Can we save Sydney's streams? Meeting stream health objectives in two typical urban catchments on Sydney's north shore

A.A. McAuley*, D.S. Knights*, S.J. Findlay** and O.J. Jonasson**

** Equatica Pty Ltd, Suite 6, Level 1, 2-12 Foveaux Street Surry Hills NSW 2012 (E-mail: alexa@equatica.com.au; david@equatica.com.au)*
*** Ku-ring-gai Council, 818 Pacific Highway, Gordon NSW 2072 (E-mail: sfindlay@kmc.nsw.gov.au; jjonasson@kmc.nsw.gov.au)*

ABSTRACT
Gordon and Lovers Jump Creeks are located in Ku-ring-gai LGA in Sydney. While the upper catchment of each creek is urbanised, the lower catchments are remnant bushland and the creeks retain significant natural value. This paper describes the development of a catchment management plan for each of the creeks, with an over-arching objective to restore and protect stream health. The strategy considered the potential actions which the local Council could take to improve stream health, including construction of stormwater treatment and harvesting systems within the public domain, applying controls to new development, and providing incentives and support for retrofits on private property. The study found that if development patterns continue as per recent years, it will be impossible to meet stream health objectives within 50 years, unless both development controls and residential retrofits form a significant element of the overall strategy for each catchment. A key implication, if stream health is to be preserved in urban areas, is the need to focus on effective planning controls and programmes for widespread lot-scale WSUD adoption.

KEYWORDS
Catchment management, stream health, frequent flows, urban streams

INTRODUCTION

Gordon and Lovers Jump Creeks are located in the Ku-ring-gai local government area (LGA) in northern Sydney. Both creeks include significant reaches retained in their natural form, with most development and channelisation confined to the upper reaches. The lower reaches of each creek are protected in National Parks. Both streams have significant natural value, including aquatic habitat, riparian vegetation and natural amenity. They are typical of the streams in Sydney's upper north shore.

The local community places a high value on Ku-ring-gai's natural environment (Ku-ring-gai Council, 2008a) and one of the key themes in Ku-ring-gai Council's "Sustainability Vision Report" (*ibid*) is protecting the LGA's bushland and open space. The "Community Strategic Plan (Ku-ring-gai Council 2009) identifies amongst its 20-year targets that "15% of Ku-ring-gai waterways demonstrate an improved riparian condition". Council has identified strong drivers and made a firm commitment to sustainable water management, including the protection of natural waterways.

During the 1990s, Ku-ring-gai Council prepared stormwater management plans for each of its three major catchments. The focus of these plans was water quality (Ku-ring-gai Council, 2008b). During the early 2000s, Council prepared a new set of stormwater management plans, which included both stormwater quantity and quality (*ibid*). However despite the long-term effort towards stormwater management, water quality and stream health indicators have remained poor (Wright *et* *al* 2007, Wright 2011). Regular macroinvertebrate surveys were conducted by Council between 1998 and 2004. SIGNAL2 scores (an indicator of the proportion of macroinvertebrates tolerant to disturbance) showed no improvement over this time (Ku-ring-gai Council 2004). Various physical water quality parameters display a similar picture (Equatica 2011).

Since the 1990s, catchment management has evolved from its earlier focus on stormwater management to a broader focus on integrated water cycle management. Recent research (e.g. Walsh *et al* 2005a, Walsh *et al* 2005b, Ladson *et al* 2006, Fletcher *et al* 2007, Walsh *et al* 2009, Walsh *et al* 2010) has helped to define the relationship between urbanisation and stream health. This research has shown that urban streams are strongly affected by changes to hydrology which occur when impervious areas are directly connected to the stream. Runoff becomes 'flashy', with a quick response to rainfall, increased peak flows and increased total surface runoff. This affects stream morphology, as well as impacting on physio-chemical and biological processes. Streams are frequently exposed to poor quality surface runoff, with high pollutant concentrations. Therefore it has been suggested that the key to restoring urban stream health is to restore catchment hydrology.

Within the context of this research, Ku-ring-gai Council saw a need to revisit its catchment management plans with renewed focus on stream health. A "Sustainable Water Management Feasibility Study" (Equatica 2011) has been prepared for Gordon Creek and Lovers Jump Creek. The objectives of the project were to:

- Set appropriate stream health objectives for the creeks
- Determine if it would be feasible to meet the objectives, and how this could be achieved
- Develop a strategy for each catchment – particularly focused on the actions which Council could take to improve stream health outcomes

METHODS

This study used the principles developed by Walsh *et al* (2010) to set stream health objectives. Walsh *et al* (2010) developed four stream health indicators, which are based on:

- The frequency of surface flows to the stream (days per year)
- The volume of subsurface flows (base flows)
- The median concentrations of TSS, TP and TN in runoff flowing to the stream
- The total volume of water flowing to the stream

The first stage of the investigations involved the definition of pre-development conditions within the streams. Ku-ring-gai Council has undertaken stream flow monitoring in Treefern Gully, which is located approximately 5 km from Lovers Jump Creek and 7 km from Gordon Creek. Treefern Gully has a low proportion of developed area within its catchment; Jonasson and Davies (2009) found that it was 8.8% impervious, with a connected imperviousness of 3.6%. However, none of the impervious areas are directly connected to the stream by pipes, with stormwater travelling overland through vegetated areas for a minimum distance of 400 m before reaching the creek. Chemical analysis of Treefern Gully confirms that the water is similar to that found in undeveloped catchments (Wright et al 2011) and aquatic macroinvertebrate sampling done by Ku-ring-gai Council in 1998 returned a SIGNAL2 score of 4.93, which is close to the average of 5.1 for reference streams in Wright (2011). Therefore Treefern Gully was used as a reference catchment to set pre-development pervious area parameters in MUSIC. A MUSIC model was set up for Treefern Gully catchment, using the rainfall data from the monitoring station. The pervious area soil parameters were calibrated to achieve a reasonable representation of base flows, storm flows and total runoff volumes in the stream. These soil parameters were then used in the Gordon and Lovers Jump creek models to define the pre-development conditions, as well as in modelling post-development pervious areas.

Post-development conditions were defined based on existing conditions in each catchment. Gordon Creek includes 331 ha urban area, which is 54% impervious. Lovers Jump Creek includes 490 ha urban area, which is 45% impervious.

MUSIC (version 4) was used to analyse pre-and post development catchment conditions, as well as a range of potential catchment management options. The models were run for a period of ten years, using a six-minute time step, and the following methodology was employed to estimate each of the stream health indicators:

- The mean annual runoff volume was estimated directly from MUSIC.
- Where a treatment system included infiltration, the infiltration volume was noted separately.
- A post-processing tool was set up to estimate the mean annual number of surface runoff days, by counting the number of days with a positive value for surface runoff.
- Median pollutant concentrations were also estimated using a post-processing tool. Daily pollutant concentrations were extracted for each day where the post-development scenario produced surface runoff.

One of our key assumptions in employing this methodology was to define "surface runoff" from a stormwater treatment system as including filtered flows and overflows but excluding infiltration (i.e. infiltration from the treatment system into the surrounding soils). In most cases in urban areas, the outlet pipe for treated flows would be designed to discharge into a stormwater drainage system, directly connected to the stream. In the case of bioretention systems, which were the principal treatment option tested for this project, the retention time in the system is relatively short, and therefore flows reach the stream relatively quickly in response to rainfall, behaving more like surface runoff. A second key assumption was the way in which pollutant concentrations were assigned to all days which would have produced surface runoff in the post-development scenario. Using standard MUSIC treatment system parameters, the background concentrations for bioretention systems were higher than the pre-development event mean concentrations. Therefore the only way to meet the pollutant concentration targets was to eliminate flows altogether. If there was no surface runoff on the 50th percentile day, the median pollutant concentration target was assumed to be met. This meant that the pollutant concentration targets essentially collapsed to the same target as the surface runoff days. For this reason, the focus in our results is on the volumetric targets and the number of surface runoff days.

A water management strategy was developed for each catchment in a collaborative process between Equatica and Ku-ring-gai Council. GIS analysis and field visits were used to identify potential sites within the public domain where new water management systems could be employed. Potential options were discussed at workshops, including options for the private domain. The strategy considered the potential for the following elements to contribute:

- Stormwater treatment in public open space (e.g. parks and reserves)
- Stormwater harvesting and reuse in the public domain (e.g. parks and reserves)
- Stormwater treatment within streetscapes
- Planning controls on new development, including rainwater tanks and bioretention systems
- Retrofits on private property (undertaken independently of redevelopment) including rainwater tanks, formal and informal rain gardens

Some analysis was done in each catchment to understand the current rate of redevelopment based on recent development applications (DAs). Council's DA database was interrogated to extract those DAs located within each catchment for the last five and a half years. A summary of this analysis is shown in Table 1, which shows that over the next 50 years, approximately 75 ha (23%) of Gordon Creek and 84 ha (17%) of Lovers Jump Creek will be redeveloped. A key assumption in our analysis is that future development continues to follow the same pattern as recent development. Equatica (2011) found that development rates are currently slightly higher in Ku-ring-gai than in Sydney as a whole.

Table 1. Residential re-development within each catchment

Catchment	Gordon Creek	Lovers Jump Creek
Total urbanised catchment area	331	490
Total number of residential lots	2160	2796
Number of DAs over last 5.5 years	342	554
DAs involving new buildings	76	82
Rate of redevelopment	0.6% of lots per year	0.5% of lots per year
Areal rate of redevelopment	1.5 ha per year	1.7 ha per year
Area redeveloped over 50 years (% of catchment)	75 ha (23%)	84 ha (17%)

RESULTS AND DISCUSSION

Key results for the pre- and post-development scenarios are shown in Table 2..It was clear from these initial results that stormwater harvesting and reuse and/or infiltration would need to form a key role in the water management strategy for each catchment. The post-development scenario produced a large volume of excess surface runoff, a significant deficit in evapotranspiration and a smaller deficit in baseflow. It would be difficult to increase evapotranspiration significantly within the urban area, and therefore stormwater flows would need to be reduced via other methods. This is consistent with findings in other similar Australian catchment studies, including Fletcher *et al* (2007) and McAuley *et al* (2010).

Table 2. Pre- and post-development catchment modelling results

Scenario:	Pre-development (1 ha)	Post-development (1 ha)
Rainfall (ML/year)	12.0	12.0
Evapotranspiration (ML/yr)	9.0	5.4
Surface runoff (ML/yr)	1.9	6.0
Baseflow (ML/yr)	1.2	0.7
Surface runoff days (No/yr)	6.7	89
Median [TSS] (mg/L)	7.4	213
Median [TP] (mg/L)	0.05	0.4
Median [TN] (mg/L)	0.6	3.3

As the starting point for developing catchment management options, a range of bioretention system configurations were tested in MUSIC. Each bioretention system included 0.6 m filter media and 0.2 m extended detention, plus a variable depth of saturated zone below the filter media. Two different infiltration rates were tested as part of each stormwater treatment option. Information on the local soil landscapes indicated that the soils within the urban area generally ranged from medium clays to coarse sandy clay loams and coarse clayey sands, therefore infiltration rates of 3.6 and 36 mm/hr were tested in the model. The infiltration rate is a key point of uncertainty, and should ideally be tested on site as part of the design for each proposed treatment system; however for this study, the two infiltration rates provided a reasonable estimate of the range of possible results.

Results for the range of tested treatment system configurations are shown in Figure 1. Note that infiltration flows would not necessarily be converted to baseflow, however without accounting for infiltration, the MUSIC results show a constant baseflow volume for all of the various post-development (with treatment) scenarios. Therefore infiltration results are presented as an indication of the potential increase in baseflow.

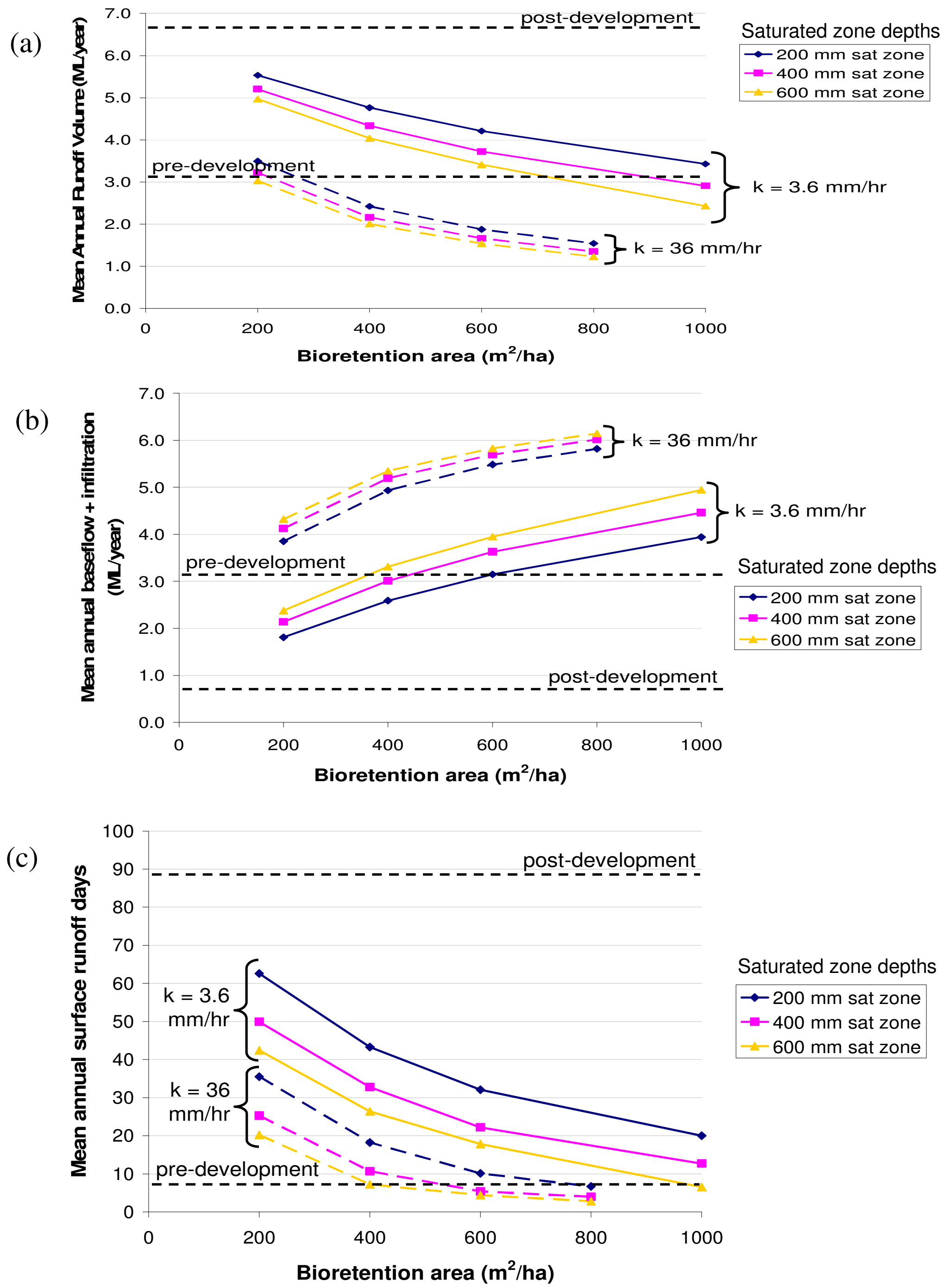

Figure 1. Results for various bioretention system configurations (a) Mean annual runoff volume; (b) Mean annual baseflow; (c) Mean annual surface runoff days. Note that k = infiltration rate

The results show that when infiltration is 36 mm/hr, the mean annual runoff volume and baseflow targets can be met relatively easily (noting that infiltration flows would not necessarily be converted to baseflow). The surface runoff days target can also be met – for example with a treatment system of at least 400 m^2/ha and a 600 mm saturated zone. However if the infiltration rate is as low as 3.6 mm/hr, then it becomes very difficult to meet the targets, particularly the number of surface runoff days. Treatment systems of 1,000 m^2/ha (10% of the catchment area) are not likely to be feasible in many situations. In Sydney this would be 5-6 times larger than a treatment system to meet current best practice objectives. Even small treatment systems are difficult to accommodate in a retrofit situation, and not all sites will be suitable to allow infiltration.

A strategy which relies on infiltration requires a fine-grained understanding of soil and bedrock characteristics – information which is not typically available at the planning stage. Therefore this study assumed that this limitation could be overcome at most sites (an optimistic assumption), and investigated the potential opportunities to accommodate stormwater treatment within each catchment, with an aim to meet the stream health targets over a 50 year time frame. This timeframe was selected arbitrarily, with a view to defining what Council could achieve in the catchments within a reasonably long-term planning timeframe.

A common approach for retrofits is to find opportunities to build treatment systems within parks and reserves. This project looked at these public domain opportunities across each catchment, and found that the total area of parks and reserves (excluding bushland areas) represented only 5% of the Lovers Jump Creek catchment and 3% of the Gordon Creek catchment. Accommodating existing facilities within public open space, it was estimated that it would only be possible to treat a further 3% of each catchment within public parks and reserves.

Opportunities for stormwater harvesting and reuse were also investigated for irrigated parks and reserves within each catchment (as these represent the key water demands within Council's jurisdiction). In each case, stormwater harvesting for irrigation of parks could only treat a small portion of each catchment, and could only make a small reduction in the surface runoff volume and number of surface runoff days. For example in Lovers Jump Creek, which includes two irrigated sports fields, stormwater harvesting from a 43 ha subcatchment could reduce the mean annual runoff volume from 6.0 to 5.8 ML/ha/year and the surface runoff days from 89 to 82 days per year. In Gordon Creek, an existing stormwater harvesting scheme could be modified with a stormwater treatment and infiltration system to treat 0.3% of the catchment to meet the flow targets. Note that rainwater harvesting was included in consideration of the private domain options discussed below.

Ku-ring-gai Council has incorporated some treatment systems into streetscapes in the LGA, but Council has found streetscape treatment systems difficult to accommodate between services, parking, existing vegetation and other constraints. Even if the streets could be retrofit so that the road pavement and footpath areas were treated within the streetscape, this would only account for a further 16% of the Lovers Jump Creek catchment and 22% of the Gordon Creek catchment. Only approximately 50% of the streets have a stormwater drainage system and after accounting for services and other constraints, it is considered optimistic to aim for up to 50% of the streets to be treated in each catchment.

Redevelopment presents a key opportunity for retrofit of stormwater management measures. Each of the catchments includes a small "town centre" area which has been earmarked for redevelopment. Opportunities for stormwater treatment were investigated in each of the town centres, but the town centres only represent 1% of each catchment, and the area which could potentially be treated is even less than this. Each town centre is located on the ridgeline at the top of the catchment, which makes it very difficult for the town centres to play a larger role in stormwater management.

Beyond the town centres, most of each catchment is residential. Typical residential scenarios were modelled in MUSIC, with water management controls including a range of rainwater tanks and infiltration systems. These results showed that with appropriate controls in place, it would theoretically be feasible for most residential redevelopment to meet the stream health targets, as long as soil conditions are relatively favourable for infiltration. It would be important to include both rainwater tanks for roof runoff and infiltration systems for runoff from other surfaces.

A summary of all the potential treatment opportunities identified in this study is shown in Table 3. This shows that within each catchment, there will still be a significant catchment area untreated after 50 years, representing more than half of each catchment. Most of this is established residential area. This result points to a clear role for residential retrofits to reduce stormwater runoff and improve stream health in each catchment.

Table 3. Opportunities for stormwater treatment within each catchment, over 50 years

Stormwater treatment opportunities	**Gordon Creek**		**Lovers Jump Creek**	
	Proportion of catchment area	**Potential catchment area treated**	**Proportion of catchment area**	**Potential catchment area treated**
Public parks and reserves:	3%		5%	
Stormwater treatment		6%		8%
Stormwater harvesting		0.3%		-
Streetscapes	22%	11%	16%	8%
Redevelopment				
Town centres	1%	0.2%	1%	0.7%
Residential	23%	23%	17%	17%
Remaining residential area	45%		51%	
Other remaining areas (schools, aged care, community, railway lands)	6%	1%	10%	2%
Total	**100%**	**41.5%**	**100%**	**35.7%**

Effectively implementing stormwater treatment in residential redevelopment and residential retrofits is a challenging proposition. Development controls would need careful consideration to ensure that controls are realistic for developers to meet (including single residential re-builds), and for Council to support through the development process. McManus (2009) observes that in Sydney councils, current WSUD development controls are often not supported by appropriate guidance for developers, nor do these councils have strong skills to assess WSUD DAs. Therefore development controls are not always successfully implemented. To date this has been a key barrier limiting the potential for the redevelopment process to achieve improved catchment management outcomes, and this would need to be overcome in Ku-ring-gai for this approach to be successful. Residential retrofits would also need to be supported by appropriate technical guidance and advice from Council; however perhaps an even more significant challenge is to design an effective education campaign and incentive scheme to encourage WSUD adoption.

CONCLUSIONS

This study developed objectives designed to protect stream health in two typical catchments in Sydney's Ku-ring-gai local government area. Analysis of potential stormwater treatment options found that if development patterns continue as per recent years, it will be impossible to meet the stream health objectives within 50 years, unless both robust development controls and widespread private property retrofits form a significant element of the overall strategy for each catchment.

A key implication, if stream health is to be restored downstream of urban areas such as Sydney's North Shore, is the need to focus on low-density residential redevelopment and retrofits as part of an effective catchment management strategy. This broadens and shifts the emphasis of WSUD from design of physical treatment systems to design of effective programmes for widespread lot-scale WSUD adoption. Suitable targets should be incorporated into local environment plans, and achievable, meaningful controls within development control plans. These need to be supported through the development process by suitable guidance, advice and assessment. Incentives also need to be provided for private landowners to adopt WSUD independently of the redevelopment process, including economic, educational and other instruments.

From a technical perspective, there is a need for suitable stormwater treatment options which are simple to design, construct and maintain, and can be easily implemented by small developers and individual households. Furthermore, infiltration capacity was found to be a key limiting factor in meeting stream health targets in the Ku-ring-gai context. Therefore for the proposed strategy to be successful, a fine-grained understanding of infiltration capacity will be important, as well as new design templates for stormwater treatment systems which encourage infiltration.

REFERENCES

Equatica (2011) Sustainable Water Management Feasibility Study and Concept Design: Gordon Creek and Lovers Jump Creek (Draft report). Prepared for Ku-ring-gai Council.

Fletcher, T.D., Mitchell, V.G., Deletic, A., Ladson, A.R. and Seven, A. (2007) "Is stormwater harvesting beneficial to urban waterway environmental flows?" *Water Science and Technology* 55:4 (265-272).

Jonasson, J and Davies, P (2009) "Stormwater management – runoff generation in the Sydney region and impact on stormwater harvesting design" The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth Western Australia.

Ku-ring-gai Conucil (2004) Comprehensive State of the Environment Report.

Ku-ring-gai Council (2008a) Sustainability Vision Summary Report 2008-2033.

Ku-ring-gai Council (2008b) Integrated Water Cycle Management Strategy.

Ku-ring-gai Council (2009) Community Strategic Plan 2030.

Ladson, A.R., Walsh, C.J. and Fletcher, T.D. (2006) "Improving stream health in urban areas by reducing runoff frequency from impervious surfaces" *Australian Journal of Water Resources* 10:1 (23-33).

McAuley, A., Gillam, P., Knights, D, Blackham, D. and RossRakesh, S. (2010) "Stormwater harvesting to meet flow management objectives" Stormwater Industry Association National Conference, Sydney.

McManus, R (2009) "A framework for assessing the organisational capacity of councils for WSUD" Stormwater Industry Association of NSW and Victoria Joint Annual Conference, Albury.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M. and Morgan, R.P. (2005a) "The urban stream syndrome: current knowledge and the search for a cure" *Journal of the North American Benthological Society* 24 (706–723).

Walsh, C.J., Fletcher, T.D. and Ladson, A.R. (2005b) "Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream" *Journal of the North American Benthological Society* 24 (690–705).

Walsh, C.J, Fletcher, T.D. and Ladson, A.R. (2009) "Retention Capacity: A Metric to Link Stream Ecology and Storm-Water Management" *Journal of Hydrologic Engineering* 14:4 (399-406).

Walsh, C.J., Fletcher, T.D., Hatt, B.E. and Burns, M. (2010) "New generation stormwater management objectives for stream protection: stormwater as an environmental flow problem" Stormwater Industry Association National Conference, Sydney.

Wright, I., Davies, P., Wilks, D., Findlay, S., and M. P Taylor (2007) Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams Pages 467 - 472 in Wilson, A. L., Dehaan, R. L., Watts, R. J., Page, K. J., Bowmer, K. H., and A. Curtis, editors. Proceedings from the 5th Australian stream management conference, Albury, NSW 21—25 May 2007

Wright, I.A. Davies, P.J. Findlay, S.J. Jonasson, O.J. (2011) A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters. *Marine and Freshwater Research.* Published online October 2011

Wright, I, A. (2011) Assessment of Aquatic Macroinvertebrates and Aquatic Ecosystem Health in Ku-ring-gai Council waterways June 2011. Report prepared for Ku-ring-gai Council.