07 - IMPACT OF BLANKET PEAT FOREST HARVESTING ON STREAM FLOW REGIME – A CASE STUDY IN THE BURRISHOOLE CATCHMENT, CO MAYO.

Liwen Xiao[1], Mark Robinson[2], Michael Rodgers[1], Mark O'Connor[1], Connie O'Driscoll[1], Zaki-ul-zaman Asam[1]

[1] *Department of Civil Engineering, National University of Ireland, Galway, Ireland*

[2] *Centre for Ecology and Hydrology, the UK*

Abstract

Approximately 10 % of Ireland's land area is covered by forest, planted mostly since the 1950s, with approximately 80% of this being coniferous (Carey 1999). The land chosen for forestry was of poor quality and was generally unsuited to agriculture; planting on blanket peat land was especially targeted. By the end of 2000, about 300,000 ha of blanket peat was afforested in Ireland (EEA, 2004). Many of these upland blanket peat forests contain the headwaters of salmonid and mussel rivers and drinking water sources and are sensitive to water pollution and hydrological alterations. As the forest planted before 1980s are reaching harvestable age, great attentions have been paid on the possible impact of harvesting these forests on receiving water quality and hydrology (Rodgers et al. 2010a, 2010b, Coillte Teo 2007).

The aim of this study was to investigate the impact of upland blanket peat forest harvesting on flow regimes in the Burrishoole Catchment. The Burrishoole catchment, located in County Mayo in the west of Ireland, consists of important salmonid productive rivers and lakes (Figure 3). About 18 % of the catchment is covered by forests that were planted in the 1970s and which are now being, or about to be, harvested. The study site (9°55'W 35°55'N), which is a sub-catchment of the Burrishoole catchment, is drained by a small first-order stream (Figure 3) and was planted with lodgepole pine (Pinus contorta) between January and April, 1971. The stream is equipped with two flow monitoring stations at stable channel sections, one upstream (US) and the other downstream (DS) of the experimental area (Figure 3). A H-flume, a water level recorder and a data logger were installed at both US and DS stations, along with a tipping bucket rain gauge at the DS station (Figure 3). The US station measures flows from the control area of 10.8 ha (area A in Figure 3) and the DS station receives flow from the control and experimental areas, giving a total combined area of 25.3 ha (areas A and B in Figure 3). The study site has an average peat depth of more than 2 m. In the catchment, the mean annual rainfall is more than 2000 mm and the mean air temperature is about 11 ^{o}C. Hillslope gradients in areas A and B (Figure 3) average 8^{o} and range between 0^{o} – 16^{o}. Bole-only harvesting was conducted in area B (Figure 3) from July 25th to September 22nd, 2005. Continuous measurements of stream flow upstream and downstream of the felling coupe commenced over a year earlier in Spring 2004. The results indicated that forest harvesting increased water yields and base flows but had very limited impact on flood risk downstream (Figure 2).

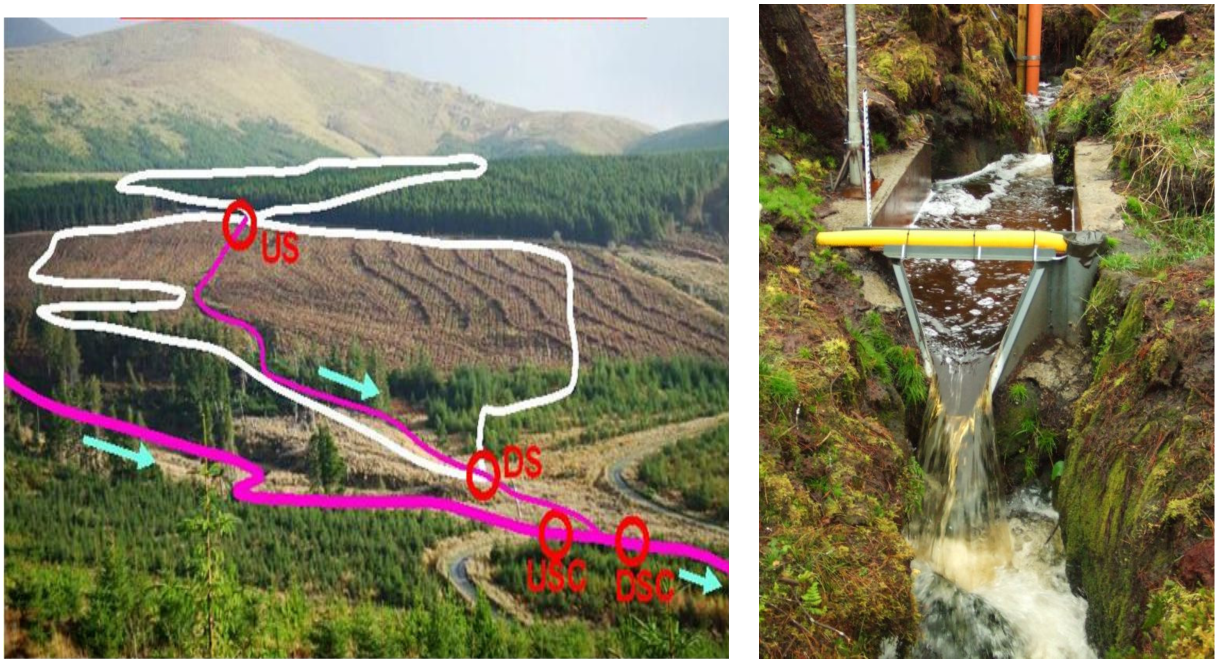

Figure 1. The study site and flume

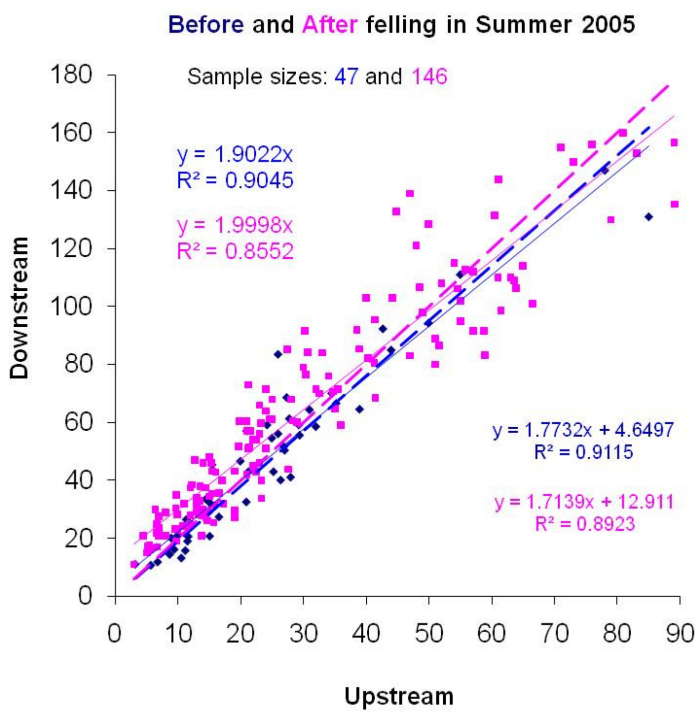

Figure 2. Comparison of peak flows before and after harvesting

1. Introduction

By the end of 2000, about 300,000 ha of blanket peat was afforested in Ireland (EEA, 2004). Many of these blanket peat forests contain the headwaters of salmonid and mussel rivers and drinking water sources, which are sensitive to water pollution and hydrological alterations. As the forest planted before 1980s are reaching harvestable age, great attentions have been paid on the possible impact of harvesting these forests on water quality and stream flows (Rodgers et al. 2010, Coillte Teo 2007).

Previous studies have indicated that forest harvesting would impact stream flow regime of the catchment. Bosche and Hewlett (1982) reviewed 94 experimental catchments and concluded that stream flow response to harvesting depends on the climate, especially the precipitation. Bruijnzeel (1988) indicated that whether the stream base flow increase or decrease after harvesting depends on the surface infiltration and evapotranspiration of the catchment. In temperate zones, base flow increase after harvesting was almost uniformly observed (Hornbeck et al. 1993, Brown et al. 2005). While increase in the intensity of peak flow and decrease in the time of concentration of flow after deforestation was reported (Hubbart and Matlock 2009), the forest harvesting impacts on floods may be small when soil conditions were maintained (DeWalle 2003, Robinson and Dupeyrat 2005). In Britain, Robinson and Dupeyrat (2005) carried out the first comprehensive study on the impact of harvesting on stream flow regimes in the Plynlimon research catchments in Wales and found that (i) the cutting of the forest increased total annual flows and augmented low flows and (ii) there was lack of impact of harvesting on storm peak. However, very few studies were conducted in upland blanket peat sites with temperate wet conditions. With shallow water tables and a low hydraulic conductivity at depth, blanket peatlands tend to generate rapid runoff and have shorter lag times and higher peat flows in response to rainfall events (Grayson et al. 2010, Rosa and Larocque 2008, Evans et al. 1999). Due to differences in tree species, soil types, forest management, catchment characteristics and climate, it is unclear how harvesting the upland blanket peat forests affect the stream flows in Ireland. Therefore, the objectives of this paper were to assess the impact of harvesting on water yield and flow regimes in the upland blanket peat in the west of Ireland.

2. Site description

The Burrishoole catchment, located in County Mayo, Ireland, in the west of Ireland, consists of important salmonid productive rivers and lakes (Figure 3). About 18% of the catchment is covered by forests that were planted in the 1970s and which are now being, or are about to be, harvested. The study was carried out in two areas – Sraveragh and Glennamong, which are sub-catchments of the Burrishoole catchment. The distance between the two sub-catchments is about 5 km. The Sraveragh study site is drained by a small first order stream (Figure 1), was planted with Lodgepole Pine (*Pinus contorta*) between January and April 1971. The stream is equipped with two flow monitoring stations at stable channel sections, one upstream (US) and the other downstream (DS) of the experimental area (Figure 1b). The US measures flows from the control area (area A in Figure 3) of 7.2 ha and the DS covers the control coupe and the experimental coupe (coupes B in Figure 3) with a total combined area of 17.7 ha. In August 2005, a wind-blown tree blocked one of the collector drains, resulting in an increase of the upstream forest control area (coupe D), to about 10.8 ha (coupes A plus D in Figure 3). Meanwhile the downstream harvested area increased to about 14.5 ha due to the blockage of a drain by brash mat during the harvesting, incorporating another part of the total harvested area (coupe C). Fortunately, in both cases the additional area had the same characteristics of vegetation and soils, and the *relative* sizes of US and DS remained unchanged – US increasing only marginally from 41% of the total area to DS before harvesting and 43% afterwards. All unit area depths in this paper have been calculated using these values. The blanket upland peat soil in all four areas A - D had been double mouldboard ploughed by a Fiat tractor on tracks creating furrows and ribbons (overturned turf ridges) with a 2 m spacing, aligned down the main slope, together with several collector drains aligned close to the contour. The trees were planted on the ribbons at 1.5 m intervals, giving an approximate soil area of 3 m^2 per tree. The catchment had an average peat depth of more than 2 m above the bedrock of quartzite, schist and volcanic rock, and the peat typically had a gravimetric water content of more than 80%. The mean annual rainfall is more than 2000 mm and the mean air temperature is about 11 ^{o}C. Hillslope gradients in areas B and C average 8^0 and range between 0^o – 16^o. Bole-only harvesting was conducted in area B and C from July 25th to September 22nd 2005. The timber was harvested using a Valmet 941 harvester, and the residues (i.e. needles, twigs and branches) were left on the soil surface and collected together to form windrows. During harvesting, the boles were stacked beside the windrow for collection. A Valmet 840 forwarder delivered the boles to truck collection points beside the forest service road. To minimise soil damage, the clearfelling and harvesting were conducted only in dry weather conditions during the period from July to September 2005. Tree residues (i.e. needles, twigs and branches) were collected together to form brash mats on which the harvesting machines travelled, thus protecting the soil surface, and reducing erosion. In the lowest part of the site where the stream is deeply incised, the trees were cut with a chain saw and left behind. The non-harvested upstream area of A and D, was used as a control area in this study as it had the same type and age of trees, similar soil, hydrologic characteristics and size, as the harvested experimental area of B and C. In the experimental area, the furrows and windrows/brash mats - formed from the harvest residues – are, in general, parallel with the study stream, which is at right angles to the contours. The surface water flows along the furrows, is collected by collector drains (arrows in Figure 3) and joins the study stream.

In Glennamong two 10 ha sites which were planted with Lodgepole Pines (*Pinus contorta*) in 1975 and are drained by semi-natural drainages are chosen for the study. Two monitoring stations were established at the sites out flow (Figure 3). The area is covered by peat with the depth of about 0.5 - 1 meter. Bole-only harvesting was conducted in the study site from February 2011 to April 2011.

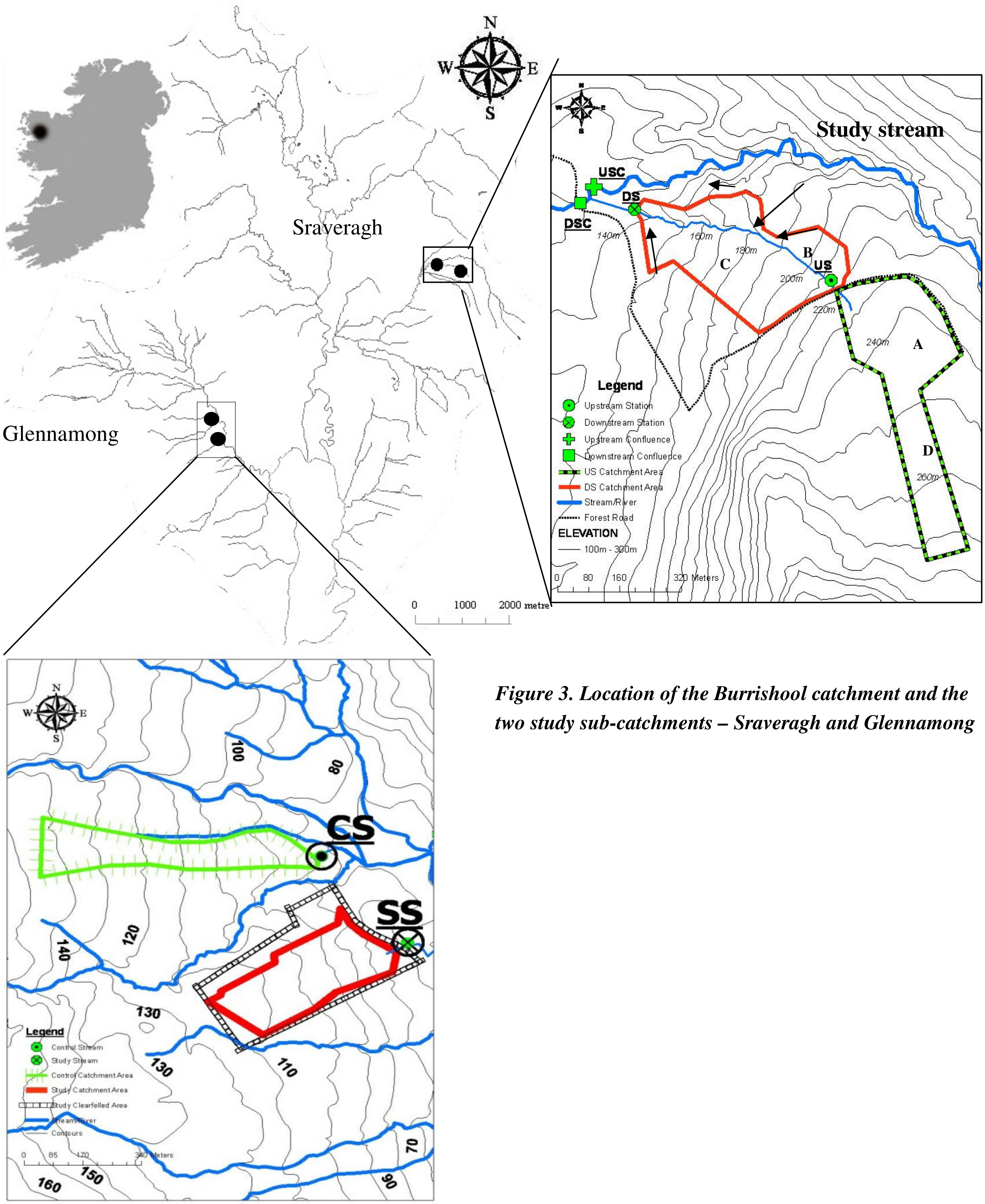

Figure 3. Location of the Burrishool catchment and the two study sub-catchments – Sraveragh and Glennamong

3. Sampling, measurement and analysis

From April 2004 - March 2005, continuous water levels in the study stream were recorded at both the upstream station (US) and downstream station (DS) in Sraveragh, and converted to flows by a rating equation based on dilution gauging and current meter measurements. In April 2005, H-flume flow gauges were installed at the sites for flow measurement. In June 2009, H-flume flow gauges were also installed at the control and study sites in Glennamong.

4. Analysis

This is a paired catchment study. One of the advantages of paired catchment studies is that they remove climate variability through the comparison of two catchments subject to the same climatic condition under different land uses (Brown et al. 2005). The impact of the felling on stream flow was assessed for monthly water yields, peak flow and base flow. The data were divided into before and after harvesting periods. March 2004 – July 2005 and July 2009 – February 2011 were used for the pre-felling control period in Sraveragh and Glennamong, respectively. September 2005 – December 2009 and April 2011 – September 2011 were used for post harvesting period in Sraveragh and Glennamong, respectively. Harvested areas (DS-US in Sraveragh and study site in Glennamong) were used as 'Experimental' sites. Control sites were untouched and used to remove the effects of any climate variability during the study period. The relationships between the different flow parameters (monthly water yield, peak flows and accumulative baseflow) of the two sites were calibrated for the pre-felling period, where the data from the control were the independent variables and the dependent variables were the parameters in the harvested sites. Then the relationships were used for the post harvesting period to estimate 'no-felling' parameters in the experimental sites using the observed data from control sites. The difference between the observed and estimated data in the control sites therefore is attributed to the harvesting. The statistical significance of any differences is determined by using Student's t-test.

5. Results and discussions

Monthly water yield

Figures 4a and 4b show the monthly water yields from the study area (DS-US) and the control site (US) before and after harvesting in Sraveragh. The pre-harvesting data was used to establish the calibration equation, where the monthly water yields in control area (US) was dependent variable and monthly flow in the study area (DS-US) was the independent variable. After harvesting, a close linear relationship was also observed between the monthly water yields of the two areas. Slightly higher monthly flow from the harvested area was observed. The calibration equation was used to predict the 'no-felling' monthly water yield in study area after harvesting, using the observed water yields in US in the same period as the independent variables. The estimated and observed water yields at DS-US after harvesting were then compared using a paired samples t-test at the 95% significance level ($P = 0.05$) (http://www.spss.com), which indicated that the observed water yields increase was not statistically significantly higher than the 'predicted' water yields ($p<0.05$). Robinson and Dupeyrat (2005) studied the impact of commercial timber harvesting on stream flow regimes in four nested catchments in mid-Wales and detected increase of total annual flows. Johnson (1998) observed 25% to 30% increase in water yield when 100% forest was harvested in the precipitation rang 800 - 2400 mm per year. In another study, Hornbeck et al. (1970) found that annual flow could increased by 40% in the year following a 100% forest clearance. The water yield increase in the harvested area was attributed to reduced canopy interception and virtual elimination of transpiration (Johnson 1998). The impact of harvesting on water yield changes depends on the reduction of forest cover in the catchment basin. A reduction in forest cover of 20% was necessary before any changes were observed (Hornbeck et al. 1993). In their study, Robinson and Dupeyrat (2005) found that the smallest catchment with the largest proportion of area felled had the greatest flow increase. Figures 4a and 4b show the monthly flows from the study and the control sites one year before harvesting and the first 6 months after harvesting in Glennamong. Significant monthly flow increase was also observed after harvesting (t-test, $p<0.1$), though the 6 months of after harvesting period was very short.

Impact of harvesting on peak flows

Figures 5a and 5b show the peak flows during the storm events at study and control sites before and after harvesting in Sraveragh and Glennamong, respectively. Slight peak flow increase was observed at both sub-catchments after harvesting. However, statistic analysis indicated that the increase was not significant. Figures 6a and 6b show the accumulative peak flows. They further confirmed that the impact of harvesting on the peak flow was small. In their studies across European, Robinson et al. (2003) found that the impact of forest harvesting on extreme flows was relatively small and difficult to detect in the North West European conifers. They complete clear felled one of their study sites - Glenturk which is close to our study sites, and only observed moderate peak flows increase. They attributed the lack of peak flow response to (1) minimum soil disturbance and (2) the presence of harvesting residues on the felled area (Robinson et al., 2003). Peak flow increases are usually due to the reduced infiltration which can be caused by soil compaction and disturbance. DeWalle (2003) also noted that where forest felling significantly increased flood flows soil was generally suffered severe disturbance. In this study, good management practices such as proper use of brash mats and harvesting only in dry weather were implemented, and soil surface disturbance were minimized (Rodgers et al., 2010).

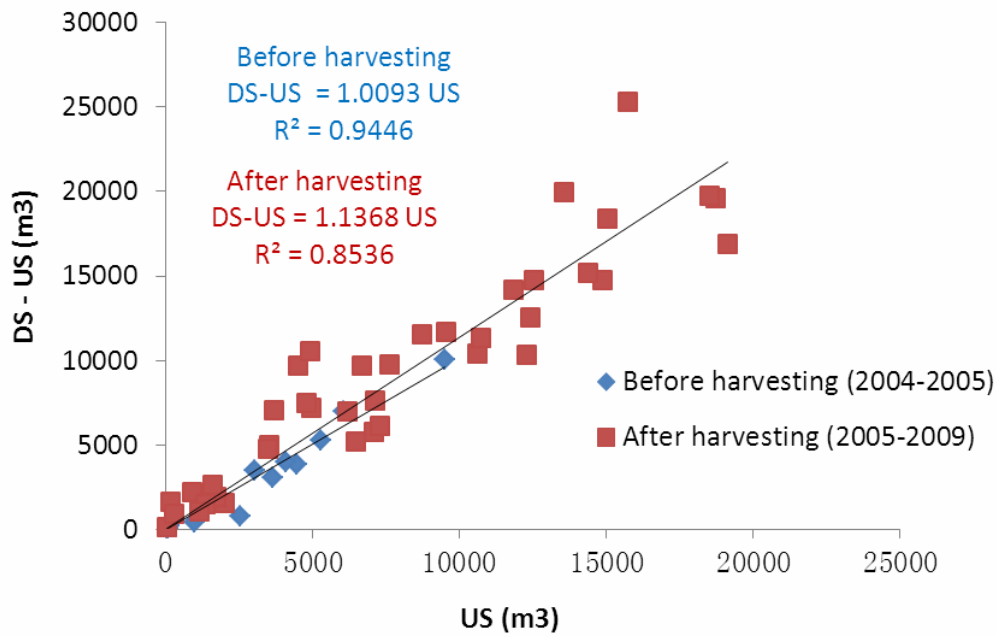

Figure 4a Monthly flow between the harvested and control areas in Sraveragh before and after harvesting

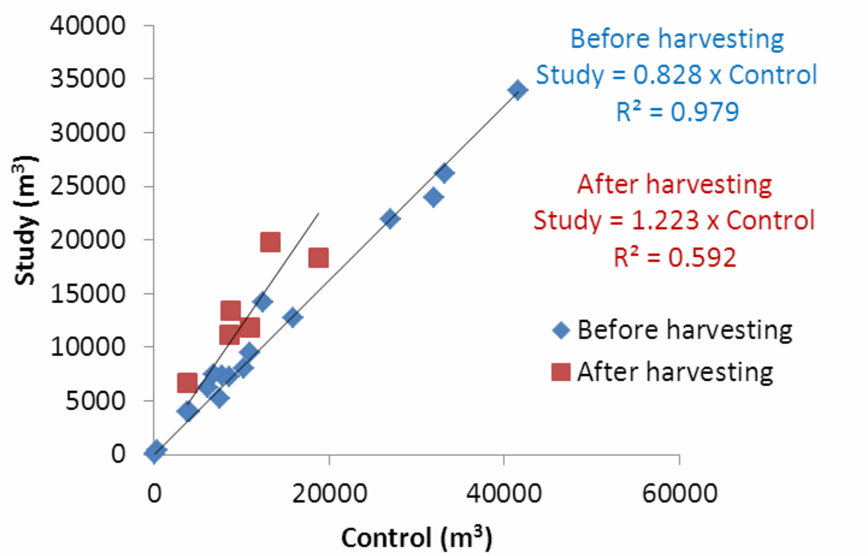

Figure 4b Monthly flow between the harvested and control areas in Glennamong before and after harvesting

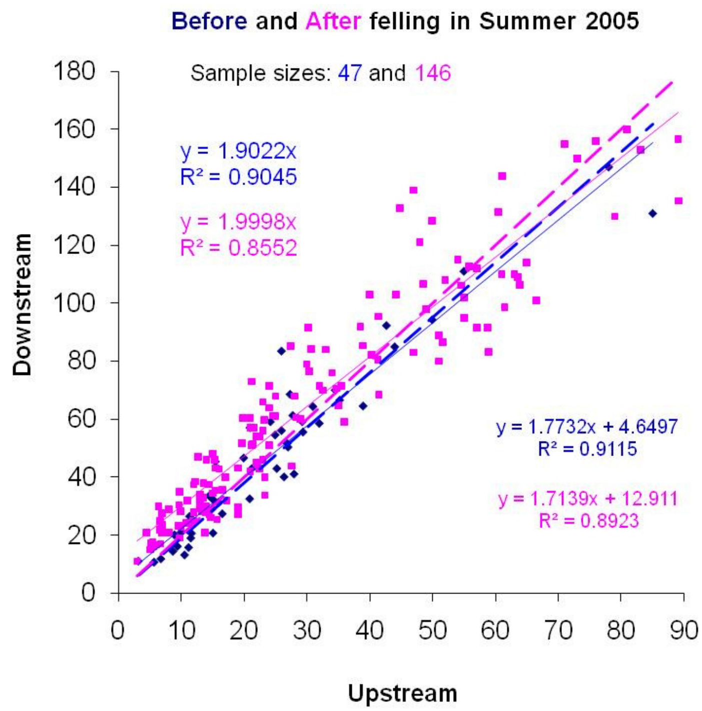

Figure 5a Peak flows before and after harvesting in Sraveragh (Robinson et al.)

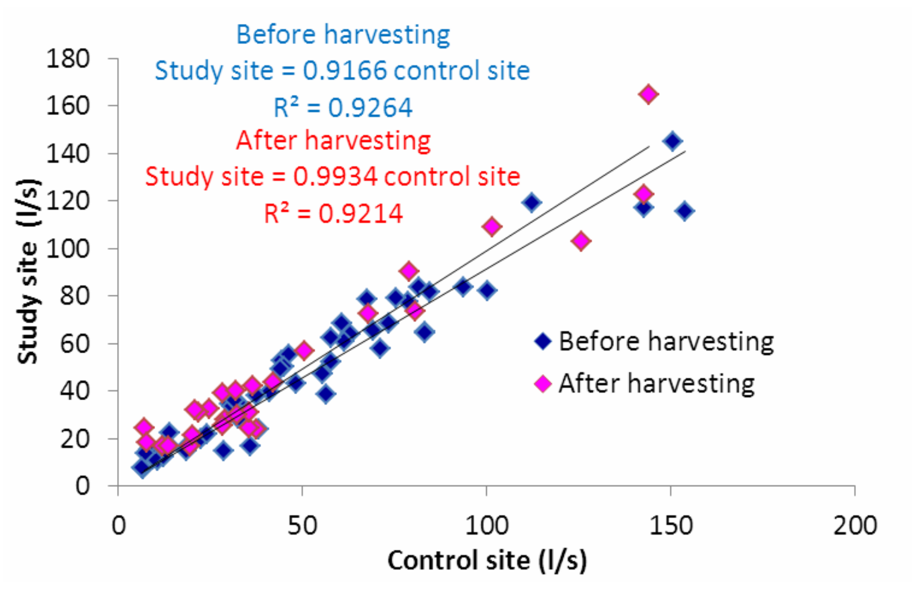

Figure 5b Peak flows before and after harvesting in Glennamong

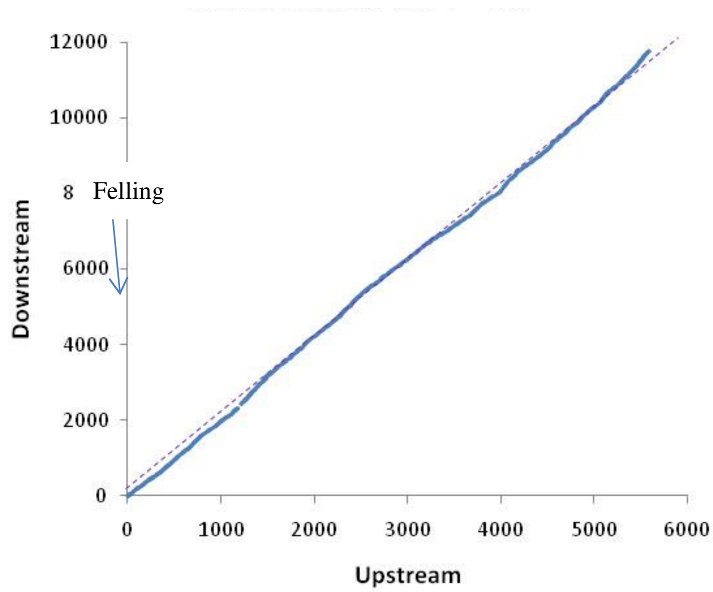

Figure 6a Chronological accumulated the peak flows in Sraveragh (Robinson et al.)

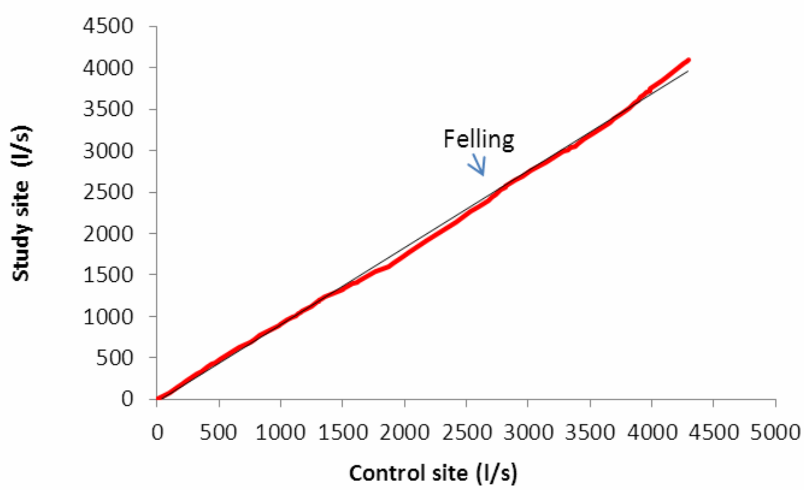

Figure 6b Chronological accumulated the peak flows in Glennamong

Impact on low flows

The 95-percentile flow is used to determine the base flow at the control sites in the two sub-catchments. Figures 7a and 7b show the chronological accumulated flows at control and study sites during the base flow periods before and after harvesting in Sraveragh and Glennamong, respectively. In both sub-catchments, harvesting significantly increased the base flows. The increase in base flow after harvesting could be due to the less evaporation (Robinson et al., 2003). Robinson et al. (2003) also observed baseflows increase in three of their experimental catchments.

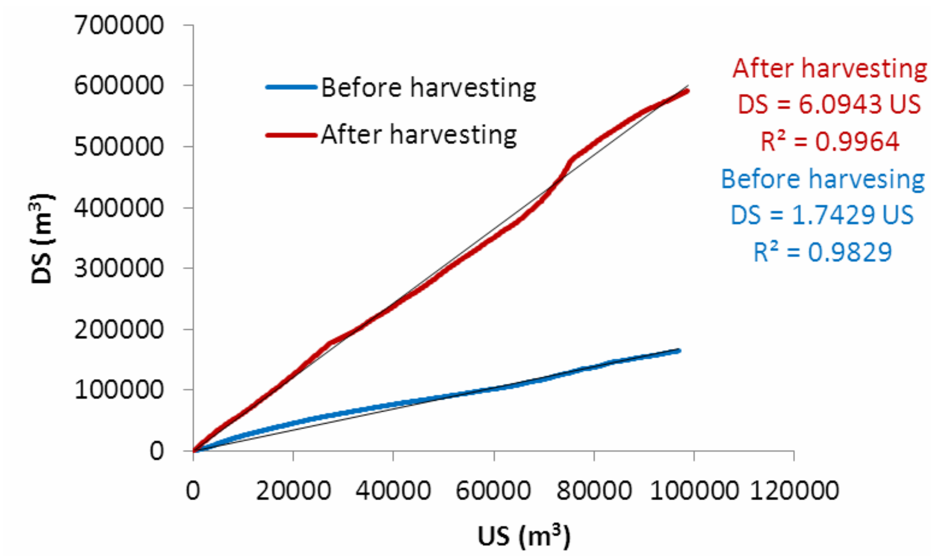

Figure 7a Chronological accumulated base flow before and after harvesting in Sraveragh

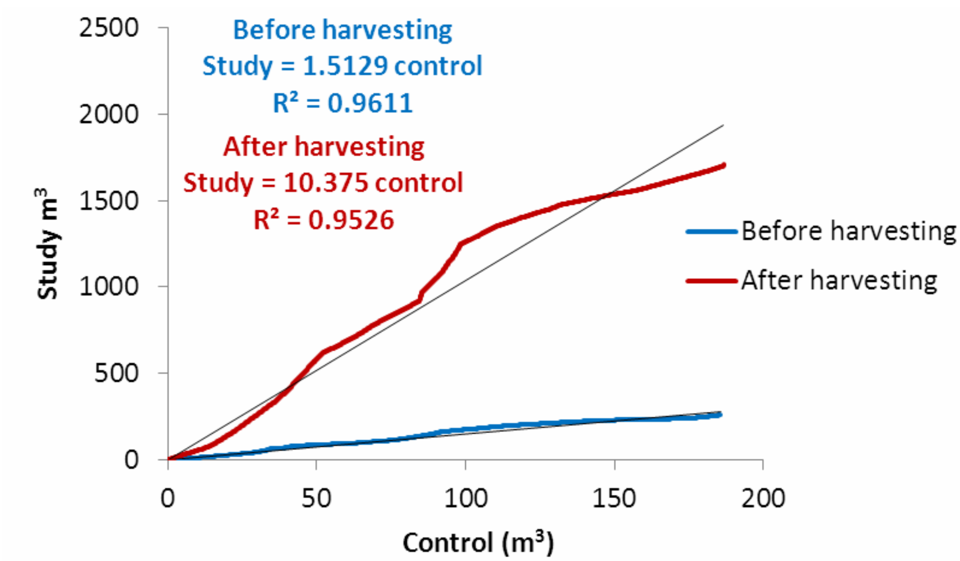

Figure 7b Chronological accumulated base flow before and after harvesting in Glennamong

6. Conclusion

Two paired catchment studies were carried out in the Burrishoole Catchment in the west of Ireland to investigate the impact of upland blanket peat forest harvesting on stream flow regimes. Monthly water yield, peak flow and base flow were used as the impact indicators. The results indicated that while forest harvesting increased the monthly water yield and base flow significantly, it had very little impact on the peak flows. This could be due to the implementation of the good management practices such as proper use of brash mats and harvesting only in dry weather minimized soil surface disturbance.

Acknowledgements

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