LID for Urban Ecosystem and Habitat Protection 2008

SESSION: Watershed Retrofit with LID: Restoring the Urban Watershed: LID and Stream Restoration
TITLE: Stream restoration through stormwater runoff management and retrofit: new objectives, new approaches.
KEY WORDS: water sensitive urban design, stream restoration, rain water tank, rain garden, auction, low impact development
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Introduction

The Little Stringybark Creek restoration project is the first of its kind, focusing on reducing stormwater runoff using LID strategies across an entire sub-watershed. Urban streams around the globe demonstrate common characteristics associated with the increased imperviousness of their watersheds, including a flashy hydrograph, elevated concentrations of pollutants, altered channel morphology, and increased dominance of pollution tolerant species (Walsh et al 2005b). 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 impervious areas delivered by drainage infrastructure in developed watersheds (Booth 2005, Bernhardt and Palmer 2007). This poses a great challenge for stream restoration, since it is much easier to implement local or reach scale in-stream or riparian projects than to reduce the

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stormwater impacts of impervious areas in a catchment. One of the key needs for the protection or restoration of streams in urban or urbanizing catchments is, therefore, a better understanding of specific and practical stormwater management objectives at the catchment and site scale aimed at addressing hydrologic characteristics that affect streams.

Recent research in moderately urbanized streams of southeast Australia (1-12% total imperviousness) demonstrated that ecological degradation in urban streams is predominantly caused by the direct connection (through pipes) of impervious surfaces in the watershed to the stream (Walsh 2005). This research showed that in catchments where impervious surfaces drained to pervious land, e.g. swales, rainfall from small rain events was retained and infiltrated, thus reducing the frequency of stormwater runoff. Even though these informal, pervious drainage conduits have potentially little effect on runoff volumes, they prevented runoff from small frequent rain events, and were associated with improved stream indicators of ecological health. This research supports other work suggesting that total impervious (TI) area alone is not an adequate determinant of stream health (e.g. Booth 2005). Instead, it is that portion of the impervious area that is directly connected to the stream system, or the effective impervious area (EI), that is most significant.

The Little Stringybark Creek project is testing the proposition that a stream can be restored by reducing hydraulically connected impervious surfaces, through the implementation of LID measures across the catchment. These measures reduce stormwater runoff through stormwater harvesting and bioretention (detention, infiltration, and evapo-transpiration). To date, LID objectives in Melbourne have primarily focused on water quality treatment or on reduction of peak flows through large scale detention projects. These objectives do not specifically address the hydrologic impact of more frequent stormwater runoff. The outcome of the Little Stringybark Creek project is the development of a new design objective for LID measures based on stream protection which integrates water quality and hydrology objectives for stream ecology, as well as reducing the demand on potable water supplies.

Study Site and Objectives

The Little Stringybark Creek is located 37 km from Melbourne, Australia and has a catchment of about 450 ha (Walsh 2005). The lower part of this catchment is primarily used for grazing agriculture. The upper part of the catchment, in the town of Mt. Evelyn, has three tributaries, each about 100 ha, and differing in urban density (Figure 1). The northern tributary (NT) has little catchment urbanization (TI = 3.6%, EI = 1.5%,). The central tributary (PC) and the southern tributary (UB) have similar levels of catchment urbanization (TI = 14.6% and EI = 10.3%). The non-rural parts of the catchment have sanitary sewers that export sewage from the catchment. About 20% of the residents have septic tanks, but these have been shown to have a negligible effect on stream health in this catchment compared to the effects of stormwater runoff (Walsh 2004, Taylor et al. 2004, Hatt et al 2005, Newall and

Walsh 2005). The three sub-catchments have a relief of about 120 m and are underlain by predominantly clay soils with low permeability (0.1 mm/hr). Annual precipitation is typically 95 cm. Under today's developed conditions, the stream receives about 132 ML/yr (4.66 mill. cu. ft./yr) more runoff to the creek than under forested conditions (136% of the pre-development flow volume), as a result of stormwater pipe conveyance and less evapo-transpiration.

The objectives of the Little Stringybark Creek project were to: 1) engage the community and the local government agency to actively participate in restoring the Little Stringybark Creek (training residents, municipal planners and engineers in LID design); 2) implement and analyse the costs of LID measures on both private and public property; and, 3) measure the response of stream health.

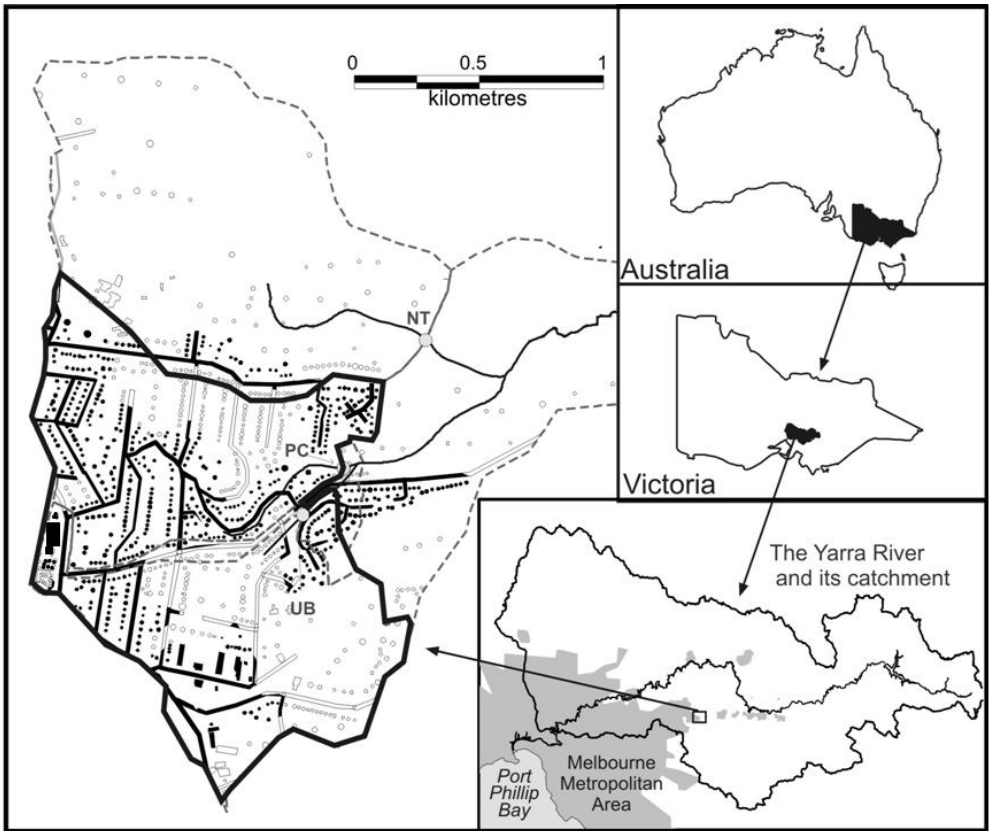

Figure 1. Little Stringybark Creek project location in the town of Mt. Evelyn. The two southern subcatchments discussed are bounded by the thick black line. Solid polygons are effective impervious areas, and hollow polygons are not connected to the stormwater drainage system. UB, PC, and NT are sampling sites.

Approach

LID Objectives Development

The primary objective of the LID 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 the conventional storm drainage. This hydrologic objective was integrated with two other LID objectives: nitrogen (and therefore other pollutant) load reduction and water conservation. Together, these objectives describe environmental benefits to be achieved from LID measures. To assess the value of each LID measure proposed across the Little Stringybark catchment, an index of environmental benefit (EB) was developed consisting of three sub-indices corresponding to the hydrologic, water quality, and water conservation objectives. As listed in Table 1, 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, Figure 1), and water conservation (water captured for use). 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	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/ water savings	0.2	Proportion of harvestable water that is captured for use	Public benefit to conserve water

LID performance evaluation based on water quality, i.e. on proportion of pollutant load reduction, has become standard practice in Australia, with a 45% reduction in the typical urban load being the current best practice standard (. The nitrogen index used is 1 minus the ratio of nitrogen load overflowing from the LID measure to the nitrogen load running off the effective impervious area before treatment. In the case of rainwater tanks, all consumed water used in household appliances is assumed to be exported from the catchment through the sewer system (unless the property has a septic tank). It is assumed that all irrigation water is taken up by plants. 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 evaluation of LID measures based on water conservation (stormwater harvested and re-used) correlates directly to water savings. The water index is the proportion of the total harvestable yield from a given effective impervious area that is collected by a rainwater tank and re-used.

We developed a new LID 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 LID measure (Walsh et al. 2008). It is assumed that runoff is generated from impervious surfaces 121 days per year, and that overland flow would have been generated from the pre-urban forest floor 15 days per year, 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). The retention capacity index (RC) compares the proportion of runoff frequency above natural conditions generated after LID measures to runoff frequency under developed conditions and is calculated as (Walsh 2008):

$$RC = 1 - \max\left(\frac{R_t - R_n}{R_u - R_n}, 0\right)$$

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 (15 days per year); R_u = frequency of runoff from the impervious area before treatment (121 days per year).

All three indices (water quality, water conservation, retention capacity) are standardized 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 LID measure, and 100 m^2 is the standard unit for evaluation of the environmental benefit.

LID Implementation

On private property, LID measures for retaining and using stormwater consist of rainwater tanks or raingardens (often called bioretention systems). These measures are being funded through an auction program as an alternative to the traditional approach of providing financial incentives through grants. A Uniform Price auction was developed to allow home owners to be paid to install rainwater tanks or raingardens according to the environmental benefit to the stream they would produce. Bids are ranked according to their 'value for money,' based on their EB. Starting with the most cost efficient bid, each tender is accepted until the pool of available funds is fully committed. The last tender to be accepted will set the standard price for the rebate. This price is expressed as dollars for 1 unit of EB ($/EB) and is then awarded to **all** successful tenders, regardless of how much they bid.

The index is scaled to 100 m^2 of impervious area, so that a property with 200 m^2 of roof and 100 m^2 of paving (300 in total), connected to the stormwater drainage system, has the potential to earn 3 EB units. Properties with large impervious surfaces that are directly connected to a piped stormwater system will have the largest potential EB.

A web-based tool (http://www.urbanstreams.net/Rpad/EBcalc.html) has been developed to assist residents in optimising their EB. Residents can 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 can then compare this with costs (provided by a list of 'preferred suppliers' for both plumbing and raingarden design/construction). EB scores for different treatment measures such as rainwater tanks and raingardens can be calculated using the tool. For simplicity the tool includes fixed end uses for tanks such as toilet flushing, garden and hot water use however allows for additional uses to be included. Raingardens can be modelled as bioretention systems that are either lined or unlined or as infiltration systems. Other variations on infiltration systems such as simple infiltration trenches (similar to septic runs) can also be modelled.

On public land, LID measures will include raingardens, infiltration systems and stormwater harvesting schemes implemented through a partnership between the regional water management agency (Melbourne Water) and the local municipality. LID measures are being designed that (a) fit readily into green spaces between the side walk and road or between the road and the riparian buffer, that double as traffic calming devices (such as curb-extensions), (b) prevent additional impacts from new impervious areas (e.g. when gravel parking lots are paved), and (c) take advantage of existing open spaces and drainage structures (such as mowed swales or stormwater detention basins). LID projects will be constructed where there are the fewest in-direct costs (e.g. utilities to be re-located) and the greatest local government and community support. To help gain local government support, Melbourne Water is working with the project team to provide municipal planners and engineers LID design training and increase their capacity to implement LID in the future. The potential benefit of these street-level, public land LID measures is assessed using the Environmental Benefit calculator.

Outcomes

LID Assessment and Needs

Modelling of the environmental benefits of LID measures indicates the critical role of a range of different LID measures at different scales, including use of rainwater from tanks and bioretention at the lot scale. In Mt. Evelyn, 50% of the impervious surface consists of roofs and hard surfaces on lots; these surfaces are typically connected to the storm drain sub-surface so that they cannot feasibly be treated on the street. Further, more space for bioretention is required to retain flow and mimic a nature runoff regime than is typically available along streets in urban areas. For the 26 proposed bioretention sites modelled, there was a large variation in retention capacity achieved for a given percent of the impervious catchment area treated (see Figure 2).

However, all vegetated bioretention areas greater than 2.5% of the impervious catchment areas had a retention capacity of at least 0.6 (i.e. days of runoff are reduced from 121 to 61 day per year).

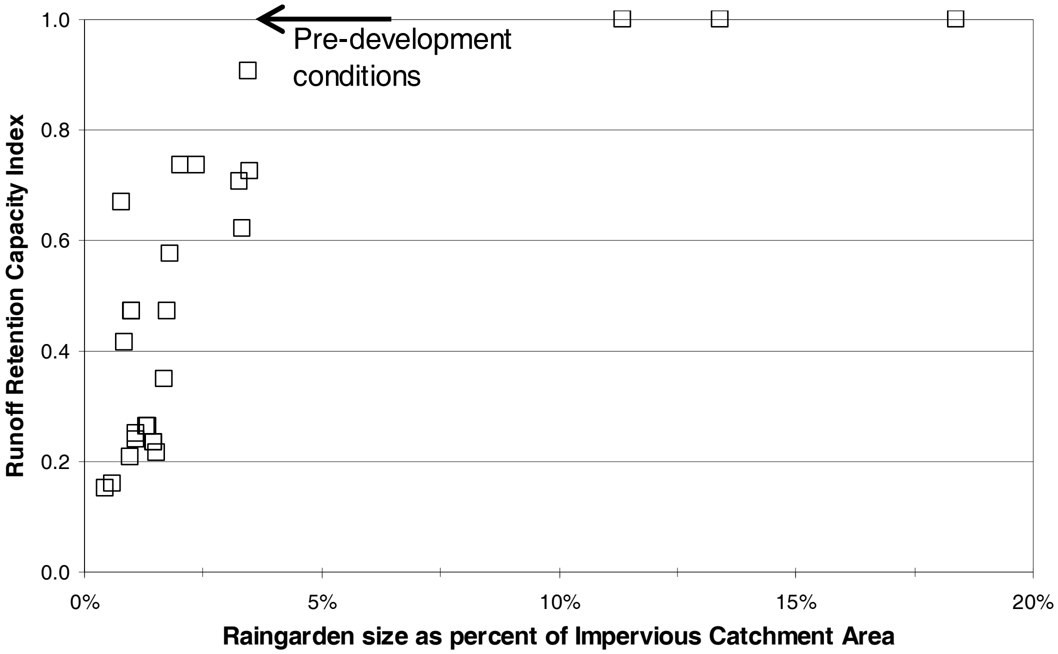

Figure 2. Runoff Retention Capacity as a function of treatment size relative to Impervious Catchment area. Results the Environmental Benefits (EB) Calculator.

With 7.65 ha of road in Mt. Evelyn, about 2000 m^2 of treatment area (vegetated bioretention systems) are needed to achieve a retention capacity of at least 0.6. This is the equivalent of about 130 raingardens of 15 m^2. In reality, this number could vary significantly depending on the opportunity for building fewer larger bioretention systems, or the need to build more smaller systems due to site constraints.

To achieve a runoff frequency within 20% of pre-urbanization conditions (RC >0.8), at the sites modelled, a vegetated treatment surface area of greater than approximately 3% of the impervious catchment area is needed. Since this space is difficult and costly to acquire in an urban environment, multiple, de-centralized measures, such as stormwater harvesting from rainwater tanks, are needed on public and private land to retain and filter stormwater, and to capture, reuse and remove excess stormwater. By adding rainwater tanks to sub-catchments where streetscape bioretention is treating road runoff, for example, runoff frequency reduction is significantly reduced over the streetscape works alone. Rainwater tanks that are plumbed to indoor uses are highly effective at reducing runoff frequency and volume, because their regular drawdown means that there is a high probability that the ‘next storm’ will be retained in the part-empty volume of the tank. For tanks, this means that the size is not the only thing that matters; the volume and regularity of use is critical in reducing runoff frequency. For raingardens, it is their size, as well as the infiltration rate of the underlying soils, and evapo-transpiration of vegetation, that determine their effectiveness. With approximately 40% of the effective impervious area comprised of roofs in the urban catchments of Mt. Evelyn and the native clay soil having an extremely low infiltration capacity, treating roofs is an important part in reducing runoff frequency.

The costs of LID measures, particularly retrofits on the street, vary widely. LID measures on private property may be as low as \$50 (for the installment of a first flush diverter which diverts the first 10 - 100 liters of runoff from a rain event away from the gutter and into the garden, or for the disconnection of a downspout into a garden), or as high as \$4000 for installation of a rainwater tank retrofit for use in in-door appliances (cost estimates for Victoria, Australia). The cost of street-level LID works also varies widely, from \$5000 to >\$10,000 per 10 m^2 raingarden, depending on the presence of utilities and difficulty in construction and associated landscaping. Assuming no major utilities will have to be removed, the cost estimates for street-level LID retrofits in Mt. Evelyn, are typically from \$200 to 400 per m^2, or from \$1,000 to \$6,000 per Environmental Benefit Unit.

LID Outreach, Project Status and Expected results

The Little Stringybark Creek project outreach has resulted in hundreds of homeowners expressing interest in implementing LID measures and entering an auction to get paid to install rainwater ranks and rain gardens. Over 50 homeowners attended a raingarden installation at a private residence in the catchment, and dozens of plumbers and landscapers have expressed interest in installing the LID measures. The auction will close on July 18, 2008, and awards will be announced by September 2008. Homeowners will have six months to install the rainwater tanks and raingardens.

While these LID measures are being installed on private property, final designs will be developed for at least six streets (including up to 26 individual sites) on public land in the sub-catchments. Modeling tools are being developed and modified to assess design performance for runoff frequency and volume reduction that will help establish integrated standards for LID aimed at protecting stream health. Street works are expected to begin being built in 2009. At two sites in the catchment with high effective imperviousness associated with industry and schools, stormwater harvesting and reuse schemes for in-door use, sports field irrigation, potential export to users outside the catchment are being investigated.

When completed, this project will provide information on the rate of LID uptake on private property, and the environmental benefit of LID retro-fits on private property and public land and how much they cost. The pre-project and post project homeowner survey will also help identify opportunities and incentives for encouraging private property owners to disconnect roofs and driveways and re-use stormwater. Most importantly, the ecological response of a stream to improvements in the runoff regime will be tested for the first time. The ecological health of the Little

Stringybark Creek has been monitored prior to LID retrofits and will be monitored following their implementation beginning in 2009.

Finally, this project aims to demonstrate that multiple strategies and scales are needed for urban stormwater source control, and that LID strategies can be designed and evaluated to quantitatively measure environmental benefits for streams. Stormwater management practices must include performance standards for LID designs to protect stream health, such as the return to near-natural stormwater runoff frequency. The stormwater retention that such standards will require will only be possible through a change in treatment of stormwater as a resource at a local and regional scale, with the accompanying modification in infrastructure.

Acknowledgements

Veronika Nemes, Claire Edwards and Andrew O'Keefe, of the Department of Sustainability and Environment, Victoria assisted with the writing of the EBI calculator and the development of the Unit Price Auction. The nitrogen removal in EB calculator is derived from research undertaken at the Facility for Advancing Water Biofiltration (FAWB: see www.monash.edu.au/fawb). We particularly wish to thank Dr. Belinda Hatt and Assoc. Prof. Ana Deletic for their contribution. The infiltration modelling was assisted by advice and calibration from Dale Browne (PhD student, Department of Civil Engineering, Monash University). The project is being funded by Melbourne Water and the Victorian Water Trust through the Smartwater Fund, in collaboration with the Shire of Yarra Ranges and Yarra Valley Water.

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