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Building capacity in low-impact drainage management through research collaboration

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Abstract: Municipalities often play the principal role in the management of urban stormwater runoff. Dominant approaches involve routing urban stormwater runoff directly to streams, which has negative impacts on waterway health. Alternative management approaches, such as low-impact drainage management, have the potential to protect or restore urban streams, but remain rarely used. The Yarra Ranges Council (YRC), a municipality in Melbourne, Australia, collaborated with a team of researchers to construct stormwater-harvesting schemes, infiltration systems, and other measures (e.g., low-flow filters for water-quality treatment), as part of a catchment-scale experiment on low-impact drainage management. We held a workshop to elicit views of staff across a range of departments on insights gained from the experiment. We also gathered information on the design and construction of works to support findings from the workshop. Over time, research collaboration increased the capacity of YRC in low-impact drainage management. This increased capacity was linked to the temporary assignment of one of the researchers to work in the municipality's engineering department. The researcher increased the confidence and trust of YRC in the use of new stormwater-management technologies. This temporary assignment into YRC helped support the long-term nature of the collaboration, which built trust over time. Our results support the views of scholars that civil experimentation can improve the capacity of municipalities to implement alternative approaches to urban stormwater management, with the aim of protecting or restoring streams.
Key words: stormwater, municipality, stream, large-scale experiment, government collaboration

In most cities of the world, municipalities play a major role in the management of urban stormwater runoff—water that runs off impervious surfaces (Walsh et al. 2010). In cities that have separate sewers, the dominant stormwater-management approach involves routing urban runoff directly to streams via conventional stormwater drainage. The primary goal of this management approach is to protect the community from flooding (Debo and Reese 2002), but it has been implicated in reducing the ecological condition of streams (Walsh et al. 2005, Wenger et al. 2009). Thus, in their role as urban stormwater managers, municipalities can have a direct bearing on the ecological health of running waters. The challenge for municipalities is to adopt alternative approaches to stormwater management that have the potential to protect or restore urban streams, while improving or at least maintaining flood protection.

The goal of one such approach, which we term low-impact drainage management, is to protect or restore important elements of the natural flow regime (Burns et al. 2012). It requires that a large proportion of urban stormwater runoff is lost through evapotranspiration or harvesting and the remaining portion infiltrates the soil. To maximize the probability of protecting or restoring urban streams, most urban stormwater runoff should never reach the stream (Walsh et al. 2012), whereas dry-weather flow and water-quality regimes should be maintained as close to the predevelopment condition as possible.

In the region of greater Melbourne, Australia, low-impact drainage management is starting to become more

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widely used (Prosser et al. 2015), but in most cases, the standard drainage practice still involves direct piped discharge to the stream (Burns et al. 2012). In an effort to change how stormwater is managed in the region, the regional water authority and primary custodian for waterway health (Melbourne Water [MW]) has sought to partner with municipalities to trial low-impact drainage methods (Brown and Clarke 2007). A strong motivator for these partnerships is that municipalities are responsible for managing urban stormwater runoff in catchments <60 ha in size, and these catchments drain the ecologically important headwaters of larger receiving waters (Meyer and Wallace 2001, Clarke et al. 2008). An important partnership for MW has been with Yarra Ranges Council (YRC), a peri-urban municipality on the outer eastern fringe of Melbourne. YRC's jurisdiction encompasses many high-value streams, including the upper and middle reaches of the region's focal waterway, the Yarra River.

In the early 2000s, MW provided financial and technical support to help YRC make a transition to low-impact drainage management by implementing new technologies (stormwater control measures [SCMs]; e.g., swales, bioretention systems, and a stormwater-harvesting system) that differed from conventional practice for the municipality (Prosser et al. 2015). While commendable, this experimentation did not create a situation of substantive learning, a process that is fundamental to enable change (Bos et al. 2013b). A lack of knowledge restricted the capacity-building of YRC (Bos et al. 2013a), meaning that familiar conventional approaches to stormwater management remained standard practice.

In 2009, a team of researchers engaged with YRC to become part of a catchment-scale experiment that involved retrofitting urban stormwater infrastructure across multiple scales in a single urban catchment (Walsh et al. 2015). The goal of the experiment was to improve the ecological health of the receiving stream, Little Stringybark Creek. The researchers initially engaged with YRC's environment department, but soon extended their engagement to the engineering department to implement essential capital works on public and private land. Therefore, the experiment was another trial of low-impact drainage management, and could help YRC deliver better stormwater outcomes.

At first, YRC was not well placed to be involved in the experiment because of limited technical capability and resources. However, collaboration with the researchers first to construct, and increasingly to co-design SCMs, increased the capacity of YRC to deliver alternative approaches to stormwater management. This ability was greatly aided by the appointment of an environmental drainage engineer (who was also part of the research team) to increase the capacity of the engineering department to implement the SCMs. Over time, involvement in the project extended to multiple departments across YRC. In turn, YRC's increased contributions to SCM design and maintenance solutions and, ultimately, to new planning provisions to protect the investments of the project have contributed to the lessons of the broader research project, and provide an exemplar of adaptation of a municipality to transition beyond the conventional 'command and control' governance of stormwater management (Karvonen 2011) to more sustainable approaches. The experiences of YRC in this transition can provide important lessons for future collaborations among stream managers, ecologists, and the managers of catchment stormwater infrastructure. Our paper reports on the lessons learned from YRC's involvement with the experiment.

METHODS

An independently facilitated workshop was held with 9 YRC staff, who were involved with the experiment, including 2 engineers who had been employed specifically to support the implementation of the project (identified here as former environmental drainage engineer and consultant project engineer). Departments responsible for engineering, environment, drainage maintenance, and town planning functions were represented.

The workshop was structured as an after-action review (Morrison and Meliza 1999), a process used by a team after or during a project to capture lessons learned from past successes or failures, with the goal of improving future performance. Attendees were asked to reflect on YRC's original objectives in relation to the experiment, the actions undertaken, achievements, challenges, the important lessons learned, and how to apply those lessons in the future. Responses were grouped around themes, and attendees were asked to provide quotations to illustrate their thoughts on the themes.

Here we report on the achievements, challenges, and important lessons learned as identified by the attendees. To identify achievements, workshop participants were asked 'What is the biggest achievement or positive factor associated with the Little Stringybark Creek Project?'. Similar questions were asked to identify challenges/negative factors and the lessons learned from the participants' involvement in the Little Stringybark Creek Project. Responses in the form of written quotations were placed in categories that were determined collectively by the participants during the workshop. We used these data as evidence to support increased capacity of YRC in low-impact drainage management. The qualitative nature of the data collected did not permit statistical analyses.

In addition to the workshop, we gathered information on the 58 SCMs constructed during the experiment to supplement the workshop findings. The information collected included: 1) description (e.g., infiltration system, draining 1000 m^2 of impervious area), 2) design personnel involved, 3) period of construction, and 4) any lessons learned.

Table 1. Yarra Ranges Council staff perceptions of the achievements and positive factors of the experiment. WSUD = Water Sensitive Urban Design (the local term for stormwater management aiming to limit environmental impacts). Environmental Significance Overlay = a planning control which addresses the problem of ongoing development in the Little Stringybark Creek catchment.

Achievements/positive aspects	Illustrative quotes
Having a common goal	"The biggest positive was the number of organisations working together for a common goal." (Town planner)
Engagement between council, the researchers, and community	"The open and consultative approach to design, construction, and maintenance worked." (Drainage maintenance coordinator)
	"Listening to constructive feedback and improving design parameters to construct better treatments helped to build relationships." (Engineering team leader)
	"Involvement of Council's construction team was key in making them [*the construction team*] aware of potential failures of WSUD systems due to construction faults." (Consultant project engineer)
	"Including development of (an) Environmental Significance Overlay allowed the project story to penetrate a lot more of Council." (Environmental officer)
	"There has been a positive response from residents with very little negativity." (Consultant project engineer)
Access to external resources and advice	"Having the university support to underpin the projects allowed them to be modified with some scientific basis (rather than scrapped) where environmental constraints were identified." (Environmental officer)
	"External funding agencies took the financial risk for the experimental systems—Council could not afford to do a project like this alone." (Environmental officer)
	"There were two-way teachings and learnings between the embedded (environmental) drainage engineer and Council, which greatly improved the delivery of the project." (Former environmental drainage engineer)
Successful projects	"It has taken about three years and several variants of projects to bring around traditional but sceptical thinking. Several successful projects built confidence in rain-garden treatments." (Engineering team leader)
	"The success of the Hereford Road project was very effective in mitigating some of the previous scepticism about the project." (Former environmental drainage engineer)
Project champions	"Having champions at various levels was critical for the ongoing success of the project." (Engineering team leader)
	". . . exemplified a strong leader and worked on all aspects of the project from the most practical to the academic. This sort of person/commitment is needed if a project is going to be successful." (Town planner)
Education and environmental awareness	"The researchers were able to provide useful WSUD knowledge to both Council and private development engineers." (Engineer)
	"The Little Stringybark Creek Project helped (Council) engineers to apply WSUD principles in practice." (Engineer)
	"I was aware of the 'big picture' and how the implementation of this type of project in catchments has the potential to significantly improve the environment." (Engineer)
	"Running the concurrent program with the residents was a great way to start conversations. I am sure the installation of the roadside works was easier because the residents already knew what it was about." (Environmental officer)

RESULTS AND DISCUSSION

Achievements and challenges

Overall, YRC staff reported more achievements than challenges associated with the Little Stringybark Creek Project (17 responses for achievements vs 10 for challenges; Tables 1, 2). The biggest achievement as reported by the surveyed staff was engagement between council, the researchers, and the community (29% of responses; Table 1). Increased education and environmental awareness also was a major reported achievement (24% of responses; Table 1). The biggest challenge concerned construction and site selection (40% of responses; Table 2). Problems with communication and clarifying objectives was the 2^{nd} largest challenge reported by staff surveyed (30% of responses; Table 2).

Important lessons learned

A recurring theme throughout the workshop was learning. Crucial to the progression of the project was that both parties adapted through learning-by-doing (Farrelly and Brown 2011). The researchers learned from YRC staff and vice versa (Table 1). An example of such learning concerned the practical constraints of implementing works in the field. "*There isn't one right way to do WSUD* (Water Sensitive Urban Design; the local term for stormwater management aiming to limit environmental impacts). *Just because a researcher or designer may have a lot of technical knowledge, it doesn't mean it is practical and sustainable in the field. One party must learn from the other to achieve a common goal*" (consultant project engineer). Participants also recognized that the learning process is ongoing. "*We're still learning about the life cycle costs and failures"* (drainage maintenance coordinator). Good examples of 2-way learning relate to how the design and construction of SCMs evolved throughout the experiment. YRC made fruitful and new contributions to the design and construction of systems. For instance, the inlets for the Hereford Road vegetated infiltration system (Table 3) were modified during construction after input from the maintenance department. The experience of constructing this system supports the view that a culture of learning should be encouraged to help organizations transition to alternative approaches to urban stormwater management (Bos et al. 2013b). Such 2-way learning is central to the concept of civil politics that Karvonen (2011) posited is the most effective means of realizing broader change to urban stormwater management for environmental protection.

The participants identified the value of working in partnership with a research organization as important. "*Partnership with the university was critical to help re-*

Table 2. Yarra Ranges Council staff perceptions of the challenges and negative aspects of the experiment.

Challenges/negative aspects	Illustrative quotes
Communication and clarifying objectives	"Council staff had different understandings of the purpose of WSUD to the research team that persisted throughout the project." (Environmental officer)
	"Often, engineers' mindsets were entrenched in conventional stormwater drainage. This at times hindered the development of projects." (Former environmental drainage engineer)
	"It is important that contractors are engaged and understand the principles and project objectives." (Drainage maintenance coordinator)
Neglecting ongoing maintenance	"Maintenance responsibilities were not discussed leaving constructed WSUD systems with little or no maintenance." (Consultant project engineer)
Resource constraints	"Council didn't have the resources to fully support the project—for example staff time, knowledge and budget for ongoing maintenance." (Environmental officer)
Staff turnover	"The length of the project has seen at least 2 changes of key staff, which while understandable, does not help the project's continuity." (Town planner)
Construction problems and site selection	"Time delays often hindered construction." (Former environmental drainage engineer)
	"Poor site selection may not only reduce the efficiency of the treatment, it may also increase maintenance costs and reduce the community's perceptions (of WSUD)." (Engineer)
	"A site for a WSUD (system) has to be carefully selected as there may be constraints, for example, trees in the vicinity." (Engineer)
	"Impacts to trees wasn't [*sic*] fully understood, not only the excavation required but also the effect that water logging in the completed rain gardens has on the trees." (Environmental officer)

solve technical issues" (former environmental drainage engineer). This partnership was fundamental in overcoming barriers to the adoption of new technologies. The credibility of the researchers was pivotal in removing historic skepticism around low-impact drainage management and building trust in the use of such technologies. Such skepticism had developed because of a perception that YRC's early attempts at low-impact drainage had failed and that these systems could not be maintained in the long term (e.g., Table 2). Having a member of the research team (the environmental drainage engineer) embedded in the engineering department to support the experiment was seen as an important factor in developing the partnership between YRC staff and the researchers. In addition, the specialist engineers greatly increased the capacity of YRC to design and implement works. In the 18 months between gaining funding for council works and employment of the environmental drainage engineer, no works were completed (Fig. 1). Once the engineer was employed, a period of increasing construction activity followed. Construction activity peaked during the period from July 2012 to October 2013 (Fig. 1) and probably was an effect of having a person dedicated to the implementation of works. The benefits of having the specialist engineers went beyond the experiment because they provided technical advice to YRC staff on how to incorporate low-impact drainage management ideas in other projects within the YRC's area. "*Having a dedicated specialist within the team was a valuable resource*" (engineering team leader). The engineers could be regarded as civic experts (sensu Karvonen 2011), and they used their technical expertise to inform decision-making for better stormwater-management outcomes.

Participants recognized during the workshop that the experimental nature of the project required a level of risk that was higher than YRC is typically willing to accept. MW and the research team (through their grants; Walsh et al. 2015) took the financial risk for the experimental systems (Table 1), but risk also was associated with the construction and operation of SCMs. "*Accept mistakes can and do happen. Take these and work toward resolving through innovations, taking risks, and looking 'outside the square'*" (drainage maintenance coordinator). Our experience supports the view that civic experimentation can change standard practice, although such transformation takes time and requires a trusting partnership between all collaborators (Bos and Brown 2012, Karvonen 2011). Certainly some municipalities will be more willing to experiment than others. Municipalities that value streams highly might be prepared to accept the perceived risks associated with low-impact drainage management. Conversely, municipalities that have limited commitment to environmental values might consider that the risks outweigh their perceived benefit. Despite YRC's strong general environmental values (Shire of Yarra Ranges 2008), the fact that responsibility for stream management fell primarily to another organization (MW) led to a desire to share the risk of systems designed for stream protection (Table 1).

The participants reported that the role of YRC in the project was not clearly defined at the start. "*There was initially a lack of understanding of what was to be achieved*" (drainage maintenance coordinator). This lack of clarity was especially strong regarding the expectation that YRC would be responsible for the ongoing maintenance of SCMs and, thus, the associated costs. Thus, objectives and roles should be defined clearly at the beginning of this type of project.

Improved project management contributed to increased construction activity. The delivery of most completed works involved the stages: conceptual design, detailed design, request for tender, and construction. For the larger works in particular, the required design and tender stages often took many months, resulting in lengthy construction lead times. The consultant project engineer instigated a practice whereby the delivery of small works (e.g., roadside rain gardens) consisted only of conceptual design and construction. For these works, a simple conceptual design was passed directly to a preferred construction contractor, which resulted in short project delivery times.

The need to commit to the long-term success of the project was identified as an important lesson. Subsequent to the workshop, YRC and MW, with support from the researchers, have shown such commitment by developing an Environmental Significance Overlay (ESO; Prosser et al. 2015) to manage ongoing development in the LSC catchment. This planning tool ensures that new development in the catchment adheres to the principles of low-impact drainage management. Effective collaboration was central to the ESO, again reflecting the strong trust among stakeholders (developed over time; Table 1).

The ongoing maintenance of SCMs was an important issue raised in the workshop. "*There needs to be a clear commitment for maintenance of WSUD assets from all stakeholders*" (engineer). At the time of the workshop, most maintenance of works was undertaken by the researchers and not council (Table 3). This practice has changed since early 2014, and YRC has signed an agreement with the researchers to maintain the SCMs. As part of the agreement, the research project (through grants) will contribute funds towards development of a systematic maintenance program, reflecting that proper and regular maintenance of SCMs is crucial to their long-term performance. One strategy to guarantee the ongoing maintenance of SCMs could be to include (and set aside for later use) the cost of maintenance as part of the total project cost (Gardiner and Hardy 2005).

Table 3. Stormwater control measures (SCMs) constructed during the experiment by Yarra Ranges Council (YRC). YRC oversaw the construction of all works with support from the consultant project engineer.

Name of SCM	Description	Design team	Date completed	Comments and lessons learned
Hereford Road	A small flood-retarding basin retrofitted into a vegetated infiltration system of 90 m^2 draining an impervious area of 10,000 m^2. The system overflows to the council stormwater system.	Mainly the researchers and engineering consultants, but with some input from council	Nov 2010	Design of surcharging inlet revised during construction phase after input from maintenance department. Initial maintenance conducted by the researchers, which has mainly involved removing sediment around the inlet. Private property owner adjacent to the system has also helped maintain the system (primarily the removal of gross litter and weeds).
Pembroke	A large harvesting system (~1 ML of storage) draining an impervious area of 23,000 m^2 (2 large schools and associated roads, plus an athletics track) used for irrigation of playing fields, overflowing to a series of vegetated infiltration systems (500 m^2). Tanks switch to slowly leaking into a large swale in 5 wettest months when irrigation demand ceases.	Conceptual design by the researchers and detailed design by engineering consultants	Early 2014	Maintenance of the system has been adopted by council's Parks and Gardens department, who see the system as a major asset for the irrigation of their playing fields.
Private property system A	Series of biofiltration systems totaling 135 m^2, draining 8602 m^2 of impervious area (40% road [740 m^2 draining to upstream nature strip biofiltration systems], 60% private property [6 of 24 properties retaining water through harvesting systems: 55 kL storage]).	Conceptual design by the researchers and detailed design by engineering consultants	Jan 2012	Works were completed in a timely manner.
Private property system B	A vegetated infiltration basin of 50 m^2 draining an impervious area of 2810 m^2 (73% road, 27% private properties, 2 of 4 with on-property harvesting).	Conceptual design by the researchers and detailed design by engineering consultants	Jan 2012	Works were completed in a timely manner. Groundwater inputs to the basin have reduced system performance.
Private property system C	Series of infiltration trenches totaling 122 m^2 combined with a swale (20 m^2). The systems drain an impervious area of 8706 m^2 (31% road, 69% private properties, 4 of 24 with on-property harvesting). Upstream SCMs treat a total of 4083 m^2 (combination of both road and private property).	Conceptual design by the researchers and detailed design by engineering consultants	Jan 2012	Works were completed in a timely manner.

(*Continues*)

Table 3 (*Continued*)

Name of SCM	Description	Design team	Date completed	Comments and lessons learned
Private property system D	Series of biofiltration systems totaling 123 m^2, draining 6786 m^2 of impervious area (18% road, 82% private properties, 1 of 23 with on-property harvesting).	Conceptual and detailed design by engineering consultants	Apr 2013	Livestock on the property have caused some impact to the systems.
Stringybark Boulevard South	A vegetated infiltration system (with no underdrain) of 20 m^2draining an impervious area of 4468 m^2 (25% road, 75% private properties, 3 of 11 with on-property harvesting), overflowing to a 47-m linear bioswale. The bioswale overflows to riparian vegetation. During large rainfall events, some overflow from the vegetated infiltration system flows to riparian vegetation.	Conceptual design by the researchers and detailed design by engineering consultants	Apr 2011	Prior to construction, council identified that a section of proposed excavation could impact the dripline of nearby trees. Because of this, council directed the construction contractors not to dig this section of soil. This meant that ~⅓ of the vegetated infiltration system's underlying soils were native (and not 'engineered'). The researchers undertook initial maintenance of the systems, which mainly involved the removal of sediment.
Mikado Road	A vegetated infiltration system of 30 m^2 draining an impervious area of 1000 m^2. The system overflows to an existing roadside swale.	Designed and managed independently of experiment through another council project (Sustainable Road Design)	June 2013	Design of retarding walls (which provide extended detention) revised after input from council.
Petrol station	A stormwater harvesting system (130 kL of storage) collecting impervious runoff from a 3000 m^2 commercial property to service a car-wash, with a dedicated filtered leak to provide baseflow. Leak water and untreated overflows are directed to the council stormwater system.	Conceptual and detailed design by the researchers, Council engineers, and engineering consultants	Sept 2013	To reduce costs, the engineering department purchased some of the infrastructure for this system independent of the construction contractor.

Newton cluster	A collection of 8 dispersed roadside vegetated infiltration systems draining an impervious area of 1,000 m^2. The small systems (mean size 6 m^2) are situated between road and footpath, and receive only road runoff.	Conceptual design by the researchers and detailed design by engineering consultants	Nov 2012	The experience of completing these works provided the proof-of-concept to undertake similar works (see row below) in much reduced construction times.
Many roadside vegetated infiltration systems (along Fernhill Road, Stringybark Boulevard, and elsewhere)	A collection of 29 dispersed roadside vegetation infiltration systems draining an impervious area of 10,400 m^2. These systems are the same as those built in the Newton cluster (described above). Mean size of systems = 7 m^2.	Conceptual design by engineering consultants. No detailed design required; conceptual design used directly by construction contractors	Nov 2013	These works were completed in short time frames by passing a simple conceptual design directly to a preferred construction contractor.
Fernhill Road (low-flow filter)	A proprietary water-quality treatment device (similar to a gross pollutant trap) draining an impervious area of 7850 m^2. The device treats low flows only; high flows bypass the device.	Conceptual design by engineering consultants and device proprietor	Nov 2013	Works were completed quickly. Initial concerns over the maintenance of the device were eased by involving the maintenance department in the early stages of the project.
Industrial estate detention tanks	A collection of 8 dispersed detention-only rainwater tanks draining an impervious area of 6141 m^2. Each tank drains the roof of a commercial property and features a dedicated filtered leak to provide baseflow (directed to the council stormwater system).	Conceptual design by engineering consultants; used directly by construction contractors	Apr 2013	Property owners were generally willing to allow Council to build the tanks, although one rejected the offer and another required a financial incentive. Council have contracted the installing plumber to inspect and maintain the tanks for the first 12 mo.
Junction Road (rain garden)	A vegetated infiltration system of 40 m^2 draining an impervious area of 19,000 m^2. There are 2 council-built SCMs upstream (Hereford Road and Petrol station; discussed above) and 7 private properties with on-property harvesting).	Conceptual and detailed design by engineering consultants	Aug 2013	Most of the vegetation died soon after construction. This occurred because the small plants could not handle the large inflows (the system is small relative to its catchment area). System water level has been temporarily lowered to allow re-establishment of plants.

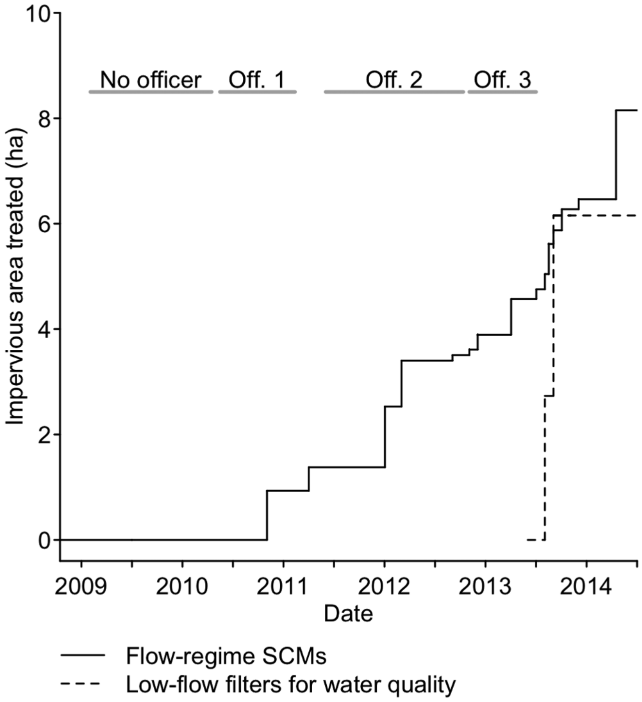

Figure 1. Impervious area treated for flow restoration (or low-impact drainage management) and area treated only for low-flow water-quality improvement over time. Horizontal bars depict important events in the research collaboration: start of experiment (No officer), researcher is embedded in the engineering department (Off. 1), researcher is replaced by new staff member (Off. 2), and consultant project engineer is engaged (Off. 3). SCM = stormwater control measure.

This experiment and partnership, with researchers, was an effective avenue for increasing the willingness and capacity of YRC to trial new approaches to urban stormwater management. The experiment led to a long-term commitment essential for the development of trust and a culture of learning among the collaborators in the project.

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