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Original Research

Provision, transport and deposition of debris in urban waterways

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A R T I C L E I N F O

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A B S T R A C T

The transport of woody debris from urban surfaces, through local urban waterways, to constriction and blockage risk locations is not well understood. Flume trials have identified debris and watercourse dimensions as influential factors on debris movement, and large woody debris movement has been traced in the natural rural environment using time series photography, active transponders, and field surveys. Using novel passive transponder technology, small woody debris has been traced through an urban case study watercourse to establish key influential factors on urban debris transport. Through incorporating urban debris transport detail into the source and deposition process, a complete picture of urban debris transport can be created, supporting effective culvert and trash screen design, watercourse maintenance and blockage risk assessment. This case study highlights that factors beyond watercourse depth and velocity are influential in debris movement within an urban watercourse. Debris dimension and source location upstream are shown to significantly affect the potential for debris to reach a downstream constriction, illustrating a possible distance limitation in nuisance flow debris blockage risk.

1. Introduction

Urban watercourses differ from large rural rivers in size, flow capacity, nature of the flood plain and bank composition, landscaping and the level of anthropogenic modification. Most importantly, from a flood risk perspective, urban watercourse blockage has the potential to cause harm and damage during flood events. The importance of urban watercourse constriction blockage is acknowledged in key flood management guidelines provided by Authorities, including the Environment Agency (Graham et al., 2009) and the Construction Industry Research and Information Association (CIRIA) (Balkham et al., 2010). The design of culverts, the use of trash screens to prevent culvert blockage, the management of urban waterway banks, and the movement of woody debris in artificial (flume) and in rural watercourses have been examined in theory and scaled physical modelling (Braudrick & Grant, 2001; Cherry & Bescha, 1989; Mazzorana et al., 2011; Wallerstein et al., 2001; Young, 1991). The scale model and rural large woody debris analysis provide insight into influential factors for debris transport, but are not directly transferable to urban watercourse.

Factors expected to influence constriction blockage include the quantity and type of debris available, the amount of this material travelling to the constriction, and the constriction characteristics. The quantity and type of debris provided through urbanisation has been evaluated in an international array of studies (Allison et al., 1997; Armitage & Rooseboom, 2000; Cornelius et al., 1994; Wallerstein & Arthur, 2012). This research establishes the significant proportion of vegetative and woody debris in urban waste. While this data informs the provision extent of the urban debris transport process, many culvert, screen, and constriction design guides and models make debris provision assumptions that do not include reach and management specific details (Roso et al., 2004). To advance these assumptions, debris delivery to a specific constriction must be defined and the factors influencing delivery included in the design of any blockage risk or prediction analysis. Current assumptions of the transport process include the influence of debris dimension, buoyancy, channel and flow characteristics, entrainment or entry location, turbulence, and flow/flood event characteristics (Bocchiola et al., 2008; Braudrick & Grant, 2001). The relationship between each of these influencing factors and debris transport has not yet been considered using urban field case studies, and, thus, current constriction design and blockage assessments continue to employ generalised debris flow input rather than reach and location specific information.

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2. Current research

Urban debris, also identified as urban gross pollutants, are defined as material, refuse, and discarded matter that has been damaged, destroyed, or is no longer in use. It can be comprised of residential waste, industrial or commercial refuse, landscape and garden material, polluted sediment, and miscellaneous items (such as cars, mattresses, road signage) (Wallerstein & Arthur, 2012). Research conducted across Northern Island, UK, identified land use type, social economy (income), and catchment characteristics as the three key influencing factors in culvert blockage by urban debris (Wallerstein & Arthur, 2013). Armitage and Rooseboom (2000) usefully describe urban waste according to industrial, commercial, and residential land use.

Table 1 illustrates the predominance of vegetative matter, woody debris and leaves, in urban gross pollutant composition. As a result of landmark research by Allison et al. (1997) on debris composition across the urban landscape, Marais et al. (2004) used field data to create a land use specific debris loading rate, defining the proportion of vegetative matter in this load. It is estimated that vegetation comprises approximately 85% of debris in residential areas, decreasing to 36% across industrial land (Marais et al., 2004).

Research completed by Armitage and Rooseboom (2000) and Wallerstein and Arthur (2012) illustrates that vegetation is a significant component of culvert blockage. Culvert and constriction blockage can result in significant increase in flood risk, through elevated flood levels and diverted flow paths through the urban area (Rigby et al., 2002). This was recently acknowledged in Australian Rainfall and Runoff revision (Project 11) where culvert conveyance calculations (ΔHe, energy loss at the culvert entrance) include a blockage ratio (BR) (Weeks et al., 2009). This incorporates the flood level impact of relative culvert blockage extents to specific culvert constrictions, illustrating the flood risk impact of urban debris build up within urban watercourses. The blockage ratio takes into account the use of trash screens as well as unprotected culverts in estimating potential blockage flood risk impact.

Culvert and constriction blockage estimation has been undertaken using case studies and laboratory experimental analysis. Large scale analysis has been undertaken to identify the influential catchment characteristics (Streftaris et al., 2013; Wallerstein & Arthur, 2012) while detailed laboratory research has defined specific elements of debris and culvert blockage activities. The field research presented in this paper functions to help create the research bridge (Fig. 1) between the catchment and blockage point research, enhancing catchment blockage analysis with watercourse and debris specific characteristics. This in turn informs debris deliver with respect to screen and culvert screen blockage potential.

2.1. Influential debris detention parameters

Catchment scale culvert blockage analysis identifies influential catchment characteristics affecting culvert blockage potential (Streftaris et al., 2013). Wallerstein and Arthur (2012) constructed a predictive debris transport tool using land use, social deprivation indices, and catchment characteristics to describe debris blockage potential within a specified river reach. This model provides a monthly or seasonal indicator of debris transport success and potential screen/culvert blockage. The probability of a significant debris load delivery to a screen (Pd), is calculated using the logistic function and yields a catchment and climate specific debris delivery potential rather than event based analysis using the following equations:

$$\begin{aligned}\mathrm{LogitPd} = \alpha &+ (\mathrm{logNL}^{*}\beta 1) + (\mathrm{SL}^{*}\beta 2) + (\mathrm{logQn}^{*}\beta 3)\\ &+ (\log\ R^{*}\beta 4) + (\mathrm{logAG}^{*}\beta 5) + (\mathrm{logSU}^{*}\beta 6)\\ &+ (\mathrm{logSO}^{*}\beta 7) + (\log\ U^{*}\beta 8) + (\mathrm{ID}^{*}\beta 9) \qquad (1)\end{aligned}$$

$$\mathrm{Pd} = \left(e^{logitPd} / \left(1 + e^{logitPd}\right)\right) \qquad (2)$$

where NL is the contributing upstream watercourse length, SL is the channel slope, Qn is the discharge and AG/SU/SO/U/R are catchment land use characteristics; agricultural, suburban, suburban open space, urban, and rural, respectively (Wallerstein & Arthur, 2012). ID is the social deprivation indices for the catchment defined as an income domain score in decimal percentage. This score is defined in Scotland through census information and is geographically clustered by land use and economic areas (Wallerstein & Arthur, 2013). Pd places weight on catchment characteristics and land use than debris dimension or detailed watercourse flow characteristics, therefore, providing a large scale blockage estimation for a given reach.

The blockage factor, as described by Bocchiola et al. (2008) is designed to assess the debris detention within a watercourse reach. Hygelund and Manga (2003) define blockage as the ratio of debris diameter (D_{log}) to water depth (d_w). Bocchiola et al. (2008) extend this to include debris length (L_{log}) and watercourse width (W_{Fl}) in their Eq. (3).

$$B = \frac{D_{log} \times L_{log}}{W_{Fl} \times d_w} \qquad (3)$$

In Hygelund and Manga's (2003) studies blockage was found to increase as debris drag increases, until a blockage of 0.3 is met. After 0.3 the drag was found to be independent of blockage (Hygelund & Manga, 2003).

2.2. Screen debris load prediction

Blanc et al. (2012) completed detailed analyses of urban, blockage causing, debris movement. The research focused on

Table 1
Urban debris loading estimations (% of total mass).

	Residential	Commercial	Industrial		General urban		
	Armitage and Rooseboom (2000), Marais et al. (2004)				Wallerstein and Arthur (2012)	Allison et al. (1997)[a]	Cornelius et al. (1994)
Domestic waste	14	33	64	21	24	20	20
Non-domestic waste					12	2	
Vegetation debris	85	67	36	78	60	77	80
Misc.	1	–	–	1	4	1	
Urban debris load (dry) (kg/ha/annum)	0.53–96, 27–155				–	20–40	0.53–1.35

[a] Estimations from graphical presentation.