IS IT JUST THE FLOW: ADDRESSING PHYSICAL HABITAT DEGRADATION IN URBAN STREAM

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Streams draining urban catchment are almost universally ecologically degraded due to the impact of urbanization. Addressing channel form or flow regime remains two key management components for restoration. Both components impact the stream hydraulic habitat, however, very little is known about the relative influence of the channel and flow alteration. This paper present the application of two-dimensional hydraulic model to investigate the relative role between the channel form and flow in impacting the in-stream habitat. The study examined different scenarios of urban and natural flow with urban and natural channel form in the context of benthic habitat disturbance which is important for a variety of ecological and geomorphic processes. The analysis used Shields stress, that quantifies the relative potential for bed mobilization, a phenomenon that is key to physical habitat degradation. Comparing the different scenarios, the results indicate that i) altered flow regime is not the only dominant control on bed disturbance frequency but also influenced by the channel form, ii) addressing just flow regimes is unlikely to restore and/ or protect stream habitat from further adjustment if the channel is fundamentally degraded. This suggest that management strategies to address instream habitat degradation should consider opportunities for self-regeneration of the channel form that mitigate bed mobility or if required rehabilitate the channel.

1 INTRODUCTION

The impact of urban development as a driver of flow regime alterations of streams through excess stormwater runoff input is well recognized [1, 2]. This has led to profound changes in most urban streams particularly physical habitat degradation. [1, 3].

Management actions to restore and/or protect in-channel hydraulic habitat has two key levers which include restoring the hydrology or channel form [4, 5]. However, to protect stream ecosystem and mitigate degradation, it is important to set objectives that are directly linked to the stream functioning [6]. Stream channels are naturally dynamic and complex, and their form and functions are directly related to the hydraulic habitat conditions. Thus, the management actions (i.e. changes made to hydrology and/ or channel form) must retain ecological relevant hydraulic habitat conditions which often has an extensive and significant impact on the aquatic biota and ecosystems. Therefore, in our attempts to address flow and channel form to improve stream health, there is the need to understand how this influence the hydraulic habitat template for ecosystem functioning.

In this regard, this study used two-dimensional (2D) hydraulic modeling to explore the relative role between the channel form and flow in impacting the in-stream habitat. The study examined this in the context of the disturbance to the benthic habitat which is key to the survival and mortality for benthic biota. The analysis used Shields stress that quantified the relative potential for bed mobilization, resulting in patchy areas of scour and sediment deposition which is key to benthic habitat degradation [7] and displacement of biota [8]. This was done by comparing the benthic disturbance potential in urban and natural reach of the same stream by exploring different hydrogeomorphic scenarios. The scenarios explored the urban and natural condition in its current state as well as management action of either addressing the flow or channel form.

2 METHODS

2.1. Study Area

Two 100-m study reaches were selected on the Cardinia creek in Cardinia catchment, south-eastern Melbourne, Australia which physically represent natural and urban settings (Figure 1a). The urban site downstream of the natural site has a simplified (wider, deeper and less topographic variability) sand-gravel bed channel whereas the natural site is a sand-gravel bed channel which has a comparatively intact, complex (meandering, defined pool-riffle sequence, point bar and benches) morphological features. The catchment has annual rainfall averaging ~950mm/year which is fairly distributed over the year. Further details of sites are reported by [8].

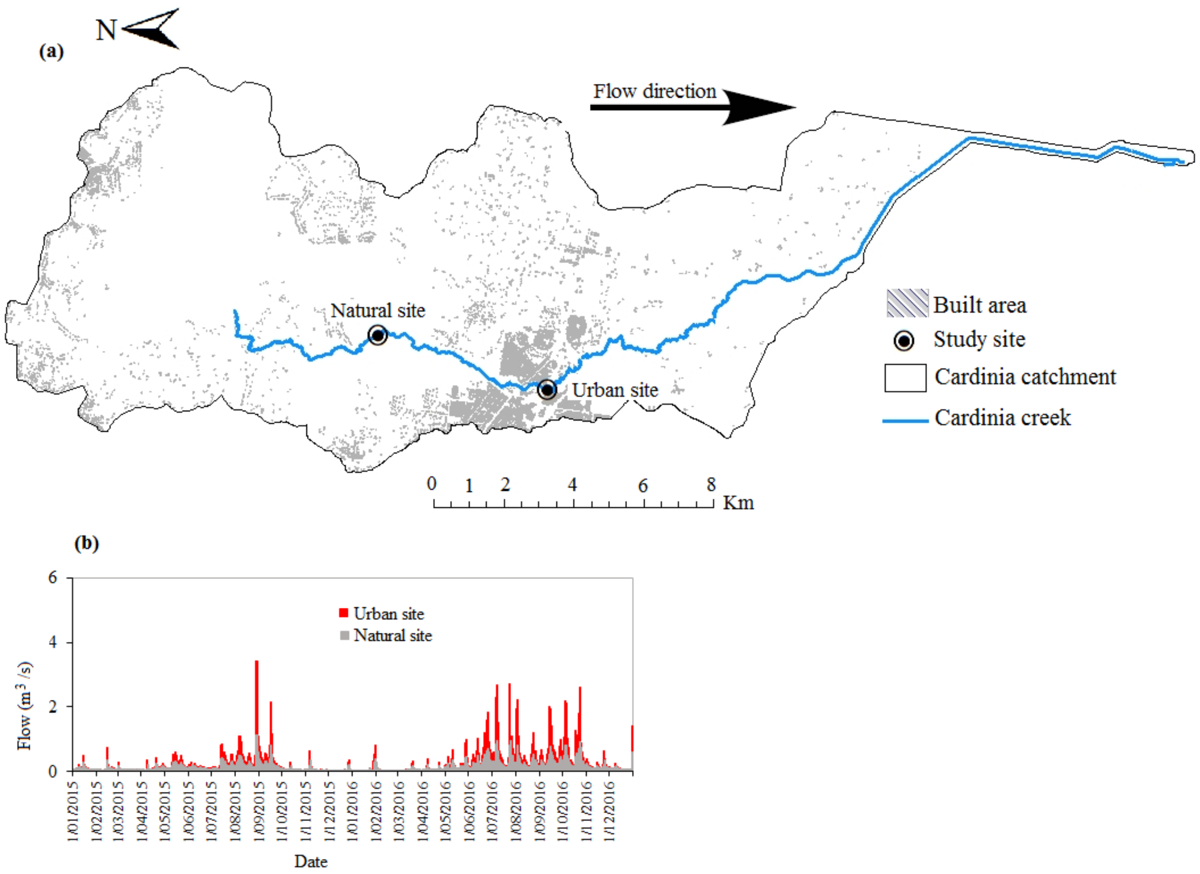

Figure 1. (a) The study sites located on the Cardinia Creek draining the Cardinia catchment, (b) Mean daily streamflow for the urban and natural study reaches during study period.

2.2 Field data collection

Topographic survey was carried out which detailed the channel topography for each reach including channel bed, banks and immediate floodplain. Streamflow for each site was monitored from January 2015 to December 2016 (Figure 1b). Water surface elevation (WSE) was also profiled at different discharge at each site along the banks which was used to calibrate the model.

2.3 Hydraulic modelling

TUFLOW 2D model was used for the hydraulic simulations. Model domain was built using DEM from the topographic survey. Simulations were performed in a steady-state mode based on representative flows observed for each site corresponding to 1-99% of time discharge exceedance. Model input and boundary conditions included inflow discharge and corresponding downstream WSE. surface friction coefficient (Manning’s n) was used as bed roughness in the model. Model calibration runs were iterated by adjusting the Manning’s n until the predicted WSE corresponded best with the measured WSE. The model was considered calibrated when the predicted WSE agreed with the measured WSE to within ±3 cm. Model output included depth-average velocity, depth, WSE in flow direction and bed shear stress

2.4 Modelling scenarios and data analysis

Four hydrogeomorphic scenarios were investigated which include:

(i) CuHu - Model urban hydrology (Hu) in urban channel form (Cu)
(ii) CnHn - Model natural hydrology (Hn) in natural channel form (Cn)
(iii) CnHu - Model urban hydrology (Hu) in natural channel form (Cn)
(iv) CuHn - Model natural hydrology (Hn) in urban channel form (Cu)

Scenario (i) and (ii) explored the current condition in the natural and urban site and (iii) and (iv) conceptually examined the management approach of either addressing hydrology or channel form.

The non-dimensionalized Shields Stress (τ*) was estimated from TUFLOW's bed shear stress output which was used for analysis to evaluate each scenario and compare for its relative potential for bed mobilization as:

$$\tau * = \frac{\tau_b}{D(\gamma p_s - p_w)} \quad (1)$$

where τ_b is the bed shear stress, D is the representative particle size of the channel bed (herein D_{50}) with a mean particle size (D_{50}) of 3mm and 6mm for the natural and urban reach respectively, p_s and p_w are the unit weight of water and bed material respectively. Critical mobility threshold (τ_c^*) of 0.045 [9] was used.

3 RESULTS AND DISCUSSION

The results showed that the benthic disturbance patterns were similar for all scenarios at very low flows but differ considerably as discharge increases particularly at higher rate for CuHu and CuHn whereas comparative small increases were observed for CnHu and CnHn. We found that urban channel (CuHu and CnHn) would likely experience substantially higher bed particle mobility making the channel bed very unstable. At very high flow, τ* generally averages 0.06, where an overturn of the bed is expected, a behaviour Sawyer, et al. [10] referred to as full transport (motion of a sheet of bed sediments). Given that the urban channel experience progressively frequent high flows, the channel adjustment is expected to accelerate which will result in benthic habitat degradation and/ and eventually habitat lost. This creates conditions where the benthic space become uninhabitable due to the effects of scour and abrasion [11]. This is consistent with previous studies reporting that benthic habitat available as refugia in urban fluvial systems diminishes particularly for systems with frequent altered flows [7, 12]. The ecological consequence of this is anticipated to be large given that regular movement of surface sediments particles will occur including the biota that lives in them which could be key factor for local extinction and declined abundance of biota. Contrarily, the natural channel (CnHn and CnHu) comparatively retained low τ* averaging 0.04 at very high flows making the channel stable with low potential of full bed movement.

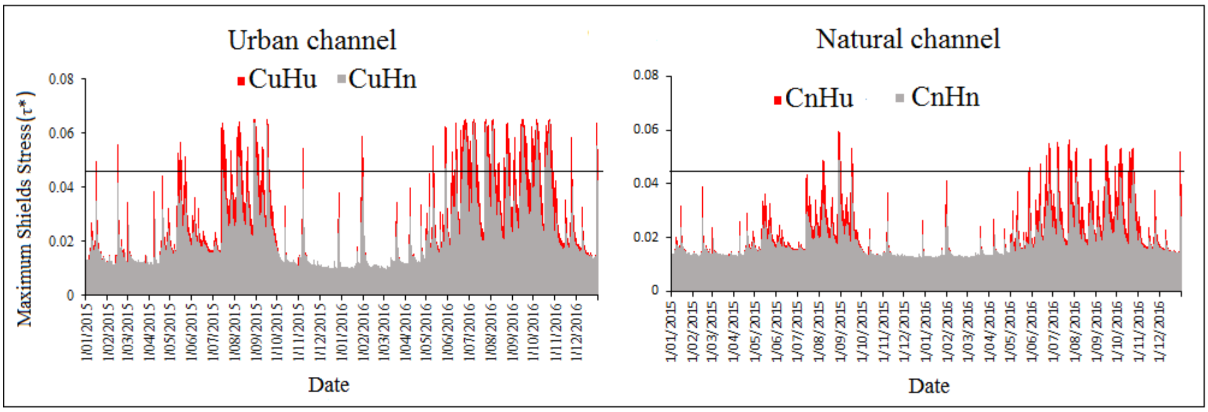

Figure 2. Daily maximum Shield stress for the two study sites for each modelled scenario. Solid horizontal black line show the critical Shields stress for bed particle mobilization (τ_c^* = 0.045).

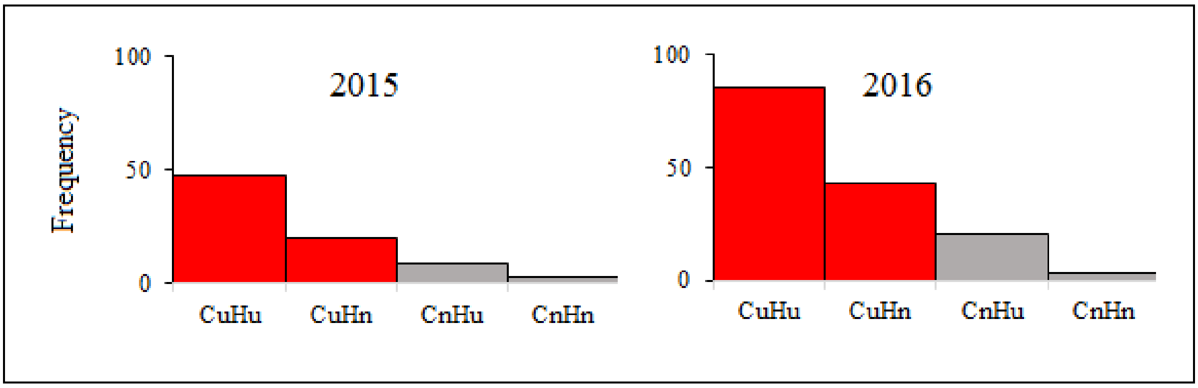

Figure 3. Number of days Shields stress was above critical threshold of the modelled scenarios during the study period. Red and Grey indicate scenarios in the urban and natural channel respectively.

The results also showed that scenario CnHu led to substantially decreased up to ~55% in frequency of likely benthic disturbance relative to the current urban condition (CuHu). Similarly, scenario CuHn led to ~20% decrease. This shows that, in the natural channel, the impact of altered hydrology did not necessarily lead to increased frequency of benthic disturbance. However, contrary to expectations, the natural hydrology in the urban channel (CuHn) did not substantially decrease benthic disturbance although the frequency was slightly reduced relative to CuHu. This suggest that relatively small reduction in benthic disturbance rate is expected when just altered flow regimes are restored in urban streams particularly with highly degraded channel.

These results improve our understanding of the relative contribution of channel form and hydrology such that the channel form is suggested here to also play dominant role in controlling the hydraulic habitat conditions. We hypothesised that the natural channel topographic variability greatly reduced the streambed areas that are subjected to high τ^* with increasing flows, which then provide opportunity for a more natural rates of bed movement. It is reported that dynamic channels direct flow such that the varying topographic surfaces turn on and off to drive diverse patterns of hydraulic habitat conditions as flow increases [13].

It is suggested here that by just addressing the urban hydrology problems, we may still fail to address negative impact on stream hydraulic habitat conditions if the channel form is fundamentally degraded. This means, addressing channel form change together with flow can give managers extra chance of maintain or protect in-stream habitat and maximize ecological benefits.

5 CONCLUSION

This study used two-dimensional (2D) hydraulic modeling to explore the relative role between the channel form and flow in impacting the in-stream habitat in the context of benthic disturbance. The main conclusions include:

i) In addition to altered flow regime, channel morphology also play dominant control on benthic disturbance patterns.
ii) Measures should be taken to protect the channel morphology from degradation particularly reducing the stormwater input that is a primary agent of geomorphic change leading to in-stream hydraulic habitat degradation
iii) Addressing just urban hydrology is unlikely to restore and/ or protect stream habitat from further adjustment if the channel is fundamentally degraded.
iv) Management actions to address instream habitat degradation should consider opportunities for self-regeneration of the channel form that mitigate frequent bed mobility or if required rehabilitate the channel.

ACKNOWLEDGMENTS

This work was supported by the University of Melbourne Research Scholarship and the Melbourne Waterway Research Practice Partnership.

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