RESTORING URBAN STREAMS BY MANAGING STORMWATER IN THE CATCHMENT

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ABSTRACT

Piped stormwater runoff from roads and roofs severely degrades urban rivers and streams. Urban stream protection or restoration requires the effective disconnection of impervious surfaces by retaining stormwater on-site so as to reduce the frequency of runoff to pre-urban levels. We used a community engagement program and a uniform-price auction to encourage the retention of stormwater on private land with rainwater tanks and raingardens. Retention measures were assessed for their environmental benefits, with the most cost effective being funded. Over 300 residents expressed interest, but only 101 submitted bids, of which 55 were successful. These properties are treating 70% of their impervious surfaces and collectively retaining over 5ML of stormwater runoff and 14.7 kg of nitrogen per year. This project demonstrates that substantial stormwater retention on private properties is possible at least as cheaply as retention measures at a larger scale on public land. Our adaptation of a uniform-price auction allowed an assessment of the private value of stormwater treatment, but the complexity of the process, short time frame and the requirement of up-front payment were barriers to participation.

INTRODUCTION

Stream degradation in urban areas is a well recognised problem that is likely to escalate given the increasing world-wide urbanisation (Paul and Meyer 2001, Walsh et al. 2005b). Urban streams around the globe display common characteristics, including a flashy hydrograph, elevated concentrations of pollutants, altered channel morphology, loss of many sensitive species and increased dominance of a few pollution tolerant species (Walsh et al. 2005b). Many also display reduced base flows and an increase in suspended solids (Walsh et al. 2005b). These common urban stream ailments are associated with the increased imperviousness of their catchments, and specifically the impervious surfaces directly connected (though pipes) to the streams. The term Effective Imperviousness (EI) is used to denote the proportion of a catchment covered by such directly connected impervious surfaces (Walsh et al. 2005a). Notably, these impacts occur even when impervious surfaces form a very small proportion of the catchment.

There is a growing awareness that urban streams cannot be restored to pre-disturbance stream health conditions without addressing the combined water quality and hydrologic disturbance (increased volume and frequency of polluted stormwater runoff) from connected impervious areas, delivered by drainage infrastructure in developed catchments (Booth 2005, Walsh et al. 2005a). The solution is the 'effective' disconnection of those impervious surfaces, such that they produce runoff to receiving waters no more frequently than would have occurred in the pre-development condition. Walsh et al. (2005a) showed that in catchments where impervious surfaces drained to pervious land (such as roadside swales), rainfall from small rain events was retained and infiltrated, thus reducing the frequency of stormwater runoff. Even though these informal, pervious drainage conduits will transmit flows from larger rainfall events, they prevented runoff from small frequent rain events, and were associated with improved stream indicators of ecological health.

Disconnecting impervious surfaces by retaining stormwater on-site in order to mitigate the impact of stormwater offers some real challenges to stream management, especially in established urban catchments. Firstly, a significant portion of the catchment's impervious surfaces will need to be disconnected. Recent research shows that EI needs to make up no more than 1% of the catchment area in order to achieve an aquatic ecosystem resembling the pre-urban state (Walsh et al. 2005a, Danger and Walsh 2008). Secondly, current common approaches to stormwater quality treatment alone will not deliver the required level of stormwater retention (Thurston et al. 2003). For example, end of pipe solutions typically require very large areas to retain and deal (through, for example, infiltration and/or stormwater harvesting) with the concentrated flows delivered by existing stormwater infrastructure. This public land space is often not available in established catchments, meaning dispersed (at source) solutions are necessary. This leads to another challenge, with dispersed solutions requiring the participation of a high proportion of the catchment's private land holders. Working with private land owners requires a dedicated engagement program and provision of support or incentives to implement stormwater retention activities.

In this project we are testing, in a practical way, the hypothesis that improving the ecological health of many urban streams requires the effective disconnection of a catchment's impervious surfaces, through the retention of runoff from all the 'small, frequent' storms. More specifically, we are examining the feasibility of implementing stormwater retention measures across a catchment, at both the allotment and neighbourhood scale. As part of this, we are exploring how extensive this stormwater retention retrofit should be in order to achieve tangible improvements in stream health as well as the resulting costs ($) of that retrofit. Importantly, the project is also testing approaches for engaging with owners of private allotments (residential and industrial). This paper reports on our first attempt to engage with owners of private allotments, explores the intermediate outcomes and lessons from this engagement and briefly describes our plans to further the project.

METHODS

Little Stringybark Creek, the focus for this project, is located 37 km east of Melbourne and has a catchment of about 450 ha (Walsh et al. 2005a). The lower part of this catchment is primarily used for grazing agriculture. The upper part of the catchment, in the suburb of Mt. Evelyn, has three tributaries, each with a catchment of ~100 ha, and differing in urban density. The northern tributary (NT) has little catchment urbanisation (Total imperviousness, TI = 3.6%, EI = 1.5%,). The central and southern tributaries have higher levels of catchment urbanisation (TI = 17.7 and 14.6%, and EI = 16.6 and 6.7%, respectively). The connected impervious surfaces in Little Stringybark Creek catchment are split evenly between private land (roofs, driveway and paving) and public (mostly roads and some buildings) land.

The three sub-catchments have a relief of about 120 m and are underlain by predominantly clay soils with very low permeability (0.1 mm/hr). Annual precipitation is typically 950mm. Under today's developed conditions, there is about 132 ML/yr more runoff to the creek than under forested conditions (136% of the pre-development flow volume), as a result of the increased impervious surfaces, stormwater pipe conveyance and reduced evapo-transpiration.

Incentives for retaining stormwater

We used a Market-based Instrument (MBI) as an alternative to the traditional approach of providing financial incentives to landholders through grants or fixed rebates. As an incentive mechanism, the MBI allowed for an equitable and cost efficient distribution of funding (Latacz-Lohmann and Van der Hamsvoort 1997, Lowell et al. 2007, Henderson & Norris 2008;). That is, participants received an agreed and standardised level of reward; participants were encouraged to cost-share and payments were made to bids that offered the best 'value-for-money'. Importantly, the MBI provided a mechanism to standardize or simplify the highly heterogeneous bids into a single, directly comparable value.

Specifically, we developed a uniform-price auction, in which a standard rebate per unit of benefit contributed to the creek was paid to all successful bids. The uniform-priced auction was chosen over a discriminative-price approach (frequently used in natural resource management applications) because it has been shown to encourage participants to bid at their lowest cost (Cason & Gangadhara 2005). The auction was promoted to the community as a "Stormwater Tender" and had a funding pool of $250-$300k, with contributions from the Melbourne Water, Smartwater Fund (Victorian Water Trust) and Water Smart Garden & Homes rebate scheme. The final amount of funding available was dependent on the nature of the stormwater retention measures adopted by participants.

There are 1065 privately owned properties in the catchment, of which 738 are known to be connected to the stormwater system in the catchment. On average, a connected property contributes 218 m^2 (range of 39 m^2 to 2,083m^2) of impervious surface, mostly as roof area (paving or driveways are only occasionally connected). Options for retaining stormwater on private properties typically consist of rainwater tanks, infiltration systems or rain-gardens (vegetated infiltration or biofiltration systems).

Community awareness and engagement was initiated by a direct mail out of an introductory letter and brochures. In the letters, the community was invited to attend one of two after-hours information sessions or to obtain further information on the project from our website (www.urbanstreams.unimelb.edu.au). A reminder letter, letterbox drop and phone calls were also used to invite community participation. To further awareness of stormwater retention, a rain-garden open day was held in the catchment, giving people the opportunity to see, first-hand, the construction of a rain-garden infiltration system.

Each property was invited to submit one or more bids to the auction, in which they were required to detail the proposed works and the amount of financial incentive required. The auction was competitive, with successful (funded) bids being those that offered the best 'value-for-money'. Bids were assessed and ranked according to their estimated contribution to the creek's health (see below), relative to the cost of their bid. Financial incentives were paid as a rebate, provided after the stormwater retention works were complete.

Assessing environmental benefit

The primary objective of the retention measures in the Little Stringybark Creek catchment was to protect the stream by reducing the frequency of runoff, which is postulated as a major ecological impact of conventional storm drainage. This hydrologic objective was integrated with two other management objectives: nitrogen load reduction (which serves also as a good indicator of the removal of other pollutants) and water conservation. Together, these provide an objective measure of the environmental benefits achievable from stormwater retention measures. To facilitate the assessment of auction bids, an index of environmental benefit (EB) was developed, consisting of three sub-indices corresponding to the hydrologic, water quality, and water conservation objectives, scaled to a unit impervious area. These indices measure reduction in runoff frequency (number of days of runoff); reduction in Total Nitrogen load to receiving waters (in this case, Port Philip Bay), and water conservation (water captured for use) (Table 1). The sub-indices were weighted according to the primary objective of the project, being to improve the health of the local receiving water.

Table 1. Summary of sub-indices comprising the Environmental Benefit Index for the Little Stringybark Creek project.

Indicator	Weight-ing	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/ water savings	0.2	Proportion of harvestable water that is captured for use	Public benefit to conserve water

The evaluation of performance of stormwater retention and treatment measures based on water quality, that is, on proportion of pollutant load reduction, has become standard practice in Australia. For example, for nitrogen, a 45% reduction in the typical urban load is the current best practice standard. The nitrogen index used is (1 minus the ratio of nitrogen load overflowing from the WSUD measure) to the (nitrogen load running off the effective impervious area before treatment). In the case of rainwater tanks, all the consumed water used in household appliances is assumed to be exported from the catchment either through the sewer system (unless the property has a septic tank), or through transpiration of plants following garden irrigation. For properties with septic tanks only the nitrogen load in water used for garden watering is used to calculate the nitrogen index, since septic tanks are efficient nitrifiers and nitrate will efficiently drain through soils to the creek. The assessment of stormwater retention measures based on water conservation (stormwater harvested and re-used) correlates directly to potable water savings by replacement with rainwater. The water conservation index is thus the proportion of the total harvestable yield from a given effective impervious area that is collected by the rainwater tank and re-used.

We developed a new stormwater retention performance standard for hydrologic performance for stream protection, which requires that adequate infiltration or storage followed by harvesting or evapo-transpiration losses is provided for each impervious surface, so as to mimic the runoff pattern in the pre-urban state. Thus, this index is a measure of the reduction in runoff frequency, or the runoff retention capacity, afforded by the retention measure (Walsh et al. 2009). It is assumed that runoff is generated from impervious surfaces 121 days per year (based on modelling of catchment in its current state), and that overland flow would have been generated from the pre-urban forest floor 15 days per year (based on modelling of the catchment in its pre-developed state) which equates to rainfall events larger than about 15 mm. Furthermore, it is assumed that any impervious areas that are not connected to the formal (piped) stormwater drainage system do not contribute to increased runoff frequency (while this is unlikely to be completely the case, such areas have no detectable environmental impact compared to the directly connected impervious areas, so they are not considered a high priority for treatment: Walsh et al. 2005a). The retention capacity index (RC) compares the proportion of runoff frequency above natural conditions generated after WSUD measures to runoff frequency under developed conditions (see Walsh et al. 2009 for detail of the equation).

All three indices (water quality, water conservation, retention capacity) are standardised by impervious catchment area by multiplying by:

$$A / 100m^2,$$

where A = the area (m^2) of currently connected impervious area to drain to the WSUD measure, and 100 m2 is the standard unit for evaluation of the environmental benefit. A property with 200 m^2 of roof and 100 m^2 of paving (300m^2 in total), connected to the stormwater drainage system, thus has the potential to earn 3 units of environmental benefit.

An interactive web-based tool was developed to assist residents in optimising their EB (www.urbanstreams.unimelb.edu.au). Participants in Stormwater Tender were able calculate their maximum EB and compare it with the average EB for the entire catchment, gaining an understanding of how easy it might be to achieve a high score. They could then compare this with costs. EB scores for different treatment measures such as rainwater tanks and raingardens could be calculated using the tool. For simplicity the tool included fixed end-uses for water from tanks, such as toilet flushing, garden and hot water use, however allowed for additional uses to be included. Raingardens could be modelled, depending on their configuration, either as biofiltration systems that were either lined or unlined or as infiltration systems. Other variations on infiltration systems such as simple infiltration trenches (similar to septic runs) could also be modelled.

OUTCOMES

Expressions of interest in Stormwater Tender were received from 303 (29.8%) private land owners, of which 101 submitted bids. The bids totalled $596,341, at an average of $5,790 (range from $100 to $22,600). The Environmental Benefit (EB) offered totalled 130 units, ranging from 0.4 to 5.25 units (average 1.26 units).

The cost per unit of Environmental Benefit ($/EB) was caculated for bids by first subtracting any rebates eligible from the Water Smart Gardens & Homes (WSGH) program and/or for the removal of Nitrogen. Bids were then ranked from the lowest (-$860/EB[1]) to highest ($6,700/EB) cost per EB. In a typical uniform price auction, bids would be accepted from the top of the list downward until the funding pool was committed. In Stormwater Tender, the low number of bids and higher than expected cost of bids cast doubt on the cost effectiveness of spending all money on the bids as submitted. To ensure that the bids collectively provided a satisfactory investment for the project, they were compared to proposed WSUD works on public land. Running concurrently with Stormwater Tender was a program to design biofiltration works on public land (titled 'Filtered Streets for Healthy Creeks'). These measures were primarily aimed at addressing run-off from sealed roads. Using the production possibility frontier approach, the cost-benefit of the public streetscape sites and private bids were compared. This analysis identified that at $2,839 per unit of EB, public and private were of equal value.

The price of $2,839 per unit of EB was therefore used as the uniform-price rebate for the private land bids. Paying bids that requested over $2,839/EB represented a poor investment, as beyond this price sites in the 'Filtered Streets for Healthy Creeks' program represented a more cost-effective option. All bids that requested less than $2,839/EB were offered a rebate equivalent to $2,839 for every unit of EB their bid provided, regardless of how much they bid. For example, a bid 'selling' 2.5 EB units at a total price of $3,300 would receive a rebate of $7,097 (2.5 x $2,839; plus any WSGH rebate or funds for Nitrogen removal). There were 32 bids that requested less than the established rebate price of $2,839/EB (range from -$860 to $2,736). Collectively, they 'sold' 62.5 units of EB (range of 0.53 to 5.25 units) and 8,760m^2 of impervious surface were proposed for disconnection. These bids were funded to the total value of $185,060.

Limiting the rebate price at $2,839 meant that only two thirds of the funding pool was allocated

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[1] A negative cost per unit of EB resulted from a bidder requesting less than the amount that they would be eligible from the Water Smart Homes and Gardens Rebate and for Nitrogen removal.

to the successful bids. To distribute the remaining funding (approximatly $120,000) in a cost effective manner, 'unsuccessful' bidders were offered a payment lower than their bid, commensurate with the $2,839/EB rebate. This 'second-round offer' was offered on a first-come-first-serve rebate, with bids accepted until the funding pool was fully committed. An additional 24 properties (out of 31 requests) were funded via the 'second round offer', purchasing a further 36.6 units of environmental benefit (range of 0.68 to 4.25). The estimated savings (the difference between dollars requested and dollars funded) of the second round offers was over $43,000.

Combined, the auction and second round offer have seen the installation of stormwater retention measures on 55 properties in the catchment, which is approximately 10% of the properties targeted for works. These works have effectively disconnected, or at least, significantly reduced the runoff form 14,353 m^2 of impervious surface, and will prevent 14.7 kg of nitrogen leaving the catchment per year and provide 5.9 ML of water savings per annum.

DISCUSSION

Managing the catchment

It is unlikely the results of Stormwater Tender, the first stage of the much broader Little Stringybark Creek project, will induce a notable improvement in the health of the creek. Reduction of EI to ~2% (i.e. effective disconnection of around two-thirds of currently connected impervious areas) is likely to be required to detect improvement in a range of ecological indicators, and reduction to <1% is likely to be required allow restoration to a condition similar to non-urban reference streams (Walsh et al. 2005a). Stormwater Tender has produced stormwater retention treatments for approximately 5.8% of the catchment's connected impervious areas. Although this is a modest outcome, it is acceptable given the relatively small pool of funding available for the auction. We believe that spending similar funding on a centralised or end of pipe solution (typical in traditional stormwater management) would not have resulted in a greater outcome. Indeed, the proposed neighbourhood works in the 'Filtered Streets for Clean Creeks' program are comparable in cost to those of the auction. In addition, the work on private allotments makes feasible works in the streetscapes to treat road runoff and 'residual' runoff from properties, reducing the required treatment area within the streetscape. The resulting outcomes of the project to creek health will be monitored over at least the next 5 years.

This project has shown that it is feasible to engage with private property owners to increase the retention of stormwater in a catchment. The total reported impervious surface for the successful properties was 19,221 m^2. That participants managed to 'treat' 14,353 m^2 (74%) of this shows that private land owners are capable of making a realistic contribution to the effective disconnection of an urban catchment. The environmental value of that disconnection was also positive. The maximum achievable environmental benefit score for the 14,353 m^2 being treated by the 55 successful properties was 143.5 units. The actual EB purchased via the auction was 99.6 units (69%). This success is largely a result of the design of the environmental benefit index, which rewarded bidders for the degree to which they managed to disconnect their impervious areas via stormwater retention and/or harvesting.

Engaging the community

The Stormwater Tender auction was an effective tool for engaging with the community. Anecdotal evidence suggests that the awareness of the Little Stringybark Creek (its existence and location in the catchment); the impacts of stormwater on the creek and ways to improve the management of stormwater are now much higher in the local community. A survey of the community awareness will be conducted to formally measure this change. This survey will build on a early community survey, undertaken prior to commencement of the project. Furthermore, the community is now more aware of the multiple benefits of installing rainwater tanks.

However, Stormwater Tender also presented significant barriers to participation by private land owners. A targeted community survey was conducted post auction of the 202 land owners who registered their interest but did not submit a bid. There were 54 (26.7%) responses, which revealed the most common barriers to participation as being: lack of time (49%), confusion over the process (43%); and the requirement for upfront payments (43%). Many respondents (31%) also reported that they were unsure what retention measures to use on their property. These reported barriers to Stormwater Tender contributed to fewer bids being submitted and perhaps the higher cost of bids. Any further incentive programs offered as part of the Little Stringybark Creek project would need to overcome these barriers. This might include: providing simplier, more direct incentives; giving more direction to land owners about what retention methods to use (more property visits); or bulk purchasing of a limited range of retenetion systems (perhaps at the cost of providing less flexibility to bidders in terms of what measures can be installed).

The bidding behaviour displayed by auction participants highlights some of these barriers. In a uniform-price auction, the best bidding strategy is to bid at the minimum acceptable price (ie. the minimum price for which the bidder is prepared to undertake the works). This strategy was repeatedly recommended to participants in Stormwater Tender via all communications and documents. The success of the second round offers (ie. Offering a lower price than the original bid) suggests that bidders did not bid in this optimal manner. That the second round offer was over-subscribed suggests that bidders either failed to understand the bidding process or deliberately sought extra funding (over their minimum price).

Assessing the cost

So how cost-effective was this approach to implementing stormwater retention across a catchment? Auctions are most efficient when they have a range of bids to choose from. This allows them to choose the best (cost-efficient) bids and obtain a good return on any investment. Stormwater Tender was disadvantaged by receiving so few (101) bids. Running the uniform-priced auction without setting a price-cap would have resulted in a rebate price of approximately $3,660 per unit of EB, and seen the project support some of the less cost-efficient bids. That is, we would have only funded 44 properties (as opposed to 55), and purchased a total of 77 (as opposed to 99) units of environmental benefit. The comparison with proposed public works and the use of second round offers provided a much greater level of efficiency in fund distribution.

At the time of final submission, we had provided rebates for completed works to 24 properties (44%), at a total cost of $133,094. The real cost for installation of these retention measures was $151,983, meaning the project has so far paid for approximately 87% of the actual costs. This shows that property owners have made only a modest contribution themselves. However, at an average rebate of $5,400 per property, we question if the retention measures could not be installed cheaper through other mechanisms. For example, through collective bargaining (ie. bulk-purchasing on behalf of the bidders), we may be able to obtain cheaper materials and/or labour rates. To achieve our goal of providing stormwater retention on at least 500 properties, we will need to search for incentive mechanisms which are more cost effective. At the current rate from this first round of the process, the estimated cost of completing all 500 properties would be $2.7m. We hope in subsequent stages to reduce this, perhaps through a bulk-purchasing scheme where landholders are offered installation of a range of 'standard options' (rainwater tanks, rain-gardens) at subsidised rates.

Broader application

The approach to stormwater management used in this project shoud be readily adaptable to other catchments within Australia, or indeed the world. Certainly, catchments will differ in the challenges they might propose. For Mt Evelyn, the challenges faced inlcuded the highly impervious soils (requireing the design of large infiltration systems); a community of modest affluency (many single income or retirees/pensioners) and a sloping elevatation (complicating the installation and design of retention systems). Yet such challenges were, in part, offset by other features, such as a relatively 'green' community that was appreciative of their local environment and gardens and generally large properties, which lent themselves to the installation of stormwater retention systems. Furthermore, the range of retention measures available and the flexibility in their design means that solutions can be found in most situations.

This project has been conceived with the aim of restoring a creek, following an ecological and landscape assessment that a relatively small effort in catchment-scale stormwater retention is likely to result in measurable in-stream ecological improvements (Walsh et al. 2005a). A critical consideration in the application of such a program elsewhere is a clear understanding of the ecology of the receiving environments to be protected or restored, and of the likelihood of ecological objectives being achieved (Palmer et al. 2005).

CONCLUSIONS

Protecting waterways from the degrading effects of urbanisation requires effective disconnection of impervious areas, through retention of rainfall events up to the magnitude which would have caused runoff in the pre-development state. As part of a large-scale restoration of the peri-urban Little Stringybark Creek catchment, a Stormwater Tender was conducted, to provide incentives for private landholders to install stormwater retention systems (rainwater tanks, and rain-gardens such as vegetated infiltration systems). The tender was a success, resulting in 55 properties being treated, over 5 ML of potable water savings, and around 15 kg per year of nitrogen retained within the catchment. However, the bids were relatively expensive, with a high proportion of submitted bids that were, per unit of calculated environmental benefit, more expensive than planned works on public land. The relatively high price resulted from a lower number of bids, which in turns was contributed to by identified 'barriers to participation', such as a lack of knowledge by landholders, or confusion in the process. In general, the process has identified the potential for private landholders to make significant contributions to the retention of stormwater on-site, so as to effectively disconnect impervious areas. However, future stages will need to explore incentive mechanisms which overcome some of the indentified barriers to participation. In addition, since around half the impervious areas are comprised of public space, a parallel program of streetscape stormwater retention systems will be installed. We will be undertaking a five-year monitoring programme to quantify changes in hydrology, water quality and aquatic ecosystem health as a result of the works.

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