Appendix 14.3

Quantifying the Contribution of Large Woody Debris Dams to Flood Water Storage in the Pickering Beck Catchment

Background

Large Woody Debris (LWD) is a term applied to wood larger than 0.1 m diameter and 1.0 m length. It includes entire trees, logs and branches that can accumulate within small rivers. When a piece of LWD falls into a watercourse and lodges against the stream bed and bank, smaller pieces of wood and leaves can gather behind it. The accumulating structure is known as a debris dam. LWD dams can play an important role in holding back flood waters and potentially reducing the risk of downstream flooding.

Most rivers lack LWD due to its active removal by river managers plus historic clearance of riparian woodland. The artificial addition of LWD into rivers provides a means of recreating woody dams within wooded reaches and accelerating their formation in newly planted sections. Constructions that mimic natural conditions are thought to be more stable because they are better able to adapt to changing channel and flow conditions.

The presence of LWD creates a variety of in-stream flow conditions depending on the depth of the water relative to the height of the LWD. Where the water level is low, a piece of LWD lying across an entire channel will result in a slow flowing pool forming upstream. Water will cascade over the LWD creating turbulent aerated zones. When water levels are high, LWD can become submerged and flow conditions less variable.

LWD dams affect woodland river environments in a number of ways, all of which are a direct consequence of their impact on flow hydraulics:

1) They increase the hydrological interactions between the river channel and its floodplain by controlling the local distribution and intensity of overbank flows, and by enhancing flows around the site of the debris dam.

2) They enhance the storage and attenuate the transport of sediments, organic matter and solutes within the river system.

3) They affect the geomorphology of wooded river channels, resulting in greater variability in channel size, an increase in the occurrence of pools and riffles, and greater overall channel stability. As a result the physical habitat diversity of the woodland river system is increased.

4) They provide a diversity of habitat patches which can support a wide range of organisms at different stages of their life cycle. LWD accumulations can have an important role in regulating water quality and in sustaining refuge habitats to protect biota during pollution episodes and high flows.

In addition, LWD accumulations provide important food sources for aquatic biota.

Past modelling (Thomas and Nisbet, 2012) has shown that LWD dams can have a marked effect on flood flows by reducing water velocities, increasing upstream water levels and the frequency of out of bank flooding, and delaying the travel time of the flood peak.

Use of LWD Dams at Pickering

About 170 LWD dams have been constructed within a number of tributaries and in main channels of the Pickering Beck and neighbouring River Seven. A subset of 104 of these, distributed between 10 'blocks' in the Pickering Beck catchment, were surveyed and modelled for this study. The location of these is displayed in Figure 1, while Table 1 provides details of the associated upstream catchment and reach characteristics of each block.

Block No.	Catchment Area	No. of Dams	Upstream Elevation	Downstream Elevation	Reach Length	Slope	Ave. Dam Spacing
	km^2		m	m	m	m/m	m
1	15	3	88.8	86.4	178	0.014	59
2	0.31	9	223.2	220.3	134	0.021	15
3	0.51	19	235.4	224.0	382	0.030	20
4	0.51	9	251.1	245.6	188	0.029	21
5	0.5	10	219.8	208.5	127	0.089	13
6	1.49	8	153.3	148.5	201	0.024	25
7	12.12	4	124.2	123.6	128	0.005	32
8	0.72	13	238.9	226.8	440	0.028	34
9	0.66	23	67.7	58.0	112	0.086	5
10	14.29	5	101.9	99.3	258	0.010	52

Table 1 Catchment and reach characteristics of each LWD block

The HEC-RAS modelling programme was used to model the flood response of each of the 10 blocks. Due to their location, the distance between sites and survey restrictions, it was not possible to model the combined effect of all of the blocks as one complete system. An allowance was made for the gap at the bottom of each dam, which is designed to allow low flows to pass unhindered, but it was not possible to model the porous nature of the main dam structure.

Flows for each LWD block were derived using the Flood Estimation Handbook (FEH) methodology applied to the Pickering Beck at Pickering and an aerial weighted reduction factor used to estimate each block's contributing catchment (Table 2). This method was applied due to most of the contributing catchments being at or below the FEH's minimum catchment area. The same method was used for the larger catchments for consistency.

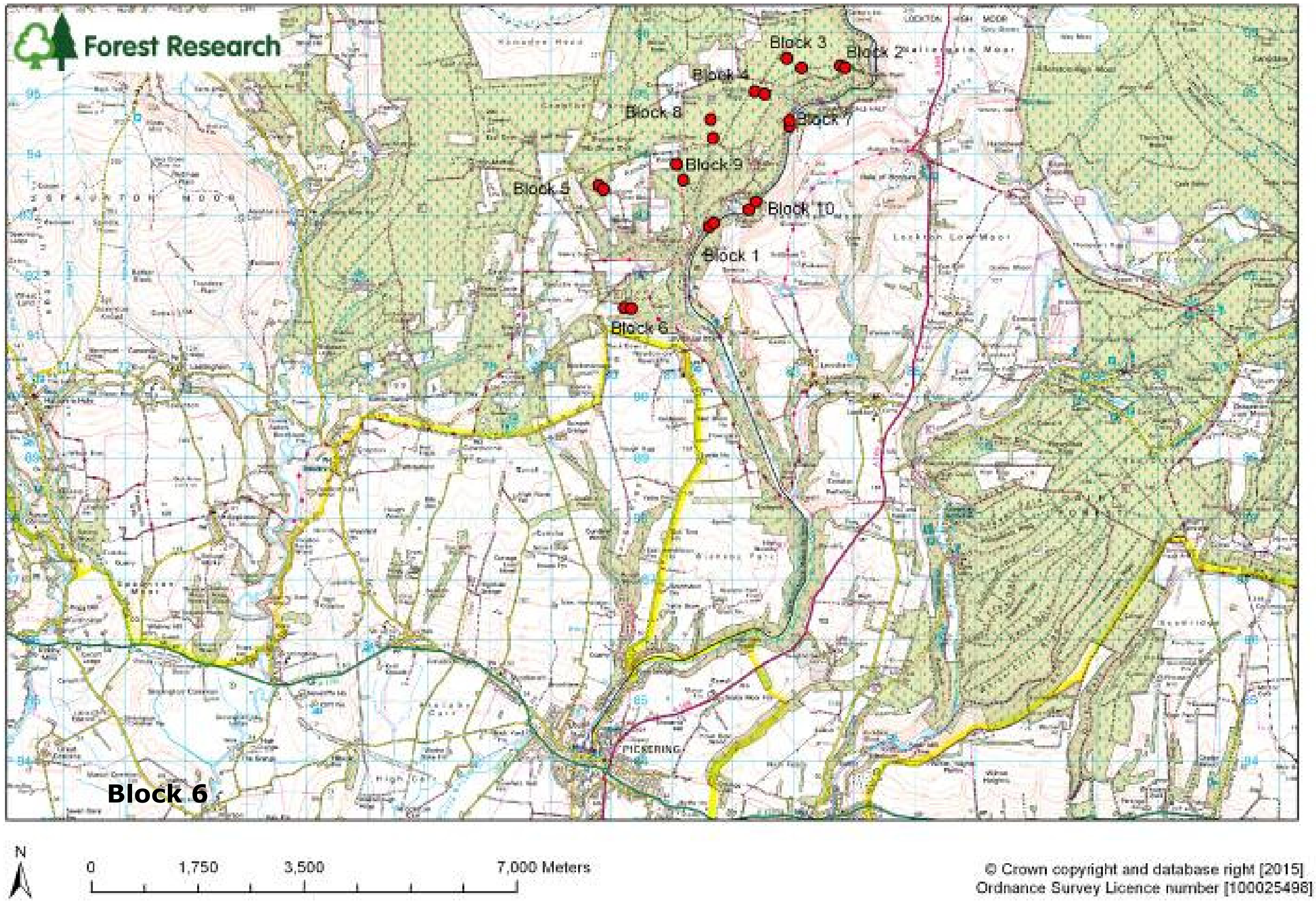

Figure 1 Map showing the upstream and downstream locations of each "block" of LWD dams in the Pickering Beck catchment

	Pickering	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10
Area (km^2)	66.38	15	0.31	0.51	0.51	0.5	1.49	12.12	0.72	0.66	14.29
Return Period (years)	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
2	7.20	1.63	0.03	0.06	0.06	0.05	0.16	1.31	0.08	0.07	1.55
5	10.61	2.40	0.05	0.08	0.08	0.08	0.24	1.94	0.12	0.11	2.28
10	13.15	2.97	0.06	0.10	0.10	0.10	0.30	2.40	0.14	0.13	2.83
25	16.91	3.82	0.08	0.13	0.13	0.13	0.38	3.09	0.18	0.17	3.64
50	20.21	4.57	0.09	0.16	0.16	0.15	0.45	3.69	0.22	0.20	4.35
100	24.03	5.43	0.11	0.18	0.18	0.18	0.54	4.39	0.26	0.24	5.17

Table 2 Predicted flows for the Pickering Beck catchment and the upstream catchment of each LWD block

Potential Flood Storage

A series of steady flow (i.e. at a fixed discharge) simulations were run to determine the additional storage that the LWD dams could provide for a range of flow frequencies. Figure 2 shows the volume of flood storage generated by each block of dams. Total storage increases from 751 m^3 to 1114 m^3 between the 1 in 2 year and 1 in 100 year flood flows. Table 3 shows the average storage volume per dam for each block.

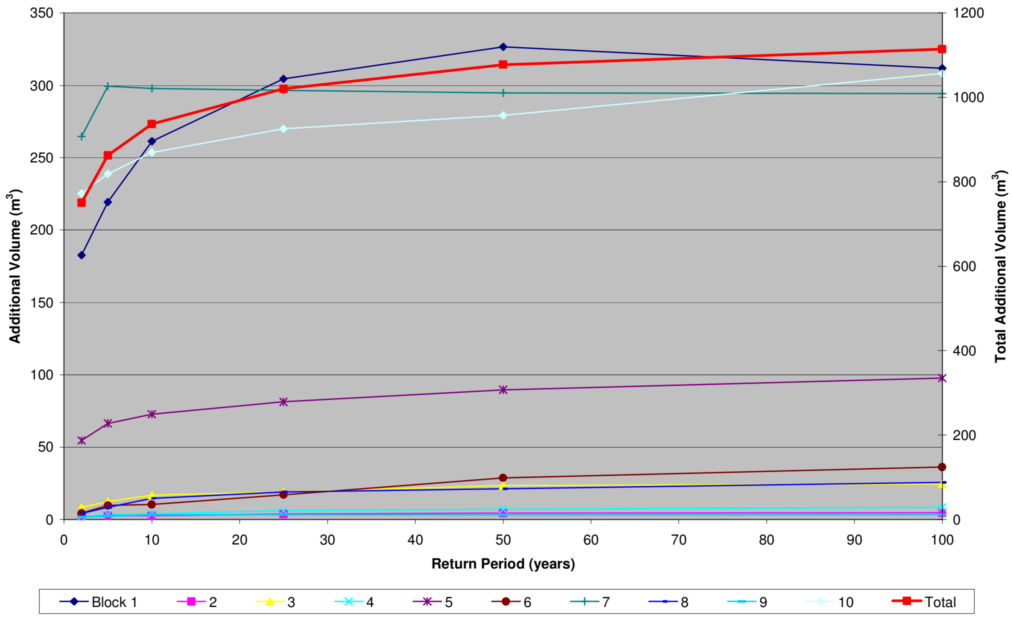

Figure 2 Additional flood storage volume for each block of LWD dams

Return Period (years)	2	5	10	25	50	100
Block No.	**m^3**	**m^3**	**m^3**	**m^3**	**m^3**	**m^3**
1	60.9	73.1	87.1	101.5	108.9	103.9
2	0.3	0.3	0.3	0.4	0.5	0.5
3	0.4	0.7	0.9	1.0	1.2	1.3
4	0.2	0.4	0.4	0.7	0.8	0.9
5	5.5	6.6	7.3	8.1	9.0	9.8
6	0.5	1.2	1.3	2.1	3.6	4.5
7	66.2	74.9	74.5	74.1	73.7	73.6
8	0.3	0.6	1.1	1.5	1.6	2.0
9	0.1	0.1	0.1	0.1	0.1	0.1
10	45.1	47.8	50.7	54.0	55.9	61.7

Table 3 Average storage potential per dam for each block of LWD dams

As noted above, the dams were modelled to allow lower flows to pass under the body of the dam but the model could not account for the porosity of the main structure.

Although the level of porosity will vary between individual dams and is likely to change through time as the dams continue to develop (e.g. by catching leaf litter, woody debris and silt, subject to reworking during high flows), it is reasonable to assume that the available flood storage will not become effective until lower frequency events.

According to Figure 2, the 104 modelled LWD dams could provide a total storage volume of around 937 m^3 if they filled during a 1 in 10 year event or 1,020 m^3 for a 1 in 25 year flood. The flood storage potential continues to grow for lower frequency flood events for most dams but at a very slow rate. This reflects their 'swamping' at increasingly higher flows.

Floodplain width and channel size are key factors determining the storage potential of the dams. Blocks 1, 7 and 10 are located on the main Pickering Beck and have floodplain widths of 5-40 m and river channel cross-sectional areas of between 8-14 m^2. This generates a significant backing-up effect and flood storage volume, ranging between an average of 51 m^3 and 87 m^3 per dam for the three blocks for a 1 in 10 year event. In contrast, average storage volumes are much lower for the smaller dams on tributary streams and drains, ranging from 0.1 m^3 to 7.3 m^3 per dam.

Reach gradient is another important factor affecting LWD dam storage volume. Figure 3 displays the relationship between storage volume and the average slope of each modelled reach for different return periods. There is a sharp decline in storage from 50-100 m^3/dam to <5 m^3/dam with increasing gradient between 0.005 m/m and 0.03 m/m, followed by a more gradual decrease to 0.1 m^3/dam at 0.09 m/m (although with a moderate outlier in the case of block 5). As expected, LWD dams are generally much less effective on steeper reaches and more likely to pose problems for channel erosion. Dam spacing is also significant, with the potential for individual dams to interact with each other and become "drowned" by the backwater from a downstream dam.

It is clear from Figure 2 and Table 3 that a small number of larger dams on a main watercourse are much better than a large number of smaller dams along drains or minor streams. For example, the 23 dams along block 9 generate a total storage volume of 3.3 m^3 for a 1 in 10 year event, which is less than 7% of the volume stored by a single dam in blocks 1, 7 & 10 on the main Pickering Beck. Nevertheless, very large numbers of small dams distributed across headwater streams could still make a significant contribution to flood storage, as well as reducing the overall speed of runoff into the main tributaries. They could also be very effective for reducing channel erosion and retaining silt, depending on local circumstances.

Effect of LWD dams on travel time

Figure 4 shows that each block of LWD dams exerts a delaying effect on the travel time of the flood peak, which appears to be unrelated to flood storage volume. While the effect is generally small, the combined impact of a network of LWD dams in a catchment could be significant for managing downstream flood risk. The modelling predicts an overall small delay (for all dams) of 7 minutes for a 1 in 25 year event and 4.5 minutes for the 100 year flood peak. It was not possible to model interactions between the different blocks of dams.

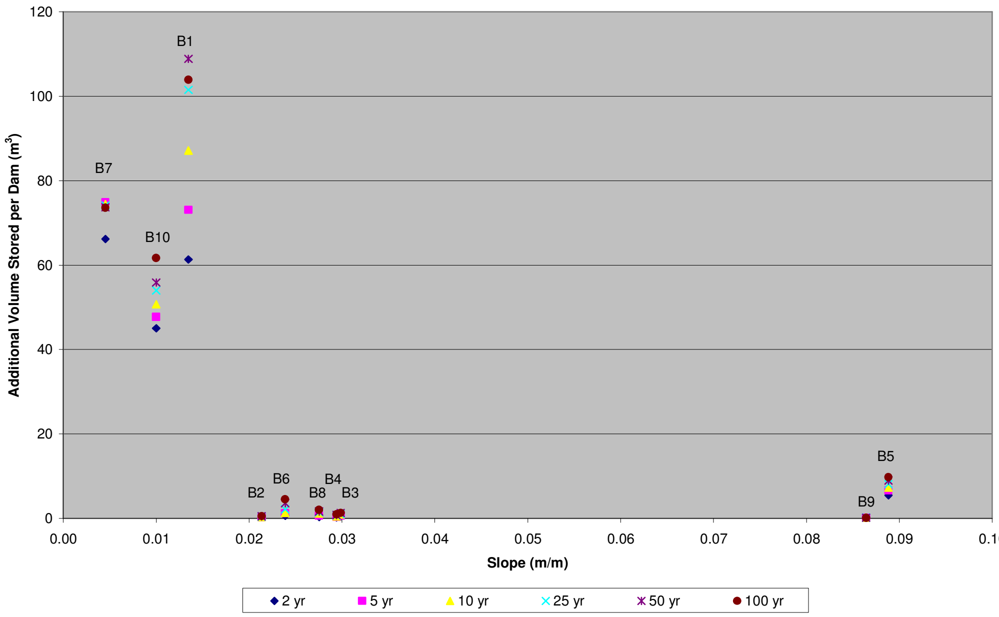

Figure 3 Additional storage per dam vs average slope for each LWD block reach

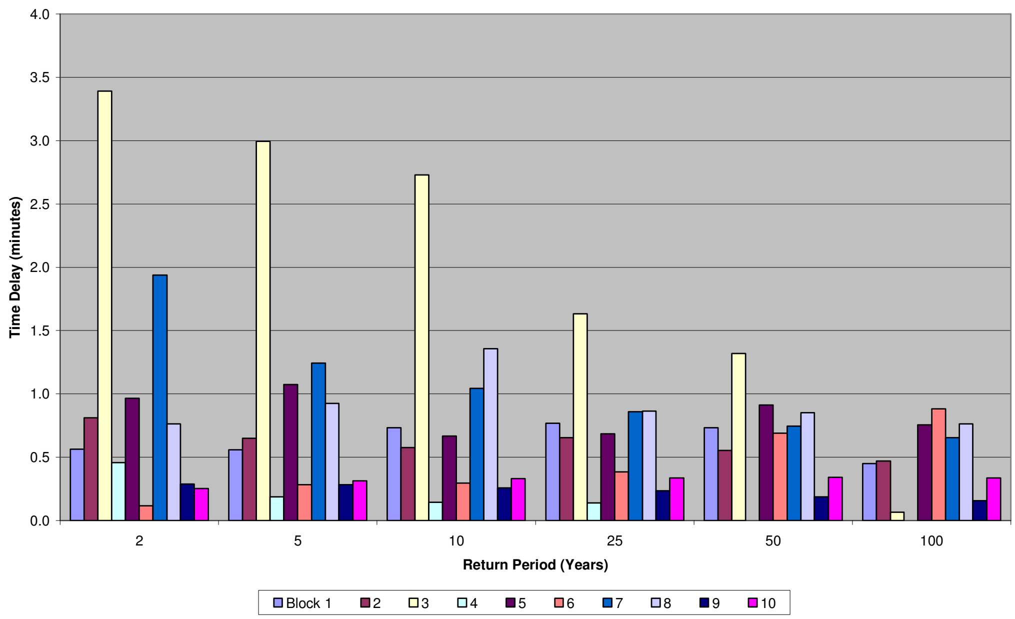

Figure 4 Effect of LWD blocks on peak travel time for different return periods

Conclusions

This study demonstrates that LWD dams have the potential to make a significant contribution to flood water storage within catchments. Model predictions show storage volumes to range between 0.1 m^3 and 103.9 m^3 for individual dams, depending on size/channel width, channel gradient, floodplain area and dam spacing. The 104 dams surveyed and modelled within the Pickering Beck catchment were estimated to provide a total of 1,020 m^3 storage for a 1 in 25 year flood, providing that there was sufficient porosity to prevent them from filling during higher frequency events. Storage volumes are predicted to generally rise with increasing flood flows as more water is forced onto the floodplain. The performance of individual dams is likely to vary through time with changing porosity, depending on the balancing effects of debris capture vs washout.

Reference

Thomas, H. and Nisbet, T.R. (2012). Modelling the hydraulic impact or reintroducing large woody debris into watercourses. Journal of Flood Risk Management, Vol 5 (2), p164-174.