Evaluating the multiple benefits of an allotment-scale stormwater retrofit auction

L’évaluation des avantages multiples d’une vente aux enchères pour la rétention des eaux pluviales à l’échelle de la parcelle

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RÉSUMÉ

Le ruissellement des surfaces imperméabilisées qui sont directement connectées au réseau pluvial dégrade les milieux aquatiques. Afin de réduire cette dégradation, il faut améliorer la gestion des eaux pluviales sur les parcelles privées ainsi que sur les espaces publics. Un index pour évaluer les bénéfices d’un tel projet d’amélioration a été créé et utilisé pour comparer les propositions d’un instrument volontaire (un concours), dans le but d’encourager l’installation d’infrastructures pour la rétention des eaux pluviales (récupérateurs d’eau et bassins d’infiltration et de biofiltration) sur les parcelles privées. La vente aux enchères a eu pour résultat la déconnexion de 1.4 ha de surfaces imperméabilisées et une réduction de 5.6 ML d’eau potable par an. L’index nous a aussi permis d’évaluer de façon objective les bénéfices environnementaux des différents ouvrages proposés par les enchérisseurs. Le fait que l’index prenne en compte de multiples avantages par rapport à un objectif unique (tel que l’amélioration du rendement épuratoire ou des objectifs basés uniquement sur des concentrations d’effluents), va sans doute optimiser les résultats du projet. Toutefois, l’index doit encore être amélioré pour une meilleure mise en valeur de la contribution d’une parcelle au débit de base du milieu aquatique. Ce nouvel index sera évalué lors d’un nouvel appel à propositions pour laquelle on testera aussi des nouvelles manières de faire participer les propriétaires, y compris la possibilité d’achats en gros pour les récupérateurs d’eau et leur infrastructure associée.

ABSTRACT

Runoff from directly connected impervious surfaces degrades receiving waters. If this degradation is to be significantly reduced, retrofit actions are needed on both private and public land. We developed an integrated index of environmental benefit to evaluate such retrofit works and used it to evaluate bids in a uniform-price auction to encourage the installation of stormwater retrofit infrastructure (rainwater tanks, infiltration and biofiltration systems) on private land. The auction resulted in works effectively ‘disconnecting’ 14 ha of impervious surfaces and delivered potable water savings of around 5.6 ML per year. The index allowed an objective assessment of multiple environmental benefits against which the cost of a wide range of differing treatment systems could be balanced. Consideration of multiple benefits is likely to lead to more optimal outcomes than would be the case with decisions based on single objectives (such as pollutant load reductions or simple concentration targets). The index could be further improved to take into account the contributions to baseflows from a property, to assess effects on baseflows in receiving waters. Further rounds of the auction will therefore test an improved index, along with more efficient methods of encouraging retrofit works, such as facilitating a community ‘bulk-buy’ scheme for rainwater tanks and associated infrastructure.

KEYWORDS

Stormwater retrofit, environmental benefit index, stormwater auction

1 INTRODUCTION

The impacts of urban stormwater runoff on aquatic ecosystems are very well documented (e.g. Walsh, et al., 2005b), with water quality pollution (Hatt, et al., 2004) and flow disturbance (Leopold, 1968) both being 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 (Roy, et al., 2008; Walsh, et al., 2009; Walsh, et al., 2004b).

The hydrological impacts of urbanisation are also well documented, with increases in peak flow rates and annual runoff volumes, along with decreases in the effective time of concentration being most commonly reported (Holman-Dodds, et al., 2003). 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). The decrease in infiltration creates a decrease in baseflow (although in some cases this is compensated by anthropogenic sources, such as water supply infrastructure or sewerage leakage).

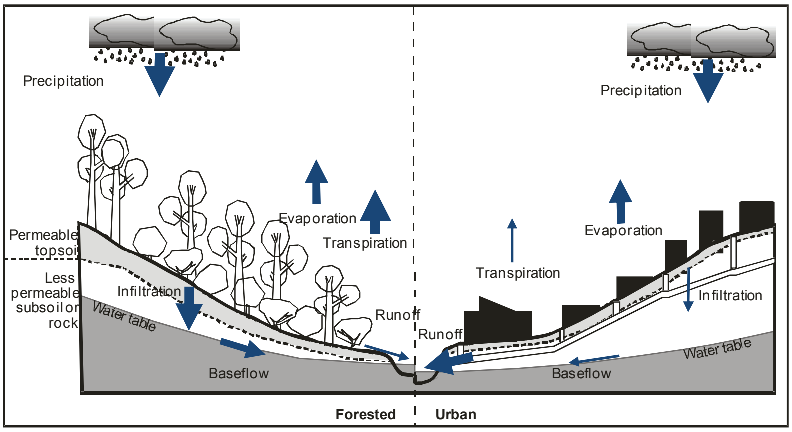

Figure 1. Changes in water cycle due to urbanization. Size of arrow indicates relative size of flux. Transpiration and infiltration are greatly reduced by urbanisation, whilst surface runoff increases both in frequency and magnitude. Imported water supply and export of sewage are not included here (Source: Walsh, et al., 2004a)

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, 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 result in runoff. The *frequency* of disturbance to waterways thus increases dramatically, even for a relatively small change in impervious cover (Figure 2). This increasing frequency of disturbance has been shown to have direct consequences for ecosystem health (Roy, et al., 2005; Walsh, et al., 2009; Wong, et al., 2000).

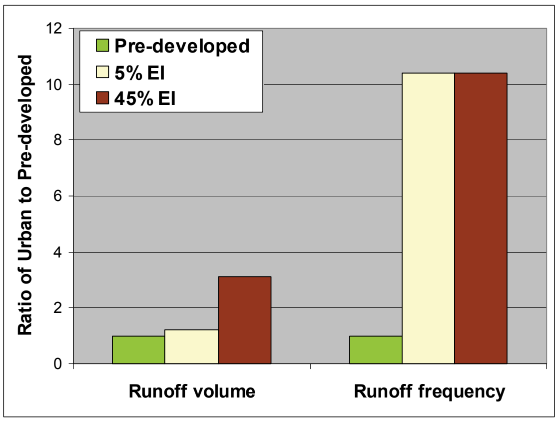

Figure 2. changes to runoff volume and frequency as a result of impervious cover. EI = Effective Imperviousness; ie. % of catchment with impervious area directly connected to receiving waters).

At the same time as receiving waters are 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 for non-potable uses, 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, whilst reducing 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 (also called bioretention systems or 'rain-gardens').

Whilst these techniques have been shown to have significant benefits in terms of water quality and flow management (Fletcher, et al., 2007), there are two problems which limit their potential to have a tangible (positive) 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 and Kunapo (2009) showed degradation of stream health with as little as 1% directly connected imperviousness. There is thus a need to apply at the full range of scales, from large regional systems, through smaller precinct and streetscape systems, right down to measures applied at the allotment scale. 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 (ARI) 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, and suggest improvements to the EBI. The project is undertaken as part of a broader project, which 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.

2 METHODS

2.1 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 (ie. 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.

In addition, current rebates extend only to rainwater tanks. Whilst this helps to encourage saving of potable water, there is no incentive to undertake other activities (e.g. installation of infiltration rain-gardens) which will help to protect receiving waters.

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. In other words, our aim was not specifically to encourage one particular technology (e.g. rainwater tanks), but to provide incentive for any appropriate technique to reduce stormwater discharges from a site, and to save potable water. 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 best 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 2.2). That is, we invited landholders to submit 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, all successful bidders are paid the price of the highest winning bid. 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 (ibid). 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). For this reason, a bidder's optimal strategy is to bid their cost. 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.

Tender Ranking	Environmental Benefit (EB)	Bid	"Value for money"	Tender Successful	Payment
1	1.5	$1 050	$700 per unit of EB	Yes	**$1 650**
2	2.2	$1 936	$880 per unit of EB	Yes	**$2 420**
3	3.4	$3 100	$912 per unit of EB	Yes	**$3 740**
4	1.7	$1 870	**$1 100 per unit of EB**	No	$0
5	2.1	$2 730	$1 300 per unit of EB	No	$0

Table 1: Uniform price auction example. Using the uniform price auction and given a total funding pool of $10 000, the price for all tenders is set at $1100 for every unit of EB provided (set by the first excluded bid). Only the top three tenders are successful. The payment they receive is calculated as their Environmental Benefit x $1100. NB: the figures used in this table are an example only, and in no way represent the distribution of actual costs or bids. (Source: La Nauze *et al.,* 2010)

To assist bidders in preparing their bids, we provided a list of "preferred suppliers", who were available to assist them in calculating the cost of the proposed works (and who would undertake the installation should the bid be successful). Bidders were not restricted to using these suppliers, however.

2.2 The Environmental Benefit Index

The Environmental Benefit Index (EBI) takes into account three measures (sub-indices): (i) reduction in runoff frequency, (ii) reduction in total nitrogen loads discharged from the site, and (ii) 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; Walsh, et al., 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) (Eqn. 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)

$$RC = 1 - \max(\frac{R_t - R_n}{R_u - R_n}, 0) \qquad \text{(Eqn 1)}$$

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

Given that Little Stringybark Creek eventually discharges to the Yarra River, which discharges into Port Philip Bay, we also took into account the degree to which a proposed project would help protect the Bay from degradation. Being nitrogen-limited (Harris, et al., 1996), there are targets for reductions in the annual loads of nitrogen which enter the bay. 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.

Indicator	Weighting	Measure	Rationale
Reduction in runoff frequency	0.5	Proportional reduction in the number of days of runoff	Increased frequency of runoff is biggest impact on urban streams
Reduction in Total Nitrogen load	0.3	Proportional reduction in annual N load exported	Port Phillip Bay is threatened by increases in nitrogen levels.
Water conservation/ volume reduction	0.2	Proportion of harvestable water that is captured for use	Public benefit to conserve water/improved performance of future downslope treatments

Table 2. Summary of sub-indices comprising the Environmental Benefit Index

The EB index (weighted mean of the 3 indices, Table 2) was are standardised by impervious catchment area by multiplying by:

$$A / 100 \text{ m}^2 \qquad \text{(Eqn 2)}$$

Where A = the 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 *Environmental Benefit (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 2) 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 (thus making their bid more likely to be successful). For example, a 5000 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).

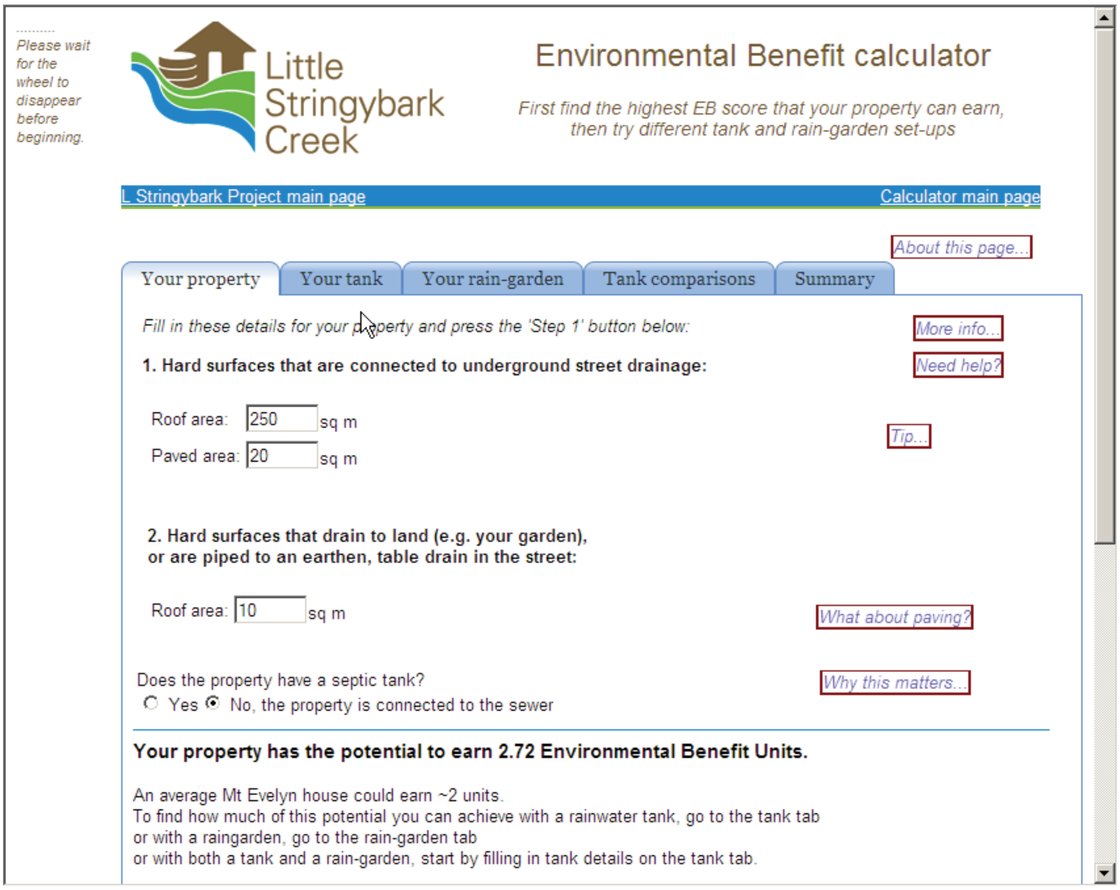

Figure 3. Web-based EB calculator tool

2.3 Pilot application in the Little Stringybark Creek catchment

The Stormwater Tender was piloted in a 450 ha catchment to the east of Melbourne. The catchment in 2009 has around 13,5% total imperviousness (TI), although most impervious areas are concentrated in the upper 200 ha (TI 25%).. With a connected impervious area of around 5.5% of the catchment, Little Stringybark Creek (LSC) has been shown to be significantly degraded by stormwater runoff, based on a range of ecosystem health indicators (e.g. Hatt & Fletcher, 2002; Taylor, et al., 2004). The catchment was chosen for the pilot application because whilst it is degraded by stormwater, we hypothesise that it is possible to 'disconnect' enough of the impervious areas to result in a tangible improvement in stream health.

Approximately half the connected impervious area in the catchment is made up of private land. There are around 1000 properties in total, of which 740 drain directly to the creek via the underground stormwater system (i.e. 740 properties are 'connected').

The tender commenced with a call for "Expressions of Interest". Those who registered were then invited to prepare full bids. Those preparing bids were provided with assistance by a member of the project team, including a number of community workshops, and then through one-on-one consultations or 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 made up of 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 $2839 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. The streetscape works are currently being constructed, which will allow a more detailed evaluation of their costs and benefits.

3. RESULTS

3.1 Stormwater tender outcomes

Of the 740 households in the catchment that were 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 per unit of environmental benefit ($/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 most expensive 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 ($2389/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.

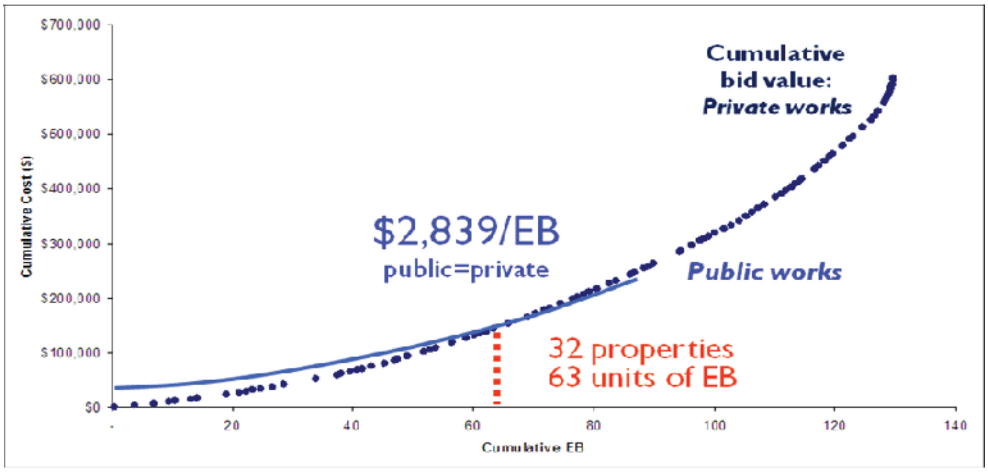

Figure 4. Evaluation of tender bids on private properties (dots), and comparison with price for works on public land (line). The results show that at a price below $2839/EB unit, the private works represent better value that undertaking works on public land. Conversely, at a price greater than $2839/EB unit, private bids are not competitive.

We thus offered a "second chance" to unsuccessful bidders, suspecting that despite the hypothesis that a uniform-price auction would avoid it, some bidders had engaged in profit-seeking behaviour. Indeed, when these bidders were offered the chance to "re-bid" at a fixed price of $2839/EB (ie. lower than their original bid), 23 landholders agreed, delivering another 38 units of environmental benefit (and saving at least $43000 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.

Parameter	Result
Number of properties treated	54
Impervious area treated (m^2)	13740
Nitrogen retained (kg/year)	14.5
Potable water savings (ML/year)	5.96
EB Units	137
Average rebate per property ($)	6000
Percentage of project cost paid by auction (%)	90

Table 3. Summary of results from Stormwater Tender

Of the 54 properties which installed some form of stormwater management, they were able to effectively 'disconnect' 74% of their collective impervious surfaces of 1.92ha. This equates to approximately 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.

3.2 Effects on community awareness & 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 (compared to 19% in the control catchment).
- Awareness of stormwater management techniques such as 'rain-gardens' (biofiltration systems) increased from 14 to 93% in the study catchment.

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

4. DISCUSSION

4.1 Lessons from the Stormwater Tender

Despite the theory that a uniform price auction should eliminate profit-seeking behaviour, evidence from this pilot auction suggests that the theory did not hold (despite a successful laboratory trial prior to the tender, in which economics undergraduate students played the role of landholders). Given the rapid uptake of the 'second chance' offers (at a considerably lower price than their original bids), we can deduce that profit-seeking behaviour was indeed present, at least in a small proportion of the population. There are a number of possible reasons for this result. The first and most likely is that the landholders did not fully understand the nature or rules of the auction, and were thus not convinced that bidding their "lowest acceptable price" was an optimal strategy. Further investment of time and resources may be required to achieve the necessary level of community understanding for the auction technique to be successful.

Another possible explanation is that people were concerned about the risk of price "blow-outs" in the installation costs (for example where the plumber encountered problems during the installation of a rainwater tank and thus demanded increased payment). Engaging service providers who are prepared to provide "fixed price quotes" may be successful in addressing this issue.

Whilst the pilot tender was successful, evidence from a survey of "non-bidders" suggests that we did not overcome a number of 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 and required to provide "fixed-price quotes". We will also commit to the rebate to the service providers directly, to avoid landholders having to await reimbursement. The range of systems eligible for funding will also be limited, in order to offer a simplified system. We hope that this approach will overcome many of the barriers identified in the last round, by (i) allowing us more time to engage with landholders on a one-on-one basis, and (ii) providing greater certainty about the cost and implementation of works. We will also consider "bulk-buy" schemes which allow rainwater tanks and associated infrastructure to be purchased at reduced cost.

3.2 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.

Indicator	Rationale
Reduction in mean annual runoff volume back to natural volume	Excess runoff volume is a primary cause of degradation to receiving waters.
Similarity between the pre-developed volume of baseflow and the volume of stormwater released as filtered flows.	As per previous (protection of downstream lentic receiving waters by ensuring baseflow hydrology maintained).
Reduction of days in which filtered flow either exceeds "pre-developed baseflow" or drops to zero back to natural frequency of subsurface flows	Protection of small streams. Rather than simply targeting a reduction in runoff frequency, we want to encourage systems which (i) retain storm runoff but (ii) contribute to baseflow up to the natural pre-development level.
Water quality concentrations (e.g. 75%ile)	Protection of small lotic receiving waters (small streams), which are sensitive to spikes in concentration.

Table 4. Proposed components for a revised Environmental Benefit Index

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 "Environmental Benefit Index" 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.

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