Restoring the health of urban streams through stormwater management: Lessons from the Little Stringybark and Dobsons Creeks Project

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Key points

- Conventional, hydraulically efficient stormwater management is a primary cause of urban stream degradation.
- A 19-year catchment-scale experiment provides proof-of-concept that restoring key aspects of stream hydrology, water quality, and ecosystem function is achievable.
- Stream restoration requires high-performance stormwater control measures that intercept and harvest runoff from nearly all impervious surfaces to mimic pre-development hydrology.
- In addition to the uncertainty of being able to fully restore stream health in existing urban areas, retrofitting stormwater control measures is costly and space-constrained, highlighting the benefits of preventing stormwater impacts on stream health during new urban developments.

Abstract

Urban streams are degraded by conventional stormwater drainage systems, typically causing substantial hydraulic, channel form and chemical disturbances that impact ecosystem health. This world-first, long-term, multi-disciplinary project tested whether dispersing stormwater control measures (SCMs) across a catchment can restore stream ecosystem structure and function by mimicking pre-urban hydrology.

The Little Stringybark and Dobsons Creeks Project involved constructing close to 1,000 SCMs on public and private land, designed for harvesting, infiltration, and evapotranspiration. A Before-After-Control-Reference-Impact (BACRI) study framework was used, with continuous monitoring of stream hydrology and intermittent monitoring of water quality and ecological indicators.

Key findings provide proof-of-concept for stream restoration in existing urban areas and provide a basis for stormwater management as part of urban development. Hydrology improved, with SCMs reducing wet weather flows for small-to-moderate rainfall events (2-8 mm). In sites with high stormwater retention, peak flows approached reference conditions for rainfall events up to ~12 mm. Phosphorus concentrations and summer temperatures were similar to reference levels during dry weather and after small rain events. Preliminary ecological outcomes varied; Little Stringybark Creek showed little change in biotic indices (although some ecological responses in specific macroinvertebrate groups were measured), while Dobsons Creek exhibited a positive trend in macroinvertebrate assemblage composition.

The results of this project provide evidence supporting the adoption of flow-based stormwater objectives, such as those outlined in EPA Victoria's 2021 *Urban Stormwater Management Guidance*. Achieving these objectives requires implementing SCMs that manage both the quality and quantity of runoff from almost all impervious surfaces. Successful implementation must be integrated across multiple-scales, from private properties to end-of-pipe systems. To ensure long-term environmental benefits, strategies should consider incentives and regulations, enhanced maintenance education,

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and potentially incorporate real-time monitoring technologies, to minimise failure rates and maximise performance.

Keywords

Catch-scale stormwater management, urban hydrology, stormwater control measures, stream function, community participation, planning controls, asset maintenance, inter-agency collaboration

Introduction

Urban streams are degraded by uncontrolled runoff from impervious surfaces (hard surfaces such as roads, roofs, footpaths, carparks) delivered through hydraulically efficient stormwater drainage networks. The resulting disturbances are both hydraulic, arising from larger, more frequent high-flow events and lower dry weather flows, and chemical, arising from the complex mixtures of pollutants associated with impervious runoff (Hawley & Vietz, 2016, McGrane, 2016, Walsh et al., 2005). Additionally, hydraulic changes alter in-stream habitat, resulting in a loss of habitat diversity (Russell et al., 2020, Vietz et al., 2014). In response to this, alternative drainage approaches have been advocated that attempt to restore the natural hydrology of a catchment through the installation of stormwater control measures (SCMs, Fletcher et al., 2015). This use of SCMs has been subject to extensive research and successfully trialed at the site scale (e.g. Ewert et al., 2018).

Although the cumulative effects of small-scale stormwater management on catchment-scale hydrology has been shown theoretically (Walsh et al., 2005), the protection, and potentially restoration, of waterway health through catchment-scale application of dispersed SCMs had remained largely untested. The Little Stringybark and Dobsons Creeks Project sought to test whether stormwater runoff from urban developments can be adequately retained, used and treated at the catchment scale to restore stream ecosystem structure and function.

This paper presents a summary of the project findings, including results from the core research on the effectiveness of catchment-scale adoption of SCMs in mitigating stormwater impacts, as well as complementary investigations. We also include practical insights from the project team involved in delivering the project. These findings and insights have been synthesised into 10 fact sheets that are available for download (https://doi.org/10.26188/32209989). We hope that the fact sheets, together with this paper, will inform the planning and delivery of future catchment-scale stormwater management projects for improved stream health.

Methodology

Over eight years, beginning in 2008, we constructed close to 1,000 dispersed SCMs projects across two peri-urban catchments (Little Stringybark Creek (LSC) and Dobsons Creek) on the eastern edge of Greater Melbourne, thereby treating runoff from 4 km^2 of urban development across both catchments. SCMs were designed to improve water quality, restore important elements of the natural flow regime and ultimately improve stream ecosystem health. SCMs were installed on private and public land. Public land works were installed in collaboration with local government (Yarra Ranges and Knox City Councils) and ranged in scale from dispersed, small, infiltrating nature strip systems (treating <100 m^2) to large complex systems (treating >20,000 m^2) that combine harvesting, re-use and infiltration. Private land systems, comprising mostly rainwater tanks connected to internal water demands (e.g. toilet flushing), were installed through incentivised community engagement programs. In addition to funded installations, the project partners collaboratively developed planning controls to minimise the impact of new impervious surfaces in the LSC catchment that would otherwise undermine restoration efforts.

We were able to install SCMs on 30-46% of private properties in the LSC and Dobsons Creek catchments. Hundreds of dispersed raingardens were installed in both catchments to capture runoff from roads. However, the extent to which we were able to reduce effective imperviousness (EI, the area of impervious surfaces draining directly to the stormwater drainage network) was limited by community participation and public space constraints, leaving large areas of impervious surfaces untreated. Nevertheless, in four out of the six sub-catchments within LSC and Dobsons Creek, we were able to reduce EI to less than 3%, which based on previous studies we hypothesized may be adequate to see improvements in stream health (Walsh et al., 2005).

Figure 1 presents a conceptual model of the hypothesized stream responses to the installation of SCMs in the LSC and Dobsons Creek catchments. To assess the impact of our SCM works, we established a Before-After-Control-Reference-Impact (BACRI) study framework in multiple catchments across the Dandenong Ranges (Figure 2): three reference, forested catchments, with little or no stormwater drainage infrastructure; two control urban catchments, with streams degraded by urban stormwater drainage, and the two experimental catchments (LSC and Dobsons Creek, Walsh et al., 2015). We continuously monitored stream hydrology (2009-2021) and intermittently monitored water quality (monthly and event; 2001-2003, 2004-2006, 2009-2019), aquatic macroinvertebrate community composition (Spring/Autumn; 2001-2003, 2004-2006, 2008-2020), diatom community composition, benthic algal biomass and leaf litter decomposition (Spring/Autumn; 2011-2018). All monitoring ceased at the start of 2022, except aquatic macroinvertebrates, which is ongoing as part of Melbourne Water's long-term waterway health monitoring programs.

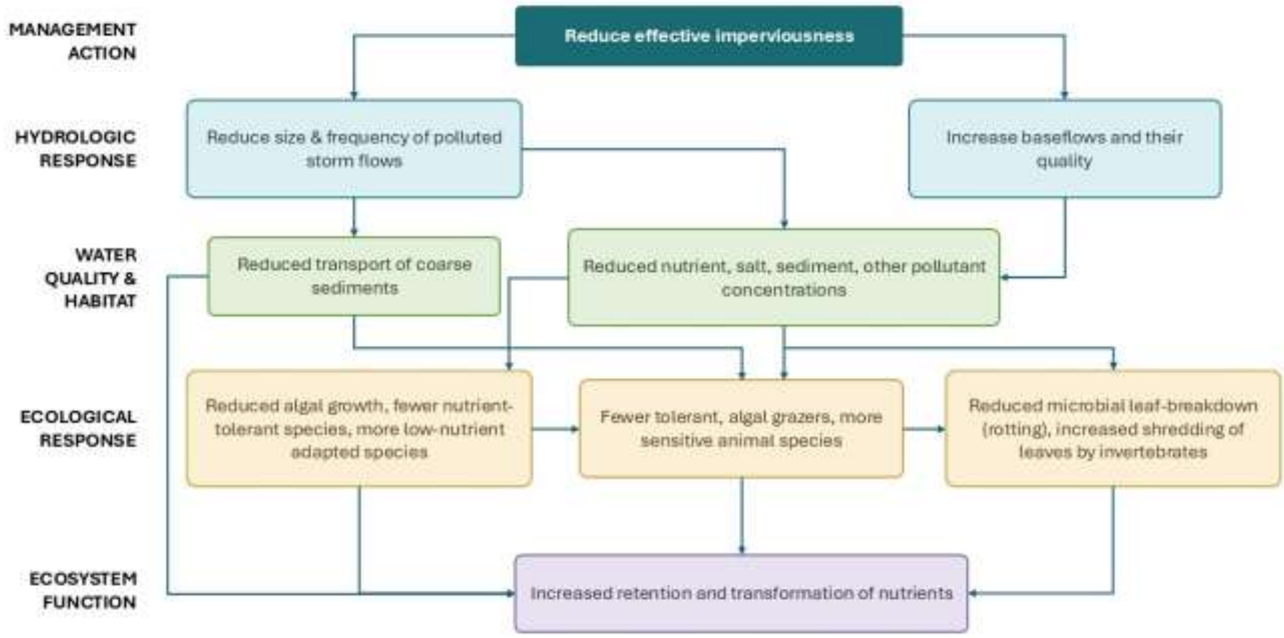

Figure 1 Conceptual model of hypothesized mechanisms and stream responses to installation of SCMs in the catchments of Little Stringybark and Dobsons Creeks

Complementary investigations were undertaken to further assess the effectiveness and value of this type of project, including the development of an Index of Environmental Benefit (EBI) to evaluate the likely benefits of SCM options. Building on the EBI, we developed improved catchment metrics to allow prediction of the effects of catchment urban stormwater runoff and SCMs on receiving streams. We also examined stakeholder motivations and challenges, namely local government and residents, and the long-term performance of residential rainwater tanks.

Results

Impact of catchment-scale stormwater management

Where EI was sufficiently reduced, interventions reduced in-stream phosphorus concentrations and summer temperatures (Walsh et al., 2022). The effect on Total Phosphorous (TP) concentrations was greatest during dry weather and when rainfall in the preceding 24 hours was 8mm or less (weather conditions which collectively occur 90% of the time), where stream TP concentrations were reduced to levels comparable to those observed in the forested reference streams. Maximum summer stream temperatures were also reduced during dry weather by 4–5^0C, (similar to those found in forested reference streams), as well as during wet weather, with the effect greatest during small to medium rainfall events of less than 8mm. Reductions in both TP and summer temperatures were smaller following less frequent, larger rain events. Additionally, SCMs reduced nitrogen concentrations, although the extent of reduction varied with weather and nitrogen species. SCMs had no clear effect on suspended solids concentrations, which were lower in urban than in reference streams. SCMs marginally increased electrical conductivity, which was already high in LSC and its tributaries: along with reduced stream temperature, this suggests that SCMs increased groundwater contributions to baseflows.

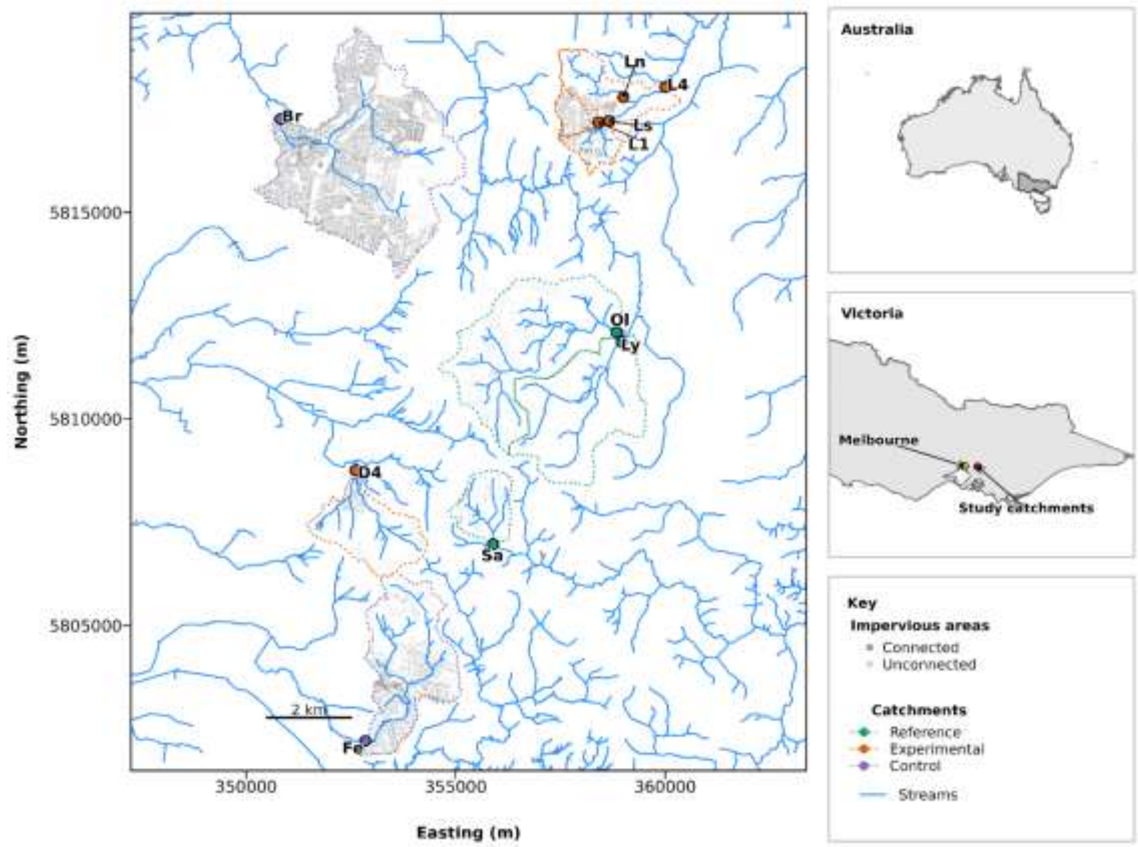

Figure 2 Monitoring sites and their catchments, coloured as reference, experimental or control. Impervious surfaces (only surfaces within the student catchments are shown) are shaded by their connection to the stormwater drainage system in 2019 (Source: Walsh et al., 2023)

The stormflow hydrology of the catchment was also positively influenced by SCMs (Walsh et al., 2023). We found that SCMs reduced wet weather volumes of quickflow (the flow that makes its way to the creek as runoff) and peak flow for small-to-moderate storm events. The largest effect on quickflow was observed in the northern sub-catchment of LSC (which had the highest levels of stormwater retention), where SCMs reduced the quickflow volume for 3 mm rain events from 0.086 mm to 0.034 mm. For peak flows, rain events up to ~12 mm were comparable to those observed in the forested reference streams. SCM-induced changes to the flow regime diminished for large storm events (> 20 mm). The reductions in storm event quickflow volume observed are commensurate with the predicted runoff retention capacity of the SCMs implemented. Decreased storm event peak flows are likely a result of both the detention and retention behaviour of the SCMs. Given that small-to-moderate storm events dominate wet-weather conditions and are therefore thought to be the main driver of stormwater degradation of stream health (Walsh et al., 2005), these observed changes to the flow regime were expected to be biologically meaningful.

Analyses of the ecological effects of stormwater interventions are continuing, however, we offer the following preliminary observations. The stormwater interventions resulted in little or no change in summary indicators of ecological health for LSC, such as the SIGNAL (Chessman, 1995) or LUMaR (Walsh & Webb, 2013) indices for macroinvertebrate assemblages or the DSIAR (Chessman et al., 2007) index for diatom assemblages. On the other hand, there was a positive trend in both SIGNAL and LUMaR in Dobsons Creek since 2013. This difference in response between the two streams may have resulted from the greater pool of colonising species from the forested headwaters of Dobsons compared to LSC, whose headwaters are primarily urbanized. Despite little change in summary indicators of ecological health, abundances of some macroinvertebrate taxa changed in response to the catchment interventions, with numbers of some moderately sensitive macroinvertebrate taxa increasing, indicating improvements in biodiversity. A single common diatom species, *Achnanthes oblongella*, which tends to be more common in less urban streams, increased in relative abundance following SCM implementation. At the same time, 12 other diatom species of varying sensitivity to urban impacts became less abundant. The overall effect was to increase the evenness of the diatom assemblage, which generally indicates reduced environmental stress (e.g. nutrient concentrations, flow disturbance). We do not yet know whether the change in diatom assemblage composition was matched by a reduction in algal growth (biomass). If algal biomass is found to be lower after SCM installation, that would provide further evidence of improved ecosystem health.

In summary, although we were unable to achieve the desired level of stormwater treatment from impervious surfaces in either the LSC or Dobsons Creek catchments, the project demonstrated the capability of distributed SCMs to improve aspects of stream health, including water quality, hydrology and ecological condition. This provides proof-of-concept that catchment-scale stormwater management can improve the health of streams in existing urban areas and is an important step forward in opportunities for urban stream management. Additionally, the project has offered a number of insights into the planning and delivery of innovative, long-term, stormwater management projects, which are summarised below.

Practical lessons

Prioritise stream protection over restoration

The project demonstrated that healthier urban streams are possible, but it was tested in the hardest context, that is, retrofitting existing urban catchments where opportunities (e.g. adequate space) for implementing SCMs are more constrained than in newly developing areas. As such, aiming to protect waterways by installing SCMs in parallel with new urban development, while not without its challenges, is likely to be more feasible and cost-effective, because there is greater scope to secure public space for SCMs and mandate SCMs in the private realm. Further, we argue that protecting streams is likely to be more effective than restoration because, even where improvements are achieved, the trajectory and extent of recovery remain uncertain. The intensive approach adopted for this project, where there were significant effort and funding in a relatively short time span to provide proof-of-concept, is unlikely to be feasible for all catchments in regions like Greater Melbourne. Instead, we envisage a longer timescale for restoration (50+ years) that works through both regulatory drivers and opportunistic investment. With this perspective, stormwater can be progressively treated by SCM installations as opportunities arise (e.g. as part of urban renewal projects or drainage infrastructure upgrades), as well as through the adoption of planning controls, as discussed below.

Collaborative stormwater management: Co-design and co-delivery for long-term success

The success of the project was aided by successful, persistent collaboration between multiple organizations and individuals (Prosser et al, 2015). A clear, compelling and shared narrative of the project's purpose is a central ingredient for successful collaboration. This narrative will help communicate the value of the project to participants and manage expectations by articulating what the project will and will not do. The narrative should evolve over time to incorporate emerging evidence, achievements, and unexpected outcomes. Equally important to successful collaboration is establishing a robust governance structure that has a clear mandate and terms of reference, and spans delivery, operation, monitoring and reporting. We found that establishing dedicated working groups for specific project components worked well. Effective delivery can be aided by identifying and maintaining at least one project champion within each organization. These individuals must have the time, accountability, and motivation to drive the work. Another core finding is the need to identify and secure necessary resources early, including staff, funding, technical knowledge, materials and specialist support (such as media and community engagement), with clear sightlines across all project phases. This planning must also consider resources for monitoring, evaluation, and reporting to facilitate learning and continuous improvement. Finally, success is facilitated by having partners willing to embrace risk, which can be underpinned by open discussion of financial and reputational risks, agreed mitigation strategies, and cultivating a “safe-to-fail” culture.

Collaborating with local government on stormwater management

Given their responsibilities for managing stormwater runoff, drainage, and flooding, local government plays a critical role in the delivery of stormwater projects across Greater Melbourne. The project was found to be an effective avenue for increasing local government’s (Yarra Ranges and Knox City Councils) willingness and capacity to deliver stormwater management initiatives (Burns et al., 2015), leading to a long-term commitment.

A key lesson from the project was the value of having a dedicated project champion within local government. For the LSC component of the project, this involved seconding a drainage engineer into Yarra Ranges Council’s engineering department, which led to accelerated construction of SCMs, improved maintenance, and increased confidence in new technologies (Burns et al., 2015). This arrangement also fostered a broader culture of knowledge exchange, where researchers contributed design and treatment expertise while local government engineers and maintenance staff provided practical construction and operational capability. This approach resulted in SCMs that were more effective, easier to operate and maintain, and better trusted across local government departments.

It was also important to secure support across all levels and relevant departments of council, including councillors, senior management, and operational staff. For the LSC project, initial under-engagement with the engineering department led to barriers to SCM installation and poor early maintenance. Clarifying organisational roles and expectations at the outset, including who is responsible for ongoing maintenance and associated costs, is vital to avoid SCM performance decline. Having a trusted relationship was found to be important, but this can take several years to develop and requires regular communication, shared objectives and mutual respect; this can be facilitated by capitalising on opportunities to work together on smaller pilot initiatives. Finally, aligning projects with existing council strategies and policies, such as integrated water management or stormwater management strategies or plans, provides a mandate for investment, helps drive organisational change, and greatly facilitates local government participation and support.

Enacting stormwater management through local government planning schemes

Local government planning schemes can be powerful tools for enacting stormwater management controls beyond that required by state-level controls. A Yarra Ranges Council Environmental Significance Overlay (ESO) was developed to set specific stormwater requirements for almost all hard surfaces on new or expanded developments within the LSC catchment. The ESO was critical to ensure that any new development was not undermining stream restoration efforts. These stormwater provisions were more stringent than the Victoria Planning Provisions, focussing not only on water quality, but also on restoring more natural flow regimes.

The ESO addressed the majority of new development in the LSC catchment and this success was attributed to it being well administered and supported. A fast-track referral process helped limit additional delays and maintain community acceptance. Expert support proved crucial: site visits and advice from a dedicated Stormwater Treatment Advisor, alongside local government and Melbourne Water planning staff, were widely used and highly valued, and found to be more effective than written guidance alone. Community support for the ESO was generally positive; an evaluation of the program found that most permits included an appropriate level of stormwater treatment, with a large majority of inspected properties having built the required SCMs.

Enhancing community engagement and participation in stormwater management

Community participation was critical to the delivery of the project, as private land contributes approximately half the impervious surfaces within the LSC and Dobsons Creek catchments. Community participation was primarily encouraged through financial incentives, ranging from heavily subsidised to free SCMs, mainly rainwater tanks. However, additional efforts were required. Having a consistent, personable point of contact over the life of the project was crucial to overcoming initial scepticism about offers of rainwater tanks, which were sometimes perceived as being 'too good to be true' (Brown et al., 2015). A single, recognisable project representative helped establish familiarity, positive first impressions, and trust, with household perceptions strongly shaped by their personal interactions. Building interest and participation in the project required time. Delivering the project over multiple years enabled repeated, tailored promotion and allowed for an adaptive engagement approach, where successive rounds of incentives and feedback were used to refine procedures, better address diverse motivations for participation, and reduce participation barriers.

Simplifying participation processes was also a critical factor (Bos & Brown., 2015). The initial use of a complex market-based instrument to provide financial incentives to residents in the LSC catchment deterred involvement because it was hard to understand and time-consuming. Subsequent rounds used a simpler process to incentivise LSC residents (which was subsequently adopted at Dobsons Creek) and this was found to be more successful. Even so, financial cost remained the single greatest barrier to installing private SCMs, and participation increased markedly when the project fully funded installations. However, it was concluded that complete community uptake is unrealistic, even with free tanks, and programs must be designed to succeed with less than full participation.

Finally, community engagement should extend beyond installation as, without ongoing contact, interest and maintenance can lapse as the novelty of an SCM fades or property ownership changes hands. Long-term strategies such as regular updates on SCM performance and stream health outcomes, information packages for new owners, asset labelling (e.g. QR codes for online resources), and periodic free inspections could help to sustain community commitment and ensure the SCMs continue to function in the long term.

Design and performance of stormwater control measures for healthy streams

Designing SCMs to restore natural catchment hydrology and improve water quality did not translate to more complex SCMs. Rather, adaptability and innovation were needed. Over the course of the project, SCM designs were progressively refined in response to lessons about performance, maintenance, and public acceptance. For example, the project introduced slow-release rainwater tanks as a more space- and cost-efficient way to combine harvesting and infiltration than installing a rainwater tank and a separate infiltration system to manage tank overflows. Adaptability was also beneficial for adjusting to the variable conditions found across catchments, such as changes in soil type or topography. SCMs design should also balance form with function. While there are clear benefits to having visually pleasing SCMs, such as maintaining community support, aesthetic elements should not come at the expense of ease of maintenance or hydraulic performance.

At the catchment scale, the project highlights the importance of building resilience into SCM networks and using a diverse mix of treatment measures. Since some SCMs will inevitably be non-operational at times, due to maintenance gaps, damage, ageing or design failures, SCM networks should incorporate some redundancy so that individual SCM outages do not undermine overall objectives. Approaches might include establishing treatment trains, where stormwater passes through multiple SCMs, or increasing the number of (or oversizing) assets. Similarly, adopting a mix of SCM types, with different failure modes, might reduce the risk of widespread failure. Having different SCM types and locations brings complementary benefits. Streetscape systems can intercept and infiltrate large volumes of stormwater, but may lack local demand for harvested water, while residential tanks effectively reduce runoff volumes when supplying internal demands (e.g. toilets and washing machines).

Operation and maintenance of stormwater control measures for healthy streams

Effective operation and maintenance of SCMs in the project depended on treating maintenance as a core design and delivery component rather than an afterthought. Designing with maintenance in mind can significantly improve ongoing performance. This includes consideration of local conditions (e.g. proximity to sediment sources that may clog filter media in SCMs), expected maintenance task types and frequencies, and the skills of and resources available to maintenance staff or local residents. We recommend involving maintenance staff early during the design process. SCMs were designed to safely bypass flows when they failed, therefore many faults were not obvious without deliberate inspection. Only proactive, regular checks (especially during rainfall events) revealed problems such as blocked inlets, clogged filter media and vegetation loss. The appointment of a dedicated SCM maintenance officer at Yarra Ranges Council led to marked improvements in SCM operation by ensuring routine inspections and timely rectification.

Clear allocation of responsibilities emerged as another critical factor. SCM networks typically involve multiple organisations, departments and private owners, so maintenance roles need to be defined before construction. In the LSC component of the project, initial failure to engage Yarra Ranges Council's bushland team (responsible for the vegetated components of SCMs) alongside civil engineers (managing the hard infrastructure such as pits and pipes) delayed establishment of effective maintenance programs for vegetated SCMs. On private land, community-based SCM maintenance brought its own challenges. While many residents were, in principle, willing to care for their SCMs, actual maintenance was often constrained by capacity, with tank or pump repairs competing with other household expenses (Bos, 2021). Long-term relationships, ongoing communication about the personal and public benefits of SCMs, clear guidance on maintenance schedules and likely failure points, and tools such as reminders or sensors can help, but some lag in repairs remains likely.

Finally, complete and accessible "as-constructed" records of SCMs are important, including process diagrams and any design changes made during construction. These records become increasingly critical as staff turns over, and they provide the foundation for effective, well-targeted maintenance programs throughout the life of the SCM network.

Monitoring the effectiveness of stormwater control measures

The first step in establishing an effective monitoring program for SCMs and their catchment-scale effects is to identify why the monitoring is required, specifically, what questions you are trying to answer and how the data will be used. Doing so shapes what is monitored, where and how often, and what level of accuracy is required. It will also help avoid the collection of irrelevant data and associated costs. Moreover, the monitoring program should be adaptive, including testing methods in pilots, reviewing early data, and revising sites, methods, or data collection frequencies where necessary.

When collecting data, ensure consistency of methods across sites and through time. Small differences between manually and automatically collected water samples, and inconsistent deployment of autosamplers, meant we could not use some datasets in key analyses. Codifying detailed protocols, carefully training staff, and using custom mobile apps helps to guide field personnel and avoid errors such as incorrect timestamps. Comprehensive field notes about site conditions, equipment status, and anomalies are vital for diagnosing equipment issues and interpreting data. Data collection was also aided by the use of near-real-time data for targeting event-based sampling and planning field work. Live data also enables "monitoring of the monitoring", allowing the functionality of systems to be checked remotely.

Collecting data is only one step in a monitoring program and substantial effort is required to organise, quality-check, process, and store data. These tasks demand dedicated resources and should influence program design, including how much and what quality of data can realistically be handled. Regular data processing and preliminary analysis are essential for early detection sensor drift, calibration needs, and other problems. Postponing data analysis until the end of a project almost guarantees failures will go unnoticed until it is too late. To build trust in the data, we recommend documenting the strengths and limitations of each dataset, retaining an untouched copy of raw data, and establishing traceable, computationally reproducible data processing workflows so that final results can be clearly linked back to their origins.

Conclusions

Stormwater is a primary driver of urban stream degradation, but this project demonstrates that its impacts can be substantially mitigated through coordinated, catchment-scale application of dispersed SCMs. Supported by planning controls and productive collaboration between agencies, local governments, and communities, this project showed that it is possible to improve the ecological structure and function of streams closer to pre-urban conditions. However, retrofitting existing urban areas with sufficient SCMs to meaningfully reduce stormwater impacts is likely to be more challenging and uncertain than integrating SCMs into new developments to protect streams. Successful stormwater management at the catchment scale depends as much on collaboration, governance, and engagement as on the SCMs themselves. Dedicated champions within organisations, clear roles and responsibilities, supportive planning schemes, sustained community engagement, and well-resourced maintenance programs were all critical to achieving improved stormwater control. We hope that the findings and fact sheets distilled from this work will continue to inform future stormwater policy, planning and on-ground programs, helping design stormwater strategies that are scientifically robust, operationally workable, and capable of delivering long-term improvements in stream condition.

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