Summary of Evidence from UK studies on the Contribution of Forestry to Flood Alleviation

Introduction

Forests have long been associated with an ability to reduce flood flows (McCulloch and Robinson, 1993), although the issue is complex and continues to be debated. This partly reflects the large number of variables involved, such as the type and size of flood event, the scale and nature of forest cover and the baseline land use, but also the difficulty of measuring the effects of land use change on extreme flows. The ultimate evidence relies on observing/demonstrating a significant change in an extreme flood peak (e.g. one with a <1% probability of occurring in a given year), ideally in response to forest planting at a large catchment scale. Aside from the practical difficulty of achieving a sufficient level of land use change to make a difference at this scale, the need for many years of baseline and post-planting data both for an experimental catchment and a nearby control (which should not be subject to any significant land use changes during the study period), explains the absence of such 'proof'. Instead, we have to rely on small-scale catchment experiments, site/process studies and modelling for an evidence base. The results from these studies are summarised below.

Small-scale catchment experiments

A large number of headwater catchment hydrology experiments have been conducted around the world, including three main studies in the UK, at Coalburn in North England, Plynlimon in Wales and Balquhidder in Scotland. Most were established to assess the effects of forestry on water yield, rather than on extreme flows, and involve relatively steep, upland catchments, conifer forest or plantation, and felling and replanting treatments, rather than new planting.

The UK and relevant European studies show that pre-planting forest drainage can increase local peak/flood flows by 15-20%, forest growth can reduce them typically by 10-20%, and clearfelling can increase them by 10-20%, depending on scale and management factors (Robinson *et al*., 2003). A review of the studies led Robinson *et al*. (2003) to conclude that the phasing of management practices in larger forests will tend to even out their contrasting impacts on flood flows, so that forestry is likely to have a relatively small role to play in managing extreme flood flows in regional or large-scale river catchments. However, it is important to note that these studies focus on evaluating the effects of managing existing forests on flood peaks, rather than on a change of land use from a more damaging activity. They are also complicated by the old-style nature of many of the forest practices in the studied forests, such as the use of intensive cultivation and drainage treatments, large-scale clearfelling and an absence of riparian buffers. There is a strong case for expecting that present-day, UK Forestry Standard practices will reduce or eliminate some of the factors that previously acted to locally enhance flood flows in conifer plantations, increasing the ability of established forests to reduce flood risk.

Site/process studies

The strongest evidence and the basis of much of our understanding of how trees and their management affect the generation and conveyance of flood flows is derived from studies of hydrological processes. Our knowledge of the different processes can be summarised as follows:

1. The potentially higher water use by trees, especially conifers, compared to shorter vegetation can reduce the volume of flood waters at source. Nisbet (2005) describes how the evaporation or 'interception' of rain water from tree canopies can reduce the volume of rainfall landing on the ground by 40% or more on an annual basis. While the effect diminishes for shorter-periods of intense rainfall associated with flash floods,

Calder (2003) noted that interception loss as a proportion of rainfall could still be up to 6-7 mm/day for conifers. Reductions in flood runoff of 10% or more may therefore be possible for complete conifer forested areas (Nisbet and Thomas, 2006). The lower interception loss of broadleaves of 1-2 mm/day means that their contribution will be much smaller (<5% for a complete broadleaved cover), especially for flood events during the leafless period.

In addition, despite the daily limit on interception losses by trees, the cumulative effect of the higher water use over consecutive days can lead to drier soils and a build-up of a higher soil moisture deficit during the growing season. This can amount to 10s of mm of additional potential soil water storage available under trees in drier parts of the country (Calder *et al*, 2003; Green *et al*., 2006), which could help to significantly reduce flood runoff during summer storms. With climate warming predicted to lead to more extreme summer rainfall events, this could become an increasingly important contribution in the future. Unfortunately, the soil-drying effect is usually lost after re-wetting of soils in the autumn and therefore has less influence on winter floods.

2. The higher infiltration rates of woodland soils, especially compared to those under agriculture impacted by livestock grazing or arable cropping, can reduce rapid surface runoff and flood generation. A tree cover protects soils from physical disturbance and together with leaf fall and tree rooting, helps build-up soil organic matter and creates good soil structure. The development of an interconnected system of soil pores or 'macroporosity' under trees encourages rainwater to enter the soil and follow deeper pathways to streams. While this effect is lost as poorly or imperfectly drained soils become saturated following prolonged wet weather, often a characteristic of extreme winter floods, it can help to slow the generation of flood waters from other soils and at other times of the year. A notable example is freely draining soils on moderate or steep slopes that have typically developed a compact surface turf as a result of many years of sheep trampling and grazing. Studies at Pont Bren in Wales found that soil infiltration rates were up to 60 times higher within young native woodland shelterbelts compared to grazed pasture soils (Bird *et al*., 2003).

3. The greater hydraulic roughness exerted by trees, shrubs and large woody debris (LWD) along streamsides and within floodplains acts as a drag on flood waters, slowing down flood flows and enhancing flood storage (Thomas and Nisbet, 2007). Work by Chow (1957) demonstrates how the hydraulic roughness associated with a dense stand of willow coppice on the floodplain can be >5 times that of grass. The presence of LWD dams has a particularly important role to play, especially where watercourse channels are incised and disconnected from their floodplains. These porous/leaky structures help to raise water levels upstream, promote out-of-bank flows and their interaction with floodplain vegetation, and as a result, slow flood flows and increase flood storage. The Slowing the Flow at Pickering Project is demonstrating how the installation of a large number of LWD dams in appropriate locations can help to attenuate flood flows (see below).

4. The ability of trees to protect the soil from erosion and interrupt the delivery of sediment via runoff to watercourses (due to the above factors) helps to maintain the capacity of river channels to convey flood waters downstream, reducing the need for regular dredging. A riparian woodland buffer is able to filter and retain sediment in surface runoff from upslope land, while tree rooting by bankside trees can be very effective in strengthening and protecting river banks from erosion. Well managed woodland is generally associated with much lower sediment losses compared to other land use activities (Collins and Walling, 2007).

Modelling studies

A wide range of hydrology and hydraulic models have been used to evaluate the impact of forestry on flood flows, which usually involves calibrating the model to a test catchment, altering one or more factors to reflect our understanding of how trees affect flood processes, and then re-running the model to predict the effects of tree planting or removal. Examples include the modelling of the combined water use and infiltration effects of trees at Pont Bren in Wales, which predicted that targeted planting of shelterbelts or the complete afforestation of the headwater catchment could reduce an extreme flood peak (1 in 180 year flood) by an average of 5% and 36%, respectively (McIntrye and Thorne, 2013). Other modelling studies have found forestry to reduce flood peaks by between 0 to 3% for riparian planting and 0 to 46% for complete afforestation, with the wide range in values reflecting differences in woodland and catchment type, size and season of flood event, baseline land use, and the nature of the model, including representation of relevant processes (McIntrye and Thorne, 2013). Thomas and Nisbet (2012) modelled the hydraulic impact or reintroducing LWDs dams into small watercourses and found that individual dams could delay the passage of a flood peak by an average of 2-3 minutes.

A number of studies show that forest location can have a disproportionate effect on flood flows, with targeted, small-scale (40 ha; <1% of catchment area) planting in the floodplain of the River Laver catchment in North Yorkshire predicted to reduce a 1 in 100 year flood peak by 1-2% (Nisbet and Thomas, 2008). Similarly, modelling at Pickering in North Yorkshire found that planting 50 ha of riparian woodland (<1% of catchment) and constructing 100 LWD dams could reduce a 1 in 25 year flood peak by 4% and a larger 1 in 100 year event by 8% (Odoni and Lane, 2010). This study was unusual in suggesting that the attenuation effect increases with flood size, which was thought to be due to the lack of connectivity between the river channel and floodplain in the Pickering Beck catchment. Notably, the percentage reduction was much greater (15-20% in the case of the 1 in 25 year flood) when expressed in terms of the margin needed to achieve the critical flow at which major flooding began in the town. This highlights the potential for limited woodland planting to make a significant contribution to flood risk management as part of an integrated package of measures.

Important caveats

The scope for trees to alleviate flooding is expected to generally decline with increasing catchment size. This is due to various factors, including the decreasing opportunity to affect a sizeable level of land use change, the potential for any effect to be swamped or opposed by concurrent/other land use or land management changes, and the increased dominance of river channel processes and river engineering within larger catchments. In general terms, smaller catchments up to 100 km^2 in area are likely to present the greatest opportunity for existing woodland or new planting to influence flood flows. Protecting major towns and cities within larger river catchments will continue to rely on conventional flood defence measures, although co-ordinated and appropriately located woodland creation could complement their effectiveness, especially in helping to address predicted increases in flood risk due to climate change.

Another important caveat is that the ability of trees to affect flood generation and conveyance is strongly influenced by woodland design, such as the type of tree, tree age, tree density, woodland shape and woodland structure. Management factors are also very important, with forestry practices having the potential to reduce or temporarily reverse the forest contribution, for example as a result of clearfelling. Guidance is available to help manage the impact of these factors.

Lastly, it is important to note that woodland planting, especially within riparian and floodplain areas, has the potential to increase flood risk. In particular, flood levels are likely to be increased within and for a short distance upstream of such planting, posing a greater risk of flooding to any properties or assets in the immediate vicinity. This is easily controlled through careful site selection. Secondly, there may be an increased risk of the washout of woody debris, which can potentially block downstream bridges and culverts, increasing local flooding at affected locations. This is a wider concern and more difficult to manage, but will depend on the sensitivity of these structures to blockage and the level of maintenance employed. There is anecdotal evidence to suggest that the development of a network of LWD dams could actually help to retain inputs of LWD, reducing the risk of washout. Finally, the slowing effect of concentrating riparian and floodplain woodland planting along a single tributary could serve to synchronise, rather then desynchronise flood flows downstream, resulting in higher flood peaks. This can be controlled by careful site selection and a whole-catchment approach to flood risk planning and management.

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