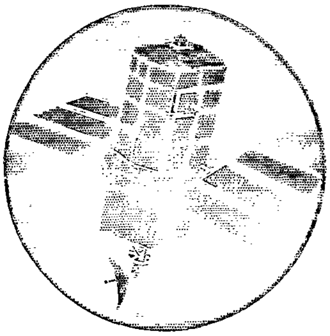
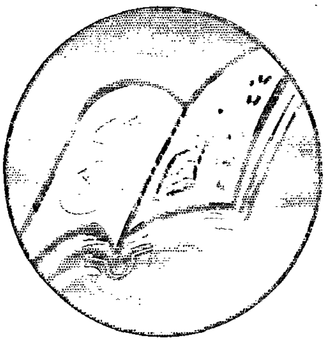
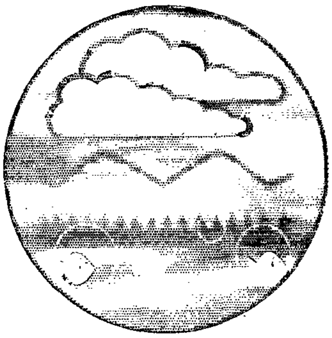
Large Wood Debris in British Headwater Rivers
Summary Report







Research and Development

Technical Report
W185

ENVIRONMENT AGENCY

Large Woody Debris in British Headwater Rivers
Physical Habitat Role and Management Guidelines

R&D Technical Report W185

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Statement of use
This Technical Report (Summary) describes a study to assess the ecological value of large woody debris in rivers in order to identify the consequences for river management. It details information to support the associated Technical Report (Main Report) W181. It will mainly be of interest to Conservation and Flood Defence staff involved in the management of river catchment headwaters.

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CONTENTS

EXECUTIVE SUMMARY

1. 'CWD' (coarse woody debris), 'LOD' (large organic debris) and, more recently 'LWD' (large woody debris) or simply 'large wood' have been the terms applied to pieces of dead wood of a variety of sizes, but now generally accepted to be pieces large than 0.1m diameter and 1.0m length. Since 'LWD' or 'large wood' are the terms used in the most recent literature, these terms are used throughout this report to refer to the entire trees, root boles, trunks, logs, branches and other large pieces of wood that can accumulate within river systems.

2. In unmanaged small streams, wood is distributed in a near-random pattern, reflecting where it enters the channel. With increasing stream size, debris dams become the characteristic form of debris accumulation. In larger river systems the geomorphology of the river channel controls the locations of large wood retention. Wood is retained locally in side streams; in floodplain woodland; on vegetated islands, where large wood pieces can brace against their upstream margins or can accumulate in their lee; and in association with features within the active channel where wood can be braced or deposited.

3. **This report focuses on headwater streams, where debris dams are the characteristic form of LWD accumulation**. The routine removal of LWD from many British rivers for flood defence purposes means that little is found in rivers wider than ca.10m. For the purposes of this report, a 10m channel width is taken to define the upper width limit for British headwater rivers.

4. **The main conclusions regarding the role of LWD in British headwater rivers**, based upon observations at locations where LWD is relatively unmanaged, are as follows:

Hydraulic impact:

- LWD accumulations cause an increase in the flow resistance of river channels. At low flows this increase in flow resistance may be considerable, but the contrast in Mannings n between channels with and without LWD accumulations converges with increasing discharge.
- The increased flow resistance induced by LWD accumulations leads to an increase in reach mean flow depth and velocity and also an increase in the variability or diversity of flow depth and velocity within the reach.
- Reaches containing LWD accumulations are more retentive than debris-free reaches, exhibiting a higher dispersive fraction.
- These complex hydraulic effects of LWD dams have important geomorphological and ecological consequences. Therefore, a simple classification of LWD accumulations in headwater streams which reflects their gross hydraulic impact, is used throughout this report:

  'partial dams' - only extend across a part of the channel width.

  'complete dams' - extend across the complete channel width, but consist of a sufficiently leaky structure, that they have no significant impact on the water surface profile at low flows.

'active dams' - extend across the complete channel width and induce a step in the water surface profile at all flows.

Geomorphological impact:

- The hydraulic changes induced by LWD accumulations result in changes in the morphology of the channel. LWD accumulations in headwater streams are associated with a range of types of pool which play an important role in retention of water, sediment, solutes and organic matter. Upstream (dammed) pools and downstream (plunge) pools are particularly common in association with active and complete dams. Pools may occur as frequently as every 2 channel widths where LWD accumulations are unmanaged.
- Dammed pools appear to be particularly important sites for organic and mineral sediment retention, so attenuating its transfer downstream.
- Dammed pools behind major, hydraulically-active dams also serve as locations of flow avulsion during high flows. Ephemerally- and intermittently-flowing channels may establish, linked to the location of major active dams. If the dams persist for long enough, this may lead to a change in the position of the main, perennially-flowing channel.

Physical habitat:

- LWD accumulations support complex suites of hydraulic and physical conditions which promote high within-dam habitat diversity. They also induce increases in the variety and complexity of habitat in the surrounding river channel and floodplain.
- The increased diversity in flow depths and velocities within reaches containing LWD accumulations lead to an increase in hydraulic habitat diversity.
- The morphological changes induced by the hydraulic effects of LWD accumulations provide high physical habitat diversity in the form of pools of different size, riffles, and marginal benches within the channel, and the development of perennial, intermittent and ephemeral channels across the adjacent floodplain surface. The plunge and dammed pools associated with many LWD accumulations also form important refuges for aquatic fauna during low flows.
- The application of the physical habitat simulation model PHABSIM has demonstrated that the removal of LWD dams reduces both the habitat quantity and quality for juvenile and adult brown trout. Proportionately greater adult habitat was lost or reduced in quality.

Stability:

- Active dams form the most stable dam type, persisting for many years at the same location, and trapping and storing mobile debris pieces. The overall stability of LWD within headwater river channels appears to be closely linked to the presence of active dams. Active dams take the longest time to re-establish after disturbance.
- Although active dams have a major hydraulic effect, they rarely cause a rigid barrier within the river. Even if the dam is braced by an entire tree which is essentially immobile, smaller wood pieces within the structure will shift with variations in river flow. Thus, although the LWD structure settles to pond back water at low flows, water (and fish) can readily pass through it at higher flows.

5. The research results summarised above suggest that **LWD accumulations have enormous importance for the structure and diversity of physical habitat, water quality and temperature, and substrate conditions within British headwater rivers**. Active dams are particularly important in this regard, and also in stabilising and trapping LWD and sediment movement within headwater river systems. **Removal of major, active LWD dams destabilises the LWD that remains and results in the mobilisation of sediment, the incision of the channel bed and a reduction in habitat diversity.** These effects not only reflect a reduction in physical habitat diversity at the sites of LWD dam removal but also have consequences for downstream channels which will receive larger inputs of LWD and sediment.

6. **LWD accumulations also have benefits in relation to the control of runoff at the catchment scale.** Reaches containing LWD accumulations have a higher flow resistance than LWD-free reaches, although the values of Manning's n converge with increasing discharge. The hydraulic effect of LWD accumulations causes geomorphological adjustments, which result in increased within-channel and floodplain water storage. Although these effects may be relatively small when only a single LWD accumulation is considered, their aggregate effect may be very significant. LWD accumulations in headwater streams provide a potentially significant contribution to flood attenuation at the catchment scale because they help to desynchronise headwater and downstream-generated flood peaks by attenuating upstream-generated floods and increasing flow travel times from the headwaters. Similar desynchronisation of floods draining from different headwater catchments would result from contrasting land uses and thus differing amounts of LWD. Such flood attenuation advantages are at best free and at worst inexpensive if the management guidelines suggested below are implemented.

7. **River and riparian management has important effects on the distribution and character of dead wood accumulations within river systems:**

- Riparian woodland management controls the species and age of trees which input LWD to the river system.
- The harvesting of trees reduces the input of the very largest pieces of wood, which would normally form the key wood pieces in stable debris dams.
- Hydrological management involves changes in the river flow regime, which changes the frequency and distance of transport of wood pieces of different sizes.
- Channel management to increase flow conveyance involves both the reduction of the river channel's wood retention capacity and the active removal of wood from the river channel.
- In general, the impact of these types of management is to reduce the size of the wood pieces that enter and are stored within the channel system, reduce the wood retention capacity of the channel and reduce the stability of debris dams. The combined effect is that the mobility of wood increases and blockages of structures such as channel constrictions, bridge arches and weirs becomes more likely.
- These adverse on-site and downstream effects give support to the view of Benke et al. (1985) that 'Although there are certain situations that may require wood removal to eliminate stream blockage, the wisest management practice is no management'.

8. **Recommendations for reach scale LWD management.** Points (i) to (viii) below build from simple recommendations about LWD removal, through guidelines on emplacement of debris and the development of a self-sustaining system of natural debris supply.

(i) In headwater rivers, indiscriminate removal of LWD should be avoided, particularly in wooded and tree-lined reaches where LWD accumulations are a natural feature of the channel.

(ii) Some removal of LWD may be necessary under certain circumstances as indicated in Figure 3.1 by the arrow of increasing economic cost of flooding. Figure 3.1 considers reaches and their riparian land use in isolation, but there are additional advantages of considering reaches within their catchment context. For example, an increase in in-channel water storage, flow avulsion, overflow channels and flooding associated with LWD dams in areas of low economic cost and high environmental benefit, such as in semi-natural woodland areas, would have a beneficial flood-attenuation impact for downstream higher-risk areas.

(iii) Where LWD blockage of man-made structures forms a flood management problem in headwater streams, complete removal of LWD may be necessary. However, this should only be undertaken along a restricted length of the upstream river channel. Such focused removal of LWD is highly cost-effective and maximises management benefits.

(iv) Where flooding is a less severe and localised problem, selective removal of debris within affected reaches is preferable to complete removal since the major environmental benefits of LWD dams are retained when the most stable pieces of wood are not disturbed (see (vi) below)

(v) Inputs of large quantities of small wood pieces (e.g. small branches, twigs and leaves) from riparian management and forestry operations can cause excessive sealing of active dams, making them too effective a barrier to fish movement. Such wood input should be avoided or selectively (see (vi) below) rather than completely removed.

(vi) The following selective removal guidelines are applicable where there is a need to increase the conveyance of a reach but where complete clearance of debris is unnecessary. Remove debris that is:

- not anchored or buried in the stream bed or bank at one or both ends or along the upstream face;
- or is not longer than the channel width;
- unless it is LWD (i.e. longer than 1m and wider than 10 cm) which is braced on the downstream side by boulders, bedrock outcrops, riparian trees, or by pieces of large wood that are stable because they do not fall into the first two categories.

(vii) The addition of LWD improves physical habitat and counteracts stream incision, particularly where LWD has previously been cleared or where, as a result of the age structure of riparian trees, the LWD supply to the river channel is low. The introduced wood pieces should be capable of forming the key pieces in stable debris accumulations. They should be at least as long as the channel width with a diameter of at least 0.1 m or 0.05 channel width, whichever is larger. In order to increase the potential for wood to form stable structures, the spacing of the introduced pieces should reflect natural spacings of LWD accumulations (i.e. 7 to 10 channel widths). Wood pieces should be introduced into stable positions (e.g. upstream of channel constrictions or braced by boulders, bedrock outcrops, or riparian trees).

(viii) Riparian woodland is the natural source of LWD. Tree clearance and pruning close to the river channel disrupt the supply of wood. Therefore, riparian tree management should be minimised within a buffer strip along the river margin, particularly in reaches bordered by natural or semi-natural woodland. Ideally this buffer strip should be 20m wide and should consist of trees of mixed age. A 20m buffer strip is ideal because it approximates the height of mature native tree species and thus it ensures that wood delivery to the river, for example by wind throw of entire trees, simulates the rate that might be expected from a more extensive tree cover. Some initial active management of trees, including tree planting, within the buffer zone may accelerate the development of a strip of mixed age and species, which will provide a good LWD supply to the river.

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KEYWORDS

Large woody debris, headwater rivers, in-stream habitat, dead wood management.

1. CONTEXT

1.1 Introduction

The view is often expressed that there is little to be gained in undertaking research on large woody debris within the United Kingdom or, indeed, the rest of Europe, because the subject has already been studied in more than sufficient detail in North America. A very significant conclusion that can be drawn from the research that underpins this Summary Technical Report and the Main Report (R&D Technical Report W181) upon which it is based, is that such a view is incorrect. The report provides an overview of the dynamics and role of large woody debris in river systems; some research results from relatively unmanaged British headwater rivers which show many contrasts with North American observations; and it makes some management recommendations for LWD in British headwater rivers.

Section 1 defines large woody debris (1.2); describes how large wood pieces are retained in river systems, with particular emphasis on the characteristic way in which wood is retained as debris dams in headwater rivers (1.3); outlines the key North American research results concerning the role of woody debris in headwater rivers (1.4); and describes some major contrasts in the quantity, wood piece size and spacing of debris dams in North American and British unmanaged headwater rivers (1.5). All of this information provides a context for the research that is summarised in section 2.

Section 2 presents baseline information on LWD in British headwater rivers as a whole, based on an analysis of information drawn from the River Habitat Survey database (2.2). This analysis shows that virtually all river channels containing extensive large woody debris and debris dams are less than 10m wide and that the presence of woody debris and debris dams is strongly associated with riparian land use and tree density. The main conclusions drawn from field observations and experiments conducted in some relatively unmanaged woodland headwater streams in the Forest of Dean, Gloucestershire and the New Forest, Hampshire are presented in 2.3. These sites were chosen to indicate the potential benefits for British headwater rivers if there was less management of woody debris. Research results are presented on the hydraulic effects of debris dams (2.3.2); the ecological significance of these hydraulic effects (2.3.3); and the impact of debris dams on river channel geomorphology, its hydrological and ecological significance (2.3.4). Finally, the results of a rather complex, but important case study are summarised (2.3.5), which illustrate how debris dam removal can actually increase the mobility of wood within the river channel and can cause a severe reduction in physical habitat diversity through the sedimentation of pools.

Section 3 draws together the research results to propose some management recommendations for large woody debris in British headwater rivers.

1.2 What is Large Woody Debris?

The role of large wood in river channels has been the subject of much research over the last 30 years, particularly within certain regions of the USA (e.g. Alaska, Pacific Northwest, Florida, California and N. Carolina). Over this period, different abbreviations have been used to refer to the woody debris 'primarily in the form of standing dead trees and downed boles and branches, (which are) abundant in many natural forest and stream ecosystems, forming major structural features with many crucial ecological functions - as habitat for organisms, in energy flow and nutrient cycling, and by influencing soil and sediment transport and storage' (Harmon et al., 1986, p133). 'CWD' (coarse woody debris), 'LOD' (large organic debris) and, more recently 'LWD' (large woody debris) or simply 'large wood' have been the terms applied to pieces of dead wood of a variety of sizes, but now generally accepted to be pieces large than 0.1m diameter and 1.0m length. Since 'LWD' or 'large wood' are the terms used in the most recent literature, these will be used throughout this report to refer to the entire trees, root boles, trunks, logs, branches and other large pieces of wood that can accumulate within river systems.

1.3 Retention of Large Woody Debris in River Systems

Within a river system, the controls on the retention of large wood fall into four categories: forest character (tree sizes/ages, species and density); hydrological processes (both river discharge and sediment transport regimes); geomorphology (river corridor width, slope and form; river channel bank and bed sediment calibre; river channel size, style/pattern and dynamics); and management as it affects the above three groups of factors.

In less-managed systems, where river channels have a natural form and are bordered by riparian forest and woodland throughout their length, the relative importance of forest character, hydrological processes and geomorphology changes in a downstream direction.

In very small headwater streams, the character of the forest is of over riding importance. Many wood pieces are large enough to span the channel width, even being supported above the channel by the valley sides in very narrow river corridors. Once they have fallen into the river channel, large wood pieces are relatively immobile because stream discharges are not sufficiently powerful to move them. The result is an apparently random distribution of wood pieces within and across the channel governed largely by the locations of wood input to the channel and the rate of wood decay. Therefore, input mechanisms such as local tree fall as a result of bank undercutting and blow down and, in very steep terrain, processes such as mass failures of hillslopes and debris torrents, dictate the distribution of large wood within the stream system.

As streams increase in size, large wood pieces are less likely to be long enough to span or jam across the channel and are more easily moved by the increasingly powerful stream discharges. As a result, other controls begin to have a significant influence on the retention of large wood. Whilst stream discharges may not be able to move the largest pieces of wood, intermediate-sized pieces can only be retained within the river channel if structures are present to brace them against the flow. Such retention structures include the very largest wood pieces, riparian vegetation (particularly the trunks and exposed roots of riparian trees), other large roughness elements within the channel such as boulders, constrictions in the width of the channel and irregularities in the channel's planform. The result is the development of accumulations or dams of wood which are braced by a few larger 'key' pieces of wood, but which then build by trapping mobile wood pieces of all sizes. The dominant control category here is the hydrological or river flow regime, since this drives the periodic movement of wood pieces during high flows and controls the size of wood pieces that move.

Once the river channel becomes so wide that it is no longer possible for large pieces of wood to span the channel, and the discharge is sufficient to transport wood pieces of all sizes during high flows, then river geomorphology becomes the most important control on the retention of wood. In particular, the geomorphological style of river channel (meandering, braided, island braided etc.) dictates the number and type of locations for large wood retention.

Management impacts on the above groups of factors and so has important effects on the distribution and character of dead wood accumulations within river systems.

- Riparian woodland management controls the species and age of trees which input LWD to the river system. In particular, tree thinning and felling can lead to the introduction of many small pieces of wood, which are easily moved by the river and, if trapped by debris dams, can clog them and so increase their flow resistance.
- The harvesting of trees reduces the input of the very largest pieces of wood, which would normally form the key wood pieces in stable debris dams.
- Hydrological management involves changes in the river flow regime, which changes the frequency and distance of transport of wood pieces of different sizes.
- Channel management, which often involves techniques to increase the flow conveyance of river channels, involves both the reduction of the river channel's wood retention capacity and the active removal of wood from the river channel.
- In general, the impact of the above types of management is to reduce the size of the wood pieces that enter and are stored within the channel system, reduce the wood retention capacity of the channel and reduce the stability of debris dams. The combined effect is that the mobility of wood increases and blockages of structures such as channel constrictions, bridge arches and weirs becomes more likely.

Although large wood plays an important geomorphological and ecological role in rivers of all sizes, its routine removal from many British rivers for flood defence purposes means that little is found in rivers wider than ca.10m and that the LWD that remains is more mobile than would be the case in less-managed systems. It is in the headwater rivers that the greatest benefits of wood retention can accrue with minimum risk of adverse consequences. This report is concerned solely with British headwater rivers; the small- and medium-sized systems discussed above, where the dominant mode of wood accumulation is the debris dam.

1.4 The Role of Large Woody Debris in Headwater Rivers

In headwater rivers, many pieces of LWD are large enough to span the river channel. Many other wood pieces, although only partly spanning the channel, have sufficient mass to remain quite stable even during high flows. The presence of these stable 'key' pieces of LWD can lead to the development of the accumulations or dams of LWD, which are so characteristic of woodland streams where routine wood debris clearance is not practised.

A great deal of research undertaken in North America over the last twenty years has shown that LWD accumulations or dams are of great importance for woodland river environments; enhancing biological diversity and productivity, regulating flows and water quality, and increasing the range of habitats within and along the river. Specifically, LWD dams affect woodland river environments in four main ways.

- First, LWD accumulations directly impact upon the hydraulics of flows within the river channel. Debris dams also increase hydrological interactions between the river channel and its floodplain by controlling the local distribution and intensity of overbank flows and by enhancing flows through the river channel bed and bank sediments around the site of the debris dam.
- Second, these hydrological and hydraulic effects of LWD accumulations enhance the storage and attenuate the transport of solutes, sediments and organic material within the river channel system and floodplain.
- Third, the influences on flow hydraulics and sediment movement affect the geomorphology of woodland river channels, resulting in an increased variability in channel size; an increase in the size, amplitude and number of pools and riffles; and an increase in overall channel stability. As a result, woodland rivers affected by LWD accumulations present a higher physical habitat diversity than those where debris dams are removed.
- Fourth, the complex physical structure of woodland river channels and their LWD accumulations provides a diversity of habitat patches which can support a wide range of organisms at different stages of their life cycles. Furthermore, LWD accumulations may have an important role in regulating water quality and in sustaining refuge habitats to protect biota during pollution episodes and high flows. In addition, the storage, breakdown and regulated release of organic matter within LWD accumulations provides temporally and spatially regulated food sources for aquatic biota.

These far-reaching effects of LWD dams are a direct consequence of their impact on flow hydraulics. As a result, a simple and useful classification of debris accumulations in headwater streams, which reflects their gross hydraulic impact will be used throughout this report:

'partial dams' - only extend across a part of the channel width.
'complete dams' - extend across the complete channel width, but consist of a sufficiently leaky structure, that they have no significant impact on the water surface profile at low flows.
'active dams' - extend across the complete channel width and induce a step in the water surface profile at all flows.

Little research has been undertaken on the role of LWD in British headwater rivers. Furthermore, there are no headwater rivers in Britain where LWD is truly unmanaged, but there are locations where wood is relatively lightly managed. The New Forest, Hampshire, is one such location, and is used here to highlight the contrasts in LWD between a relatively unmanaged British woodland environment and the old growth river systems studied in North America:

(i) The influence of LWD on the geomorphology and ecology of headwater streams is fundamentally influenced by the amount of wood and the number of debris accumulations that are present. The amount of LWD (i.e. the debris loading) reported for rivers draining old growth forests in the United States ranges from 3.5 to 85.0 kg.m^{-2}, whereas field surveys by the present authors and others in the Highland Water, New Forest, Hampshire, indicate typical LWD loadings of ca. 2 kg.m^{-2}, rising to a maximum of ca. 10 kg.m^{-2}. Thus, the debris loading in the North American research sites is very high in comparison with the New Forest, which in turn has the highest stream debris loadings of any British sites known to the authors. Furthermore, virtually all of the North American studies relate to coniferous tree species, and so little information is available for deciduous woodland, which is characteristic of many lowland British river corridors.

(ii) Debris dam spacings quoted in the literature for North American sites, are generally smaller than those in the New Forest. Whilst there is some similarity in the dam spacing observed in third order streams (ca. 4 LWD dams / 100m channel), the New Forest appears to have a lower debris dam frequency in first and second order streams than have been observed in North American studies (ca. 7 and 5 dams / 100m channel of first and second order streams in the New Forest compared with ca. 20 and 14 dams / 100m channel, respectively, in North American study areas).

(iii) Another contrast between LWD accumulations or dams in the New Forest and those described in many North American studies, is the quantity and size distribution of the wood pieces making up these structures. For example, the median length of LWD pieces within streams in the Cascade Range of Oregon and Washington, and the Coast Range of Oregon are estimated to be ca. 17m, in comparison with a median of the largest individual debris pieces in New Forest LWD accumulations of ca. 3m.

This brief comparison of observations from North American old-growth forest streams with observations drawn from the New Forest, indicates that even in a relatively unmanaged British woodland catchment LWD loadings are lower; LWD pieces are smaller; and LWD dams are more widely spaced, particularly in the smallest (lowest order) streams. Whatever the causes of these differences, they undoubtedly affect the environmental role of LWD accumulations, including their influence on flow hydraulics, channel geomorphology and ecology. These are explored in section 2.

2. LWD IN BRITISH HEADWATER RIVERS

2.1 Introduction

This section provides information on LWD in British catchments by presenting a summary of the results of analysing data from the Environment Agency's River Habitat Survey (2.2) database and from field experiments and observations undertaken by the authors (2.3).

2.2 Information derived from the RHS Database

The River Habitat Survey (RHS) has been developed by the Environment Agency to create a classification of rivers that is nationally applicable, based on their habitat quality (Raven *et al.*, 1997). LWD is recorded in the RHS within the sweep up as a feature associated with trees, and debris dams are recorded as a feature of special interest. Raven *et al.* (1998) state that, although LWD and debris dams provide a 'wild' character and habitat diversity, relatively few RHS sites have these features as a result of channel management for drainage, flood defence and fisheries. Although no size definition is given for LWD or debris dams in the RHS, descriptive definitions are provided. LWD is defined as 'trees, large branches, etc., swept downstream and temporarily occupying part of the channel' and a debris dams is defined as a 'log jam of woody debris creating an obstruction across the channel and ponding back water' (RHS 1997 Field Survey Guidance Manual). This latter definition is equivalent to the active dam type used elsewhere in this report. LWD and debris dams are recorded in the RHS as being either absent, present or extensive in each 500m RHS site, where extensive indicates that they are present on ≥33% of the site length.

Information from 4518 RHS sites in England and Wales was analysed during the research for this report. This analysis illustrated the limited quantity of LWD and of debris dams present in British rivers. For example, only 3.3% of the sites contained extensive LWD. Information on debris dams was recorded for 3030 sites. Of these, debris dams were present at 18.3% of sites and were extensive at only 0.06%.

Analysis also revealed important associations between LWD, channel size and riparian land use / vegetation. Figure 2.1 shows the cumulative frequency of sites with LWD absent, present and extensive in relation to banktop channel width. The cumulative frequency of channel widths for all data is also shown. Channels with extensive LWD tend to be smaller than channels where LWD is present, which are in turn smaller than channels containing no LWD. Figure 2.2 shows the cumulative frequency distribution of channel widths for all sites and for sites with debris dams absent and present. Debris dams tend to occur in channels with smaller than average width. This decreasing abundance of debris dams and LWD with increasing channel size is consistent with the downstream decrease in retentiveness of streams for LWD, which was discussed in 1.3. It also probably reflects more thorough removal of LWD from larger British river channels. Figures 2.1 and 2.2 clearly illustrate that virtually all river channels with extensive LWD or debris dams are less than 10m wide.

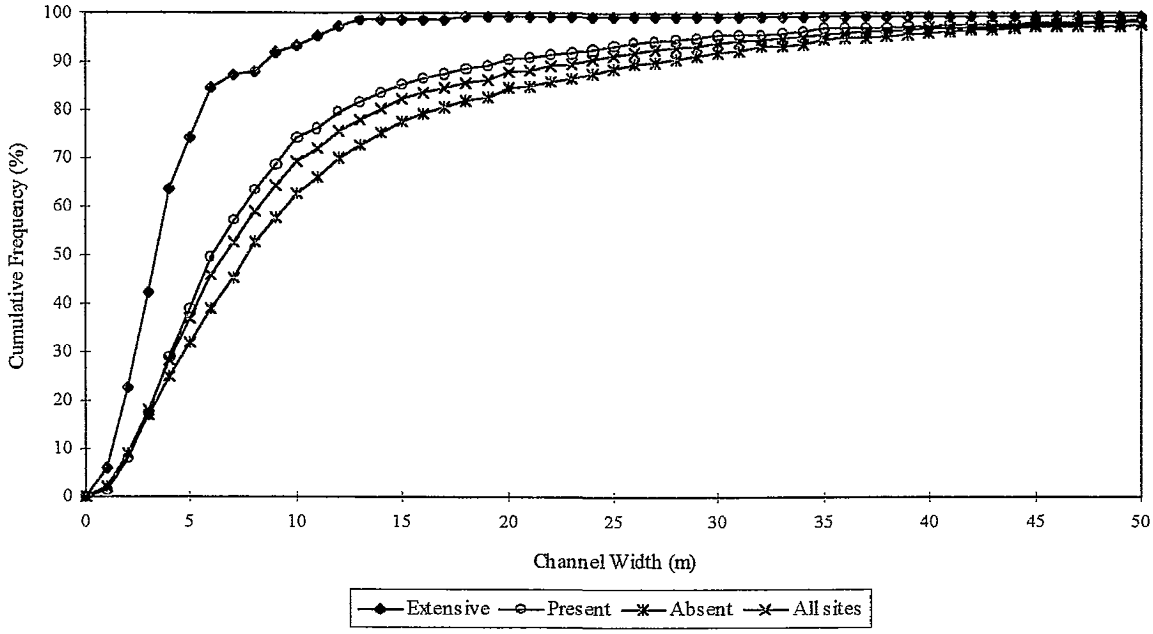


Figure 2.1 **Cumulative frequency of channel widths for all sites and with LWD absent, present and extensive.**

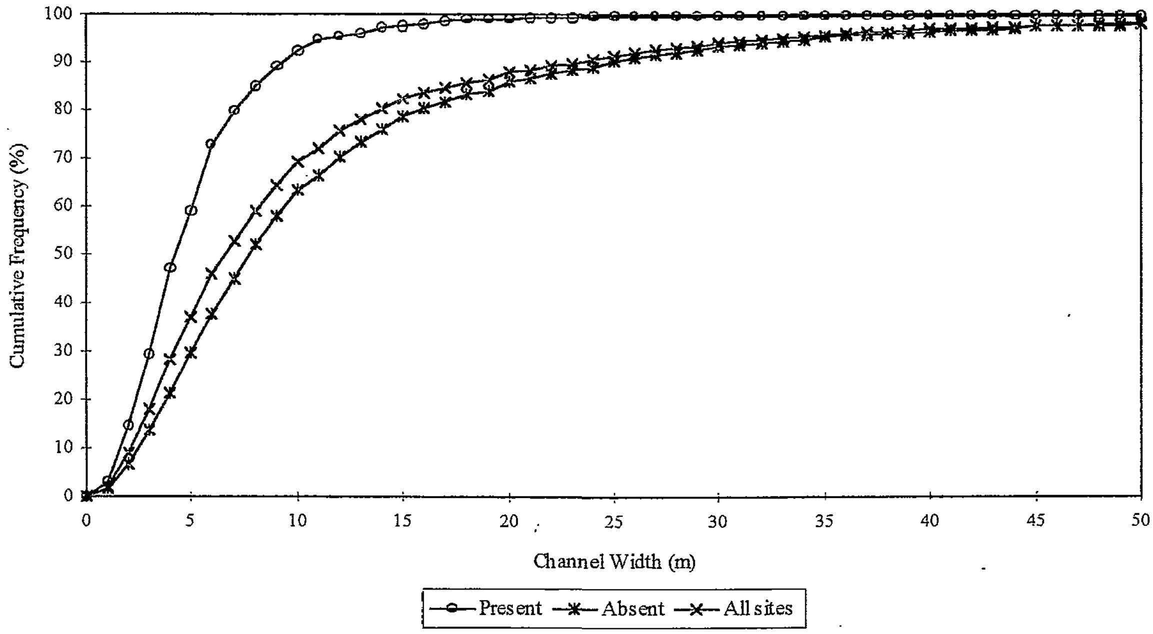


Figure 2.2 **Cumulative frequency of channel widths for all sites and with debris dams absent and present**

Riparian land use can have an important influence on LWD and debris dams because riparian vegetation acts as the local source of LWD. Both LWD and debris dams were found to be most abundant at sites with broadleaf/mixed woodland, coniferous plantation and scrub on both banks. The association between land use and the abundance of sites containing LWD and debris dams is likely to be largely a reflection of the density of riparian trees. Figure 2.3 shows the proportion of sites with LWD absent, present and extensive for differing densities of riparian trees on both banks. There is a clear trend of decreasing LWD abundance with decreasing riparian tree density. The proportion of sites with LWD extensive or present ranges from 83.8% for sites with continuous trees to 5% for sites with no trees. A similar pattern emerges when debris dams are considered. Figure 2.4 shows the proportion of sites with debris dams absent and present for each riparian tree density class. Sites with higher tree densities have a higher abundance of debris dams. For example, sites with continuous or semi-continuous trees on both banks have debris dams present on 27.3% of sites whereas sites with no trees have debris dams present for only 1.3% of sites.

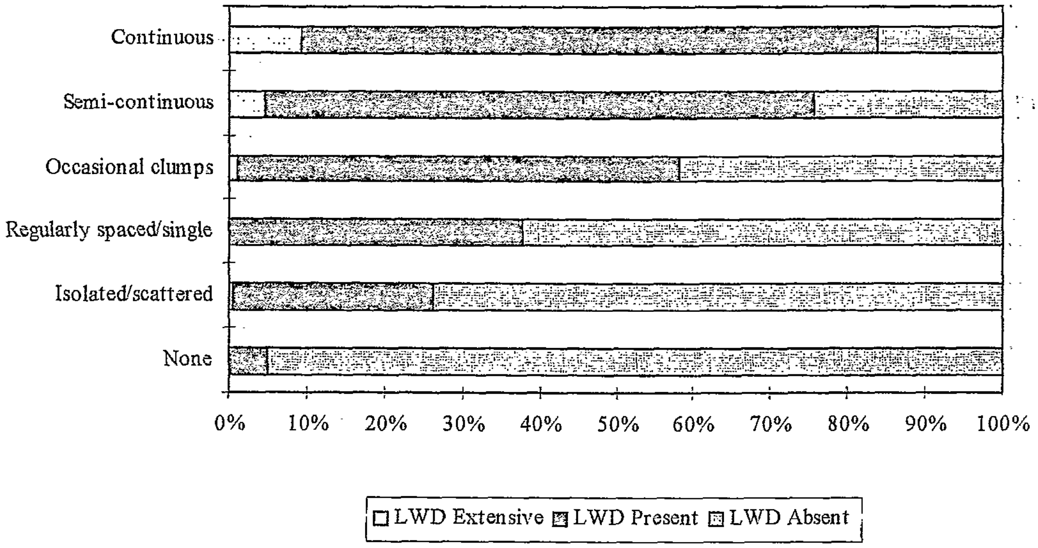


Figure 2.3 Occurrence of LWD for sites with differing level of tree density.

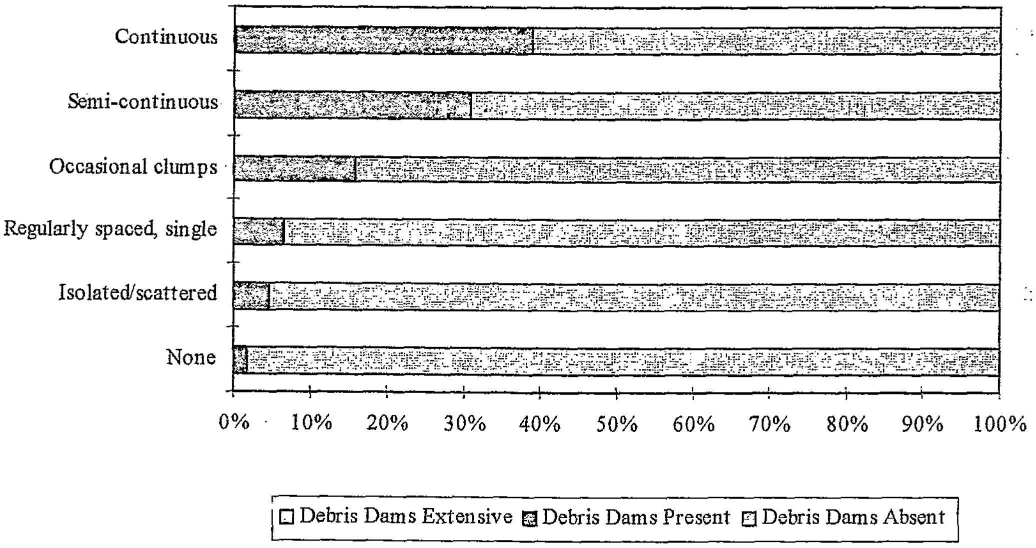


Figure 2.4 Occurrence of debris dams for sites with differing levels of tree density.

2.3 Hydraulic, Geomorphological and Ecological Impacts of LWD

2.3.1 Introduction

North American research has shown that the primary influence of LWD on river channel processes is on hydraulics. LWD dams form major roughness elements within the river channel, altering the spatial distribution, variability, range and average values of flow depths and velocities, and so increasing the hydraulic diversity within the channel. The increase in hydraulic diversity provides suitable conditions for a wider range of aquatic fauna over a wider range of discharges than a more uniform channel with lower hydraulic diversity. However, the increased roughness due to LWD is also assumed to significantly increase the local flood hazard as a result of the increased depth associated with longer flow retention times.

The hydraulic effects of LWD dams lead to changes in the erosion, transport, sorting and deposition of sediment. These changes result in increases in the diversity of substrate sediment size; in higher sediment retention within the river channel system; and in an increase in the frequency of riffles and of pools. The combined effects of LWD dams on flow hydraulics, sediment transfer and channel morphology lead to an increase in physical habitat diversity and refuge habitats and an increase in the retentiveness of the river system for organic matter that can act as a food source for aquatic organisms.

In addition to the potential increase in localised flood hazard as a result of the presence of LWD dams, another important management aspect is the stability of dams. If dams are highly unstable, they may break during flood events and the wood pieces that are released may cause obstructions at sites such as weirs and bridges, where localised flooding may be particularly undesirable.

The research results summarised here illustrate the above effects using examples from British headwater rivers in the Forest of Dean and the New Forest. LWD within these rivers remains relatively unmanaged and so the research results provide baseline information on the potential functioning of LWD within British headwater rivers in general.

2.3.2 The Hydraulic Effect of LWD Dams

Three experimental reaches were established in the Forest of Dean to investigate the effect of LWD on channel hydraulics over a range of discharges. Reach one contained no LWD in order to estimate natural variability in the hydraulic parameters over the time scale of the study. Reaches two and three contained active debris dams. For a range of discharges, depth and mean velocity measurements were taken at 10cm intervals across ca. 10 cross sections in each reach and water surface slope was determined. After measuring variations in depth and velocity across the cross sections at a range of discharges, the LWD was removed from reaches two and three. After an 8 month recovery period the measurements were repeated at a range of discharges within all three reaches. The presence of LWD dams was found to significantly change channel hydraulics:

- **Reach mean depth** was found to increase when a LWD dam was present. The removal of LWD had the greatest effect upstream of the LWD accumulations as a result of the loss of the dammed backwater. Reduction in the average depth downstream of the LWD accumulations also occurred because of sedimentation of plunge pools as a consequence of debris dam removal. The deeper areas of water associated with backwaters dammed upstream of active LWD dams and downstream plunge pools form important refuges and rest areas for aquatic fauna as well as contributing to increased physical habitat diversity.

- **Reach mean velocity** was lower when LWD dams were present. Velocity distributions along cross sections below LWD accumulations in both reach two and reach three displayed higher variability than sections above the accumulations due to the manner in which the flow passes through LWD dams. When flowing through or over LWD dams the flow concentrates where there are gaps in the LWD matrix or at the lowest points of the accumulation resulting in threads of high velocity downstream. This type of velocity pattern creates good feeding habitat for salmonids because energy expenditure is reduced by holding in the low velocity areas and there are adjacent areas of high velocity with high drift rates for feeding.. These sites also have the advantage of the additional cover provided by LWD. Upstream of LWD accumulations the width and depth of the flow is increased by the backwater created by the LWD and velocities are significantly reduced, resulting in a more uniform distribution of velocity across the channel.
- The increased **channel roughness** due to LWD is a major reason for its removal from streams and it is, therefore, important to quantify the effect of LWD on channel roughness over a range of discharges. Figure 2.5 shows that the increase in Manning's n due to the presence of LWD dams is greatest at low flow and decreases rapidly with a small increase in discharge, resulting in convergence of n with and without LWD as discharge increases. All observed flows were within-channel and further convergence would be expected as discharge approaches bankfull

Tracer experiments were carried out on 25 reaches within a 4.5km section of the Highland Water, New Forest, Hampshire during a period of sustained low flows in order to assess the impact of different types of LWD dams on reach hydraulics. Eight of the reaches contained active dams, two contained complete dams, six contained partial dams, and nine reaches without dams were monitored as control reaches.

- **Depth.** There was a significant reduction in channel size in an upstream direction over the section where data were gathered. To correct for this variation, reach depth was divided by water surface width to produce a dimensionless measure of depth. The average dimensionless depths for active/complete, partial and control reaches were 0.178, 0.088 and 0.063, respectively. The depth of active/complete reaches was statistically significantly greater than either partial or control reaches.
- **Velocity.** Average velocities for the active/complete, partial and control reaches were 0.038m.s^{-1}, 0.059m.s^{-1} and 0.084m.s^{-1}, respectively. The average velocity in active/complete reaches was statistically significantly lower than in control or partial reaches .
- **Channel Roughness.** The calculated values of Manning's n for the active/complete, partial and control reaches were calculated to be 0.963, 0.634 and 0.286, respectively. Manning's n was statistically significantly greater for active/complete and partial reaches than control reaches.

The overall hydraulic effect of LWD dams can also be usefully summarised in terms of the dead zones that are created within the river channel. Dead zones are important for nutrient retention and for stream ecology. For example, these low velocity areas create, refugia which are important for the survival of macroinvertebrates and fish during periods of high flow. The Aggregated Dead Zone (ADZ) model (Beer and Young, 1983; Young and Wallis, 1986) uses a systems approach whereby all dead zones in a reach, at all scales, are aggregated as a single dead zone which accounts for all the dispersive properties of the reach. The model is calibrated by monitoring a slug-injected solute wave as it passes through the reach. Once the Aggregated Dead Zone (ADZ) model is calibrated, the ratio of the ADZ volume to the volume of water in the reach, termed the dispersive fraction (D_F), can be calculated from the model parameters. D_F provides an objective, scale independent, measure of dispersive properties.

Two experimental reaches were established in the Forest of Dean to examine the relationship between LWD-created dead zone and discharge. One of the experimental reaches, which acted as a control, contained no LWD, whereas the other reach contained a single, active, LWD accumulation. Figure 2.6 shows the dispersive fractions of the LWD and control reaches plotted against discharge. The LWD reach displays a considerably higher D_F than the control reach, indicating its higher retentiveness and refuge potential.

2.3.3 Assessment of the Ecological Effects of Changed Hydraulic Conditions resulting from LWD Dam Removal

Using the hydraulic data from reach three in the Forest of Dean, the Physical Habitat Simulation model (PHABSIM) was used to assess the changes in the quality and quantity of physical habitat in the reach as a result of LWD removal. PHABSIM is the simulation component of the Instream Flow Incremental Methodology (IFIM), a conceptual framework for assessing instream habitat developed by the United States Fish and Wildlife Service (Bovee, 1982). The PHABSIM model uses standard hydraulic modelling techniques with data from a range of flows to predict water surface levels and velocities for cells across selected stream cross sections at a series of user-specified discharges. These hydraulic and other channel attribute data are then combined with suitability curves which quantify the suitability of these conditions for a target species life stage, to assess the quality and quantity of instream habitat for that species life stage over a range of discharges. The usable area (UA) is calculated as the total area of all cells that are usable to any degree. The weighted usable area (WUA) can be calculated using several algorithms but the one used for this study was the sum of the products of cell areas and their suitability values. The WUA, therefore, gives a combined index of habitat quality and quantity. Suitability curves for adult and juvenile brown trout were used in this research to provide an illustration of habitat changes as a result of LWD removal.

Figures 2.7 and 2.8 show some of the results of the application of PHABSIM. Figure 2.7 shows that the water surface area when a LWD dam is present increases rapidly with discharge, and is greater than when there is no LWD present in the stream. Figure 2.7 also shows the WUA calculated for juvenile brown trout. It can be seen that there is significantly greater WUA for juveniles when LWD is present in the reach. Figure 2.8 shows the WUA and total area for adult brown trout in the reach before and after LWD removal. As would be expected for a reach such as this, with relatively shallow water over most of its length, the WUA is lower than that for juvenile brown trout. As with juvenile habitat, WUA before LWD removal is considerably higher than the WUA after LWD removal and it increases with discharge, whereas without LWD WUA is low and relatively constant over most of the range of modelled flows..

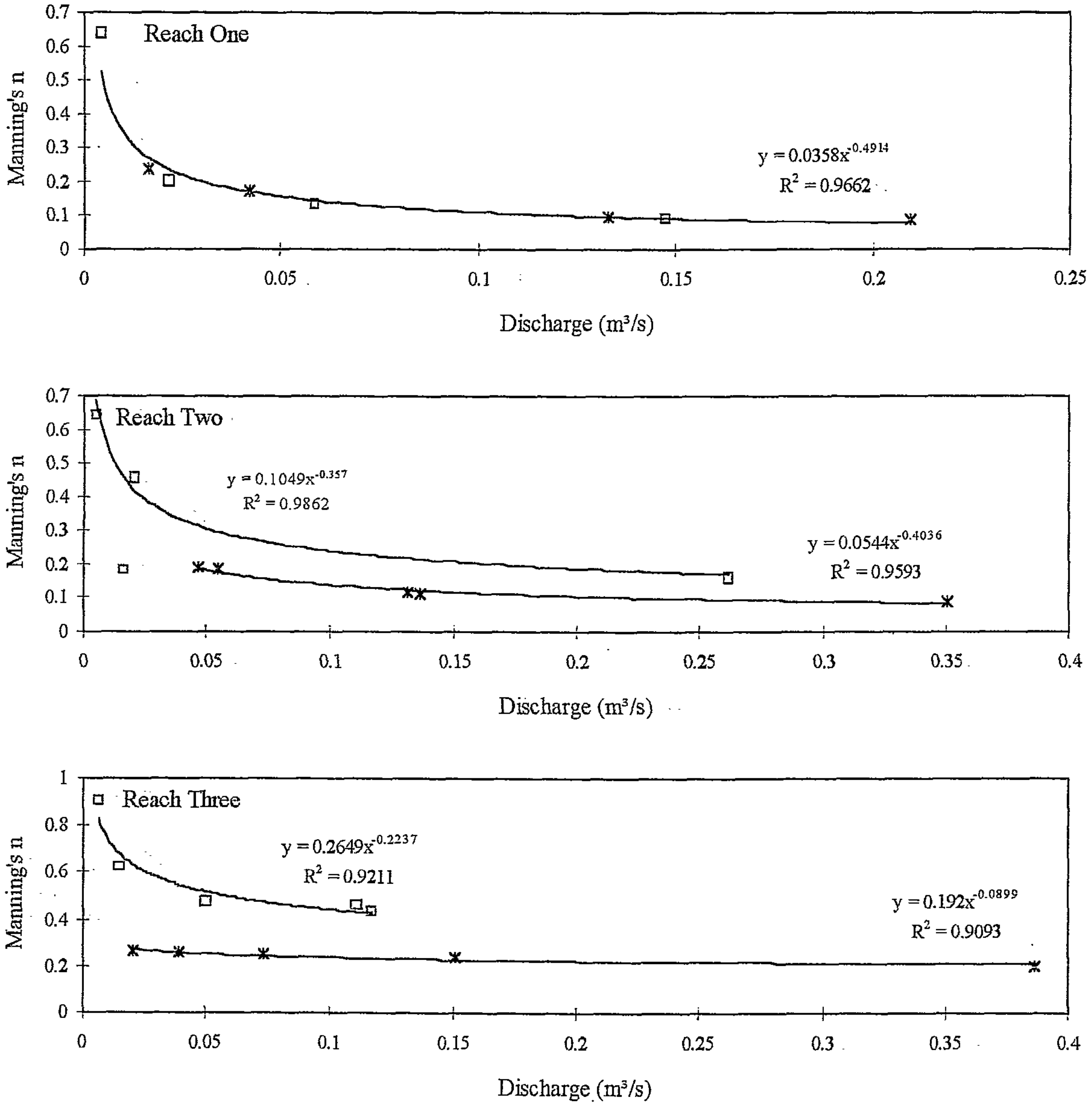


Figure 2.5 **Manning's n against discharge for reaches one, two and three with and without LWD**

It was demonstrated in 2.3.2 that at low flows hydraulic conditions with and without LWD were similar. The results presented here show that habitat quality and quantity are also similar with and without LWD at low flow, but diverge as discharge increases. The output from PHABSIM, in terms of usable area and weighted usable area, shows that for both adult and juvenile trout there is more habitat of better quality when LWD dams are present. Much of the reach is unsuited to adult trout as the flow is too shallow, which is demonstrated by the much lower percentage of total water surface area that is UA and WUA for adults. The results also show that the removal of LWD has a greater effect on adult than on juvenile habitat. This is due to the fact that, although adults are more suited to the higher velocities, the reduced depths after LWD removal have a greater impact on adults.

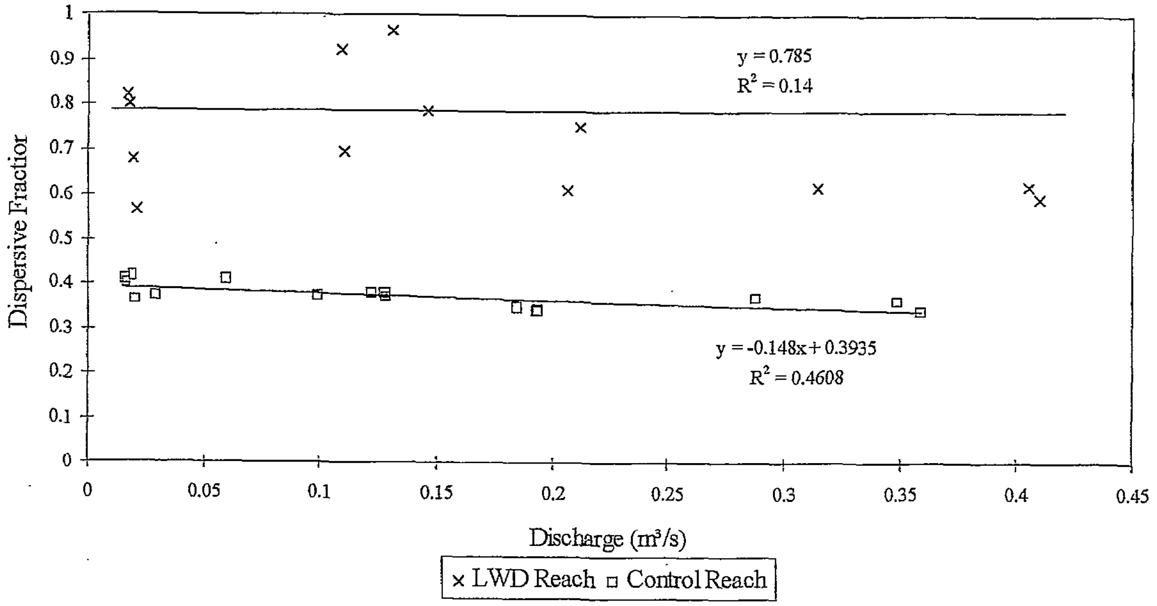


Figure 2.6 Variation in D_F with discharge for LWD and control reaches

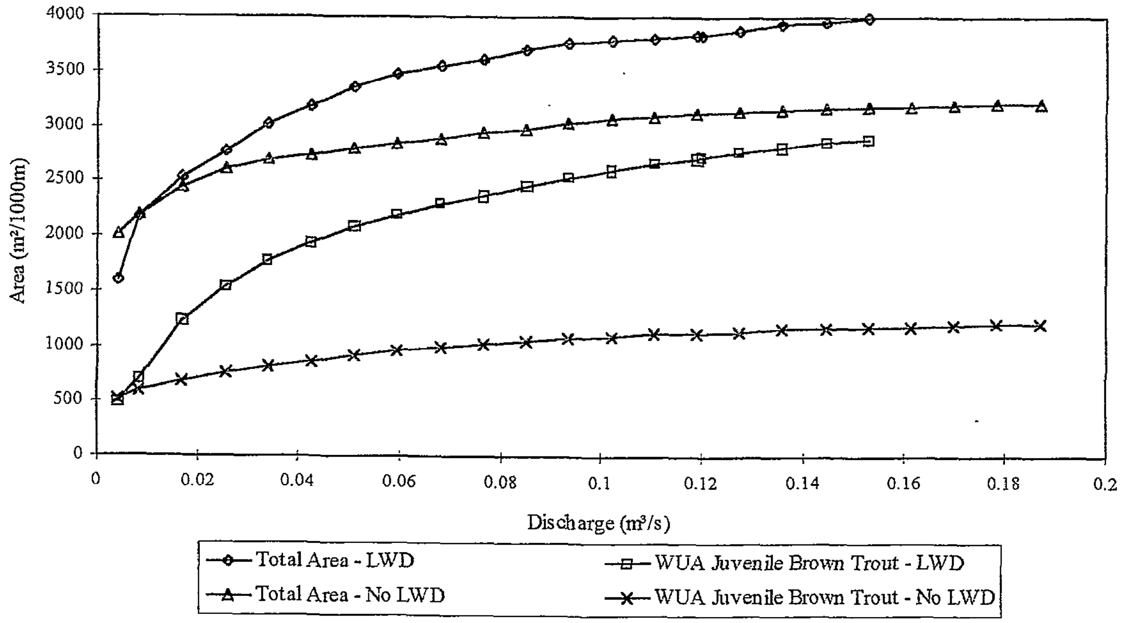


Figure 2.7 WUA and Total Area for Juvenile Trout.

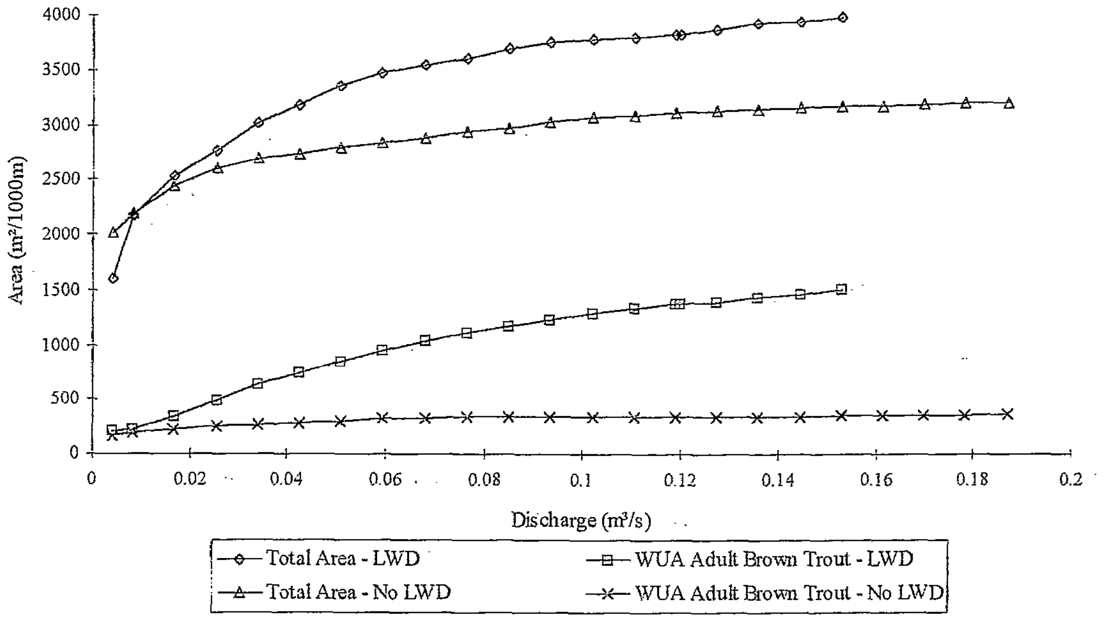


Figure 2.8 **WUA and Total Area for Adult Trout.**

2.3.4 The Geomorphology of Woodland Streams

So far the discussion has concentrated on the hydraulic effects of LWD accumulations and their ecological consequences. The hydraulic effects of LWD accumulations impact upon sediment scour, transport and deposition, and so affect the geomorphology of woodland headwater rivers. These geomorphological changes are ecologically important. This section explores the geomorphological impacts of LWD dams within relatively unmanaged headwater streams using information from the New Forest.

Pools and riffles are fundamental geomorphological elements of many types of river channel. They are a result of the erosion, transport and storage of bed sediment within the river channel. They are ecologically important, providing locations of differing flow depth, flow velocity and substrate, which contribute to the diversity of physical habitat within the river channel. It is widely accepted that naturally-occurring pools and riffles have an average spacing of 5 to 7 channel widths. However, smaller average spacings than 5 to 7 channel widths had been found in unmanaged channels as a result of the influence of LWD dams, indicating particularly high physical habitat diversity. This decreased spacing is observed in the Highland Water. Figure 2.9 plots the number of dams against pool spacing, expressed in channel widths, for 100m stretches of the Highland Water. Figure 2.9 shows (i) that the spacing between pools decreases with an increase in the number of dams; (ii) that reaches containing more than 5 dams have an average pool spacing that is less than 5 channel widths; and (iii) that there appears to be a minimum pool spacing of two channel widths. This suggests that in the Highland Water a pool spacing of two channel widths (considerably less than the generally-accepted 5 to 7 channel widths) could be achieved if there was no management of LWD.

The increased frequency of pools and riffles in channels affected by LWD is a result of the hydraulic influence of the LWD accumulations. A number of different types of pool may be associated with LWD accumulations. For example, upstream or dammed pools and downstream plunge pools occur widely in association with active dams. Pools of differing type display differences in their relative depth and sediment calibre, providing a range of hydraulic, temperature and substrate conditions.

Upstream pools dammed behind active or complete debris dams can cause avulsion during high river flows (i.e. overflow of water from the river channel onto the floodplain). Three types of channel can often be seen at avulsion sites: perennial, intermittent and ephemeral. Low flows are contained within a single perennially-flowing channel; seasonally higher flows extend into intermittently-flowing channels; and flood flows extend even more widely into ephemerally-flowing channels. If dams persist at a particular location, the above effects on the channel structure and dynamics can result in more permanent flow diversion and channel pattern change.

These impacts of LWD accumulations on both channel form and stream network structure and dynamics have both hydrological and ecological importance. The pools provide areas for surface water storage at low flows, sustaining surface water for longer periods during drought conditions. At high flows, the pools and backwaters behind LWD accumulations and water storage in ephemeral and intermittent channels result in increased flood peak travel times and attenuation of flood hydrograph shape. Further hydrological impacts of in-channel water storage behind LWD accumulations are improved hydrological connectivity between channel and floodplain and enhanced underflows within the channel bed at LWD dam locations. All of these hydrological effects have important consequences for stream ecology by greatly enhancing the hydraulic and physical habitat diversity within the channel and riparian zone and by affecting water quality.

A major management concern is the stability of LWD, since high LWD movement during floods could cause blockage and flooding around structures such as bridges and weirs. There have been no studies of the dynamics of individual LWD pieces, but there have been a number of surveys of the locations of LWD dams in the New Forest study area. These surveys show that the debris dams are far more mobile than those reported in North American studies. However, the most substantial, hydraulically and geomorphologically important, active dams are the most stable. These dams may change in type from active to complete and back over time, but they tend to persist at particular locations. Major active dams, particularly those where the key piece or pieces of LWD are particularly large, can persist for decades, acting as a retention structure for smaller pieces of debris and for sediment, and so providing an important control on the rate of downstream transfer of woody debris and sediment as well as being the most important influence on the geomorphology of woodland headwater rivers.

2.3.5 A Case Study illustrating the Impact of LWD Clearance on LWD and Pool Dynamics

Although river channels and LWD are lightly managed in the New Forest in comparison with most British rivers, occasional LWD dam clearance has occurred and channels have been straightened to aid forest plantation drainage. Observations on one section of the Highland Water, where a 600m section was channelised into a straight uniform channel in the 1960s in association with tree planting, and a major clearance of LWD dams was undertaken over a 5 km length of channel in 1989, provides insights into the impacts of LWD management. The details of the case study, which are quite complex, are described in the Main Technical Report of this research (R&D Technical Report W181). Only the summary findings can be provided here.

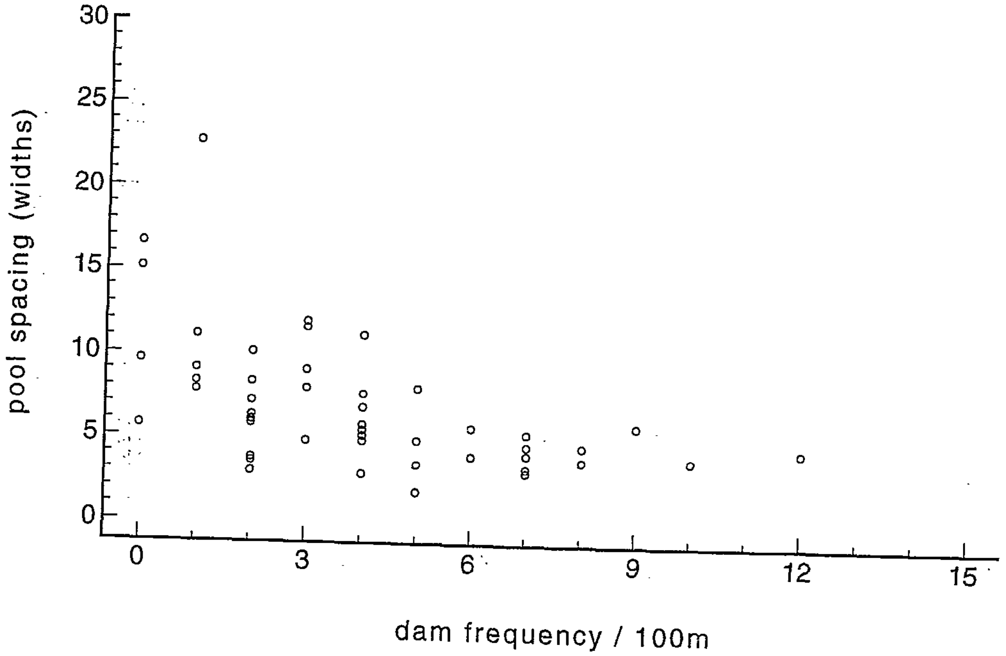


Figure 2.9 **The relationship between pool spacing (in channel widths) and debris dam frequency in the 52 100m reaches of the Highland Water in 1996/7.**

A series of six surveys of the location and type of debris dam, spanning the period 1982 to 1997, provides information on the recovery of LWD accumulations after clearance in 1989.

- Although the total number of dams in 1996/7, 8 years after LWD clearance, was greater than that in 1982, the hydraulically-important active dams had not re-established to pre-clearance levels. This is very important because complete and active dams control LWD movement, and are also highly significant for the retention of smaller organic matter and mineral sediment.
- Clusters of dams that appeared and then disappeared from some reaches within a year of debris dam clearance were mainly unstable partial dams. In the absence of active dams, LWD pieces associated with these partial dams was very mobile and was easily transported downstream during high flow events.

Comparison of geomorphological maps of the channel for 1982 and 1996/7 shows:

- A marked reduction in the number and size of pools in all but the channelised section. These changes seem to be associated with the release of stored sediment as a result of LWD dam removal.
- Particularly large reductions in pool frequency and size immediately downstream of the channelised section suggests that erosion within this section (caused by an increase in the channel slope, as a result of channel straightening, and a lack of LWD dams to dissipate flow energy and to trap moving sediment) has further increased the sedimentation of pools downstream. Here almost half of the pools observed in 1982 have disappeared completely, one third have decreased in area, and one quarter have experienced more than a 50% reduction in area.
- An increase in the number and size of pools in the channelised section can be seen in the field to result from bed scour during channel incision.
- In summary, LWD removal is associated with pool sedimentation causing both the disappearance of pools and a reduction in the size of remaining pools. High rates of erosion associated with channel incision in the straightened section have increased the rate of pool sedimentation in the reaches immediately downstream. This important change has occurred recently despite the fact that the channelisation is quite old. This indicates the importance of active LWD dams as controls of the long profile of the river, which can counteract bed incision.

3. SUMMARY AND RECOMMENDATIONS FOR MANAGEMENT

3.1 Observations on the role of LWD in British headwater rivers

This report has presented research observations from several British sites where large wood remains relatively unmanaged. The main conclusions regarding the role of LWD in British headwater rivers, based upon these observations, are as follows:

3.2.1 Hydraulic impact:

- LWD accumulations cause an increase in the flow resistance of river channels. At low flows this increase in flow resistance may be considerable, but the contrast in Mannings n between channels with and without LWD accumulations converges with increasing discharge.
- The increased flow resistance induced by LWD accumulations leads to an increase in reach mean flow depth and velocity and also an increase in the variability or diversity of flow depth and velocity within the reach.
- Reaches containing LWD accumulations are more retentive than debris-free reaches, exhibiting a higher dispersive fraction.

3.2.2 Geomorphological impact:

- The hydraulic changes induced by LWD accumulations result in changes in the morphology of the channel.
- LWD accumulations in headwater streams are associated with a range of types of pool which play an important role in retention of water, sediment, solutes and organic matter. Upstream (dammed) and downstream (plunge) pools are particularly common. Pools may occur as frequently as every 2 channel widths where LWD accumulations are unmanaged.
- Although not specifically researched for this report, dammed pools appear to be particularly important sites for organic and mineral sediment retention, so attenuating its transfer downstream. Where plentiful sediment is available, dammed pools may become filled with sediment creating a physical step in the bed profile.
- Dammed pools behind major, hydraulically-active dams also serve as locations of flow avulsion during high flows. Ephemerally- and intermittently-flowing channels may establish linked to the location of major active dams. If the dams persist for long enough, this process may lead to a change in the position of the main, perennially-flowing channel.

3.2.2 Physical habitat:

- LWD accumulations contain important and complex suites of hydraulic and physical conditions which promote high within-dam habitat diversity. They also induce increases in the variety and complexity of habitat in the surrounding river channel and floodplain.

- The increased diversity in flow depths and velocities within reaches containing LWD accumulations lead to an increase in hydraulic habitat diversity.
- The morphological changes induced by the hydraulic effects of LWD accumulations provide high physical habitat diversity in the form of pools of different size, riffles, and marginal benches within the channel, and the development of perennial, intermittent and ephemeral channels across the adjacent floodplain surface. The plunge and dammed pools associated with many LWD accumulations also form important refuges for aquatic fauna during low flows.
- The application of the physical habitat simulation model PHABSIM has demonstrated that the removal of LWD reduces both habitat quantity and quality for juvenile and adult brown trout. Proportionately greater adult habitat was lost or reduced in quality.

3.2.3 Stability:

- LWD accumulations have been shown to be less stable in British headwater rivers than has been observed in North American studies. Active dams form the most stable dam type, persisting for many years at the same location, and trapping and storing mobile debris pieces. The overall stability of LWD within headwater river channels appears to be closely linked to the presence of active dams. Active dams take the longest time to re-establish after disturbance.
- Although active dams have a major hydraulic effect, they rarely cause a rigid barrier within the river. Even if the dam is braced by an entire tree which is essentially immobile, smaller wood pieces within the structure will shift, mainly as a result of flotation, with variations in river flow. This means that although the LWD structure settles to pond back water at low flows, water (and fish) can readily pass through it at higher flows.

3.2 Recommendations for LWD management

The research results summarised above suggest that LWD accumulations have enormous importance for the structure and diversity of physical habitat, water quality and temperature, and substrate conditions within British headwater rivers. Active dams are particularly important in this regard, and also in stabilising and trapping LWD and sediment movement within headwater river systems. Removal of major, active LWD dams destabilises the LWD that remains and results in the mobilisation of sediment, the incision of the channel bed and a reduction in habitat diversity. These effects not only reflect a reduction in physical habitat diversity at the sites of LWD dam removal but also have consequences for downstream channels which will receive larger inputs of LWD and sediment.

LWD accumulations also have benefits in relation to the control of runoff at the catchment scale. Reaches containing LWD accumulations have a higher flow resistance than LWD-free reaches, although the values of Manning's n converge with increasing discharge. The hydraulic effect of LWD accumulations causes geomorphological adjustments, which result in increased within-channel and floodplain water storage. Although these effects may be relatively small when only a single LWD accumulation is considered, their aggregate effect may be very significant. LWD accumulations in headwater streams provide a potentially significant contribution to flood attenuation at the catchment scale because they help to desynchronise headwater and downstream-generated flood peaks by attenuating upstream-generated floods and increasing flow travel times from the headwaters. Similar desynchronisation of floods draining from different headwater catchments would result from contrasting land uses and thus differing amounts of LWD. Such flood attenuation advantages are at best free and at worst inexpensive if the management guidelines suggested below are implemented.

The adverse on-site and downstream effects of LWD removal give support to the view of Benke et al. (1985) that 'Although there are certain situations that may require wood removal to eliminate stream blockage, the wisest management practice is no management'.

Our management recommendations, which are specifically for British headwater streams develop from North American recommendations summarised in Gurnell et al. (1995) but are tailored on the basis of our research results for the British environment:

1. First it is important to define a 'headwater river' for the purposes of applying the management guidelines. In the present context, a headwater river is a river where LWD can accumulate into dams across the entire channel. Thus the size of a headwater river in relation to LWD is one where the channel is narrower than the length of the larger pieces of wood delivered to it. On the basis of typical key wood piece lengths observed in active dams and evidence from the analysis of RHS data (see section 2), **10m seems to be a suitable upper limit of headwater river widths in British river systems.**

2. In these headwater rivers, indiscriminate removal of LWD should be avoided. This is particularly important for wooded and tree-lined sections, where LWD accumulations are a natural feature of the channel. Figure 3.1 lists a gradient of riparian land use from natural woodland to heavily urban and gives preferred in-channel and riparian zone management strategies, emphasising the importance of LWD minimising management within natural and semi-natural woodland sections.

3. Some removal of LWD may be necessary under certain circumstances as indicated in Figure 3.1 by the arrow of increasing economic cost of flooding. Figure 3.1 considers reaches and their riparian land use in isolation, but there are additional advantages of considering reaches within their catchment context. For example, an increase in in-channel water storage, flow avulsion, overflow channels and flooding associated with LWD dams in areas of low economic cost and high environmental benefit, such as in semi-natural woodland areas, would have a beneficial flood-attenuation impact for downstream higher-risk areas. The following circumstances can be viewed in a site and catchment context:

(i) Where flooding and LWD blockage of man-made structures forms a major management problem in headwater streams, complete removal of LWD may be necessary. However, this should only be undertaken along a restricted length of the upstream river channel. Such focused removal of LWD is highly cost-effective and maximises management benefits, since upstream retention of active dams will reduce the delivery of LWD to the site from which it has been removed. It also has a relatively small geomorphological and ecological impact because LWD accumulations, particularly large active dams, are retained elsewhere. Active dams are particularly important for river morphology and ecology and play an important role in attenuating the delivery of wood to downstream cleared reaches.

(ii) If flooding is a less severe and localised problem, selective removal of debris within affected reaches is preferable to complete removal since the major environmental benefits of LWD dams are retained when the most stable pieces of wood are not disturbed (see point 4. below)

(iii) Inputs of large quantities of small wood pieces, particularly small branches, twigs and leaves from riparian management and forestry operations can cause excessive sealing of active dams, making them too effective a barrier to fish movement. Such wood input should be avoided. If small wood pieces from the above activities become a problem, selective removal (see point 4. below) rather than complete removal is recommended. If the riparian forest is not being managed, it is extremely unlikely that any LWD accumulations will present a problem for fish movement and so debris removal is unnecessary.

4. When debris removal is necessary, selective rather than complete removal is preferable. Again, risks and benefits must be assessed in relation to the type of riparian land use associated with the headwater reach and also in association with the potential risks and benefits for downstream reaches. The following guidelines are relevant where excessive amounts of small wood pieces have entered the channel or where there is a requirement to increase the conveyance of a reach but where complete clearance of debris is unnecessary. Remove debris that is:

(i) not anchored or buried in the stream bed or bank at one or both ends or along the upstream face; or is

(ii) not longer than the channel width; unless it is

(iii) LWD (i.e. pieces longer than 1m and wider than 10 cm) which are braced by boulders, bedrock outcrops, riparian trees, or by pieces of large wood that do not fall into categories (i) or (ii).

5. LWD accumulations are a natural component of headwater streams bordered by riparian woodland. The addition of LWD will improve physical habitat in woodland streams where LWD has previously been cleared or where, as a result of the age structure of the riparian trees, the LWD supply to the river channel is low. It will also help to counteract channel incision and the downstream delivery of high, pulsed sediment loads. The introduced wood pieces should be capable of forming the key pieces in stable debris accumulations, so they should be at least as long as the channel width with a diameter of at least 0.1 m or 0.05 channel width, whichever is larger.

In order to further increase the potential for wood to form stable structures, the spacing of the introduced pieces should reflect expected natural spacings of LWD accumulations. Based upon our field observations, a spacing of approximately 7 to 10 channel widths is appropriate. Wood pieces should be introduced into stable positions such as upstream of channel constrictions or braced on the downstream side by boulders, bedrock outcrops, or riparian trees. Where necessary, wood pieces can be secured to prevent downstream movement, but wherever possible, it is preferable to leave the introduced wood loose to adjust its position, move locally and settle unconstrained into the channel.

6. Riparian woodland is the natural source of LWD. Tree clearance and heavy pruning close to the river channel disrupt the supply of wood to the river. Therefore, riparian tree management should be kept to a minimum within a buffer strip along the river margin, particularly in reaches bordered by natural or semi-natural woodland. Ideally this buffer strip should be 20m wide and should consist of trees of mixed age and size. A 20m buffer strip is ideal because it approximates the height of mature native tree species and thus it ensures that wood delivery to the river, for example by wind throw of entire trees, simulates the rate that might be expected from a more extensive tree cover. Where this approach is adopted to accompany forestry operations, some initial active management of trees, including tree planting, within the buffer zone will accelerate the development of a strip of mixed age and possibly mixed species woodland, which will provide a good LWD supply to the river.

Points 2. to 6. build from simple, easily applicable recommendations about LWD removal, through more far-reaching guidelines on emplacement of debris and the development of a self-sustaining system of natural debris supply. Whilst a more sophisticated approach to removal than complete clearance (points 2. to 4.) is easily supported on both cost-benefit and environmental grounds, a more holistic management of the riparian-river channel system through the development of riparian woodland buffer zones has cost implications which need to be set against the enormous environmental benefits for the river corridor. Figure 3.1 attempts to summarise some of these management suggestions and to emphasise that the environmental gains resulting from sensitive LWD management achieve a maximum in headwater streams with natural or semi-natural riparian woodland. LWD has environmental benefits wherever it occurs but as riparian land use becomes more intensive, the economic consequences of flooding become more severe and LWD dams become more difficult to sustain because of low wood input rates and a reduction in wood piece sizes.

Figure 3.1 Management suggestions for LWD in British headwater rivers

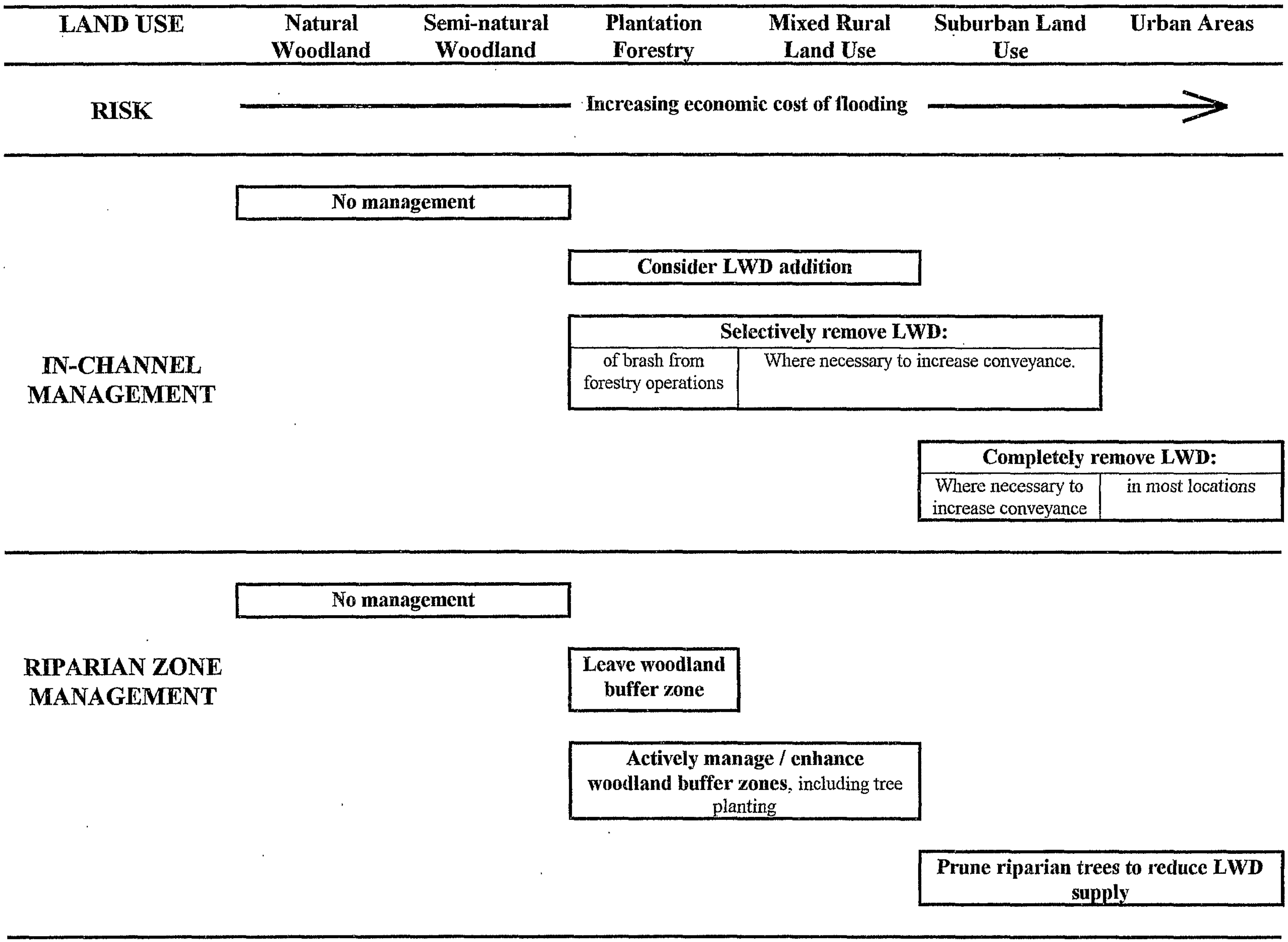
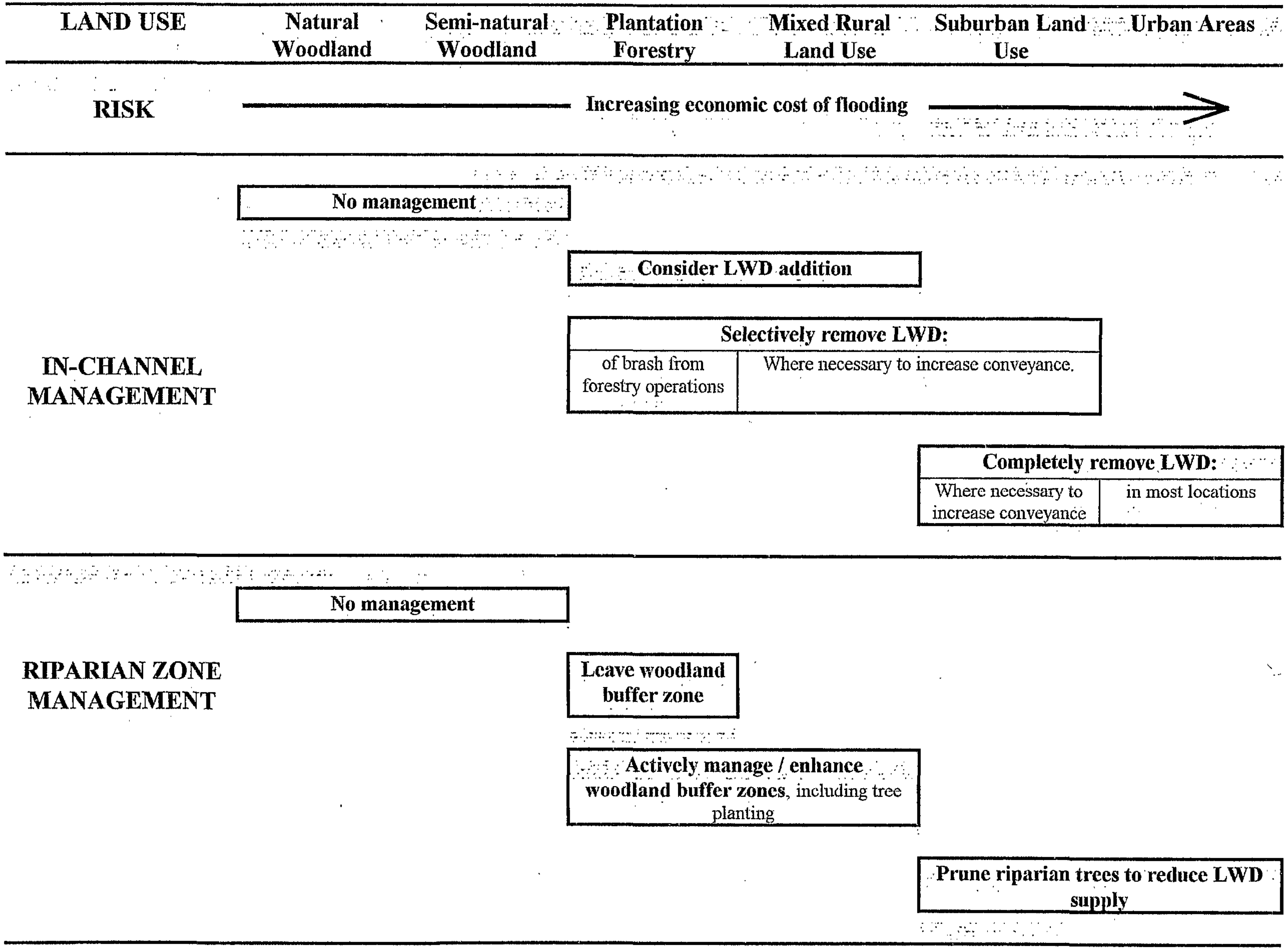


Figure 3.1 Management suggestions for LWD in British headwater rivers



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