Scottish Woodlands

Threestoneburn Forest Environmental Statement – Addendum To The Hydrology Section

May 2008

FINAL REPORT

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REVISION HISTORY

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CONTRACT

This report describes work commissioned by Scottish Woodlands under the letter dated 13 March 2008. Scottish Woodlands's representative for the contract was Ian Robinson. Steve Rose, Dave Archer and Sebastien Tellier of JBA Consulting carried out the work.

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PURPOSE

This document has been prepared solely as an addendum to an Environmental Statement for Scottish Woodlands. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

ACKNOWLEDGMENTS

JBA Consulting would like to acknowledge the help of a number of individuals in the production of this report. These include Ian Robinson (Scottish Woodlands), Tim Matthewson (Lilburn Estates), Suzanne Hall and Fiona Morris (Environment Agency) and Ronald Campbell (Tweed Foundation).

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ABBREVIATIONS

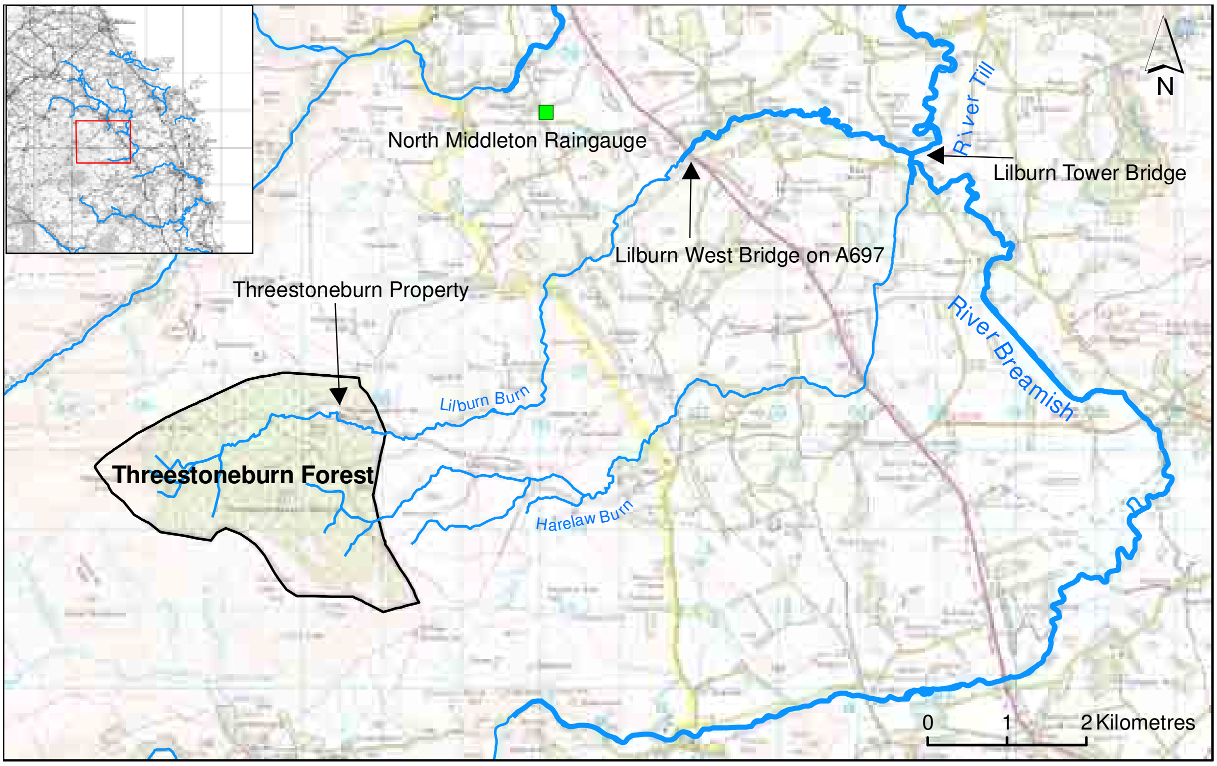
AOD	Above Ordnance Datum
Al	Aluminium
BOD	Biological Oxygen Demand
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
FC	Forestry Commission
FEH	Flood Estimation Handbook
GQA	General Quality Assessment
K	Potassium
N	Nitrogen
P	Phosphate
pH	Potential Hydrogen
SS	Suspended Sediments

1 INTRODUCTION

1.1 Background To The Study

Threestoneburn Forest is located 10km to the south-west of Wooler in North Northumberland on the eastern flank of the Cheviot Hills, on the eastern slopes of Hedgehope Hill. Figure 1.1 illustrates the study area. The study area falls within an altitude range of about 305-704m AOD.

Figure 1.1 Study Area



Scottish Woodland submitted on the behalf of Lilburn Estates an Environmental Statement to the Forestry Commission (FC) and following their review the FC requested more information on the following specific points:

- Information on the methodology to be used for the water quality baseline survey;
- How the water quality will be monitored during and after the felling;
- Provide more detail, where possible, on the anticipated changes to the water chemistry as a result of the deforestation proposals, based on the location of the site and scale of the proposals.

We proposed to add the following point to these FC requirements:

- Assessment of the impact of deforestation on flood risk around Threestoneburn House and downstream of Threestoneburn Forest.

1.2 About The Report

This report updates and expands upon the hydrology section of the draft Environmental Statement for the Threestoneburn Forest and addresses the specific points mentioned above. The stream water quality issue is discussed in **Section 2**, which also include a short literature review of the possible impact of deforestation on stream water quality. **Section 3** focuses on the impact of deforestation and afforestation on flood risk and three sites located downstream of Threestoneburn Forest are assessed in terms of potential flood risk due to the deforestation proposal.

2 ASSESSMENT OF THE IMPACTS OF DEFORESTATION ON STREAM WATER QUALITY

2.1 About This Section

This section starts with a short literature review regarding the possible impacts of deforestation on stream water quality in United Kingdom. Then section 2.3 looks at a proposed stream water quality monitoring programme and finally section 2.4 looks at the potential impacts of stream water acidification on fish populations.

2.2 Literature Review

A considerable amount of research work has been undertaken on the impact of forest harvesting on the water quantity and water quality following the introduction of extensive coniferous plantation in the UK plantations over the last 50 years or so, with the Plynlimon catchment in the headwaters of the River Severn at the forefront of this work (Neal, 2004). Here we are going to look more specifically to the water quality research in relation with the proposed felling programme for Threestoneburn forest.

2.2.1 Impact of Deforestation On Streamwater Quality

Following around 20 years of research at Plynlimon (Neal, 2004) the typical water quality responses to the felling of coniferous plantation would be described as:

- An increase in nitrate concentrations;
- Possible increases in Dissolved Organic Carbon (DOC), potassium (K), Aluminium (Al) and acidity (i.e. lower pH and lower alkalinity);
- Decreases in 'sea-salt' components such as sodium and chloride, which derive from atmospheric sources, due to reduced evaporation (greater runoff increasing dilution) and reduced scavenging of mist and particles from atmosphere by the vegetation. This is more prevalent in western forests within the UK.

These changes then recede over a few years (1-2 years) as nitrate uptake by the succeeding vegetation increases and the concentrations of acid anions decreases. The largest changes occur after clear felling, whereas there is a spreading and reduction of the impacts in phased felling, which is proposed for Threestoneburn Forest.

There are marked variations in the water quality at the local scale but not necessarily at the catchment scale. Nitrate concentrations are higher for one or two years post-felling, but can then decline to levels lower than before felling. The decline is quicker if whole-trees are harvested, rather than the brash being left on the ground surface as with conventional harvesting (which would normally provide nutrients to a succeeding tree crop). Scottish Woodlands is proposing two different schemes for Threestoneburn forest felling operation:

1. Whole tree felling on drier areas with the timber and brash being further processed on the road side;
2. Partial tree felling on wetter areas with the tree felled to a low stump and brash deposited along the road to act as a protective mat for the peat surface.

Biological activity within the soil affects the concentrations of nitrate, K, (Neal *et al.*, 1992). Biological activity occurs at four levels:

1. Decomposition of brash and stumps- releases K, DOC and nitrate;
2. Break in nutrient cycle as there is no longer any uptake by the trees leading to more K and nitrogen being available for leaching;
3. Increased mineralisation of organic matter leading to soil water being supplied with DOC and organic N;
4. The changing hydrological flow pathways alter the proportions of acidic and aluminium-bearing soil waters and less acidic and aluminium-depleted groundwaters entering the stream. The nitrate supplies also increase due to nitrification of ammonium and aluminium is more soluble in acid conditions.

2.2.2 Soil erosion

The significance and magnitude of soil erosion during timber harvesting operations are related to:

- soil properties;
- topography, including slope length and steepness;
- rainfall, amount, intensity, and duration;
- vegetation cover; and
- movement and workings of heavy machinery and transportation vehicles.

Felling generally results in increased erosion and sediment yields in streams (Stevens and Reynolds, 1993) as summarised in Table 2.1 below.

Table 2.1 Comparison of conventional and whole tree harvesting (from Stevens and Reynolds (1993)

Advantages	Disadvantages
Forestry operations – Conventional harvesting	
Nutrients from felling debris remain on site	Difficult replanting conditions
Erosion risk decreased	
Forestry operations – Whole tree harvesting	
Clean planting conditions and good establishment	Possibilities of nutrient limitation in succeeding crops and enhanced soil acidification through base cation depletion
Rapid re-establishment of vegetation and removal of brash is more visually attractive	Severe competition for nutrients from re-established vegetation
Water quality – Conventional harvesting	
Erosion risk reduced	Duration of nitrate pulse and associated acidification is longer
Water quality – Whole tree harvesting	
Duration of nitrate pulse and associated acidification shorter	Possible long term acidification of soil/water likely through base cation depletion, unless

	ameliorated by liming or wood ash application

The intensive use and disturbance of forest roads/tracks during the felling operations are the major cause of soil erosion, together with damage to ditches and plough furrows. Site operators should be aware of the causes and consequences of soil compaction and soil disturbance during the felling operations and the use of mitigations measures as detailed in Forest and Water Guidelines (Forestry Commission, 2003).

The observed physical impacts of fine sediments on the receiving streams can be as shown in Table 2.2 (after Information And Advisory Note Number 22, Scottish Natural Heritage, 2008):

Table 2.2 Fine Sediment Impacts On Stream Water Quality And Its Habitat

Physical Impacts	Nature of the disturbance
Fine/suspended sediments can reduce the habitat for fish and macro-invertebrates	By modifying the substrate composition, changing the in-stream channel morphology
	By creating marginal changes to the in-stream morphology
	By reducing the permeability of the bed material
Fine/suspended sediments can increase the stream water turbidity and impact on fish and micro-invertebrate populations	By reducing the photosynthetic activity for submerged plants, it can reduce the food source for higher trophic populations (invertebrates, fish)
	By causing direct damage to fish, via fish gill abrasion and clogging
	By attracting bacteria and fungus due to higher sediment concentration in the stream, they impact negatively on fish populations

2.3 Stream Water Quality Monitoring Regime

The Forestry Commission requested a surface water quality monitoring programme to be included in the final Environmental Statement. This programme will cover the three phases: pre-felling (baseline), felling and post-felling. The pre-felling (baseline) analysis is described in Section 2.4 below.

During the felling operations, including the construction and maintenance of the road/track network through the forest, the procedures to minimise runoff risk, erosion risk and potential water quality issues that are detailed in the current Forests & Water Guidelines (Forestry Commission, 2003) should be closely followed.

It is recommended that **monthly water samples** are submitted for laboratory analysis for the following determinands: pH, nitrate-N, ammoniacal-N, orthophosphate-P, suspended solids, Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), aluminium and iron.

The results should be compared to the pre-felling sample results to ascertain whether any major changes have occurred, especially with respect to pH, BOD, aluminium and nitrate-N. In addition, any observations by the felling personnel of discoloured or turbid water (high suspended solids) reaching the main arterial watercourses from the areas being felled should be investigated immediately and remedial measures taken if necessary to divert the discoloured or turbid water away from the main watercourses and into either silt traps/sedimentation ponds or into land areas that are disconnected from the arterial drainage network.

Following the felling phase, a lower sampling frequency will be needed, once every 1-2 months during the winter period (Oct-Mar inc.) and once every 2-3 months during the drier summer months (Apr-Sep inc.).

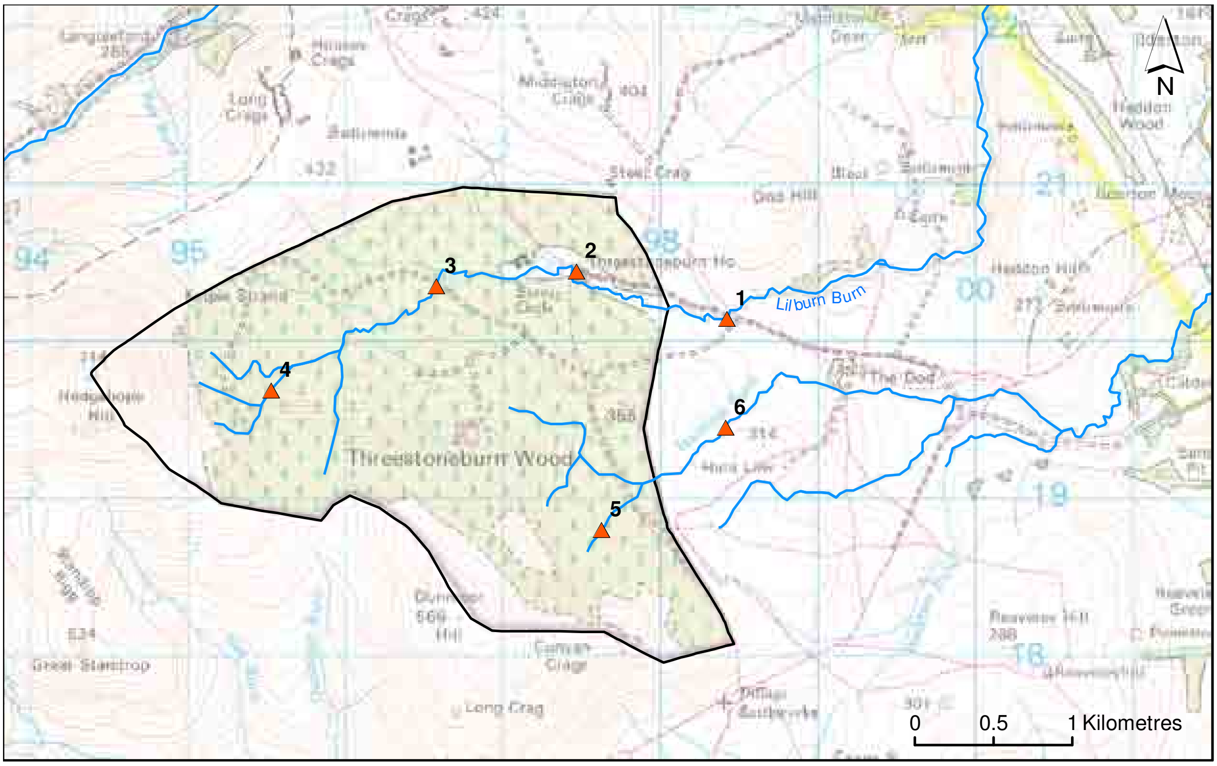
The number of sample points could also be potentially reduced to include just sample points 1, 3, 5 and 6 (see Figure 2.1), thereby reducing the replication of similar sample points in the forest and analytical costs. This post-felling monitoring should continue for 3 years after completion of the felling operation to check whether the longer water quality effects.

The next section is focused on the analysis of the water quality sampling undertaken for this project.

2.4 Baseline Water Quality Analysis

Lilburn Estates have taken water samples from six locations within the study area on 3 occasions (19 November 2007, 17 March 2008 and 10 April 2008), representing the winter period with the existing forest in its current (baseline) state. Four of the sample locations (1-4) are on Lilburn Burn and two are on Harelaw Burn (5-6) as shown on figure 2.1 below.

Figure 2.1 Water Quality Sampling



On Lilburn Burn, location 1 (OS NGR NT9842 2013) is just downstream of the forested area, location 2 (OS NGR NT9747 2043) is in the unforested area next to Threestoneburn House, location 3 (OS NGR NT9657 2033) is just upstream of the large pond near the old quarry and location 4 (OS NGR nt9554 1971) is towards the top of the forested area on the eastern slope of Hedgehope Hill.

On Harelaw Burn location 6 (OS NGR NT9842 1994) is downstream of the forested area and location 5 (OS NGR NT9762 1880) is towards the top of the tributary within the forested area.

The general hydrological conditions at the time the water samples were taken can be ascertained with reference to the Lilburn Estates daily raingauge at North Middleton House, North Middleton, Wooler at an altitude of about 130m AOD. The study area falls within an altitude range of about 305-704m AOD. Therefore, it could reasonably be expected that the Lilburn Estates raingauge will generally underestimate the rainfall that would fall within the study area and in particular the amount of snowfall.

The water sample that was collected in November 2007 was actually taken during a generally dry period at the study area (especially August –September 2007). The March 2008 sample was taken after a very wet January and a very dry February. However, during this period and into April the study area received quite significant snowfalls, which may not have been recorded by the Lilburn raingauge due to its the lower altitude. March 2008 received about the average rainfall and the early part of April 2008 was wet prior to the April water sample being taken.

Table 2.3 Monthly Rainfall Recorded At The Lilburn Estates Raingauge

Month	2007	2008	8 year average (2000-2007)
January	68.6	139.6	61.9
February	67.8	27.3	64.5
March	31.3	52.2	54.4
April	9.2	-	57.3
May	76.9	-	57.3
June	116.4	-	65.7
July	94.2	-	55.5
August	51.0	-	91.8
September	38.5	-	54.6
October	25.2	-	113.1
November	77.5	-	79.7
December	69.8	-	72.2
Total	726.4	-	828.0

The water samples that were collected were analysed at the UKAS accredited Pattinson Scientific Service Ltd laboratory in Newcastle upon Tyne and the results can be found in Appendix A. The analysis suite included:

- pH;
- Biochemical Oxygen Demand (BOD);
- Dissolved Oxygen (DO);
- Suspended Solids (SS);
- Ammoniacal-nitrogen;
- Nitrate-nitrogen;
- Phosphate;
- Aluminium;
- Iron;
- Potassium.

This suite of determinands was developed in discussion with the Environment Agency and permits a classification of the water quality with respect to the Environment Agency General Quality Assessment (GQA). The GQA is designed to provide an accurate and consistent assessment of the state of water quality and changes in this state over time. The scheme consists of separate windows on water quality. The chemical GQA describes quality in terms of chemical measurements which detect the most common types of pollution. It allocates one of six grades (A – very good to F - bad) to each stretch of river, using the same, strictly defined procedures, throughout England and Wales. A grade is defined by standards for the determinands biochemical oxygen demand (BOD), ammonia and dissolved oxygen (DO). A grade is assigned to each river reach to the worst determinand. These determinands are indicators of pollution that apply to all rivers, first because of the widespread risk of pollution from sewage or farms, and second because of the toxicity of ammonia and the requirement for dissolved oxygen for aquatic life, including fish.

It should be noted that the data from the on-site sampling cannot be directly correlated with the GQA classification because the GQA requires that sites are sampled at least 12 times per year and that at least 3 years of data are available to provide the overall GQA assessment. However, the site results can described comparatively to the GQA grades. The pH value, nitrate-nitrogen, aluminium, iron and potassium concentration provide valuable information about the possible surface water acidification issues in the catchment.

The pH of the water samples was always in the range 6.2-6.9 for the Lilburn Burn and 6.0-6.8 for Harelaw Burn. This is quite a high pH for watercourses draining very acid soils, such as those found in the study area, though similar in magnitude to pH values reported by Neal *et al*. (2004) for the pre-felling conditions on the Afon Hafren stream draining deep peat in mid-Wales. The Afon Hafren forest was mainly Sitka Spruce with some Norway Spruce, similar to Threestoneburn Forest.

BOD levels in the Lilburn Burn ranged from less than 2mg/l to 5.1mg/l, whilst those in the Harelaw Burn ranged from <2mg/l to 4.7mg/l. If these values are compared to the Environment Agency General Quality Assessment (GQA) for Rivers (Chemistry) these BOD levels would be classified as grade A-C (very good to fairly good), see table B1 in Appendix B).

Suspended sediment levels ranged from <5mg/l to 23 mg/l for Lilburn Burn and <5mg/l to 9mg/l in Harelaw Burn.

Ammoniacal-nitrogen concentrations were less than 0.05mg/l for all the samples taken from both watercourses. Under the GQA system this would grade the water quality as Grade A (very good), see Table B2 in Appendix B.

Nitrate-nitrogen concentrations were less than 1mg/l for all the samples taken from both watercourses. Under the GQA system this would grade the water quality as Grade 1-2 (very low to low concentrations), see Table B3 in Appendix B.

Total phosphate levels are less than 2 mg/l for all the samples taken to date. This indicates that the orthophosphate-P concentrations (as used in the GQA nutrient assessmen, see Table B4 in Appendix B) would be less than 0.67mg/l for all samples. However, the exact GQA phosphate grade cannot be given as the analytical limit of detection is too high to assign the concentrations to a particular grade.

Aluminium concentrations ranged from 72-183mg/l in Lilburn Burn and 48-286mg/l in Harelaw Burn. These values are in the ranged measured by Neal *et al.* 2004 in mid Wales.

Iron concentrations ranged from 117-1857μg/l for Lilburn Burn and 204-918μg/l for Harelaw Burn. These concentrations are high when compared to the Neal *et al.* (2004) studies in mid Wales and are probably due to the particular physical characteristics of the local soils in the study area including the ironpan stagnopodzols.

Potassium concentrations ranged from 0.38-2.9mg/l in Lilburn Burn and 0.6-1.9mg/l in Harelaw Burn, which are similar to those measured by Neal *et al.* 2004 in mid Wales.

The Environment Agency undertake a routine GQA assessment on Lilburn Burn approximately 9km downstream from Threestoneburn Forest near East Lilburn. GQA chemistry datasets for this sampling point were downloaded from the Environment Agency web site[1].

[1] http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=riverquality&ep=query&lang=_e&windowdiameter=396&x=402700.0&y=624390.0&scale=4&layerGroups=5&location=Lilburn%20Tower,%20Northumberland

These Environment Agency data indicate that for the main GQA chemistry parameters (BOD, DO and ammoniacal nitrogen) over the period 1998-2006 the Lilburn Burn is classified as Grade A or Grade B (i.e. very good or good quality). For phosphate (1993-2006) the classification is Grade 1 or 2 (very low or low concentrations). The nitrate GQA is generally Grade 2 or 3 (low to moderate concentrations) over the same period, which may be a response to some diffuse agricultural inputs entering the watercourses from the catchment area downstream of the forest. For chemical water quality, the Lilburn Burn is therefore a good quality watercourse that can sustain good aquatic ecosystems.

2.5 Potential Water Quality Impact On Existing Fish Population

Figure 1.1 shows that Lilburn Burn drains into the Till which then flows into the Tweed. The River Tweed Commission is charged under the Scotland Act 1998 with the general preservation and increase of fish population in the River Tweed and its tributaries. The River Tweed is a Special Area of Conservation and there are responsibilities on upstream proposals to have no detrimental impact on the reasons for which the Tweed was designated – one of which is Atlantic Salmon. Donald Campbell from the Tweed Foundation was contacted regarding the fish count in Lilburn Burn and the possible impact of acidification on existing fish population. He provided us with a summary of the fish count done in the last 20 years on Lilburn Burn, on Lilburn Estates land. Lilburn Burn was sampled at Lilburn Tower and the results of the fish counts show an increase of Salmon since the July 1993 count. This change is likely to be due to the removal of an obstruction upstream of Lilburn Tower as it permitted the re-establishment of a salmon population.

Table 2.4 Tweed Foundation Fish Count Survey Between 1988-2004

Date	Easting	Northing	Estimated Population	95% CL	Est. Pop	95% CL	Comment
07-Jul-04	402100	623950	33	3	35.5	2.66	
23-Aug-99	402100	623950	55	3	0	0	Access re-opened
07-Jul-93	402100	623950	0	0	0	0	Access blocked at Lilburn bridge
06-Jul-88	402100	623950	22	29	0	0	

As mentioned in section 2.2.1, aluminium is more soluble and therefore can be released into the stream waters under acidic conditions, which could then severely impact on the existing fish populations. However, the actual toxicity of aluminium to fish is dependent on its state, either solid or in solution. Weng *et al.* (2002) describes the aqueous form of aluminium, the inorganic monomeric aluminium as the most toxic form to fish. Aluminium concentration in water is inversely proportional to the pH and its solubility increases below about pH 4.5, when it becomes the most important factor for fish kills in acidified lakes (Walker *et al.*, 2001). At low pH it combines with the organic molecules present in peaty waters, flocculates them and takes them out of the water column. The resulting molecules can then accumulate in fish organs (kidney, skeleton and gills) and harm the existing population. The acidification of the water can be spotted visually as one of the symptoms is its clarity (R. Campbell, *personal communication*). During the felling process, the site manager would have to be vigilant and check the colour of the stream to determine if this process is occurring.

The current baseline water sampling shows the pH remaining above 6.0, which is well above the critical pH value. The water samples collected during and after the felling phase will provide further information about any changes in the pH and aluminium levels and, hence, whether they might create a fisheries problem.

2.6 Conclusions

The analysis of the water samples taken to date have indicated that the watercourses within, and draining from the study area, in its current condition are of good quality. The removal of the trees and disturbance of the soils, tracks and watercourses during the felling operations could potentially generate some water quality problems, though most research has indicated that this is likely to be short-term (2-3 years). However, adherence to the risk mitigation measures detailed in the Forests & Water Guidelines (Forestry Commission, 2003), together with vigilance by the site operators in terms of identifying and mitigating against potential water quality problems (especially, with respect to runoff generation and erosion) should minimise the risk to the downstream receptors. A formal water quality monitoring programme would provide evidence of any potentially negative impacts of the felling operation on the surface water quality and the aquatic ecosystem it maintains.

3 ASSESSMENT OF THE IMPACT OF AFFORESTATION AND DEFORESTATION ON FLOOD RISK DOWNSTREAM OF THE THREESTONEBURN FOREST

3.1 Introduction

The impact of afforestation and deforestation on river hydrology and on flood flows has been the subject of extensive hydrological research both in Britain and internationally. It is now widely accepted that coniferous forests can enhance interception relative to shorter vegetation such as moorland grasses due to their greater aerodynamic roughness. An increase in forest cover also enhances total annual evapotranspiration losses.

However, the knock-on effects of these process changes on flood risk are highly varied and depend primarily upon the detailed climate conditions of the catchment, on the areal scale of forest development and upon forest management strategies. Further hydrological variation may depend on geology and soils and on the particular species that have been used. Newson (1994) labels forest hydrology a ‘regional science’ meaning that the particular set of intrinsic (forest) and extrinsic (climate) factors which evoke a particular hydrological effect is almost unique within regions. Therefore caution is necessary in interpreting the results of one analysis to another location, even when the location is within the temperate environment of the United Kingdom. As a consequence there are no standard methods in use for assessing the impact of deforestation (or afforestation) on flood flows. The Flood Estimation Handbook (FEH) provides background but no specific solutions. One must therefore be guided by experimental results from previous catchment studies and examine how these resemble or differ from environmental conditions on the Threestoneburn catchment that may influence hydrological response.

Previous experimental studies in the UK have centred on three main upland sites, at Plynlimon in mid Wales (Kirby et al, 1991), Balquidder in the Central Scottish Highlands (Johnson, 1995) and the Coalburn catchment in the northern Pennines (Robinson et al, 1998). Comparative references are made to these studies even though the change has been in the opposite direction (moorland to forest) to that proposed at Threestoneburn Forest.

3.2 Environmental Conditions At Threestoneburn Relevant To Hydrology

3.2.1 Effects Of Interception And Transpiration

The Threestoneburn forest is located on the east side of the Cheviot Range, on the eastern slopes of Hedgehope Hill and is therefore in the rain shadow of both the Cheviot and Pennine Hills. The forest elevation ranges from approximately 350 to 555m Above Ordnance Datum (AOD). Rainfall for a given altitude is therefore lower than at equivalent elevations in Wales, Scotland or on the western side of the Pennines, and in particular compared with much of the Kielder Forest and the experimental catchment at Coalburn. Average annual rainfall at Threestoneburn is 1050 mm compared with 1300 mm at Coalburn, about 2500 mm at both Balquidder and the Plynlimon catchment on the upper Severn. Robinson *et al.* (2003) presented hydrological results from 28 forested basins across Europe sampling a wide range of forest types, climate conditions and ground conditions. None of the coniferous forests investigated had an average annual rainfall of less than 1200 mm. The only study on a catchment with lower rainfall was that carried out by Gash and Stewart (1977) on a Scots pine forest at Thetford in East Anglia with an annual rainfall of around 600 mm.

Figure 3.1: The Effect Of Mature Conifer Plantations On The Interception Ratio At Different Annual Precipitation (after Calder and Newson 1979)

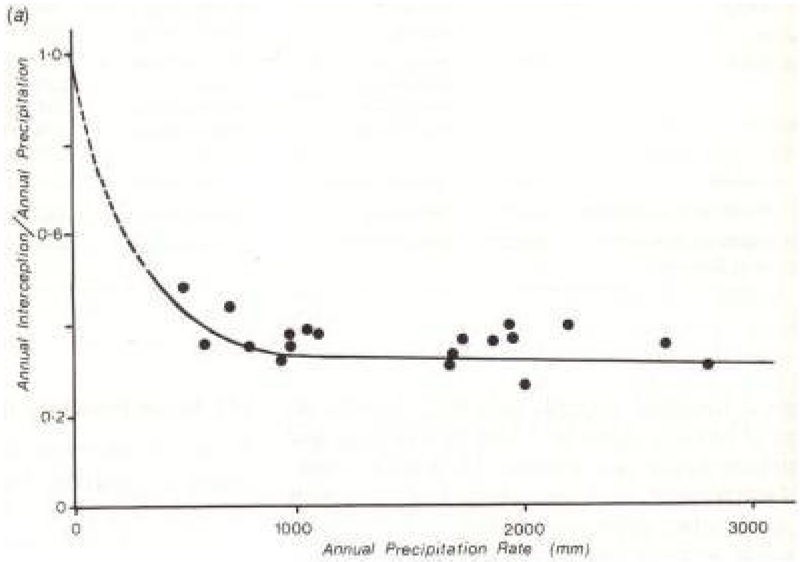
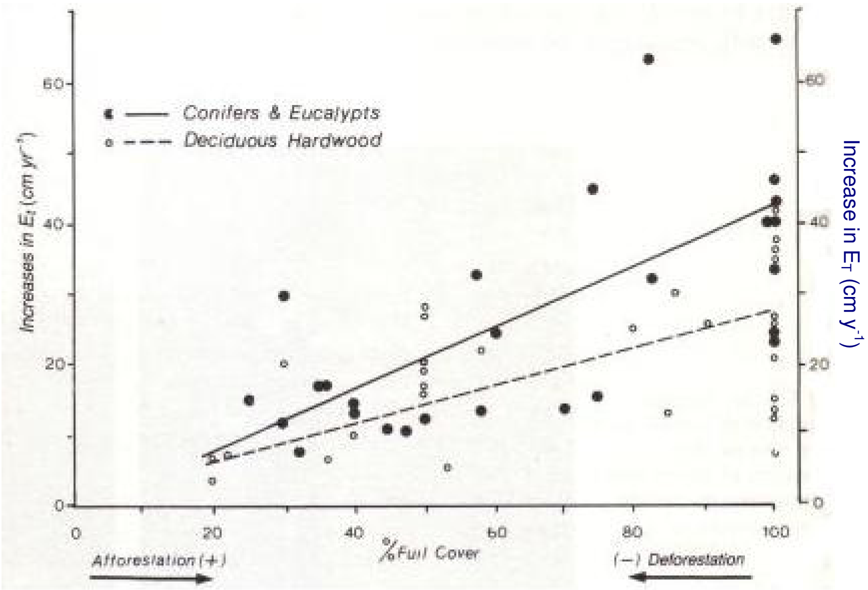


Figure 3.1 shows the generally increasing interception ratio with decreasing rainfall, with ratios of more than 0.40 at the annual rainfall experienced at Threestoneburn Forest. Interception plays a dual role in flood generation. The direct effect is in limiting the amount of storm rainfall which reaches the ground; this effect is quite limited especially at high rainfall amounts and intensities as proportions of storm rainfall are quite small. In addition and more important, is persistent interception which reduces the contribution of rainfall to soil moisture storage, increases soil moisture deficit and can have a major impact on percentage runoff and thus on peak discharge. Soil water measurements generally show drier soil conditions under established forest than nearby grass (Hudson, 1988; Robinson and Cosandey, 2002).

Such effects are likely to be more profound on the Threestoneburn catchment than at the experimental catchments with higher rainfall. With forest clearance, interception losses will sharply diminish, soil moisture storage will increase and the annual duration when soils are at field capacity will extend at either end of the winter period.

Transpiration rates are also significantly higher in coniferous forests than on moorland. Fig 3.2 shows an example from Bosch and Hewlett (1982) of changes in evaporation following either afforestation or deforestation.

Figure 3.2: Effects Of Afforestation And Deforestation On Rates Of Annual Evaporation (From Bosch And Hewlett, 1982)



Annual evaporation 'losses' (i.e. the difference between annual precipitation and annual runoff) in the largely forested Plynlimon catchment is about 200 mm more than on the adjacent grassland Wye catchment (Kirby et al 1991). In fact, the primary purpose in instrumenting the Plynlimon catchments was to address the question 'do trees use more water than grass?' Results from this research showed that annual evaporation from the forest was nearly double that of grassland, principally owing to the enhanced evaporation of water intercepted on the aerodynamically rough forest canopy (e.g. Calder, 1996). Roberts (1983) lists annual transpiration rates of about 300 to 350 mm for several tree species in upland Britain and elsewhere. This is again a much higher proportion of annual rainfall at Threestoneburn than at the comparable moorland catchments. The reapportioning of the water balance after forest felling is likely to increase significantly the volume of rainfall that is directed generally to runoff and specifically to storm runoff.

3.2.2 Effects Of Scale

The problem of scale is a fundamental one in hydrology (Dooge, 1989). The relative importance of different processes changes from the field plot to catchment and with increasing size of catchment. At the plot scale, processes of interception, infiltration and storage dominate, but with increasing catchment size, channel processes assume a greater role in the stream hydrograph. Thus there are considerable problems in extrapolating results from one scale to another.

Nowhere are the scale problems more evident than in the impact of land use change. For example Robinson (1990) has shown that the impact of drainage on rainfall runoff response may operate in different directions at the field scale and the small catchment scale. As a result of these complicating factors, there has been no unequivocal demonstration of the effect of upland drainage and afforestation on peak flood flows on catchments greater than 10 km^2 in the UK. Archer (2003) however found some evidence of the influence of afforestation on flashiness of response on the Irthing catchment (over 300 km^2 of which is approximately 18% is forested).

The forested area at Threestoneburn is 568 ha (5.68 km^2) compared with the Coalburn research catchment (1.5 km^2) and the 8.70 km^2 upper Severn catchment at Plynlimon. There is definite evidence of effects of afforestation on flood flows at Coalburn but partial felling at Plynlimon produced only a weak tendency for higher peaks to increase, while the smaller peaks were actually reduced (Robinson et al 2003). Threestoneburn is intermediate in scale and in this respect is likely to show less impact of land use change than the small Coalburn catchment but perhaps more than on the Plynlimon catchment. However, the effects of scale are confounded with those of climatic and management effects and may be difficult to distinguish.

The effects of land use and land use changes will also diminish downstream as the proportional area affected decreases. At the potentially vulnerable property on the edge of the forest, Threestoneburn House, the upstream afforested area is 61% of the total catchment. The proportion reduces to less than 30% where the river as Lilburn Burn crosses the A 697 and 26% at the bridge adjacent to Lilburn Tower.

3.2.3 Management Effects

Forestry management practices may have a more profound influence on flood runoff response than the actual change in land use. Of particular significance is the drainage of moorland which often precedes forestry planting. Such effects can obscure the direct effect of afforestation and the effects may persist for many years or even decades as the forest is maturing. Degraded remnants of such drains may still have some influence on hydrology after felling. The precise nature of pre-afforestation drainage and planting at Threestoneburn is not known although the Environmental Statement (Scottish Woodlands, 2007) indicates that 'when the forest was planted by the FC, it was ploughed and drained in accordance with the standard guidelines at the time'. However, the report indicates that many of the drains are now vegetated.

By comparison, afforestation of the Coalburn occurred in the spring of 1973 and was preceded by ditch drainage carried out in 1972. The land was ploughed with ditches 0.8 m deep and at 4.5 m spacing giving a drainage density of about 200 km/km^2. Turf ridges were created from the excavated material adjacent to the furrows in order to provide drier elevated sites for planting. This pattern of land preparation and planting was common on deep peats in the 1970s. The use of shallower drainage furrows and a regular system of cross drains were more widespread but these are unlikely to have had a significantly different hydrological effect. Robinson (1990, 1993, and 1998) and Robinson *et al.* (1998) have extensively studied the impact of drainage on flood flows. He notes that 'drainage of peaty soils by open ditches or furrows can significantly increase peak flows and shorten the rise time of flood hydrographs. The enhanced flood risk can last for 20 years in slow-growing coniferous tree crops. After drainage and afforestation at Coalburn, England, peak flows immediately downstream were increased by about 15% over the short to medium time scale'. The reverse effect will of course not occur on deforestation but it is worth noting that deforestation will not return the Threestoneburn catchment to a 'natural' moorland state and the persistent effect of drainage will form part of the difference.

Further management practices during felling may also have an influence on flood runoff response. The main evidence comes from hydrological studies of felled forests at Plynlimon (Robinson and Dupeyrat, 2004). Harvesting commenced in the mid-1980s and since then about half the forest has been felled. Changes in annual water yield and extreme flows were studied in four nested catchments ranging in area from about 1 to 10 km^2 and compared with an adjacent benchmark grassland catchment. As expected from earlier process studies the cutting of the forest increased total annual flows.

However, a particularly notable result was the lack of impact of the harvesting on storm peak flows. They interpreted this as a possible result of the application of forest management guidelines designed to reduce soil damage and erosion during the harvesting, and an indication that the forest itself has a limited impact on flooding.

It is worth considering in detail the management practice at Plynlimon associated with these results. Tree harvesting involved the removal of the main stems although much of the brash from the side branches was left on the ground. The accumulated deep forest leaf litter of conifer needles precluded any forest understorey vegetation so the felled areas were initially devoid of vegetation. Felling was carried out according to the national guidelines (Forestry Commission, 2003), which vary with the site conditions. On drier and flatter sites where the soil damage risk was judged to be low, whole trees were removed, whereas on wetter and steeper sites the trees were cut and the small branches removed onsite to create protective thick brash mats along the vehicle access routes. In areas close to the streams the trees were cut down manually and the delimbed poles were dragged (skidded) off. In this case new tree planting was carried out through the residual brash and any old drainage channels were not cleaned out.

It is anticipated that some, but by no means all, of these practices will be applied on deforestation at Threestoneburn. These differences arise from differences in the intended future land use, replanted forest in the case of Plynlimon and restoration of blanket bog and moorland at Threestoneburn. In particular, the amount of brash left to decompose will be much less than at Plynlimon although brash and trees below merchantable size will be chipped to waste and spread across the site. It is not clear whether chipped waste and brash will have the same hydrological impact. In either case hydrological effects are likely to persist for only a limited period after deforestation is complete.

It might be concluded from this Plynlimon analysis that with proper application of Forestry Guidelines to harvesting, access and use of machinery, that flood risk is likely to be unchanged. However, the principal difference between this site and Threestoneburn is in the annual rainfall and in the annual progress of soil moisture status. With an annual rainfall of 2500 mm at Plynlimon and all monthly averages more than 125 mm, soils at Plynlimon are likely to remain near field capacity throughout the year even under forest conditions. Therefore, removal of forest (with or without application of forestry guidelines) is likely to have less effect on soil moisture status and on percentage runoff in floods at Plynlimon than at Threestoneburn.

3.2.4 The Example Of Coalburn

In terms of environmental conditions as well as proximity, the forestry experimental catchment at Coalburn offers the best guidance as to what effect deforestation might have on flood response at Threestoneburn. However, it is recognised that Coalburn has been a drainage and afforestation sequence rather than deforestation. Felling at Coalburn is not planned until 2013. Other aspects of environment differences are described above.

Records of annual maximum peak flows have been extracted and arranged in terms of the sequence from moorland to mature forest from 1967 to 2006 and shown in Table 3.1 (Archer, unpublished)

Table 3.1. Median Annual Maximum And Seasonal Maximum Flows And Rates Of Rise For Sequential Periods Of Progress From Moorland To Mature Forest At Coalburn

t		Peak flow m^3/sec		Rate of rise (1 Hr) m^3/sec/hr	
Land use	**Period**	**Annual Max**	**Apr-Sep Max**	**Annual Max**	**Apr-Sep Max**
Moorland	1967-72	1.94	1.16	0.74	0.39
Drained and planted	1974-82	1.89	1.46	1.12	0.84
Maturing forest	1983-90	1.73	1.14	0.86	0.61
Maturing forest	1992-99	1.64	0.88	0.63	0.28
Mature forest	2000-06	1.81	0.57	0.70	0.21
Full period	1967-2006	1.83	1.14	0.70	0.48

It is recognised that period of 6 to 8 years provide an insufficient length of record to assess the variability in flood response for changing land use periods, so the results can be regarded as indicative rather than definitive. With respect to annual maximum flow, the moorland peak (1.94m^3/sec) is the highest of all the periods, marginally exceeding even that of the post-drainage period. However the differences are small through the full period to mature forest. However seasonal maxima from April to September display a more distinctive pattern of change. There is a sharp rise in summer maximum after drainage and then a steady decline with maturing forest and reducing impact of drains.

Taking the contrast between response of the mature forest and moorland as representative of deforestation suggests that the annual maximum flood (which mostly occurs during the winter months) will change very little. However, there may be a sharp increase in summer flooding but generally not exceeding the winter flood maximum. The period following drainage and planting is likely to have been the period of greatest summer flood risk; restoration to moorland will not make conditions worse than the period following drainage. These Coalburn results provide a model of expected response on the Threestoneburn catchment.

Archer (2007) found that short period rates of rise and fall in flow were more responsive to land use change than flood peaks. Annual and seasonal maximum rates of rise in 1 hour for Coalburn are also shown in Table 1.1. Annual values show a distinct rise from moorland to the period following drainage but the subsequent fall brings the values to a level little different from the original moorland. The summer (April to September) rates of rise are even more distinctive than peak flows with rates more than doubling from moorland to post-drainage and then declining under mature forest to 25% of the post-drainage value and just over half the moorland value. Conversion from forest to moorland is likely to have a noticeably increasing effect on rates of rise throughout the year but especially during the summer months.

This analysis is with respect to median annual maximum floods. With respect to extreme floods, the effects of land use change are likely to be even smaller. Really extreme or prolonged rainfall has the potential not only to satisfy both the limited interception storage and also soil moisture storage whether the land is afforested or not. An example of an extreme flood on an afforested catchment is the event which occurred in August 1977 on the Plynlimon catchment but not on the neighbouring Wye catchment (Newson, 1978). This event provided not only the highest flood peak of the record but also the highest rate of change. Peaks and rates of rise were higher than any experienced on the neighbouring Wye for the same record period. The highest observed peak discharge in the Coalburn catchment also occurred in summer (1975).

3.2.5 Conclusions

1. There are no standard methods for assessing the impact of deforestation on flood risk;
2. The hydrological effects of a change from forest to moorland are likely to depend on the climate of the catchment, the scale of the change, and the management practices adopted in felling; Experimental forested catchments in Britain are significantly different from the Threestoneburn catchment;
3. Having considered how experimental catchments, on which hydrological analysis has been carried out, differ from the Threestoneburn catchment, it is concluded that annual flood peaks are likely to change little with deforestation;
4. However, summer peaks and rates of rise are likely to increase significantly following deforestation, but with the exception of rare extreme events these are likely to remain below those experienced during the winter months which mainly contribute to annual maxima;
5. Summer peaks and rates of rise are likely to be lower than those experienced in the decade following drainage and planting;
6. Extreme storm and flood events appear to be little affected by land use or changes in land use.

3.3 Flood Risk Estimation For Threestoneburn House and Bridges on Lilburn Burn

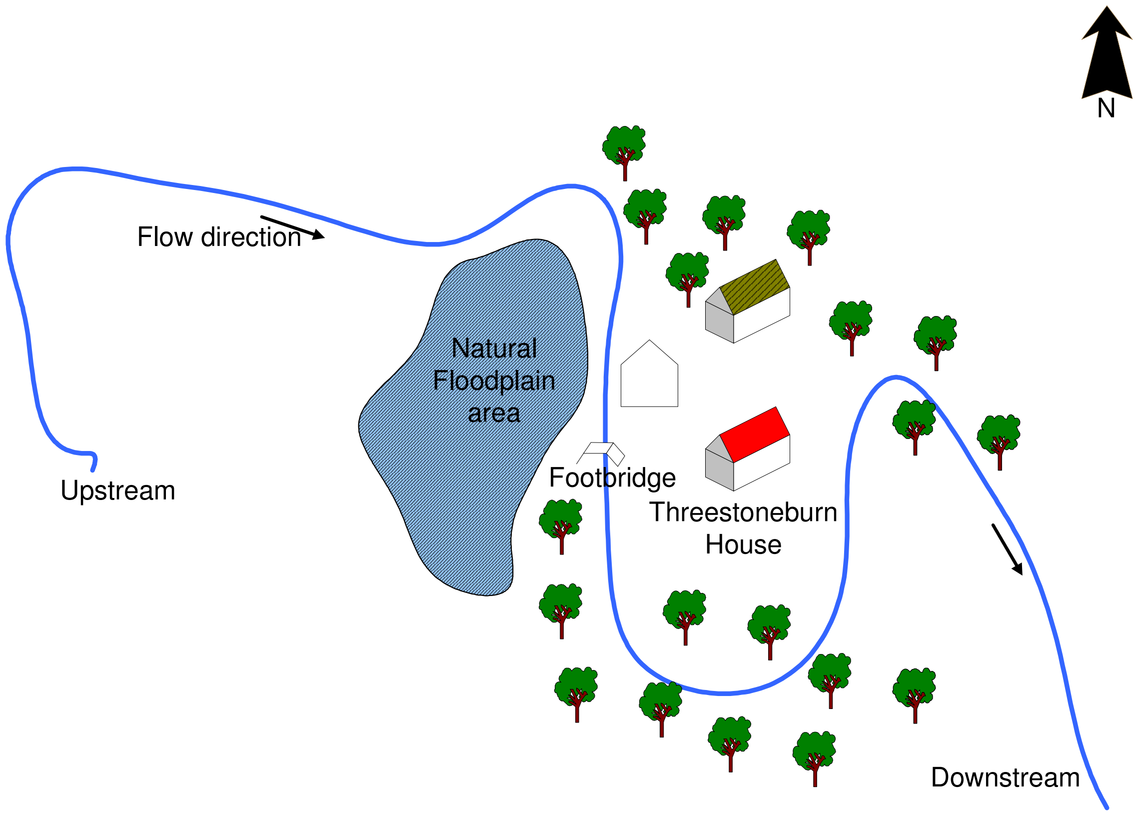
On the 7th April JBA undertook a site visit around Threestoneburn Forest with Tim Matthewson from Lilburn Estates and Ian Robinson from Scottish Woodlands, looking at the existing forest drainage system and then at the three potential flood risk areas, which are:

1. Threestoneburn House, located within an unforested part of the Threestoneburn Forest catchment;
2. Lilburn West Bridge, located 6 kilometres downstream of the forest; and finally
3. Lilburn Tower Bridge located 500m downstream of the A697 bridge.

3.3.1 Flood Risk Estimation For Threestoneburn Property

Threestoneburn House is a Grade II listed property, which lies within Threestoneburn Forest boundaries. It is currently privately owned and occupied mainly during weekends and holiday periods. At this location, Threestoneburn Forest represents 61% of the total catchment draining past Threestoneburn House. The site visit identified three existing buildings (main house and two farm buildings) and one footbridge on the property. Figure 3.3 shows the location of the different buildings in relation to the river. The buildings are located on the left bank of the river, looking downstream and were identified as being on higher ground than the ground on the right bank of the stream. The right bank is shown below as the natural floodplain at this location and during the site visit, there were few visible signs of any recent out-of-bank flood events (e.g. little tree debris and stones found on the floodplain) However, the presence of a 5cm deep covering of snow at the time of the visit might have obscured some material.

Figure 3.3 Threestoneburn House Schematic



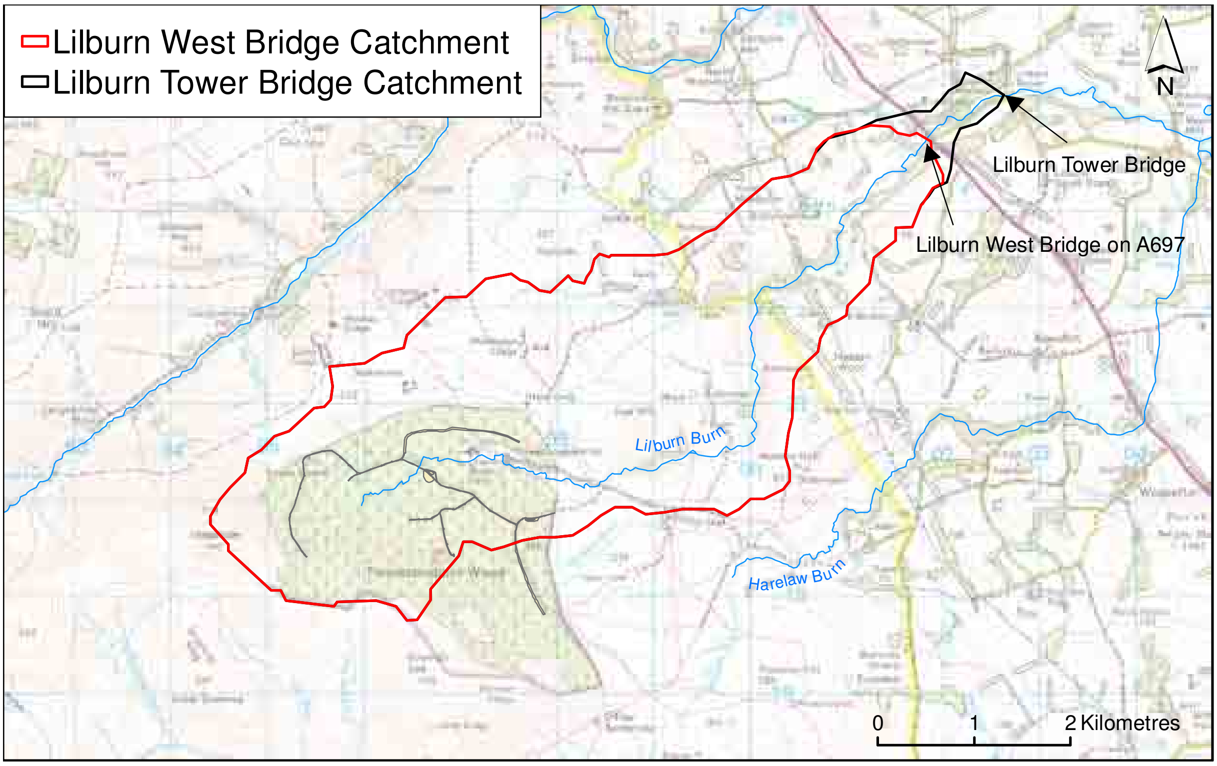
As mentioned in the previous section there is no standard method to assess the possible impact of deforestation on the Lilburn Burn flows and consequently on Threestoneburn House. However, a more detailed assessment of the flood risk at this property would require a detailed river survey (cross-section survey over a distance of 300-600m upstream and downstream of the property), and a detailed survey of the footbridge (including the invert of the channel and the opening of the bridge relative to the banks and floodplain).

3.3.2 Flood Risk Estimation For A697 Bridge And Lilburn West Bridge

Six kilometres further downstream of Threestoneburn Forest, Lilburn Burn is crossed by two bridges: the Lilburn West Bridge and then Lilburn Tower Bridge. As mentioned in section 3.2.2 the effects of land use and land use change will also diminish downstream as the proportional area affected decreases. Here, the proportion reduces to less than 30% where the river as Lilburn Burn crosses the A 697 and 26% at the bridge adjacent to Newton Mill (Figure 3.4).

The site visit allowed us to describe the bridge in terms of its general capacity to pass more extreme floods through it (possibly including some woody material originating from the felling operations) without causing any hydraulic problems and should not be taken as a thorough flood risk assessment, as this would need further requirements (cross-section survey, structure survey, hydraulic modelling etc).

Figure 3.4 Lilburn West and Lilburn Tower Bridges



Lilburn West Bridge was built in early 20th Century and has a 12m cast iron span opening. The span rests on stone abutments on both sides of the bridge. Figure 3.5 shows an upstream view of the bridge, with very low banks on both sides of the Lilburn Burn. There are numerous boulders under the bridge and downstream. Figure 3.6 shows downstream view of the bridge where different size boulders have been deposited by the river during a high flow event. Some branch debris was also found on the left bank, 1m above the river bed. This gives an indication of the level the river can reach during a large event, which is well below the lowest soffit level of the bridge deck.

Figure 3.5 Lilburn West Bridge – Upstream View

Figure 3.6 Lilburn West Bridge – Downstream View

Lilburn Tower Bridge is a stone bridge with three openings (central arch and two smaller arches on both sides) with considerable overall capacity. Figure 3.7 is an upstream view of the bridge and shows the flows entering the bridge on a river bend. The current morphology of the river is currently eroding the left bank as shown on the figure. The banks upstream of the bridge are low lying and constitute the natural floodplain, where water could be stored during high flows.

Figure 3.8 shows the existing fish pass in the middle of the central arch. On the day of the site visit the left bank downstream of the bridge was showing some signs of erosion. This erosion was probably caused by local land management issues (extensive sheep grazing on unprotected banks). The fences across the river downstream of the bridge are designed to rotate and open during high flow conditions and should therefore not be prone to blockage by debris. However, this should be checked on a regular basis during the felling operations.

Figure 3.7 Lilburn Tower Bridge – Upstream View

Figure 3.8 Lilburn Tower Bridge – Downstream View

In this chapter, we have reviewed the potential flood risk increase at three locations along Lilburn Burn. During the felling phase, the site manager may have to regularly inspect the bridges, especially after major rainstorms, in order to remove any tree debris which could have the potential of blocking the flow under the bridge or through the fish pass at Lilburn Tower Bridge and cause localised flooding upstream of the bridge.

Overall, the flood risk either for Threestoneburn House near the edge of the forested area or affecting downstream bridges is unlikely to be altered significantly due to the felling operations.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Trees felling and planting operations are the most likely to give rise to some adverse environmental effects as many of the associated activities have a direct impact on the amount of water, and the amount of suspended solids in the water, leaving the site. Impacts upon water quality in the network of streams radiating from Threestoneburn Forest may impact receptors (e.g. environmental, population, property, land) sited at some considerable distance from the felled area. Chemical and sediment pollution of the surface waters is a continual risk throughout all phases of the felling operation and requires constant control and management through adherence to the current Forestry Commission guidelines.

The hydrological effects of a change from forest to moorland are likely to depend on the climate of the catchment, the scale of the change, and the management practices adopted during the felling phase. Having considered how experimental catchments, on which hydrological analysis has been carried out, differ from the Threestoneburn catchment, it is concluded that annual flood peaks are likely to change little with deforestation. However, summer peaks and rates of rise are likely to increase significantly following deforestation, but with the exception of rare extreme events these are likely to remain below those experienced during the winter months. Extreme storm and flood events appear to be little affected by land use or changes in land use.

We reviewed the potential flood risk increase at three locations along Lilburn Burn. During the felling phase, the site manager may have to regularly inspect the bridges, especially after major rainstorms, in order to remove any tree debris that could have the potential of blocking the flow under the bridge or through the fish pass at Lilburn Tower Bridge and cause localised flooding upstream of the bridge.

Overall, the flood risk either for Threestoneburn House on the edge of the forested area or affecting downstream bridges is unlikely to be altered significantly due to the felling operations.

4.2 Recommendations

For the revised Environmental Statement we would recommend a series of preventive measures against the possible negative impacts of deforestation on the Lilburn Burn. These are:

- Site staff being vigilant during the felling phase. Regular visual assessment of the colour of the stream or drainage ditch water regarding suspended sediments and possible acidification, particularly during rainfall events. If the stream water is found to be coloured, identify sources immediately and mitigate, if possible, by a suitable means;
- Undertake regular bridge inspections (including Lilburn West Bridge and Liburn Tower Bridge) during the felling phase for tree debris and especially during/after major rainfall events. Clear any accumulated debris, if necessary;
- Engage in regular communication with the Environment Agency Development Control Team for land drainage consent issues such as culverting, diverting, filling or obstructing flow in any of the watercourses;
- Undertake a regular water sampling regime.

Finally, the impacts of land use changes on a catchment scale are still high on the research agenda in United Kingdom. In 2004 Defra commissioned a review of the impacts of rural land use and management on flood generation (O'Connell *et al*., 2005) and one of the conclusions was to point out that there is still a lack of good quantitative evidence collected from the research work in this area. This deforestation project could be used to investigate the impact of felling operations on the hydrological response of Lilburn Burn. As research is based on data collection and site monitoring and assessment, the installation of a level gauge in the stream (just downstream of Threestoneburn Forest), together with a raingauge in the catchment could provide quantitative evidence of these impacts. This information would be very valuable to the UK research community, especially for a study area of this size (5.6km^2) and characteristics (upland, moderate rainfall regime).

APPENDICES

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Appendix A: - Water Quality Sampling Data

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A.1 WATER QUALITY SAMPLING DATA

Table A.1: Water sample analysis in Lilburn Burn

		d/s Site 1	d/s Site 1	d/s Site 1	House Site 2	House Site 2	House Site 2	Pond Site 3	Pond Site 3	Pond Site 3	u/s Site 4	u/s Site 4	u/s Site 4
Determinand	**Units**	**19/11/07**	**17/03/08**	**10/04/08**	**19/11/07**	**17/03/08**	**10/04/08**	**19/11/07**	**17/03/08**	**10/04/08**	**19/11/07**	**17/03/08**	**10/04/08**
pH	value	6.3	6.8	6.2	6.6	6.8	6.3	6.7	6.9	6.4	6.6	6.9	6.5
BOD	mg/l	<2	4.6	3.1	<2	5.1	3.7	<2	5.1	3.6	<2	4.9	3.6
DO	mg/l	n/a	14.4	13.0	n/a	14.7	13.3	n/a	14.7	13.0	n/a	14.8	13.4
Suspended solids	mg/l	20	6	11	6	<5	<5	23	<5	<5	<5	<5	<5
Ammoniacal-N	mg/l	n/a	<0.05	<0.05	n/a	<0.05	<0.05	n/a	<0.05	<0.05	n/a	<0.05	<0.05
Nitrate-N	mg/l	n/a	<1	<1	n/a	<1	<1	n/a	<1	<1	n/a	<1	<1
Phosphate (P)	mg/l	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Aluminium (Al)	mg/l	72	84	102	83	72	148	92	72	183	101	82	88
Iron (Fe)	µg/l	1026	538	508	1857	435	485	1140	342	336	294	117	129
Potassium (K)	mg/l	2.9	1	0.53	2.4	0.69	0.53	1.9	0.61	0.49	1.6	0.38	0.34

Table A.2: Water sample analysis in Harelaw Burn

		d/s Site 6	d/s Site 6	d/s Site 6	u/s Site 5	u/s Site 5	u/s Site 5
Determinand	**Units**	**19/11/07**	**17/03/08**	**10/04/08**	**19/11/07**	**17/03/08**	**10/04/08**
pH	value	6	6.7	6.2	6	6.8	6.5
BOD	mg/l	<2	4.7	3.3	<2	4.5	3.2
DO	mg/l	n/a	14	12.8	n/a	13.8	13.2
Suspended solids	mg/l	<5	<5	<5	6	9	<5
Ammoniacal-N	mg/l	n/a	<0.05	<0.05	n/a	<0.05	<0.05
Nitrate-N	mg/l	n/a	<1	<1	n/a	<1	<1
Phosphate (P)	mg/l	<2	<2	<2	<2	<2	<2
Aluminium (Al)	mg/l	212	51	188	286	48	112
Iron (Fe)	μg/l	918	314	326	655	204	524
Potassium (K)	mg/l	1.9	0.6	0.53	1.9	0.9	0.55

Appendix B: - Environment Agency General Quality Assessment Scheme

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B.1 ENVIRONMENT AGENCY GENERAL QUALITY ASSESSMENT SCHEME

Table B.1 Standards for the chemical GQA

GQA Grade	Dissolved Oxygen (% of saturation) 10-percentile	Biochemical Oxygen Demand (mgl^{-1}) 90-percentile	Ammonia $mgNl^{-1}$ 90-percentile
A	80	2.5	0.25
B	70	4	0.6
C	60	6	1.3
D	50	8	2.5
E	20	15	9.0
F	<20	-	-

NOTES:

- 90-percentile compliance – the river should contain less than the specified levels for at least 90% of the time;
- 10-percentile compliance – levels should not fall below the standard for more than 10% of the time;
- mgl^{-1} – milligrammes per litre ;
- $mgNl^{-1}$ milligrammes per litre of ammoniacal Nitrogen.

Table B.2: Grades of river quality for the chemical GQA

Chemical Grade		Likely Use and Characteristics
A	Very Good	All abstractions Very good salmonid fisheries Cyprinid fisheries Natural ecosystems
B	Good	All abstractions Very good salmonid fisheries Cyprinid fisheries Ecosystems at or close to natural
C	Fairly Good	Potable supply after advanced treatment Other abstractions Good cyprinid fisheries Natural ecosystems, or those corresponding to good cyprinid fisheries
D	Fair	Potable supply after advanced treatment Other abstractions Fair cyprinid fisheries Impacted ecosystems
E	Poor	Low grade abstraction for industry Fish absent or sporadically present, vulnerable to pollution ** Impoverished ecosystems **
F	Bad	Very polluted rivers which may cause nuisance Severely restricted ecosystems

*providing other standards are met
**where the grade is caused by discharges of organic pollution

Table B.4 Nitrate Classification

GQA Grade	Grade limit ($mgNO_3l^{-1}$) Average	Description
1	<5	Very low
2	>5 to 10	Low
3	>10 to 20	Moderate
4	>20 to 30	High
5	>30 to 40	Very high
6	>40	Excessively high

NOTES:
$mgNO_3l^{-1}$ - milligrammes per litre of Nitrate

Table B.3 Phosphate Classification

GQA Grade	Grade limit ($mgPl^{-1}$) Average	Description
1	<0.02	Very low
2	>0.02 to 0.06	Low
3	>0.06 to 0.1	Moderate
4	>0.1 to 0.2	High
5	>0.2 to 1.0	Very high
6	>1	Excessively high

NOTES:
$mgPl^{-1}$ – milligramme per litre of orthophosphate (as phosphorus, P).

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