The Effect of Large Woody Debris Dams upon Flow Resistance

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1-Introduction

A critical issue in fluvial engineering is the prediction of flow resistance associated with vegetation. One type of vegetation which has a significant impact upon flow resistance is Large Woody Debris (LWD) which can account for significant proportions of flow resistance despite only covering a small proportion of the channel bed (Manga and Kirchner, 2000). Originally the presence of LWD in rivers was deemed undesirable due to its flow resistance, subsequent impact upon conveyance and associated flood risk. In addition, at its most extreme LWD can completely block the channel leading to a backwater effect that has implications for the location, frequency and manitude of local flood inundation (Gippel *et al.*, 1992; Jeffries et al., 2003). It is this hydrological and hydraulic influence that makes the improvement in prediction of LWD roughness necessary, especially given the recent use of LWD as a restoration tool for stabilizing incised channels (Shields *et al.*, 2004), enhancing ecological habitat (Lehane *et al.*, 2002) and increasing hydraulic diversity (Shields *et al.*,2001).

2-Methodology

In order to assess the roughness contribution of LWD dams to the reach-scaled hydraulics of a lowland forested stream it was necessary to partition the total roughness into a series of constituent parts which could be estimated using standard formulae:

$$f = f' + f'' + f'''$$

where f' and f'' are the grain and resistane du to internal distortion at bends respectively and f''' is the component due to LWD . Bed roughness was estimated using the Hey (1979) formula for gravel-bed rivers. Bend resistance was approximated using head loss coefficients and a methodology suggested by Gippel *et al.* (1992) was implemented in order to predict the resistance offered by the LWD within the reach. This required the collection of a range of data in the field in order to calculate the Darcy-Weisbach friction factor (f). The Darcy-Weisbach friction factor was used as it is dimensionally correct and has a sound physical reasoning when compared to other commonly used roughness coefficients (Hey, 1979). Field data were collected from a small lowland gravel-bed river in Southern England over the winter of 2004/2005. A range of LWD accumulations were measured in order to accommodate different roughness combinations. In addition, a Froude-scaled flume experiment was undertaken to collect the same datasets data from a controlled environment. This dataset was extended to include three other stream and LWD types using data in the literature for the Obion River () the Tumult river (Shields and Gippel, 1995) and from step-pool channels (Curran and Wohl, 2003). Table 1 shows characteristics of these different channels.

	Drainage area (km^2)	Slope	Average Channel width (m)	D_{50} (m)	Hydraulic radius
Obion River (Shields and Gippel, 1995)	927	0.0006	17.62	0.0044	Not Specified
Tumult River (Shields and Gippel, 1995)	Not specified	0.001	38	0.022	2.85
Coweeman River (Curran and Wohl, 2003)	0.635	0.115	2.05	0.0345	0.0935
Deschutes River (Curran and Wohl, 2003)	2.2	0.093	4.8	0.087	0.18
Puyallup River (Curran and Wohl, 2003)	0.943	0.114	3.16	0.0598	0.116
White River (Curran and Wohl, 2003)	1.2	0.15	2.8	0.073	0.1
Cle Elum River (Curran and Wohl, 2003)	1.74	0.0865	3.225	0.084	0.0915
Taneum River (Curran and Wohl, 2003)	2.95	0.145	2.5	0.038	0.0605
Ahtanum Creek (Curran and Wohl, 2003)	5.625	0.114	3.375	0.07	0.124
Highland Water	11.2	0.0057	1.88	0.065	0.4109
Flume	N/A	0.005	0.8	0.02	0.175

Table 1:- Channel Characteristics of the different studies used in this analysis

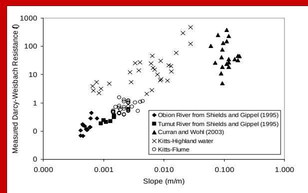

Figure 1:-Measured Darcy-Weisbach Friction Factor versus Slope

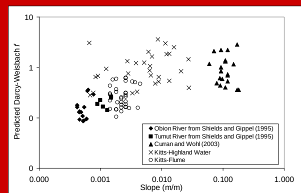

Figure 2:-Predicted Darcy-Weisbach Friction Factor versus Slope

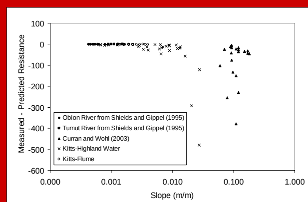

Figure 3:- Residual Darcy-Weisbach Friction Factor versus Slope

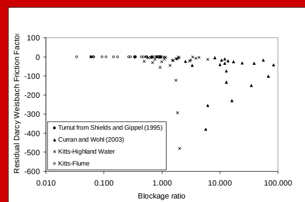

Figure 4: Residual Darcy-Weisbach Friction factor versus Blockage Ratio

3-Results

By comparing slope with measured Darcy-Weisbach friction factor (Figure 1) it is apparent that there is a continuum from the low-gradient streams of Shields and Gippel (1996) with relatively low resistance, to the high-gradient channels of Curran and Wohl (2003) with larger resistance. This trend is also observed when the resistance predicted from Shields & Gippels (1995) form drag approach, is plotted against slope (Figure 2). A plot of residual error between predicted and measured resistance factors shows an increase in the residual with slope (Figure 3). This residual also seems to display a similar pattern with blockage ratio (Figure 4). However the blockage ratio is a misleading parameter as it can often be greater than one when dealing with complex LWD accumulations.

Figure 3 suggests that the resistance offered by LWD dams in higher gradients is poorly predicted by the form drag approach suggested by Shields and Gippel (1995). Curran and Wohl (2003) argue that in high-gradient streams, form resistance offered by large woody debris is not as big a factor as spill resistance. The data was plotted against the Froude number (Figure 5) which is known to affect the friction factor when changes in free-surface configurations occur (Colosimo *et al.*, 1988). This shows a pattern of decreasing residual error with increasing Froude number. For LWD dams that cause a step in the water surface profile there was a much stronger relationship between Froude number and residual error (Figure 6).

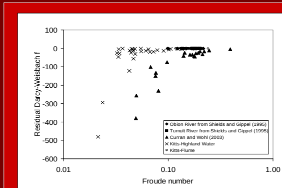

Figure 5:- Residual Darcy-Weisbach Friction Factor versus Froude Number

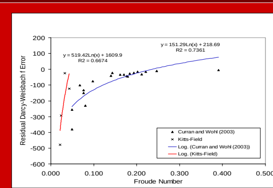

Figure 6:- Residual Darcy-Weisbach Friction Factor versus Froude Number for LWD Dams with Water Surface Steps

4-Conclusions

LWD debris dams offer significant amounts of resistance to flow. Methods which allow the prediction of the resistance contributed have been developed although these work better in low-gradient channels where form drag dominates. In high-gradient channels and where the LWD dams create a step in the water surface profile, spill resistance dominates. Preliminary analysis shows that some of the residual between observed and predicted resistance can be accounted for by the Froude number which is known to affect resistance in cases of free surface variability.

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