IMPACT OF LARGE INSTREAM LOGS ON RIVER BANK EROSION

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There has been abundant research into the effect of tree roots on stabilizing river banks, and also on the effect of trees on bed-scour after they have fallen into the stream, but there is little research into the effect of instream logs on bank erosion. Here we develop the hydraulic theory that predicts local and reach scale bank erosion associated with instream logs with various configurations and distributions and conclude that individual log can increase local bank erosion, but multiple logs can reduce overall reach erosion. Where there is consistent bank strength, the local erosion varies in a non-linear way with the angle, size and position of the log. The reach scale effect of multiple logs depends on the distribution of logs and the proportion of the reach occupied by logs. Erosion effects of instream logs are difficult to measure. We are testing the above theory of erosion associated with instream logs in a series of anabranches of different sizes that experience consistent irrigation flows each year (on the Murray River in SE Australia). These channels have high erosion rates, abundant logs, and are like a giant flume that allows us to measure erosion processes, as well as hydraulics, in a controlled setting.

1 INTRODUCTION

Large instream wood alters the hydrological, geomorphological, and ecological structure of rivers, as it induces diversity of flow hydraulics and channel form, and provides habitats and nutrition for aquatic fauna [1]. There is substantial literature on the influence of live riparian trees on bank stability [2], and on bed complexity due to scour around fallen trees [3], but there is little research into the bank erosion adjacent to fallen trees. Concern about erosion around fallen trees is one of the major reasons why river managers continue to remove wood from low-land streams in Australia. Log loads in rivers are increasing as wood is artificially returned to rivers, and as riparian vegetation is reestablished, and it is useful to understand the erosion effects of this increase understanding the bank erosion effects of instream logs allows us to predict the revegetation program and a scheme for optimal log distributions of rehabitation plans. Instream logs alter the channel geomorphology through hydraulics. The two hydraulic functions of instream logs identified in previous research include flow deflection and flow resistance [4, 5]. In this paper we describe the hydraulic theory of erosion associated with logs of different configurations and distributions based on the two hydraulic functions at the local and reach scale. We then briefly describe our approach to testing the theory in the field.

2 THEORY

A log can deflect flow into a confined area between the log and the bank (a hydraulic jet), providing an additional shear stress which causes the boundary shear stress to exceed the critical shear stress of the bank [6, 7]. In this process, a single log can increase local bank erosion. At reach scale, logs act as roughness elements, producing drag to decelerate flow and decrease boundary shear stress [8]. In this process, logs can reduce reach scale bank erosion. Our theories of local increase of erosion around a single log and reach scale changes of erosion associated with multiple logs are described below.

2.1 Single log

The local increase of erosion around a single log can be estimated by the additional shear stress. For given bank resistance, the additional shear stress around a single log can be estimated from the log characteristics including size and angle of the log and distance from the bank. For the same log angle, the additional shear stress around a log increases with log size (log cross section area which is the product of log length and diameter), and decreases with the distance from the bank (Figure 1). As the log angle decreases from 90^o (perpendicular to flow) toward

30°, the additional shear stress decreases non-linearly; and beyond 30° the magnitude of the hydraulic effect of the log is small (Figure 2), but the extent of the erosion increases with the length of the log, since the hydraulic jet is constricted between the log and the bank (Figure 3).

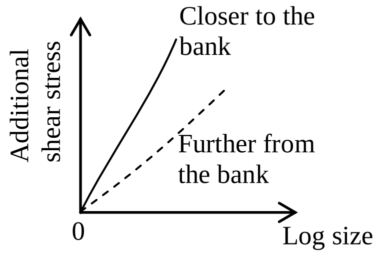

Figure 1. Relationship between the additional shear stress and log size and distance between log and bank.

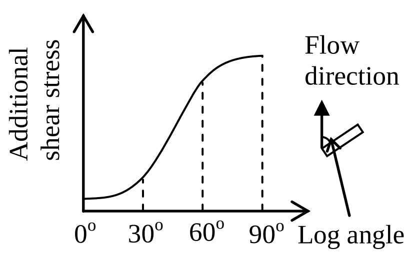

Figure 2. Relationship between the additional shear stress and log angle.

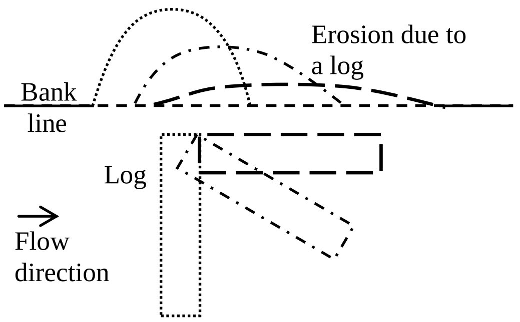

Figure 3. Relationship between the pattern of erosion along the bank and log angle.

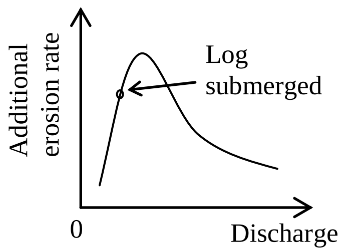

Figure 4. Relationship between the additional shear stress and discharge.

The additional shear stress around a single log also varies with discharge (Figure 4). The additional shear stress peaks after the log is fully submerged and decreases as the log is drowned-out.

Combining the variables described above, a model is developed to predict boundary shear stress around a single log based on the mass continuity and energy conservation between the approaching flow and contracted flow around a log. The additional shear stress $\Delta\tau$ can be estimated by the approaching flow condition and the log characteristics which is expressed by a designated partial blockage ratio B_c. The partial blockage ratio represents the contraction rate of the deflected flow when passing through the gap between the log and the bank. The boundary shear stress around a log τ_0' is given by

$$\tau_0' = \tau_0 + \Delta\tau = \tau_0 + \frac{1}{2P_c d}\rho(1-B_c)^{-2}B_c v_a^2 \tag{1}$$

where τ_0 = boundary shear stress of approaching flow; $\Delta\tau$ = additional shear stress; P_c= wetted perimeter in contracted area; d = log diameter; ρ = water density; v_a = mean velocity of approaching flow.

2.2 Multiple logs

At reach scale, logs provide flow resistance, elevated water surface level and reduced mean flow velocity. The reach scale effect of multiple logs on bank erosion can be estimated from the changes in water surface profile which is influenced by the flow pattern between logs. Spacing between logs can determine the flow pattern between logs. Four types of flow pattern at different spacings can be identified given the influence of wake flow [9, 10] on a downstream log, and backwater on an upstream log.

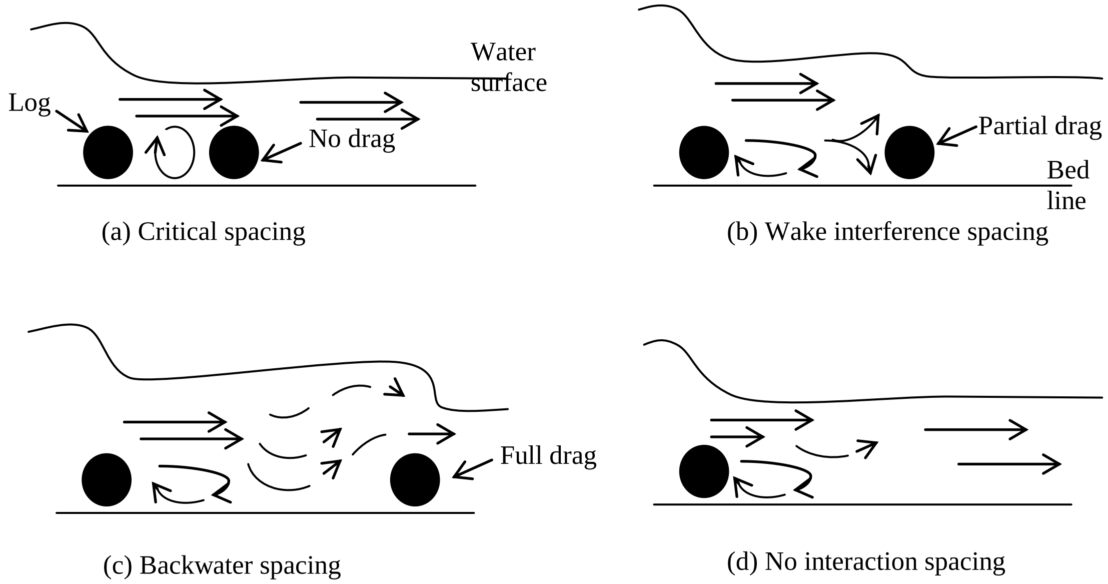

Figure 5. Flow patterns between logs with different spacing.

At a critical spacing (0 – 4*d*, where *d* = log diameter), skimming flow forms on top of logs and a recirculation zone forms between logs (Figure 5-a). In this spacing, drag of a downstream log is suppressed by the upstream log and the afflux of the downstream log is negligible. The log group produces the same amount of afflux as a single log.

At a 'wake interference spacing' (4*d* – which is the extent of the wake from an upstream log), wake interference flow forms between logs. The effect of the downstream log is suppressed by the wake of the upstream log, and the downstream log produces less drag and afflux than without the upstream log. Water level at the upstream log is elevated by the backwater of the downstream log, and an accumulated afflux is created upstream of the upstream log (Figure 5-b).

At a backwater spacing (extent of the wake from an upstream log – the extent of the backwater from a downstream log), the influence of the downstream log is no longer suppressed by the wake of the upstream log and both of the logs produce drag as single logs. The upstream log is still under the influence of the backwater from the downstream log and an accumulated afflux is created upstream of the upstream log (Figure 5-c).

At a 'no interaction' spacing (extent of the backwater from a downstream log – ∞), there is not hydraulic interaction between the logs. They both act as single logs and produce backwater upstream (Figure 5-d).

Based on the flow patterns of the four spacings, a modified drag coefficient, which addresses the drag force of a downstream log according to the spacings from the upstream logs, can be substituted into the predictions of afflux from previous studies [11, 12], which then combined with the extent of backwater can be used to estimate the water surface profile in the light of afflux accumulation. The reach scale reduction of bank erosion due to the flow resistance of instream logs can be estimated by the newly calculated water surface profile. The total effect of instream logs on bank erosion can be estimated by combining the local scale increase of erosion to the reach scale reduction of bank erosion.

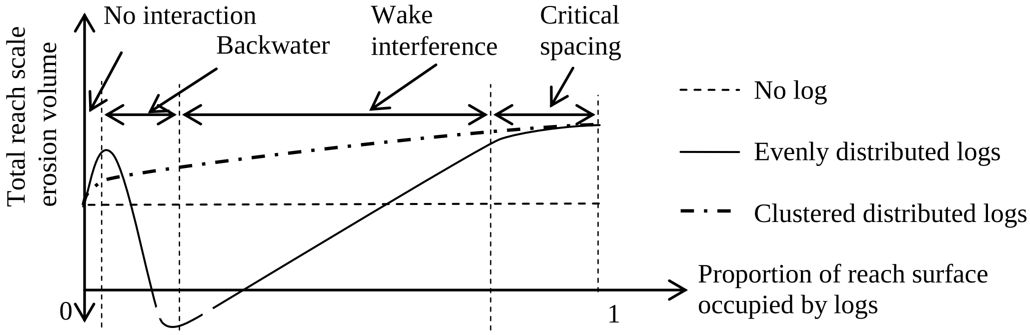

Figure 6. Reach scale effect of instream logs on bank erosion related to the load and distribution of logs.

The total effect of instream logs on bank erosion changes with the distribution of logs (Figure 6). Clustered logs (where the spacing between the logs is 0 in Figure 6) increase the total reach scale bank erosion, and the erosion increases with the proportion of reach surface occupied by logs. Evenly distributed log (which represents logs that are equally spaced throughout the reach in Figure 6) can decrease the total reach scale bank erosion and the peak reduction appears when logs are spaced over the wake interference spacing.

3 FIELD TESTING

It is difficult to confirm the theory proposed above because there are so many variations in the logs, the flow and the channel characteristics. It could be done in a flume, but it is notoriously hard to measure bank erosion in a flume. Instead we are testing the theory in a field setting where we can control as many of the variables as possible. A reach of the Murray River in SE Australia is heavily regulated for irrigation flows from a large dam (Hume Weir), and the channel below the dam consists of multiple anabranching channels with (a) a huge range of channel sizes that experience very consistent seasonal flows; (b) high erosion rates that deliver large numbers of large trees to the river channel (river red gums, *Eucalyptus camaldulensis*). As a result we can, over successive irrigation seasons, measure erosion (using repeat Sonar scanning and erosion pins), as well as hydraulics (using an acoustic Doppler velocity profiler), in order to test the above theory in a controlled environment. The erosion and hydraulics are being related to wood characteristics including length, diameter, orientation, and distance from the bank. The erodibility of the bank material will be tested by a hydraulic jet apparatus.

REFERENCES

[1] Abbe T. and Montgomery D., “Patterns and processes of wood debris accumulation in the Queets river basin, Washington”, *Geomorphology*, Vol. 51, No. 1, (2003), pp 81–107.

[2] Abernethy B. and Rutherfurd I., “Where along the river's length will vegetation most effectively stabilise stream banks?”, *Geomorphology*, Vol. 23, No. 1 (1998), pp 55-75.

[3] Abbe T. and Montgomery D., “Large wood debris jams, channel hydraulics and habitat formation in large rivers”, *Regulated Rivers: Research & Management*, Vol. 12, No. 23, (1996), pp 201-221.

[4] Keller E. and Swanson F., “Effect of large organic material on channel form and fluvial processes”, *Earth Surface Processes*, Vol. 4, No. 4, (1979), pp 361-380.

[5] Shields D. and Gippel C., “Prediction of effects of woody debris removal on flow resistance”, *Journal of Hydraulic Engineering*, Vol. 121, No. 4, (1995), pp 341-354.

[6] Daniels M.and Rhoads B., 2003. “Influence of a large woody debris obstruction on three-dimensional flow structure in a meander bend”, *Geomorphology*, Vol. 51, No. 1, (2003), pp 159–173.

[7] Die Moran A., Abderrezzak K., Mosselman E., Habersack H., Lebert F., Aelbrecht D. and Laperrousaz E., “Physical model experiments for sediment supply to the old Rhine through induced bank erosion”, *International Journal of Sediment Research*, Vol. 28, No. 4, (2013), pp 431-447.

[8] Gippel C., “Environmental hydraulics of large woody debris in streams and rivers”, *Journal of Environmental Engineering*, Vol. 121, No. 5, (1995), pp 388-395.

[9] Zdravkovich, M., “Review of flow interference between two circular cylinders in various arrangements”, *Journal of Fluides Engineering*, Vol. 99, No. 4, (1977), pp 618-633.

[10] Knight, D. and Macdonald, J., “Hydraulic resistance of artificial strips roughness”, *Journal of Hydraulic Division*, Vol. 105, No. 6, (1979), pp 675-690.

[11] Ranga Raju K.G., Rana O. P. S., Asawa G. L., and Pillai, A. S. N., “Rational Assessment of Blockage Effect in Channel Flow Past Smooth Circular Cylinders”, *Journal of Hydraulic Research*, Vol. 21, No. 4, (1983), pp 289-302.

[12] Azinfar H. and Kells J.A., “Backwater effect due to a single spur dike”, *Canadian Journal of Civil Engineering*, Vol. 34, No. 1, (2007), pp 107-115.