Lessons learnt from Lalor Creek restoration works in Blacktown City Council

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Abstract

Lack of adequate monitoring after completion of urban stream restoration works is a major failing of urban stream management and is a significant barrier to refining the process of setting and achieving objectives for urban stream restoration projects and learning from project outcomes (failures and successes). Blacktown City Council has recognised the need to pursue best practice management of urban streams, including monitoring of stream restoration projects. The restoration of Lalor Creek provided a case study of a monitoring strategy aimed at determining the effectiveness of restoration activities against project objectives, which were: 1) ameliorate and mitigate against bed and bank erosion; 2) improve water quality; 3) increase flood capacity; and 4) improve biodiversity.

To determine if project objectives were met and assess timelines for detectable improvements, monitoring was done at an un-restored stream reach, a reach restored two years ago, and a reach restored five years ago. The 4 indicators measured includes aquatic macroinvertebrates and benthic diatoms (as indicators of both water quality and biodiversity), riparian vegetation (as an indicator of both biodiversity and bed and bank erosion) and stream channel condition (as an indicator of bed and bank erosion and flood capacity). These results were also compared to macroinvertebrate monitoring completed in 2013 at the same location. The results of the study revealed that the objective of mitigating against bed and bank erosion and flood mitigation was achieved, however biodiversity improvement occurred in the riparian ecosystem only and that there were no improvements in water quality. Aquatic biodiversity and water quality objectives were not achieved as the project did not address urban stormwater flows, and in hindsight were not realistic objectives given the type and scale of the restoration works. Results of this study provide waterway managers with valuable information on the lessons learn by Blacktown City Council on setting realistic and achievable objectives for urban stream restoration projects.

1. INTRODUCTION

It is well known that urban stormwater run-off causes severe impacts to streams. The phrase ‘urban stream syndrome’ (Walsh et al 2005a) was coined to describe the multiple common symptoms occurring in urban streams, including degraded water quality, geomorphology, hydrology and biodiversity. Urban run-off also effects riparian ecosystems by altering riparian soil chemistry such as to promote invasive plant colonisation and ultimately displace native species (Riley and Banks 1996, Grella et al 2014). Impacts to urban stream systems caused by stormwater run-off not only degrade the quality of urban ecosystems but also affect the overall amenity and liveability that these areas offer the human population (Palmer et al 2014).

Over the past few decades, efforts have been made to rehabilitate urban streams and globally a multibillion-dollar industry has emerged (Palmer et al 2005, Kenney et al 2012). A large majority of urban stream restoration projects aim to return the stream to a pre-development condition and improve aquatic biodiversity (as measured by various macroinvertebrate indices) (Shoredits and Clayton 2013, Smith et al 2016). The major shortcoming to this approach is that most urban stream restoration projects are conducted at the reach scale and focus on habitat restoration and channel reconfiguration (Palmer et al 2010), without mitigating landscape scale constraints on achieving restoration success.

In the urban context, the scale of land use change and the associated severity of stream degradation make it unlikely that a return to pre-development condition is achievable (Palmer et al 2014) without catchment scale intervention. Given that urbanisation involves an increase of impervious surfaces, with concomitant alteration of flow and water quality of receiving waterways, effective mitigation of impacts primarily involves disconnection of the stormwater drainage network from urban streams (Walsh et al 2005b, Walsh et al 2004, Violin et al 2011). That is, if we wish for urban streams to perform multiple ecological, social and economic functions, we need to stop using them as drains.

Despite the availability of guidelines to rehabilitate urban streams (e.g. Schueler and Brown 2004, Riley 2016) it seems there is a widespread misconception about how successful an urban stream restoration project can be in terms of resurrecting a pre-development stream condition and increasing aquatic biodiversity. Given that many stream restoration projects have been completed throughout the world, there is very little documentation on the outcomes of such projects, with only a limited subset addressing urban projects. However, what is available overwhelmingly highlights the failures of stream restoration projects to improve biodiversity. For example, Palmer et al (2010) evaluated the ecological outcomes of 78 stream restoration projects undertaken in a mix of urban, farmland and forested streams and found that only two (i.e. < 3%) had significant gains in biodiversity. In recent studies, Cockerill and Anderson (2014) showed no significant ecological outcomes were achieved in a study of four urban stream restoration projects, while Rundus (2017) reported a mixed response from various ecological indicators used to gauge project success.

The lack of information highlighting the results of urban stream restoration projects is owing to several factors, including inadequate planning, lack of funding and poorly designed comparative studies (Kondolf and Micheli 1995). Yet there is a multitude of literature stating that without broad scale disconnection of stream catchments from the urban stormwater system, improvement to stream hydrology, geomorphology and aquatic biodiversity is unlikely (e.g. Palmer et al 2010, Walsh et al 2004, Ladson et al 2006).

So, the question remains, why do urban stream managers continue to undertake reach scale restoration projects with aquatic biodiversity improvement highlighted as a project objective when the proposed project does not address catchment scale disconnection from the urban stormwater system?

Cockerill and Anderson (2014) noted that there is strong evidence that waterway managers do not consult relevant literature and that there is a notable communication disconnect between waterway managers and researchers. This inevitably continues the cycle of projects failing to achieve their proposed objectives, particularly those with objectives to improve aquatic biodiversity (Cockerill and Anderson 2014).

In this study, we evaluate if an 850m reach scale stream restoration project met its objectives of ameliorating and mitigating against bed and bank erosion, improving water quality, increasing flood capacity and improving biodiversity and, whether those objectives were realistic. We set out to measure project success/failure by applying a range of commonly used indicators of stream condition which includes aquatic macroinvertebrates and rapid assessment of stream channel and riparian vegetation.

Outcomes of this research will assist Blacktown City Council's waterway managers in implementing a monitoring program to assess outcomes against objectives and better frame their project objectives based on what is feasible or achievable within that reach based on upstream imperviousness and site constraints..

2. STUDY AREA

The headwaters of Lalor Creek rise in the Hills Shire Council and flow south to the Blacktown Local Government Area (LGA) where the majority of the catchment lies. The Lalor Creek catchment is approximately 730 ha, and the catchment has approximately 37% total impervious cover (Blacktown Council 2017). Catchment land use is mainly residential, whilst there is also a small area of land with commercial uses, most land use intensification occurred in the late 80's and early 90's. The reaches subject to restoration are in the mid to upper catchment and combined are approximately 850 m long (Figure 1). Refer to Figure 4 for a detailed map of the different reach areas.

For this study, three stream reaches were identified and include:

- Reach 1 (upstream of Troubadour Reserve), a stretch of approximately 150 m of unrestored creek with a catchment area of x hectares which is located in the upper most section of the study area and directly upstream of the restored reaches 2 and 3.
- Reach 2 (Troubadour Reserve), directly downstream of Reach 1 with a catchment area of x hectares, where restoration was completed approximately two years prior to the present study and works consisted of bank stabilisation, installation of in-stream bank and flow mitigation structures and replanting of native riparian vegetation across approximately 450 metres of the stream.
- Reach 3 (Pearce Reserve), directly downstream of Reach 2 with a catchment area of x hectares, is approximately 400 metres long and had similar restoration works to Reach 2, but those were implemented approximately five years prior to the present study.

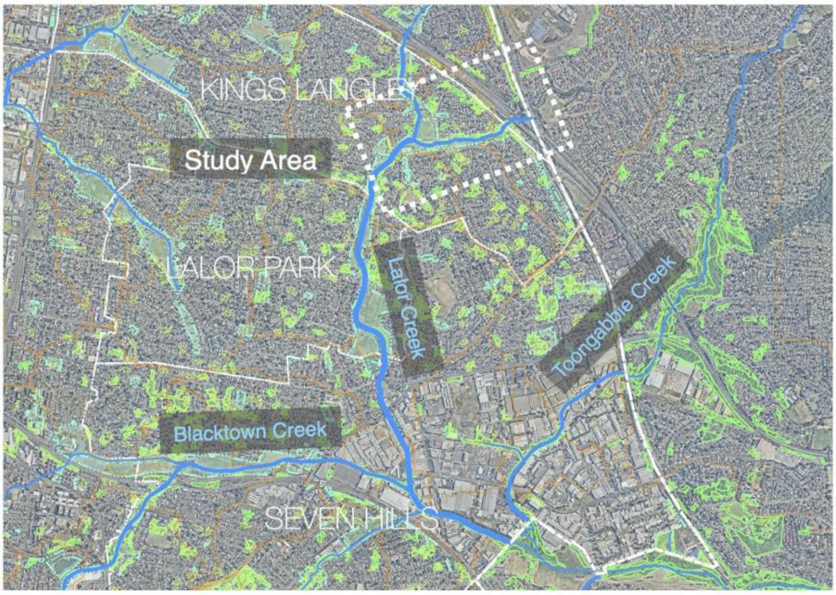

Figure 1: Map of Lalor Creek and indication of the study site.

Restoration of the creek has occurred in two distinct stages across two adjacent reaches. The first stage of restoration (Reach 3) was completed in 2012 and the second stage (Reach 2) was completed in 2015.

These Reaches of Lalor Creek required restoration as the creek bed was heavily incised, banks rapidly eroding and slumping, flood conveyance issues, and riparian vegetation was not providing any real ecological benefit as it was dominated by weeds and less than 10m wide in most areas. The images in figure 2 were taken pre-construction of both Reaches (2 and 3) and represent the degraded nature of the creek bed and banks.

As part of the restoration works, Blacktown Council identified four key objectives, which were:

i) Ameliorate and mitigate against bed and bank erosion;
ii) Increase flood capacity
iii) Improve water quality; and,
iv) Improve biodiversity.

To achieve these objectives the restoration works for both reaches had an approximate cost of $1.3 M and involved:

- Removal of all weeds and juvenile native vegetation while preserving as many mature trees as possible
- Stream realignment
- Reshaping of the banks to increase flood capacity while attempting to maintain a batter ratio of at least 3 to 1 (horizontal to vertical)
- Flatting of the creek bed to 0.5% and installation of drop structures
- Armouring the toe and lower banks with sandstone logs to minimise erosion

- Installation of jute matting and mulch on the mid to upper banks
- Revegetation of bed, banks and adjacent areas using seed collected from the local area, whenever possible.

Figure 2 – Pre-construction photos of Lalor Creek in Reaches 2 and 3.

The images in Figure 3 are a general representation of the post construction works in both Reach 2 and 3.

Figure 3: Images of Reaches 2 and 3 post construction.

Due to site constraints, such as lack of available space with surrounding residential areas, existing services (power poles, Sydney Water sewer/potable pipeline etc.) and mature tree preservation, some sections of the creek banks have very steep banks that consist of stacked sandstone logs acting as a retaining wall. The stacked logs were required to protect services and to ensure the batter did not exceed a 3 to 1 ratio for safety reasons.

3. PROJECT OBJECTIVES

The objectives of this evaluation project were to:

- **M**onitor the current ecological and geomorphic condition of Lalor Creek and compare results across an unrestored reach and the two restored reaches.
- **E**valuate if stream restoration works have met the original project objectives of improving biodiversity, mitigating against creek bed and bank erosion, and to improve water quality.
- **R**eport the results to Council and determine how creek restoration works can be improved for future creek restoration projects.
- **I**mplement improved approaches to creek restoration across the Blacktown Local Government Area (LGA) for all future projects.

This is one of the first times that creek restoration projects have been evaluated post construction within Blacktown City Council in detail.

4. METHOD

To determine if the objectives of the creek restoration works were achieved CTENVIRONMENTAL and Blacktown City Council applied the following methods. Figure 4 below represents where these monitoring activities were undertaken.

Figure 4: Map of post construction monitoring activities in each Reach.

4.1. Creek channel and riparian vegetation

To assess the relative conditions of riparian vegetation and creek channel, the Rapid Riparian Assessment (RRA) developed by Findlay et al (2011) and later refined by Dean and Tippler (2016) was applied. This method combines the assessment of both instream and riparian habitat metrics and was developed in the Sydney region for visual assessment of urban streams. Assessments were undertaken at 100 m intervals, which resulted in a total of 10 assessments being conducted; one (1) in Reach 1, five (5) in Reach 2 and four (4) in Reach 3.

4.2. Aquatic macroinvertebrates

Along each assessment Reach, three (3) quantitative benthic macroinvertebrate samples were collected from random locations. Each sample was collected in a kick net (frame of 30 x 30 cm and 250 µm mesh) from within a 1 m x 1 m area of creek edge substrate that was disturbed for 30 seconds. Net contents were then placed into a sorting tray, and all taxa live-picked from the sample and preserved in ethanol for later identification. Specimens were identified to the taxonomic level of Family, with exception of Chironomidae (non-biting midges) which were identified to subfamily and oligochaetes which were identified to class. Specimens were identified using the identification keys by Hawking and Smith (1997) and Gooderham and Tsyrlin (2002).

Biotic indices of taxon richness and SIGNAL-SF scores were calculated for each sample. Results for each sample were combined to provide an average for each assessment Reach.

4.3. Comparison to previous macroinvertebrates studies

In 2013 Blacktown City Council engaged Sydney Water to conduct water quality monitoring of Lalor Creek post Reach 3 construction and pre Reach 2 construction. Due to budget constraints of post restoration monitoring there are a number of differences between the Sydney Water (pre-construction) and CTENVIRONMENTAL (post-construction) sampling methods, as demonstrated in table 1.

Table 1: Comparing the difference between the macroinvertebrate sampling techniques of pre and post construction studies

Comparison	**Pre-construction 2013**	**Post-construction 2017/2018**
Index applied	AUSRIVAS	SIGNAL SF
Sampling method	10 metre stretch x net width (30cm) = 3m² sample area	1x1m quadrant = 1m² per replicate, three replicates per reach = 3 m² sample area
Location and number of sites	4 locations (1 site in reach 1, 2 in reach 3, and 1 site downstream of reach 3) – missing reach 2 however reach 1 had a very similar condition to reach 2 pre-construction	3 locations (3 sites in each reach)
Seasons collected	Both autumn and spring	Only winter
Number of replicates	3 replicates of the 4 sites 3 times per season = 72	3 replicates per reach. 1 replicate for each site = 9

It should be noted that results from the pre-construction macroinvertebrate monitoring did not provide any real variation between the two seasons and the number of replicates is excessive compared to what was required to provide an accurate indication of waterway health. Research across the Sydney Basin (Tippler et al 2014) has indicated that there is little comparison between results from macroinvertebrate monitoring any time of year. Blacktown City Council has recently modified its water quality monitoring plan to only collect macroinvertebrate samples once a year as the results over a 12 year span indicated no real difference between results between spring and autumn. Although, given the differences in methods, comparisons between the pre and post construction studies should be interpreted cautiously as they only provide a broad indication of change over time.

4.4. Benthic diatoms – surrogate for water quality

Benthic diatoms are a robust indicator of water quality and are less influenced by changes in flow owing to land use intensification than macroinvertebrates (Sonneman et al 2001).

From each assessment reach, one (1) diatom sample was collected from rock substrata, following the methods provided by Chessman et al (no date). This was achieved by scraping organic matter from hard rock substrata from three areas within the lower end of each assessment Reach. Samples were preserved in 100% ethanol and sent for identification and count by a taxonomic specialist. The proportion of diatom taxa was determined for each assessment Reach.

Algal diatoms were analysed with OMNIDIA 7 software to calculate the metrics of relative abundance, diversity and Diatom Trophic Index (DTI) (Lecointe et al 1993 and 2003) which provides an assessment of the tropic status of freshwaters. The higher the DTI, the more eutrophic (i.e. nutrient enriched) is the assessed water body.

5. RESULTS

5.1. Riparian vegetation and creek channel condition

Results of riparian vegetation and creek channel condition assessment using the Rapid Riparian Appraisal shows all assessment sites, with exception of Lalor-31 (Reach 2) and Lalor-28 (Reach 3) were in poor condition (Table 2). Therefore, at the time of assessment, there were no apparent differences in the overall condition of riparian vegetation and channel between assessment Reaches.

This result reflects the width of the riparian buffer along the creek typically being less than 40 m, with surrounding land being a mix of parkland, residential and road. The ongoing presence of weeds contributed to low RRA scores and although the regenerated riparian vegetation community along Reach 3 was re-planted with a mosaic of native canopy species, planting was dense and excluded establishment of midstory and groundcovers which detracted from the vegetation index score (Table 2). However, the vegetation index scores for Reach 2 were higher than those at Reach 1 and 3 which reflects the complexity of plantings along this reach and the presence of a native midstory and well-established ground cover.

Bed and bank stabilisation works along Reaches 2 and 3 were found to have reduced erosion, as indicated by erosion index scores at those Reaches being higher than at the unrestored Reach 1 (Table 2). In addition, in the restored reaches there were less restrictive channel bars deposited owing to sedimentation, indicated by higher deposition index scores (Table 2).

The channel feature index score was considerably higher in the unrestored Reach 1 when compared to Reaches 2 and 3. This is due to the absence of large woody debris and riffle zones and less percentage cover of overhanging vegetation along the restored reaches, which were surrounded by replanted vegetation at immature growth stages (Table 2).

Table 2: Results summary of assessment of riparian vegetation and creek channel condition by application of RRA

Reach	Site	Site Features x/26	Channel Features x/13	Vegetation x/46	Deposition x/3	Erosion x/1	Site Total x/89	Site Condition
1	Lalor-35	5.6	7	-1.5	-2	-6	3.1	**poor**
2	Lalor-30	-12.8	-5	8.1	0	0	-9.7	**poor**
2	Lalor-31	-3.8	1	12	-1	0	8.2	**fair**
2	Lalor-32	-6.2	-3	8.2	1	0	0.0	**poor**
2	Lalor-33	-7.2	-1	9.3	-1	0	0.1	**poor**
2	Lalor-34	-12.4	1	15.5	1	1	6.1	**poor**
3	Lalor-26	-6.6	1	-0.6	-1	1	-6.2	**poor**
3	Lalor-27	-13.4	1	4.8	-1	1	-7.6	**poor**
3	Lalor-28	-8	4	13.6	0	0	9.6	**fair**
3	Lalor-29	-12.8	2	2.5	0	0	-8.3	**poor**

5.2. Aquatic macroinvertebrates and comparison between pre and post construction studies

Mean macroinvertebrate taxon richness from the post construction monitoring was marginally higher at Reach 2 than Reach 1 (where no restoration works were implemented) and lowest at Reach 3, where restoration actions were first implemented, as indicated in figure 5.

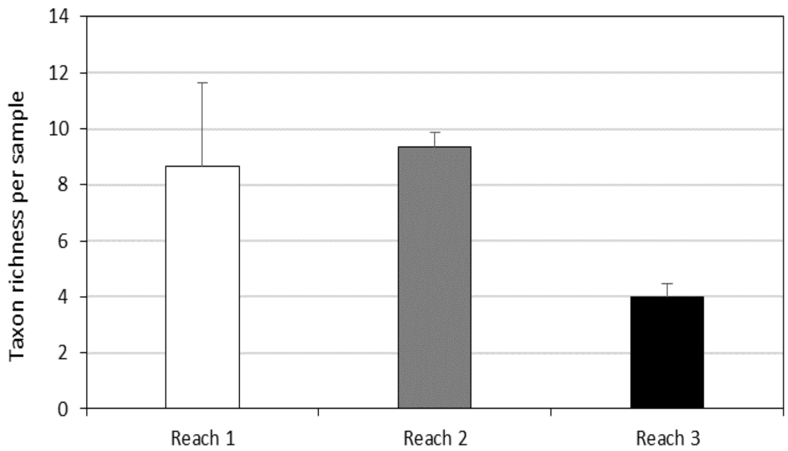

Figure 5: Mean taxon richness of macroinvertebrate communities (+ 1 SD) at Lalor Creek assesssment reaches.

In comparison to the pre-construction aquatic macroinvertebrate monitoring the mean richness and number of taxa does vary. The pre-construction monitoring had an average of between 10 to 13 taxa per reach. However, the post construction monitoring ranged between 4 (Reach 3) to 9 (Reach 2). The large difference in taxa richness/number in reach 3 could be due to the limited number of replicates between the two studies, however it is more likely due to the change in environment from an open water body to a fully shaded environment as the canopy cover has now matured, reducing the grazing feeding group of organisms.

Results of SIGNAL SF calculations from the post construction study show all Reaches fell within quadrant 3 of the SIGNAL-SF vs. taxon richness biplot, indicative of all being subject to harsh physical conditions and/or toxic pollution (Figure 6). On that biplot, Reach 2 was close to the border with quadrant 4, which is associated with particularly harsh conditions owing to human development.

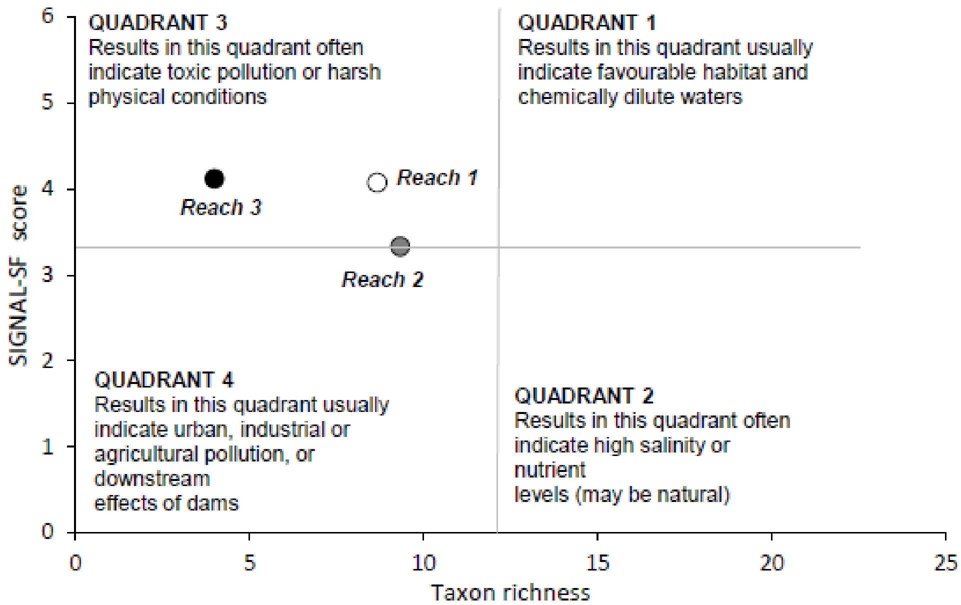

Figure 6: Bi-plot of mean SIGNAL scores and taxon richness for macroinvertebrate communities.

These results when compared to the pre-construction study indicate that although there is a different monitoring technique the SIGNAL scores are quite similar however reach 2 showed a significant drop in score between pre and post construction.

Table 3: Comparison between the pre and post construction studies when analysis the SIGNAL SF scores and average EPT richness of each reach

	Pre-construction study		Post construction		% difference	
	SIGNAL SF score	EPT richness	SIGNAL SF score	EPT richness	SIGNAL SF %	EPT richness %
Reach 1	4.1	0.95	4.1	1.33	0%	40%
Reach 2	4.05	0.95	3.3	1.33	-19%	40%
Reach 3	4.1	1	4.1	0.33	0%	-67%

5.3. Benthic diatoms

Benthic diatom communities in each Reach were found to have only slight variation in taxon richness and Trophic Diatom Index (TDI). Reach 2 had the lowest diatom taxon richness and TDI, however the difference between reaches was marginal (Figure 7) and these results indicate the consistent presence of elevated nutrients and low oxygen, a result which is typical of urbanised streams.

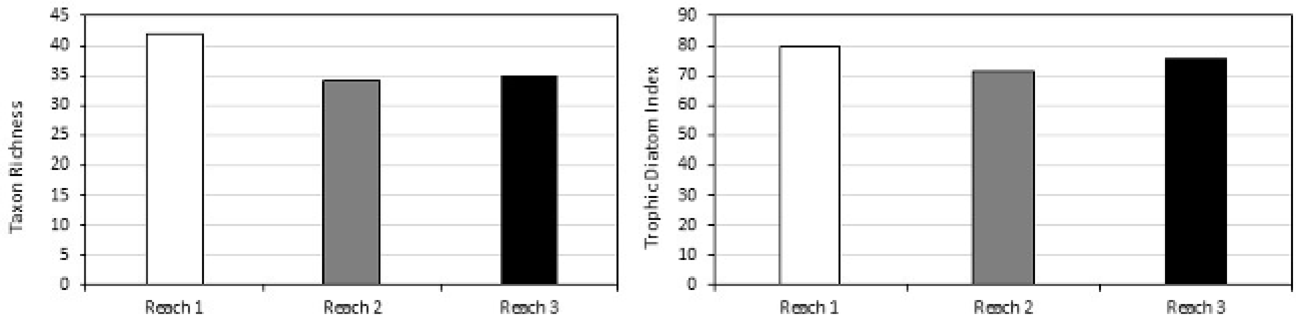

Figure 7: Benthic diatom taxon richness and Trophic Diatom Index for Lalor Creek.

6. DISCUSSION

Three of the four of Councils objectives of the restoration works were met. Mitigation and amelioration against bed and bank erosion was achieved in both restored Reaches. Sandstone block lining of the bed and lower bank appeared to have stabilised the creek and evidence of sediment deposition was observed. In comparison, Reach 1 continued to be deeply incised, with significant bank slumping, undercutting and lack of sedimentation. It is unsurprising that the objective of erosion control was achieved as significant investment and hard engineering was applied to meet this investment and the end result is an approximately 850 m rock armoured channel which has been designed to protect the creek from further erosion.

The objective of flood mitigation was achieved by the addition of stormwater flow capacity by widening the creek bed and bank. This was proven through flood modelling of the modified channel.

The objective of water quality improvement was not achieved. Benthic diatoms are a robust indicator of water quality and are less influenced by changes in flow owing to land use intensification than macroinvertebrates (Sonneman et al 2001). There were only marginal differences in taxon richness and TDI, which indicates water quality in all three Reaches was eutrophic. This is reflective of no change in water quality occurring as water flows from the upstream unrestored Reach through the downstream restored Reaches. This result is also reflected by the SIGNAL index, which indicates the macroinvertebrate communities at all Reaches were affected by toxic pollution and/or harsh physical conditions, with no notable differences between study Reaches. It is unsurprising that the objective of improving water quality was not achieved. It is well documented that to improve water quality of urban waterways effective stormwater management is required (e.g Walsh et 2005b, Bernhardt and Palmer 2007). No broad scale disconnection of Lalor creek from the stormwater system or stormwater quality devices were included in the restoration works and therefore no capacity for significan improvement in the water quality in the creek could be achieved.

Biodiversity improvements were achieved in the riparian vegetation zone where native vegetation was replanted, but not in aquatic habitats (for either macroinvertebrates or diatoms) as initially proposed. Although the initial concept was for improvement to aquatic biodiversity, it is unlikely this objective could be met without effective stormwater management and disconnection of Lalor Creek from the conventional stormwater system (Booth 2005, Walsh et al 2005b). However biodiversity gains in the form of plant richness were made in the riparian vegetation zone which, although was not a major consideration, is an important outcome. Riparian corridors in urban settings are known to provide important habitat for urban biodiversity (Ives et al 2007, Pennington et al 2008) and in our opinion should be the focus of restoration in urban settings as biodiversity outcomes may be more easily 'won' in this environment rather than in the aquatic zone.

The failure of stream restoration projects to meet objectives is not uncommon, particularly when improvement to water quality and aquatic biodiversity are a focus. As highlighted it is unlikely that reach scale restoration to meet the original objectives will achieve these outcomes without broad scale stormwater management and the results of this study reiterates this.

Although most indicators assessed during this project showed marginal changes between assessed reaches, this should not be reason to conclude that future change will not occur. There is likely to be considerable time lag between implementation of restoration works and any detectable ecological response (Harding et al. 1998). With only five years since the first phase of the restoration was implemented it may be too early to determine the full extent of physical and ecological change, as these may take decades to occur (Rutherfurd et al 2004).

It is recommended that objectives for future stream restoration do not include improvement to water quality and aquatic biodiversity if the project is reach based. These objectives should only be included if the planned works incorporate the inclusion of WSUD features in the upper catchment to reduce stormwater quantity and/or improve water quality entering the system.

It is also recommended that monitoring frameworks are embedded into waterway management projects. Careful consideration should be given to electing metrics and indicators that are best suited to assessing the objectives, whilst monitoring should be conducted over time scales that account for lags between works and detectable improvements.

7. RECOMMENDATIONS

Results of this study reiterate that change to water quality and aquatic biodiversity are unlikely outcomes of reach scale creek restoration projects that do not address the effects of stormwater. We advocate that outcomes be focused on asset protection, riparian biodiversity improvement and incorporate social outcomes. We also advocate that stormwater managers looking after creek restoration projects include a long-term monitoring strategy to assess the success of such projects.

Some of the key lessons learnt from this study include:

- **A key component of an adaptive management framework is feedback from adequate monitoring**. Whilst significant funding resources are directed to implementing stream restoration works, frequently no resources are allocated to allow evaluation of whether predetermined objectives used to justify those works were achieved. Monitoring using appropriate indicators and over appropriate timescales should be included in creek restoration projects.
- Overarching objectives used to prioritise and guide urban stream restoration typically include asset protection, ameliorating erosion, flood mitigation, improving water quality, increasing native biodiversity and enhancing aesthetics. **Stream restoration projects are unlikely to meet objectives linked to water quality and aquatic biodiversity improvement if broad scale stormwater management is not applied.**
- Creek restoration projects that use **a mosaic of native plant species in the riparian zone are more likely to achieve greater biodiversity outcomes** in the riparian zone. Reach 3 used considerable more canopy trees than Reach 2 and the RRA reflected the impacts of a

high tree density as it reduced complexity in the under and mid storey through competition of light.

- Given the limitations of reach-scale management, the objectives of **reach-scale restoration projects should focus on what is realistic**, including societal benefits.
- **Consider the addition of structural habitat complexity.** Fauna may be more likely to become established in restored reaches by incorporating wooden logs and debris in the creek channel during the design and construction phase, as woody debris provides ideal habitat for a range of native wildlife. Large wood can also protect banks from erosion, slow flows, encourage sediments to accumulate and aid establishment of in-stream vegetation (Figure 8). This approach has been used by many creek restoration projects and with appropriate planning can be integrated into urban stream restoration projects.

Figure 8: Example of large woody debris integrated into an urban stream restoration project.

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