British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Development of soil hydraulic properties below grassland, ancient forest and plantation forests

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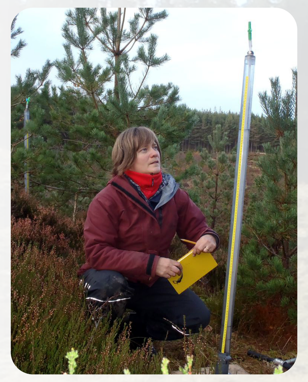
Introduction

Woodlands in particular have the potential to alleviate flooding by delaying the downstream passage of flood flows, reducing the volume of runoff through interception (Calder et al. 2003) and promoting rainfall infiltration into the soil (Thomas & Nisbet, 2006). The natural processes which occur below ground to enable a change in hydraulic pathways and storage are complex and are dependent not only on geology, but also on landuse. We focus this study on below-ground changes that influence soil water characteristics, such as soil hydraulic conductivity, soil water retention and soil structure, which are all important in understanding how the planting of trees can mitigate localised flooding.

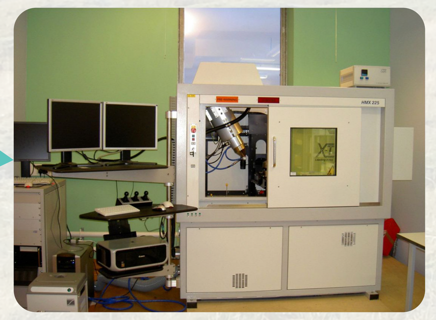
Site area

Five areas were chosen in the Feshie headwaters, within the Cairngorm mountains, Scotland. These were: 6 year old, 48 year old plantations and remnant 350 year old individual Scots Pine (*Pinus sylvestris*), a two hundred year old grazed area located in the Glen Feshie Estate and a remnant Ancient Caledonian Forest within a Scottish Heritage conservation area. The superficial geology ranges from glacial fluvial deposits in the valley to hummocky glacial deposits on the hillslopes and granite outcrops on the higher steep slopes.

Methodology



FIELD TECHNIQUES
In each field site, field-saturated hydraulic conductivity (K_{fs}) was estimated using a constant-head well permeameter (CHWP) as designed by Talsma and Hallam (1980). Replicate soil cores were taken at 0.06 to 0.1 m, 0.16 to 0.20 m and 0.26 to 0.40 m from 3 soil pits within each site. Coarse roots (>1mm) were counted using Bohms's acetate technique (Bohm, 2012) and soil pits were described.



LAB TECHNIQUES
X-ray micro-computed tomography was used to obtain microscopic 3D images of the internal pore geometry of undisturbed soil samples..

To estimate water storage, water release curves were measured for all soil cores. Matric potentials ranging from -0.5, -1, -2.5, -5, -10, -25, -50 kPa were used to equilibrate the samples.

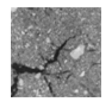
Results

Photos of field areas

Soil/root profiles: 0 to 0.35m depth

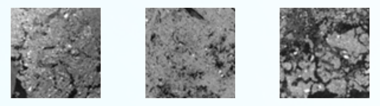
Ancient Caledonian Forest: 4000 years old (AF)

X-ray tomography: 0.16 to 0.20m depth (512 x 512 voxels)



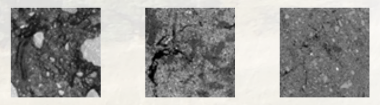
Significantly high macroporosity (>30µm), microporosity (between 30 µm to 0.2 µm) and pore connectivity. High organic matter at 0 to 0.10 m and 0.26 to 0.4 m

Old Scots pine Trees: 350 years old (OT)



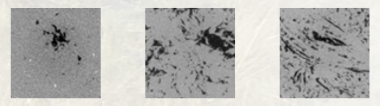
Significantly high macroporosity (>30µm) and pore connectivity. High organic matter at 0 to 0.20 m

Scots pine 48 year old plantation (48 yr)



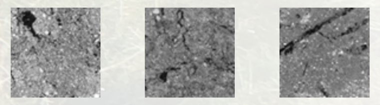
Significantly high macroporosity (>30µm) and pore connectivity. High organic matter at 0 to 0.20 m

Scots pine 6 year old plantation (6 yr)

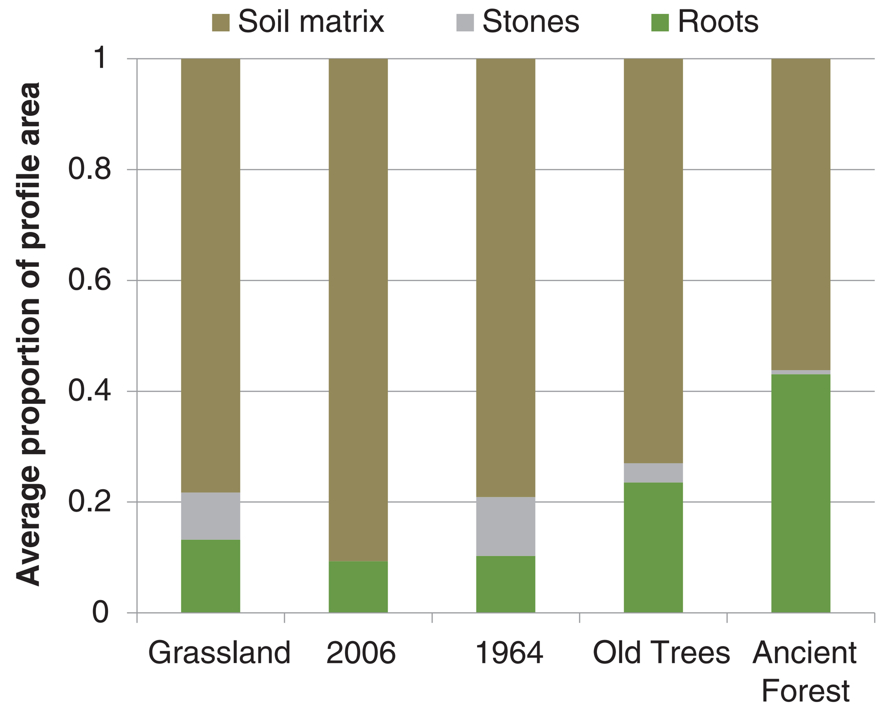


Significantly low macroporosity (>30µm) and pore connectivity. Highly organic matter at 0 to 0.40 m (mean 0.92 g/100 dry soil). Poorly structured throughout.

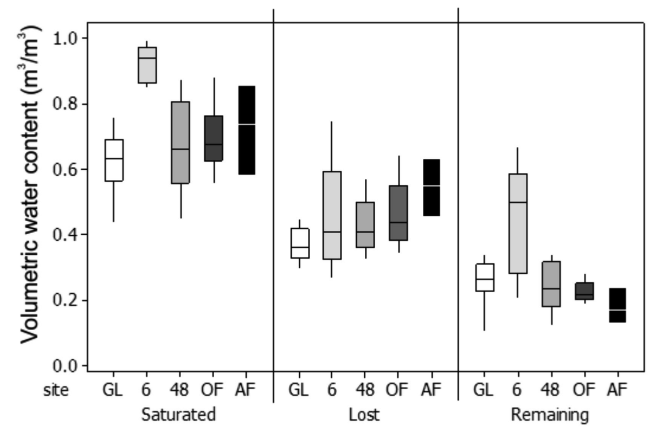
>200 year old rough grazing area (GL)



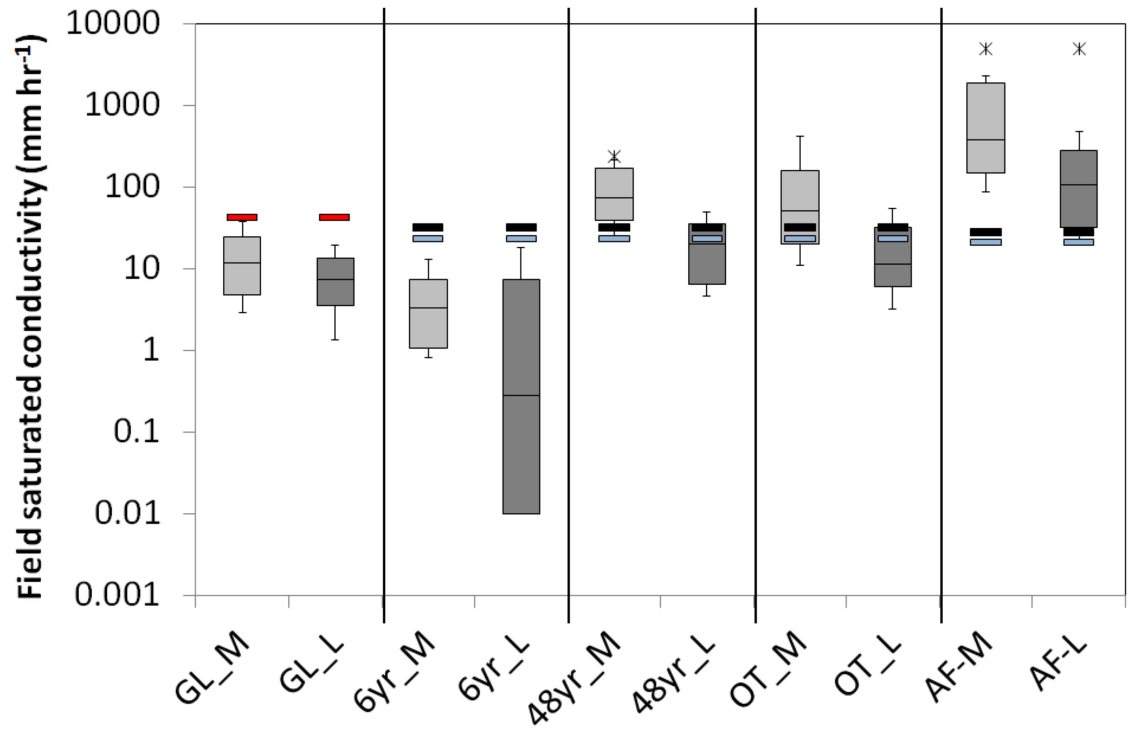
Significantly low macroporosity (>30µm) and pore connectivity. Low organic matter at 0 to 0.40 m (mean 0.13 g/100 dry soil). Well structured throughout.



The Ancient Forest and Old Trees sites had significantly greater proportion of coarse roots (>5 mm) per m², than all the other sites ($F = 3.99$, $DF = 4$, $p\text{-value } 0.035$).



The column 'Saturated' is the saturated water content for cores taken from the three pits (0.05 to 0.35 m soil depth) for each site. 'Lost' is the amount of water removed after 250 kPa matric potential has been applied to the cores for each site. 'Remaining' is the amount of water left in the soil cores for each site after 250 kPa matric potential has been applied to the cores.



Box plots of measured field saturated hydraulic conductivity (K_{fs}). _M denotes 0.04 to 0.15 m soil depth and _L denotes 0.15 to 0.25 m soil depth. The thick red lines show the limits of modelled 1 in 10 year 15 minute maximum rainfall (I_{max15}). The double lines for tree covered sites show the 1 in 10 I_{max15} reduced by 25% rainfall interception (upper black line) and 45% rainfall interception (lower blue line). If the box plots are below these lines, overland flow will occur at these sites for 1 in 10 year I_{max15} event

Conclusions

- Areas of high K_{fs} (sites AF, OT and 48 yr) have a higher proportion of macropores (>30µm) and roots than the other sites, suggesting that high macroporosity and presence of roots are important for increasing infiltration rates in Natural Flood Management.
- The AF site has a remarkable range of K_{fs} (12 to > 4922 mm hr⁻¹), high proportion of macro-porosity >30 µm (0.27 to 0.59), saturated water content (0.47 to 1.0) and organic matter (OM) (1.5 to 96.2 g/100g). This infers that the AF site has the greatest capacity for storm rainfall to infiltrate and transport to deeper soil layers via preferential flow where it can also be stored within the soil matrix because of the presence of high OM and micropores.
- The 6 yr old plantation shows evidence that cutting down of previous plantation and the ploughing, drainage installation and re-afforestation, increases OM, reduces pore connectivity and K_{fs}. However, the peat soil at this site may also have a contributing affect to the reduced pore connectivity and low range of K_{fs} (<0.001 – 6 mm hr⁻¹). More research needs to be done to understand forest management and peat soils in terms of Natural Flood Management.
- The 48 yr site and OT sites have similar soil characteristic values. This maybe because at the OT site, the original 50 year old plantation had been cut down 5 to 6 years ago and the old individual Scots pine trees remained, creating high K_{fs}, OM, macroporosity, proportion of roots and saturated water content values near the individual remaining trees and low soil characteristic values in open areas, resulting in average values which were similar to the 48 yr old plantation.
- There is high variability of macropores and pore connectivity at the microscale, indicating that many measurements need to be taken at this scale to understand soil forming process and land use management.

ACKNOWLEDGEMENTS
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