tender – was found to be an effective strategy for engaging private landholders in the retrofit of stormwater retention measures on their properties. Despite its overall success, we found that the use of a uniform price auction, where all bidders are paid a uniform price per unit of environmental benefit delivered, did not completely avoid profit-seeking behaviour. We hypothesise that this was due to a lack of understanding by bidders of the auction process. Development of an integrated ‘EBI’ was essential to allow bids to be ranked in terms of the level of benefit they would deliver to the receiving water that we aim to protect. The index considers pollutant loads, frequency of runoff from the site and the level of potable water savings. However, the index in its current form does not consider the full range of hydrologic indicators necessary to properly assess the impact of a proposed stormwater retrofit measure.
on the hydrologic regime being delivered to the receiving waters. We propose to expand the index to include measures of (i) contribution to baseflow and (ii) reductions in annual volume, as well as to consider the pollutant concentration regime (rather than just pollutant loads). Our aim is to develop a more sophisticated index which can be used to encourage stormwater management strategies which deliver the flow and water quality regime necessary to protect intact waterways, or to facilitate the restoration of those which are already degraded by stormwater impacts.

ACKNOWLEDGEMENTS

This project is a collaboration between The University of Melbourne, Monash University, Melbourne Water, the Shire of Yarra Ranges and Yarra Valley Water. We particularly thank Melbourne Water for its extensive funding and inkind support, and the SmartWater fund (Victorian Government) for funding the pilot Stormwater Tender. We also acknowledge funding support through the Commonwealth Caring for Our Country scheme.

REFERENCES


Cooperative Research Centre for Catchment Hydrology 2005 MUSIC (Model for Urban Stormwater Improvement Conceptualisation (Version 3.0.1)). Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.


Walsh, C. J., Fletcher, T. D. & Ladson, A. R. 2005a Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the...


*Journal of Hydrologic Engineering* 14 (4), 399–406.

First received 1 July 2010; accepted in revised form 3 September 2010