International Journal of GEOMATE, Sept., 2016, Vol. 11, Issue 25, pp. 2468-2473
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

DESIGNING URBAN RIVERS TO MAXIMISE THEIR GEOMORPHIC AND ECOLOGIC DIVERSITY

Melissa Neave[1] and Scott Rayburg[2]

[1]Centre for Urban Research, RMIT University, Australia; [2]Faculty of Science, Engineering and Technology, Swinburne University of Technology, Australia

ABSTRACT: River geomorphic complexity is vital to support abundant and diverse ecological assemblages in river environments. With the ever increasing population of global cities, and the consequent spread of urbanized land, pressures on engineers and land planners to modify and control urban rivers channels could be detrimental to their ecological diversity. This research project provides an analysis of the geomorphic complexity and heterogeneity of an urban stream. The study compares different sections of Orphan School Creek in western Sydney, Australia to investigate how channelization and/or alternations in riparian vegetation impact on geomorphic heterogeneity. The sections of Orphan School Creek examined range from freely meandering to fully concrete channelized reaches. The results of this research project clearly show that urbanization has detrimental effects on the geomorphic complexity of urban streams, due to both catchment urbanization and channelization. Through the analysis of Orphan School Creek it was concluded that channelization reduces river geomorphic complexity, with concrete channels providing little or no geomorphic complexity or diversity. However, if managed and/or designed with a view towards optimising geomorphic complexity, urban rivers can attain meaningful ecological benefits while still being controlled to prevent damage to the urban environment from flooding and/or erosion.

Keywords: Pools and riffles; geodiversity; channelization; asymmetry

1. INTRODUCTION

Urban rivers are often extremely compromised, having dramatically altered flow regimes, geomorphologies, and ecologies in comparison to their non-urban counter-parts [1]-[3]. This occurs because urbanization within river catchments is typically associated with increases in impervious surface area that cause the adjacent rivers to be ‘flashy’ (i.e., have relatively high peak discharges and short flow periods), while most urban rivers are physically transformed (i.e., channelized) in some way to reduce both flooding and erosion. This channelization typically involves channel straightening and smoothing, and the reinforcement of the bed and banks with a non-erodible material that both enhances smoothness and prevents ongoing channel migration. In addition to these impacts, stormwater runoff from the catchment transports high pollutant loads that degrade water quality.

One of the most obvious outcomes of stream channelization is a loss of physical diversity that further manifests itself in the river through reduced hydraulic and habitat diversities. Morphologic adjustments to rivers can greatly affect the availability of physical habitats, particularly in association with the simplification of fluvial structures (e.g., bed features) in the down- and cross-stream directions [4]. Indeed, there is a strong link between biotic diversity and spatial heterogeneity [5] and it is generally expected that geomorphically variable and complex landscapes will have a higher chance of supporting diverse ecologic assemblages by providing a greater selection of niche spaces [6]. Conversely, geomorphically simple rivers, such as those created through channelization, will have fewer available habitats and an associated reduction in aquatic ecologic diversity.

There are several ways to compare the physical diversities of channelized and non-channelized river reaches, perhaps the most obvious of which is to consider channel planform, or the view of a channel from above. Natural river planforms vary from straight to highly sinuous or meandering, although natural straight systems are not particularly common and occur mostly when a river is constrained in some way (e.g., by geologic structure). In contrast, channelized rivers are often straight or only mildly sinuous, which is designed to increase flow velocities and thereby reduce flooding [7], [8]. Straightening a channel however, also reduces its geomorphic and hydraulic complexity, which means such a channel typically exhibits limited physical diversity. Planform is relatively easily investigated, using parameters that quantify the degree of meandering [9], such as sinuosity (SI) which is the ratio of the channel length to the long valley length [10], [11]. Meandering reaches are generally defined as having a sinuosity ratio of at least 1.05 whereas heavily channelized reaches have a sinuosity of less than 1.05 and often close to 1.0.

The physical diversity of a river channel can also be considered in terms of longitudinal variations in its bed. Many natural rivers have alternating deeps and shallows (or undulations) on their bed. These features, typically identified as pools and riffles (especially in gravel-bed systems), are thought to reduce the rate of energy expenditure by increasing flow length [12], [13], but are often removed during channelization. Thus, most channelized rivers have a smooth bed with a constant slope in the downstream direction [8], [9]. Pools and riffles create non-uniform flow conditions [14] that offer a range of habitats for aquatic organisms. Thus, the removal of pools and riffles (or bed undulations) from streams results in a concomitant loss of habitat variability. The geomorphic complexity and diversity of rivers in the longitudinal direction can be assessed using several bedform parameters, such as the extent to which a bed varies from a straight condition in the downstream direction and undulation asymmetry [15]-[17].

A final characteristic of river channels that can be used to assess physical diversity is cross-sectional variation in channel form. Indeed, [18] argues that cross-sectional asymmetry and variability imply a tendency towards irregularity and complexity. Natural streams typically have highly asymmetric cross-sections along much of their length, whereas urban or channelized systems are often highly symmetrical to ensure the rapid throughflow of water [19]. Cross-sectional asymmetry can be quantified using a number of indices, most of which represent some form of comparison between left and right channel areas [19].

This research investigates relationships between the physical diversity (i.e., geomorphic complexity and heterogeneity) of an urban stream, its degree of channelization and the general condition of its riparian vegetation. These findings are further considered in terms of the stream's habitat potential. Thus, the specific aim of the research is to establish a link between urbanization, channelization and geomorphic complexity in an urban river system.

2. STUDY SITE

To assess the relationship between urban river complexity and/or heterogeneity and urbanization and/or channelization, survey data were collected from Orphan School Creek in western Sydney, Australia (Fig. 1a). Orphan School Creek is approximately 12.5 km long and is a tributary of Prospect Creek, which flows into the Georges River and Botany Bay. Orphan School Creek has two small tributaries, Clear Paddock Creek (~5 km in length) and Green Valley Creek (~5.6 km in length), and a total catchment area of 34.3 km^2 [20]. The catchment is highly urbanised and the creek itself has been extensively modified over the last 50 years. Thus, the creek is 'naturally' vegetated at both its upstream and downstream ends but has an approximately 1.5 km long section in the middle where it runs through firstly a pipe and then a concrete lined trapezoidal channel.

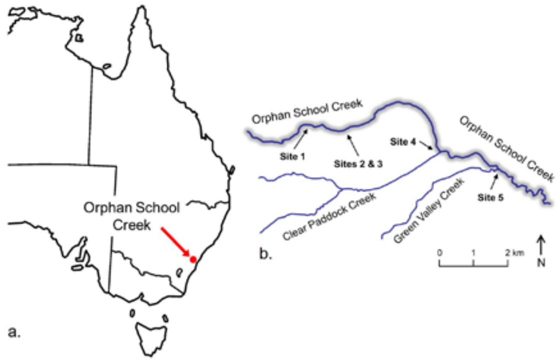

Fig. 1 Position of Orphan School Creek in western Sydney, Australia (a) and location of the five study sites used in this research [21].

The Orphan School Creek system is managed by the City of Fairfield, who balances a need for flood protection with a desire to improve the overall health of its river systems in general. The mean annual maximum temperature of the region is 23.1 ºC while the mean minimum temperature is 12.2 ºC [22]. The average annual rainfall is approximately 870 mm, the majority of which falls in January through March, although all months average at least 45 mm [22]. Major floods in 1986, 1988 and 2001 caused significant damage in the catchment and increased community pressure to develop and implement flood protection measures. At the same time, the Council has instigated a Creek Care Program that aims to produce river environments that support biodiversity and provide for community engagement [23]. Activities under this program include cleaning (e.g., direct litter removal and stormwater quality improvement), weed control, bush regeneration and stream channel rehabilitation.

3. METHODS

Orphan School Creek exhibits a variety of conditions along its length, ranging from naturally vegetated to fully channelized. Five sections within the first 7 km of the creek, which differed both in terms of channel form and condition and the type and extent of surrounding vegetation, were investigated for this study (Fig. 1b, Fig. 2). Site 1 is in the most upstream section of the creek and is extensively vegetated, with native trees and shrubs (dominated by *Eucalyptus* and *Casuarina* species) on both banks. This site is positioned about 900 m downstream of the creek headwaters. Site 2 is approximately 800 m downstream of Site 1. The creek in this region is grassed on both sides, although there are trees relatively close to the southern bank. This site is immediately downstream of a culvert and, subsequent to the present study, has been partially rehabilitated by the Council who reinforced the banks for erosion control. Site 3 is approximately 200 m downstream of Site 2 and is positioned within a narrow (approximately 50 m) but dense patch of native trees. The channel in this region has not been extensively modified. Site 4 is a further 2.5 km downstream and is a trapezoidal concrete channel running through a grassed parkland. Site 5 is another 2.3 km downstream and sits adjacent to a sports reserve. A ranking of these sites from best to worst, in terms of vegetation cover and degree of channelisation, would be as follows: Site 1 ('best'), Site 3, Site 2, Site 5 and Site 4 ('worst').

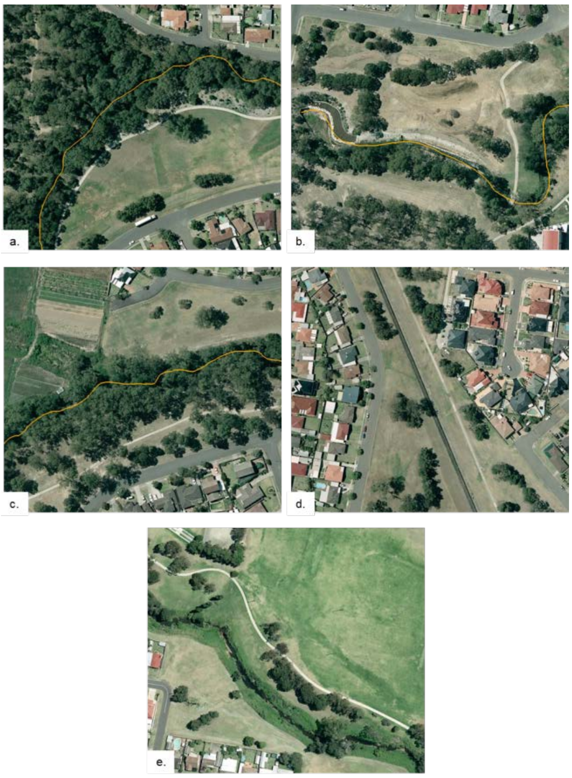

Fig. 2 Aerial views of Sites 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e) on Orphan School Creek.

Within each of these five sites both cross-sectional and downstream surveys were performed using an automatic level. The cross-sectional surveys were collected along an approximately 80 m channel length and positioned roughly 10 m apart, depending upon channel conditions. The downstream surveys were taken along the thalweg, with data points collected every 1-2 m.

The survey data were used collectively to compute a series of cross-sectional, planform and longitudinal variables. These variables include bankfull width (W), depth (d), area (A) and hydraulic radius (R) and sinuosity (SI) and bed elevation range. In addition, cross-sectional thalweg asymmetry (A_t from [16]) was calculated using Eq. (1)

$$A_t = (A_{rt}-A_{lt})/A \quad (1)$$

Cross-sectional centerline asymmetry (A^* from [18],[19]) was calculated using Eq. (2)

$$A^* = (A_{rc}-A_{lc})/A \quad (2)$$

Two longitudinal asymmetry parameters (A_a and A_{L2} from [17] were calculated using Eq. (3) and Eq. (4)

$$A_a = (A_p-A_r)/A_{pr} \quad (3)$$

$$A_{L2} = (L_p-L_r)/L \quad (4)$$

Where: A is the cross-sectional area; A_{rt} and A_{lt} are the cross-sectional areas to the right and left of the thalweg, respectively; A_{rc} and A_{lc} are the cross-sectional areas to the right and left of the middle of the channel, respectively; A_p and A_r are the areas below and above a longitudinal trendline, respectively; A_{pr} is the total area around a longitudinal trendline; L_p and L_r are the pool and riffle lengths, respectively; and L is the total longitudinal length. Both A^* and A_t have limits of -1 to 1, with 0 being symmetrical and 1 or -1 being extremely asymmetrical.

Thus, ten variables were calculated for each survey site, six of which were cross-sectional, three of which were longitudinal and one of which was planform. These variables were subsequently compared between the five survey sites using Mann-Whitney U and Levene's W tests to examine means and standard deviations, respectively.

4. RESULTS

Representative cross-sectional surveys for each of the five sites on Orphan School Creek are presented in Fig. 3. Averages and standard deviations for the six cross-sectional variables that were calculated at each site are presented in Table 1 and statistics comparing results between sites are presented in Table 2. These data indicate that the sites that have been more extensively modified (4 & 5) are deeper, have larger channel areas and are smoother. In addition, for most parameter values there is a statistical difference between the more modified sites and the less modified sites.

Longitudinal surveys for each of the five sites on Orphan School Creek are presented in Fig. 4. Averages for the longitudinal asymmetry variables and ranges of depths are provided in Table 3. These data suggest that the bed is less regular in the downstream direction in the unmodified reaches than the modified reaches.

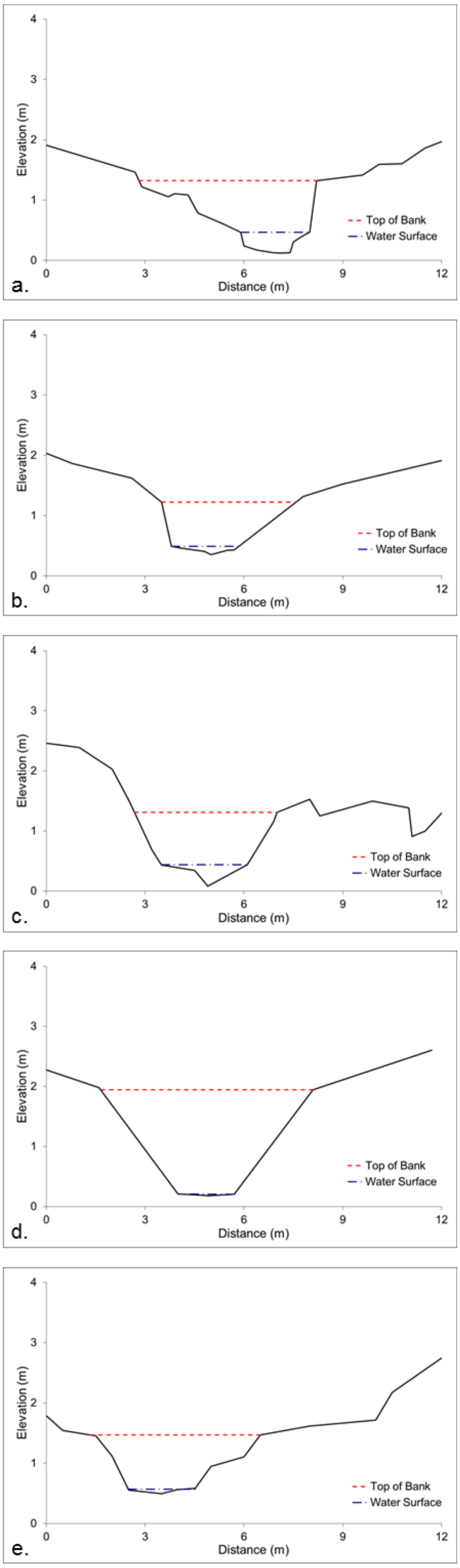

Fig. 3 Representative cross-sections for Sites 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e) on Orphan School Creek, Australia.

Table 1 Averages (Avg) and standard deviations (SD) for six cross-sectional variables at five sites on Orphan School Creek, Australia.

Site	W (m)		d (m)		A (m)	
	Avg	SD	Avg	SD	Avg	SD
1	6.05	1.66	0.40	0.09	2.45	0.95
2	4.21	1.68	0.41	0.25	1.53	0.61
3	4.55	1.19	0.49	0.12	2.16	0.51
4	6.13	0.42	0.82	0.10	4.99	0.49
5	6.30	2.29	0.37	0.09	2.34	1.12
Site	R (m)		A*		A_t	
	Avg	SD	Avg	SD	Avg	SD
1	0.34	0.07	0.28	0.23	0.35	0.22
2	0.27	0.07	0.18	0.10	0.23	0.23
3	0.36	0.06	0.19	0.19	0.38	0.23
4	0.69	0.08	0.00	0.00	0.00	0.00
5	0.31	0.06	0.16	0.15	0.22	0.26

Table 2 Statistically different cross-sectional parameter comparisons between sites (e.g., Sites 1 v 2 were statistically different only for W) based on the Man Whitney U analyses.

Mann Whitney U					
Site	1	2	3	4	#
1					8
2	W				8
3	W	A			6
4	D,A,R,A_t,A^*	All 6	All 6		20
5	A^*	W,A		D,A_t,A^*	4
Levene's W					
Site	1	2	3	4	#
1					3
2					2
3	A^*	A^*			7
4	D,A,A_t,A^*	D,A_t,A^*	D,R,A_t,A^*		17
5			W,A	All 6	6

Note: # is the number of statistically significant differences observed for each site.

Table 3 Averages for two longitudinal asymmetry variables and ranges for flow depth at five sites on Orphan School Creek, Australia.

Site	No.	A_a	A_{L2}	Range (m)
1	2	0.05	0.00	0.73
2	1	0.00	0.26	0.91
3	4	0.18	0.28	1.38
4	0	0.00	0.00	0.14
5	1	0.29	0.19	0.54

Note: No. = the total number of deviations above and below the bed observed at each site.

Finally, in terms of planform Site 1 had a sinuosity ratio (SI) of 1.21. Sites 2 and 3 each had an

SI of 1.14. Site 4 had an SI of 1.00 and Site 5 had a SI of 1.10. This indicates that the more modified reaches (e.g., Sites 4 and 5) were straighter than the well vegetated and unconfined reaches.

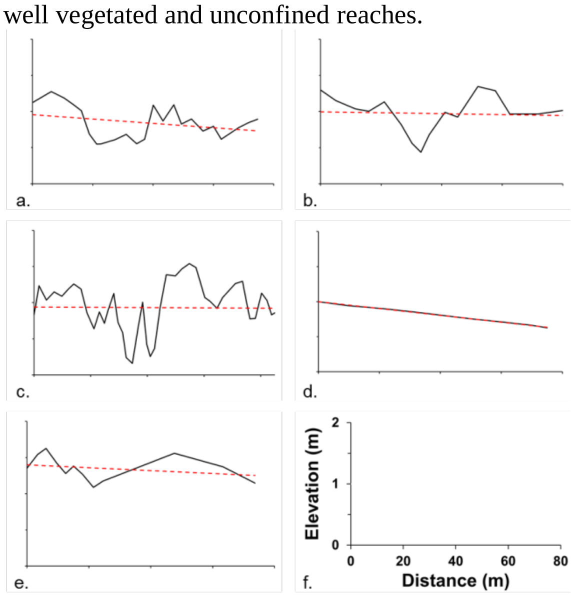

Fig. 4 Longitudinal streambed profiles for Sites 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e) on Orphan School Creek, Australia. All profiles were on the same axes (f).

5. DISCUSSION

This research analysed and contrasted data from five sites along an urban stream in Sydney's western suburbs, ranging from a 'natural' (unconfined) reach with relatively dense native riparian vegetation (i.e., trees) on both banks (Site 1) to a straight concrete channel flanked by grass covered surfaces (Site 4). The objective was to identify differences in the geomorphic complexities of these channel types and to try and explain these differences in terms of channelization and bank vegetation. Statistical comparisons between the average cross-sectional parameters for the five sites (Table 2 Mann-Whitney U) indicate that Site 4 (channelized) was the most different in terms of physical character. It was typically larger (both deeper and wider) than the other sites, especially Sites 1, 2 and 3 which were better vegetated and had not been channelized. Site 4 differed the least from Site 5, which also lacked a dense vegetation cover and was relatively straight. Indeed, Sites 4 and 5 were statistically different only in terms of depth. This confirms previous research that indicates that urbanisation and channelization lead to both channel widening and deepening as a result both of human intervention (i.e., channelization and devegetation) and changes in runoff from urbanising catchments [24], [25].

The Levene's tests, which compare the variances between samples, reinforced that Site 4 was significantly different to the other sites for virtually all cross-sectional parameters. The low standard deviations for this site for most parameters indicate that this reflects a lack of variability of form.

An assessment of the cross-sectional asymmetry parameters (A^* and A_t) for the five sites on Orphan School Creek shows a clear trend of declining asymmetry with channelization. The highest cross-sectional asymmetry values were recorded at Sites 1 and 3, which had the densest vegetation covers and were the least confined. In contrast, Sites 4 and 5, which were the most altered reaches, had the most symmetrical cross-sections. This finding is relevant to discussions of fluvial ecologic diversity, with asymmetrical systems offering greater diversity in terms of flow and habitat than symmetrical ones. Thus, these findings support previous work that shows that an increase in urbanisation can lead to more uniform channels and [26] and that this has implications for aquatic biodiversity.

In addition to channel cross-sectional form, urbanisation and channelization have the potential to influence a river's planform and longitudinal structure. The sinuosity of Orphan School Creek decreased with increasing channelization, with Sites 1-3 having the highest sinuosity ratios. This confirms the trend evidenced in the cross-sectional asymmetry data of decreasing channel diversity with increasing intervention.

The longitudinal asymmetry data (Table 3) are a little more difficult to interpret. Sites 3 and 1 show the greatest variability in bed structures in the downstream direction (Fig. 3), although this isn't necessarily reflected in the longitudinal asymmetry results (Table 5). Indeed, Site 5, which had limited riparian vegetation and a relatively low SI, returned the largest A_a value, which suggests that it has the greatest longitudinal variability. However, the bed survey data (Fig. 3) indicate that this isn't necessarily the case and points to a need to examine the data in concert with a visual assessment. Likewise, the total variation in bankfull depth along these channels (as indicated by Range in Table 3) was considerably lower for the more modified sites (4 & 5) than the less modified sites (1, 3 & 2).

6. CONCLUSIONS

This research identifies some of the impacts of urbanization and channelization on urban streams, particularly in terms of geomorphic complexity and heterogeneity. The study examined five sites along Orphan School Creek in western Sydney, Australia. Overall, unconfined sites with relatively dense native vegetation covers exhibited higher diversities in their in-channel physical form (in both the cross-sectional and downstream dimensions). In contrast, as the impacts of channelization became more apparent, through direct interventions in the channel (e.g., straightening and enforcement) and alterations in the type and density of riparian vegetation (e.g., transformations to grass covered banks), there was a reduction in the physical diversity in the channel. These findings have important implications for fluvial ecosystems, with increased geomorphic complexity and heterogeneity known to support increased biodiversity through the provision of diverse niche spaces for organisms to occupy. Recognizing the importance of geomorphic diversity for biota should help those designing urban rivers to make more informed decisions about their systems.

7. REFERENCES

[1] Baer KE, Pringle CM, "Special problems of urban river conservation: The encroaching megalopolis", Global perspectives on river conservation: Science, Policy and Practice. Boon PJ, Davies, BR, Petts, GE. Eds. John Wiley & Sons, 2000, pp. 385-402.

[2] Roesner LA, Bledsoe BP, "Physical effects of wet weather flows on aquatic habitats", Final Report to Water Environment Research Foundation, 2002, WERF Project Number 00-WSM-4. 250 pp.

[3] Vaughan IP, Diamond M, Gurnell AM, Hall KA, Jenkins A, Milner NJ, "Integrating ecology with hydromorphology; a priority for river science and management", Aquatic Conservation, Vol. 19, pp. 113-125.

[4] Gregory KJ, Davis RJ, Downs PW, "Identification of river channel change due to urbanization", Applied Geography, 1994, Vol. 12, pp. 229-318.

[5] Huston M, "Biological diversity: the coexistence of species on changing landscapes", Cambridge University Press, 1994, 681 pp.

[6] Hunter ML, Jacobson GL, Webb T, "Paleoecology and the coarse-filter approach to maintaining biological diversity", Conservation Biology, Vol. 4, 1988, pp. 375-385.

[7] Emerson JW, "Channelization: a case study", Science, Vol. 173, 1971, pp. 325-326.

[8] Brooker MP, "The ecological effects of channelization", The Geographical Journal, Vol. 151, 1985, pp. 63-69.

[9] Lofthouse C., Robert A, "Riffle-pool sequences and meander morphology", Geomorphology, Vol. 99, 2008, pp. 214-223

[10] Mueller JE, "An introduction to the hydraulic and topographic sinuosity indexes", Annals of the AAG, Vol. 58, 1967, pp. 371-378.

[11] Boano F, Camporeale C, Revelli R, Ridolfi, L, "Sinuosity driven hyporheic exchange in meandering rivers", Geophys. Res. Lett., Vol. 33, 2006, L18406.

[12] Yang CT, "Formation of riffles and pools, Water Resources Research, Vol. 7, 1971, pp. 1567-1574.

[13] Wohl EE, Vincent KR, Merrits D, "Pool and riffle characteristics in relation to channel gradient", Geomorphology, Vol. 6, 1993, pp. 99-110.

[14] Julien PY, "River Mechanics", Cambridge University Press, 2002, 434 pp.

[15] Richards KS, "The morphology of riffle-pool sequences", Earth Surface Processes, Vol. 1, 1976, pp. 71-78.

[16] Rayburg SC, Neave M, "Morphologic complexity and diversity in natural and channelized streams", Engineers Australia, Vol. 4, 2008, pp. 1902-1911.

[17] Rayburg SC, Neave M, "Assessing morphologic complexity and diversity in river systems using three-dimensional asymmetry indices for bed elements, bedforms and bar units", River Research and Applications, Vol. 24, 2006, pp. 1343-1361.

[18] Leopold LB, Wolman MG, Miller JP, "Fluvial processes in geomorphology", Freeman, 1964, 522 pp

[19] Knighton AD, "Asymmetry of river channel cross-sections: Part I. Quantitative indices", Earth Surface Processes and Landforms, Vol. 6, 1981, pp. 581–588.

[20] Sinclair Knight Merz, "Flood study for Orphan School Creek, Green Valley Creek and Clear Paddock Creek. Final Report", 2008, http://www.fairfieldcity.nsw.gov.au/upload/dkryh96595/FinalReport3TribsOct08Part1.pdf.

[21] Fairfield City Council State of the Environment Report 2005-2006: Chapter 2: Creeks, http://www.fairfieldcity.nsw.gov.au/upload/tilhz85984/soe0506_Creeks_ch2.pdf.

[22] Australian Government Bureau of Meteorology, http://www.bom.gov.au.

[23] City of Fairfield, Catchments Creeks and Wetlands, http://www.fairfieldcity.nsw.gov.au/default.asp?iNavCatId=2181&iSubCatId=2194.

[24] Douglas I, "The impact of urbanization on river systems", Proceedings of the International Geography Union Regional Conference, 1974, pp. 307-317.

[25] Roberts CR, "Flood frequency and urban-induced change: some British examples", Floods: Hydrological, sedimentological, and geomorphological implications. Beven K, Carling P, Eds. John Wiley & Sons, 1989, pp. 57-82.

[26] Hammer TR, "Stream channel enlargement due to urbanization", Water Resource Research, Vol. 8, 1972, pp. 1530-1540.

International Journal of GEOMATE, Sept, 2016, Vol. 11, Issue 25, pp.2468-2473.
MS No. 5164 received on June 27, 2015 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in Sept. 2017 if the discussion is received by March 2017.
Corresponding Author: Melissa Neave