Water(way) sensitive urban design: addressing the causes of channel degradation through catchment-scale management of water and sediment

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Waterway channel morphology is primarily the product of two main agents: water and sediment. Urbanisation of a catchment alters these agents and drives degradation of channel morphology. The common management response involves expensive, site-scale works (e.g. rock protection) that have been found to not improve ecological condition. An alternative channel restoration approach that will better support aquatic ecosystems is to depart from addressing the symptoms of urbanisation and focus on the catchment-scale causes, but this requires a better understanding of relationships between urbanisation and channel morphology (specifically ecologically important physical attributes). This paper summarises research that demonstrates the influence of conventional urban stormwater drainage systems on the morphology of waterways, and how altered sediment supplies exacerbate this influence, and uses this as a basis to outline two catchment-scale strategies. This approach requires a paradigm shift in both the scale and geomorphic consideration of restoration activities: but one that finds many synergies with current urban initiatives.

Keywords: geomorphology, channel physical condition, physical habitat, stream health, stormwater, bedload sediment

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Introduction

It is well known that urbanisation of a catchment alters urban hydrology, and in turn, the morphology of stream channels (Wolman, 1967). Widening and deepening is most commonly but changes also include increased bank instability, loss of bedload sediments, loss of bars and benches and low supplies of wood (Vietz et al., in-press). These changes in the morphology and physical habitat contribute to the reduced ecological condition of waterways draining urban catchments (Walsh et al., 2005).

Channel intervention works (e.g., rock protection) are the most common reaction to addressing the symptoms of urbanisation: societal concerns are commonly focused on infrastructure protection (due to accelerated channel erosion) and flooding (due to increased streamflow). The resulting stabilized streams, however, exhibit lower habitat values (e.g., Violin et al., 2011) and often require higher capital and maintenance costs (e.g. Grable and Harden, 2006).

The desire to work with geomorphic processes for the purposes of reducing capital works and enhancing ecological condition is increasing (Gurnell et al., 2007). There is a push for urban waterway channels that are complex (e.g. incorporating bars, benches, hydraulic and sediment diversity; Violin et al., 2011; Laub et al., 2012), dynamic (e.g. sediment movement, erosion as an attributes; Gurnell et al., 2007; Vietz et al., 2012), and better able to support aquatic ecosystems, particularly within Australian cities (Australian Government, 2011). To achieve this, however, requires a paradigm shift in management from combatting the symptoms of urbanisation to one that addresses the causes, through a better understanding of how changes to the two central geomorphic agents — water and sediment — drive geomorphic processes and channel degradation.

This paper summarises the results of a recent study on urbanisation and geomorphology by Vietz et al. (in-press) that demonstrates relationships between catchment urbanisation, conventional stormwater drainage systems, altered sediment supplies, and the resultant morphology of waterways. We use these findings as a basis to highlight catchment-scale opportunities that will reduce urban waterway degradation and enable channels that may better support aquatic ecosystems and minimise capital works costs.

Methods

A field and desktop study by Vietz et al. (in-press) assessed 17 sites located within independent catchments on the eastern fringe of Melbourne, Australia. The range of sites represents a gradient of urbanisation from almost completely undeveloped to medium-density residential. The sites were originally chosen because of their relatively intact riparian zones, thus focusing the major anthropogenic disturbance on catchment imperviousness and the role of the stormwater drainage system (Taylor et al., 2004).

For each site Vietz et al. (in-press) used measures of urban density determined by Taylor et al. (2004): total imperviousness (TI) and effective imperviousness (EI, where EI = TI x drainage connection) using GIS layers of impervious surfaces (buildings, roads, carparks) coupled with city and council stormwater drainage plans. Total imperviousness is expressed as the percentage of the watershed area that is impervious, while EI is expressed as the percentage of the watershed that has impervious surfaces directly connected to waterways by pipes. The use of EI explicitly accounts for the effectiveness of the drainage network in delivering stormwater runoff from impervious surfaces through pipes or open drains to discharge directly into the waterway. It recognizes that impervious surfaces not directly connected to the drainage network (e.g., park shelters, informal backyard structures, raingardens) can informally drain to pervious surfaces (e.g., lawns, gardens), thus delaying and mitigating stormwater delivery to the waterway.

Geomorphic variables assessed by Vietz et al. (in-press) were width/depth ratio (W/D), bedload sediment depth, bank instability, presence of bars and benches, and large wood, chosen for their ecological associations. Field assessments and statistical analyses are described in detail in Vietz et al. (in-press).

For this manuscript we have analysed Vietz et al. (in-press) data to develop a generic geomorphic condition score for each site. Each geomorphic attribute is given a total score out of 1 by dividing each value by the maximum value for that attribute. Scores for each attribute are averaged by site to develop an overall geomorphic condition score for each of the 17 sites (where a value of 1 represents the highest value reference condition from the relatively undisturbed sites).

Conventional stormwater drainage is an important variable in channel degradation

Vietz et al. (in-press) demonstrate that the use of EI as a measure of urban density provides consistently better predictions of changes to channel morphology than using TI. The regression relationship (R^2) was consistently better for EI models compared with TI (e.g. channel incision, Figure 1), and EI models were either equally plausible or more plausible than TI models. The lower level of incision for Sassafras Creek, for example (Figure 1, Sa), is better explained when EI is used and the small proportion of drainage connection (8.3%) is taken into account. Where sites are informally drained — road swale drains, roof drainage to gardens — with a small proportion of impervious surfaces connected to the waterway the level of incision is much lower for similar levels of impervious cover. EI is a more appropriate metric for predicting the impacts of urbanisation on stream morphology and highlights drainage connection as an important factor.

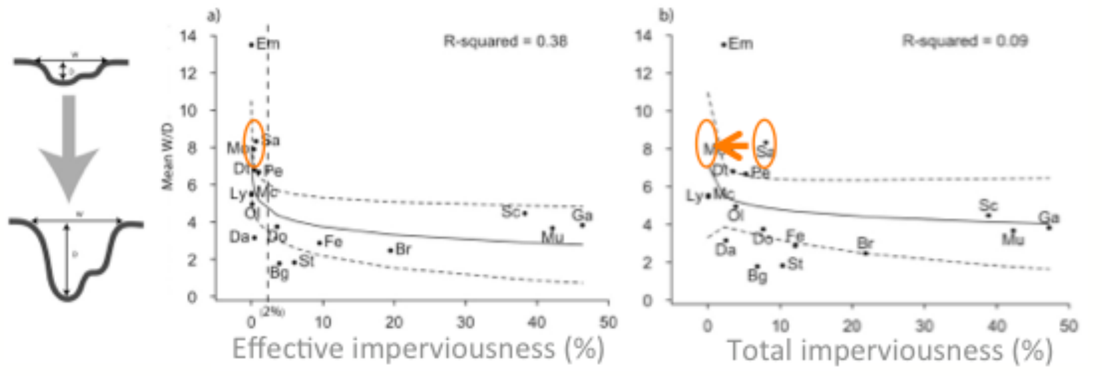

Figure 1. Level of channel incision for all 17 sites plotted against EI and TI (after Vietz et al., in-press). Circled example for Sassafras Creek (Sa) — with low levels of drainage connection — highlights the improved relationships for EI relative to TI.

Geomorphic condition is negatively correlated with EI with changes occurring at low levels of EI: for EI > 3% geomorphic condition is consistently low (Figure 2). Geomorphic condition is a function of increases in channel incision and bank instability and decreases in bedload sediment depth, bars and benches and large wood for increasing EI. Whilst the influence of connections are most evident at low levels of urbanisation, the implications of conventional stormwater drainage systems are relevant to the full range of urban densities.

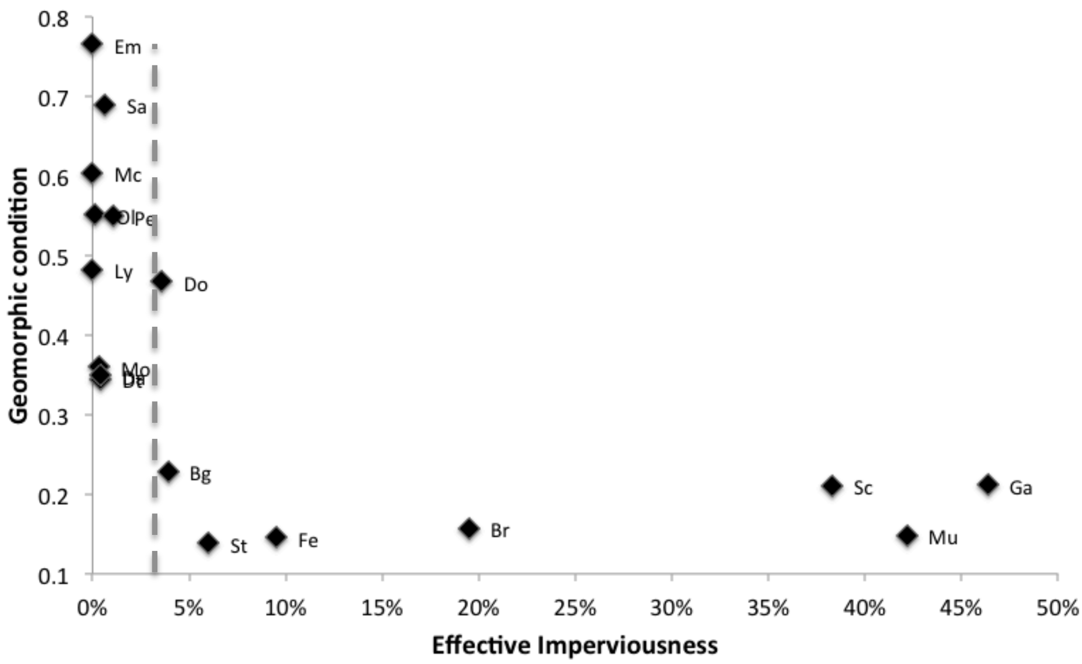

Figure 2. Impacts of urbanisation, and particularly conventionally drained impervious surfaces: geomorphic condition (average score for 5 geomorphic attributes) against EI. The dashed line represents 3% EI.

Reduced sediment supply exacerbates channel degradation

The influence of urbanisation on sediment dynamics is less understood than the influence on hydrology (Douglas, 2011). Coarse-grained sediment supply commonly diminishes with time since urbanisation, following initial increases, however, this depends on catchment characteristics (Vietz et al., in-press).

Due to the supply-limited nature of catchments in Melbourne, Vietz et al. (in-press) found that the erosion of banks that contain coarse-grained sediments (e.g. gravels, cobbles) provides a source of autochthonous (local) sediment. Liberation of these sediments improved geomorphic condition. For example, the high score for Dobsons Creek (Do, Figure 2) could be attributed to it containing a high level of cobble-sized sediments in the bank (46%), making it less incised with greater depths of bedload sediment than Bungalook Creek (Bg, Figure 2), even though they have a similar urban density. But while sediment supply reduces the influence of excess stormwater runoff it does not eliminate it: channels eventually reach a quasi-equilibrium, slowing the rate of erosion and sediment liberation.

Opportunities to manage water and sediment

Drainage connections from impervious surfaces directly to the waterway efficiently translate rainfall into energy that can 'do work' on the channel. A decrease in bedload sediment supply to a channel also increases the energy available (Lane, 1955). Thus urbanisation could be considered the 'double-edged sword' driving geomorphic change leading to channel degradation. Understanding their role highlights opportunities and the multiple activities that can address the causes of urban stream degradation (Figure 3).

The challenge is the extent to which altered flow and sediment can be addressed. The feasibility of addressing waterway channel condition through catchment-scale activities may indeed be a long-term approach (realistically 10–50 years) dependent on synergies with urban planning initiatives that consider alternative water supplies, urban cooling and flood control (Wong et al., 2013). Greenfield sites provide the greatest potential but opportunities for brownfield sites also exist through infrastructure upgrades and redevelopment (Vietz et al., 2012). The need for space to implement stormwater control measures and re-engage floodplains (for both channel migration and flow attenuation) is an important consideration.

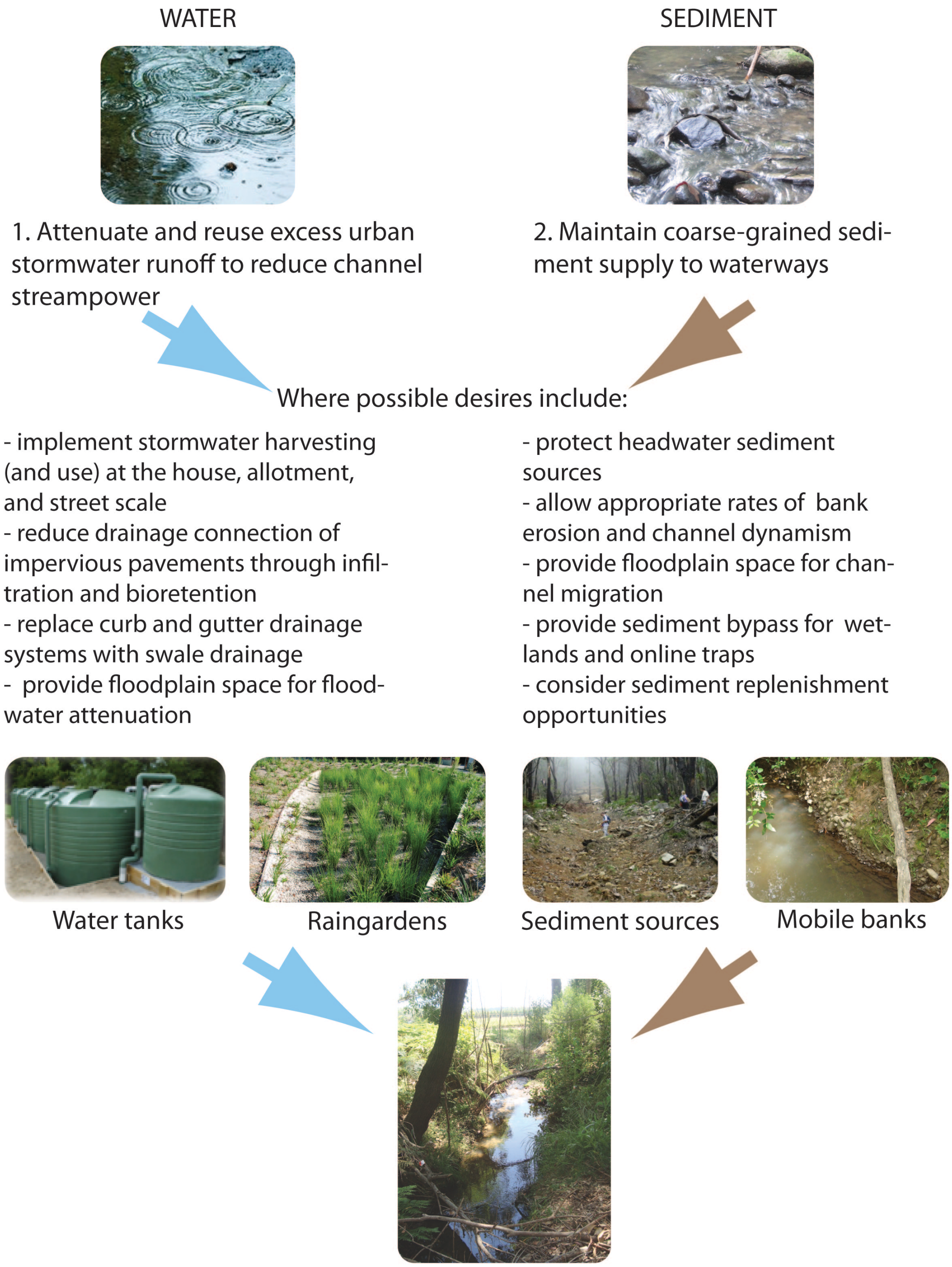

Figure 3. Opportunities and activities that can help to address the two main agents of geomorphic change in urban streams.

Uptake of stormwater management approaches to protect aquatic ecosystems is modest despite the well known ecological benefits (Walsh et al., 2012) and practical solutions (Burns et al., 2012). A shift toward catchment-scale activities requires significant institutional reform (Brown, 2005), for example, through coordination of stormwater and waterway management strategies. These changes will lead to waterway sensitive urban design that better support aquatic ecosystems, as well as reducing capital expenditure on symptomatic channel restoration works.

Conclusions

- Changes to waterway channel morphology by catchment urbanisation are better predicted by EI (effective imperviousness) compared to TI (total imperviousness)
- The stormwater drainage system and reductions in coarse-grained sediment supply play a significant role in waterway channel degradation
- Addressing the geomorphic condition of waterways requires strategies to address stormwater runoff sediment supplies to waterways

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