Case study 24. Investigating the impact of upland conifer afforestation on catchment hydrology at Coalburn, northern England

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Main driver: Water resources

Project stage: Long-term catchment experiment

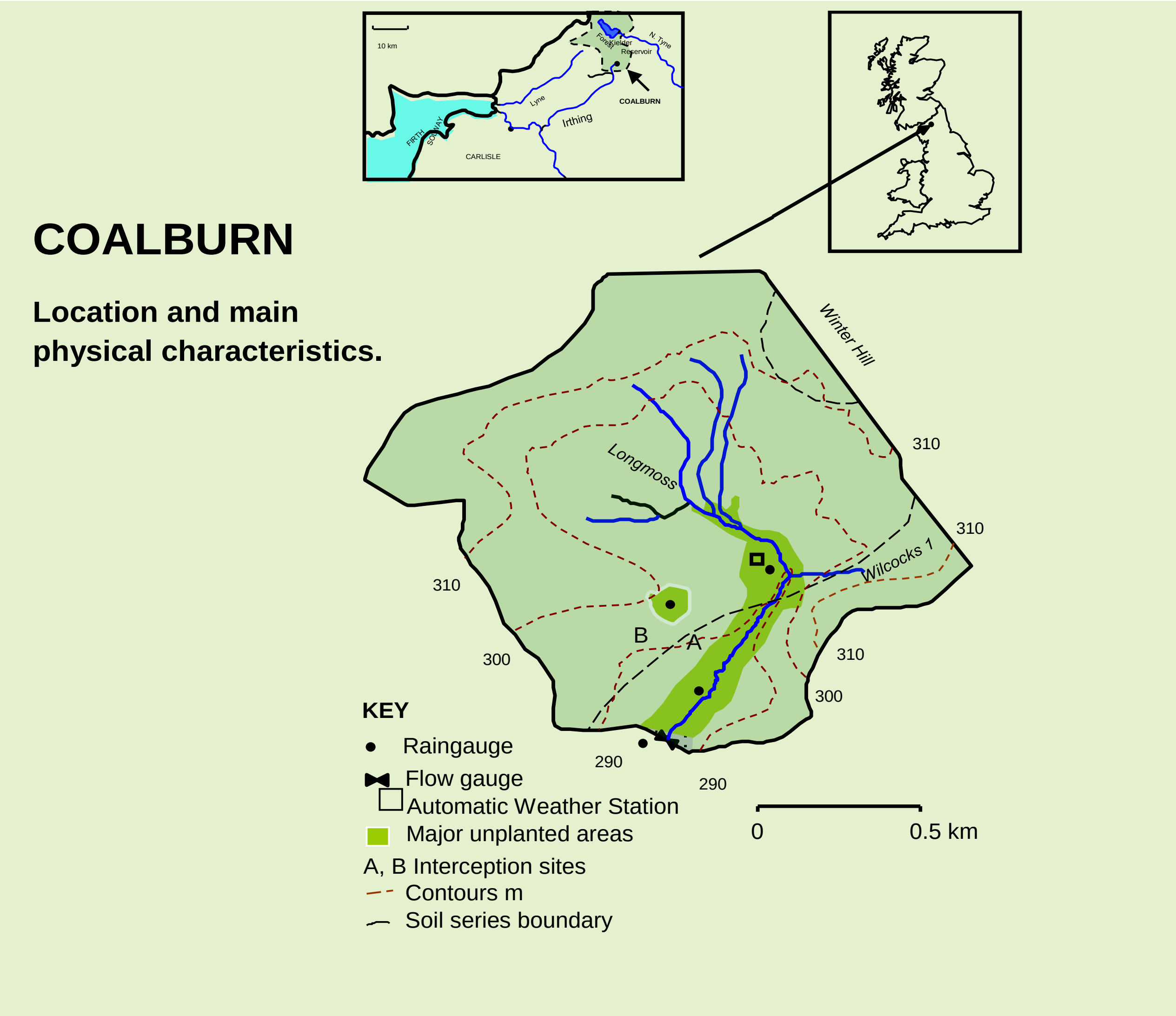
Photo 1: Weir on a watercourse in Coalburn catchment

Project summary:

The project was set up in 1966 as a research catchment for the study of the long-term effects of conifer afforestation on upland water supplies. After a 5-year period of baseline measurements, 90% of the 150ha moorland catchment of the Coalburn was deep ploughed and planted with predominantly Sitka spruce in 1972 to 1973. Stream flow, rainfall and other measurements have continued throughout the study to capture the effects of a full forest growth cycle on catchment hydrology. Results show that the different stages of the forest cycle differ markedly in terms of their impact on catchment water yield and extreme flows. This case study focuses on reporting the effects on peak flows.

Key facts:

Land use change from moorland to conifer forest has had marked effects on catchment hydrology, which vary through time. At first pre-planting cultivation and drainage dominated by increasing peak flows by 15–20% and reducing time to peak by a third. These changes appeared to decline with increasing peak height, as well as reduced over time. A progressive increase in water use by the growing forest then took over and appeared to reduce peak flows, although identifying a trend was hampered by rising annual rainfall totals. Use of modelling to decouple the effect of climate variability found evidence of peak flows declining by 10–15% with forest growth. The reduction decreased with increasing event size and appeared to be lost as the return period approached 100 years. The results indicated that forest growth reduced the frequency of discharge events by around 50% (for example, an event with a return period of 13 years became a return period of 20 years).



Map 1. Location of Coalburn research catchment in northern England

1. Contact details

Contact details	
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2. Location and catchment description

Catchment summary	
National Grid Reference:	NY 694777
Town, County, Country:	North of Haltwhistle, Northumberland, UK
Regional Flood and Coastal Committee (RFCC) region:	Northumbria
Catchment name(s) and size (km^2):	Coalburn, 1.5km^2
River name(s) and typology:	Tributary of River Irthing; mid, small and organic
Water Framework Directive water body reference:	GB102076074100
Land use, soil type, geology, mean annual rainfall:	Predominantly conifer forest on peat and peaty gley soils overlying boulder clay derived from Carboniferous sediments Mean annual rainfall: 1,350mm (1967 to 1996)

3. Background summary of the catchment

Socioeconomic/historic context

Coalburn drains part of Kielder Forest, now Britain's largest, predominantly productive, conifer forest, which extends over an area of 600km^2. The research catchment was established in 1966 in response to concerns that planned large-scale upland conifer afforestation of acid moorland could threaten water resources. Trees and conifers in particular are known to have a higher water use compared with grass and therefore could reduce the reliable water yield. Forecasts at the time of population and economic growth indicated a possible shortage of water, which led to the subsequent construction of the nearby Kielder Water, northern Europe's largest man-made lake. Local farmers and other landowners were also concerned that the soil cultivation and drainage preceding upland afforestation would increase the frequency and magnitude of local floods. The study was therefore established to quantify the hydrological effects of upland conifer afforestation to help guide decision-making over future forest expansion and the management of water resources.

Flood risk problem(s)

The project is a research study and was not designed to address a specific flood problem. Flooding is an issue in the wider River Irthing catchment and especially after the river joins the River Eden and flows through the town of Carlisle, where more than 500 properties are at risk of flooding from a 1% annual exceedance probability (AEP) event. The relatively small scale of forest cover in the larger catchment draining to this point means that forestry is less likely to exert a significant influence on flood risk at this level. However, there is greater scope for afforestation in the headwaters to affect local rivers and the flooding of farmland and associated properties. In the 1960s, the focus was on the risk of afforestation increasing rather than decreasing flood flows due to the potential for intensive forest cultivation and drainage of peaty soils to enhance site run-off.

Other environmental problems

The water body is at moderate ecological status due to failures for sediment and fish, thought to be linked to dairy and beef farming.

4. Defining the problem(s) and developing the solution

What evidence is there to define the flood risk problem(s) and solution(s)

The project is a research study designed to quantify how conifer afforestation affects water yield and extreme flows through time as the forest becomes established and grows to maturity. It was not designed to deliver flood protection and flooding is not a significant issue in the upper catchment, at least in terms of communities at risk. However, the results are being used to inform and guide future forest expansion in the wider country by improving understanding of how tree cover can affect flood flows. The project has also helped to shape changes to forestry practice to minimise the potential for some activities to increase run-off, thereby enhancing the overall scope for forestry to reduce flood risk.

What was the design rationale?

The project was designed as a traditional 'before and after' catchment research study to determine the hydrological effects of land use change from acid moorland to 90% conifer forest. The nature of the topography, soils and geology offered a sealed catchment, allowing all drainage to be captured as surface run-off. Catchment boundaries were less well defined in some flatter peat areas and so 2 parallel boundary ditches were cut as close as possible to the natural topographic divide to demarcate the contributing area. A compound crump weir was installed to contain and measure streamflow across a wide range of flows, while a network of ground level and standard rain gauges measured rainfall inputs. An automatic weather station has provided detailed meteorological data and a wide range of other hydrological measurements have been made throughout the project.

After a 5-year period of baseline measurements to characterise the hydrological response of the original moorland covered catchment, 90% of the area was deep ploughed in 1972 and then planted with young Sitka spruce and Lodgepole pine trees in 1973. The trees were initially slow to establish, but subsequently closed canopy and have since grown to approaching maturity. Felling and timber harvesting of parts of the crop began in 2016 and will progressively extend over the remaining forest in the next 10–15 years.

Project summary	
Area of catchment (km^2) or length of river benefitting from the project:	Research catchment covers an area of 1.5km^2.
Types of measures/interventions used (Working with Natural Processes and traditional):	Land use change from acid moorland to conifer forest, which extends over 90% of the catchment.

Numbers of measures/interventions used (Working with Natural Processes and traditional):	As above – standard forestry practices (for example, in terms of ground preparation, planting and tending) that applied at the time were implemented.
Standard of protection for project as a whole:	Not applicable
Estimated number of properties protected:	Not determined – no local properties at risk

How effective has the project been?

The project has been very effective in quantifying the long-term changes in water yield and extreme flows in response to upland conifer afforestation and subsequent tree growth to maturity. The results have demonstrated that land use change from moorland to conifer forest has a marked effect on catchment hydrology. At first pre-planting and deep ploughing of peaty soils increased peak flows by 15–20% and reduced time to peak by a third, although these changes appeared to decline with increasing peak height, as well as reduced through time. A progressive increase in water use by the growing forest then took over and appeared to reduce peak flows, although identifying a trend was hampered by rising annual rainfall totals. Use of modelling to decouple the effect of climate variability found evidence of peak flows declining by 10–15% with forest growth. The reduction decreased with increasing event size and appeared to be lost as the return period approached 100 years. The results indicated that forest growth reduced the frequency of discharge events by around 50% (for example, an event with a return period of 13 years became a return period of 20 years).

A separate analysis of the long-term streamflow data that used a statistical technique to remove the influence of changes in rainfall supported the findings described above. The analysis found that the annual number of peak flow events/pulses first increased in response to pre-planting and deep ploughing, and then displayed a greater, progressive decrease over time (40% below those for the original moorland cover), accompanied by an increase in pulse duration (by more than 20%), with tree establishment and growth. Changes declined with increasing peak size and were largely lost for peaks greater than 30 times median flow, although the number of very high peak flows in the data record was small. Upscaling the assessment to the whole of the River Irthing catchment using the flow gauging station at Greenholme (19% forest cover in 335 km2 catchment) showed little evidence of change in peak flow response following ploughing and tree growth to 20 years of age. However, a small reduction in pulse numbers and an increase in mean pulse duration are evident in the data since 1991.

5. Project construction

How were individual measures constructed?

The 'measure' was upland conifer afforestation but this was not specifically designed for the purpose of Natural Flood Management. In fact it was viewed at the time (in the late 1960s) as posing a risk of increasing flood flows due to the impact of pre-planting cultivation and drainage operations. The forestry practices employed were much more intensive than used today, pre-dating the introduction of the Forestry Commission's Forests and Water Guidelines and the shift to more minimal forms of ground cultivation, an emphasis on controlling drainage and the incorporation of buffer areas.

How long were measures designed to last?

Conifer afforestation represented a permanent change in land use from acid moorland to predominantly conifer forest.

Were there any landowner or legal requirements which needed consideration?

Government policy at the time was to build the nation's timber resource through supporting large-scale expansion of conifer forestry on land of least agricultural value in the uplands, where rural employment was most needed. Land was purchased by the Forestry Commission for planting with, unlike today, limited consideration being given to wider environmental objectives such as landscape, recreation, wildlife, carbon and water.

6. Funding

Funding summary for Working with Natural Processes (WWNP)/Natural Flood Management (NFM) measures	
Year project was undertaken/completed:	The project was established in 1966 and is ongoing.
How was the project funded:	The project has received funding from a wide range of sources over the years. Research council monies – directed through the Institute of Hydrology (now Centre for Ecology and Hydrology) and the University of Newcastle – have funded many of the component research studies, while core funding to steer, service and maintain the efficient running of the project has been mainly provided by the Forestry Commission, the Environment Agency and United Utilities (and their predecessors). The European Commission also contributed significant funding to certain phases of the project through its Science Framework and Interreg programmes.
Total cash cost of project (£):	Not available – probably in the range of £1 million to £5 million over the period of study to date
Overall cost and cost breakdown for WWNP/NFM measures (£):	Not available in terms of original planting costs in 1973 Rural Development Programme planting grants apply today – see Forestry Commission and Natural Resources Wales websites for details.
WWNP/NFM costs as a % of overall project costs:	Not applicable
Unit breakdown of costs for WWNP/NFM measures:	Not applicable
Cost–benefit ratio (and timescale in years over which it has been estimated):	Not applicable

7. Wider benefits

What wider benefits has the project achieved?

The primary focus of the study has been on catchment hydrology, which has included both water quantity and quality aspects. The research directly informed the introduction of the Forestry Commission's Forests and Water Guidelines in 1988 and continues to support the development of these, which now underpin the UK Forestry Standard. Improvements in understanding gained from the Coalburn project have helped to drive and shape advances in forestry practice to tackle potential issues such as the scope for ground cultivation and drainage to increase peak flows and sediment losses. This has helped to maximise the opportunities for tree planting to benefit water, including to reduce downstream flood risk.

How much habitat has been created, improved or restored?

Around 136ha of conifer forest

8. Maintenance, monitoring and adaptive management

Are maintenance activities planned?

The catchment is managed as a productive conifer forest. Core scientific instrumentation for measuring changes to catchment hydrology continues to be maintained and data are collected.

Is the project being monitored?

Yes – measurements continue for streamflow, rainfall and other aspects of site hydrology.

Has adaptive management been needed?

Instrumentation has had to be repaired and replaced throughout the duration of the study, including the main flow measuring structure with a new, compound, broad-crested weir constructed in 1991.

9. Lessons learnt

What was learnt and how could it be applied elsewhere?

Long-term research catchment studies are vital to understanding and quantifying the impact on flood flows of NFM measures such as tree planting. Quality instrumentation and consistency of data collection and checking are essential to minimise errors and maximise the scope to detect changes in infrequent events such as high peak flows. This can be aided by the inclusion of a control catchment, but this doubles costs and can be difficult to preserve, especially over a long time period.

An important finding from the project is that the effects of forestry on flood flows can vary greatly during a forest growth cycle and be strongly influenced by forest design and management factors. There is therefore significant scope for forest management to enhance the ability of forest cover to reduce downstream flood risk, depending on the scale and location of forest cover upstream of communities at risk.

10. Bibliography

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Project background

This case study relates to project SC150005 'Working with Natural Flood Management: Evidence Directory'. It was commissioned by Defra and the Environment Agency's Joint Flood and Coastal Erosion Risk Management Research and Development Programme.