The impact of semi-natural woodland and pasture on soil properties and streamflow.

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Abstract

The increased frequency of flood events has motivated interest in natural flood management (NFM), in particular the potential for woodlands to reduce flooding. Woodlands can reduce the risk of rainfall-generated flooding through increased interception, soil infiltration, and available storage. Despite growing evidence, there is still low confidence in woodlands as a flood mitigation method due to limited empirical data available, particularly for semi-natural woodlands. We established a correlation catchment study in Haweswater, Cumbria, UK. Nine small upland catchments, each less than 0.2 km2 in area, were established on semi-natural broadleaf woodland sites where no stock grazing occurs or pasture with varied grazing intensity. At each site soil characteristics were investigated, namely soil moisture, permeability and bulk density. In addition, a v-notch weir was installed within in each catchment to calculate flow. The specific peak discharge (SPD), peak runoff coefficient, volume runoff coefficient and time taken to flow response was determined at each site for 28 storm events, of up to 205 mm, identified over a 13-month period. We found that semi-natural woodland reduced SPD by 33-52 % compared with pasture, reducing SPD by 36 % during larger storms (> 1 mm/hr peak discharge). Woodland reduced the peak runoff coefficient by 31-52 % and the volume runoff coefficient by 13-22 % compared to pasture. Additionally, response to storm events took 1-4 hours longer in woodland. These differences in flood response can be somewhat explained by the more permeable woodland soils, 4.6 times greater than pasture soil. Our analysis strengthens the argument that woodlands can reduce rainfall-generated flooding as a land use management method of NFM. Data collected here should be used to inform the parameters in flood prediction models and contribute to the evidence base for NFM.

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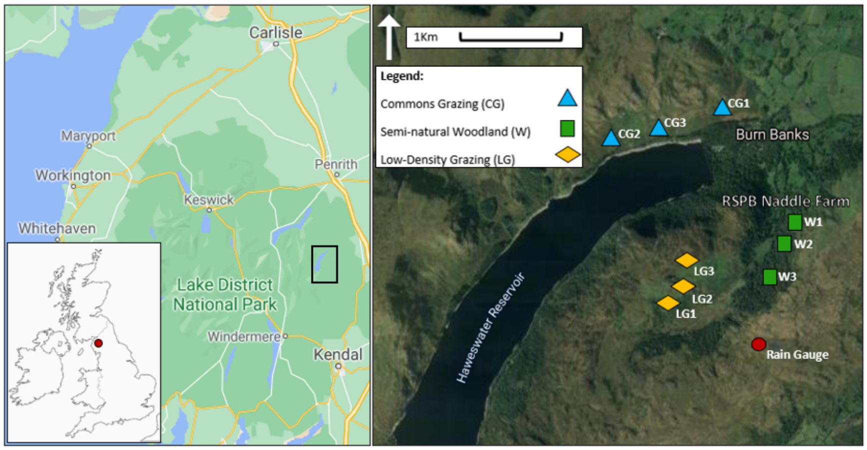
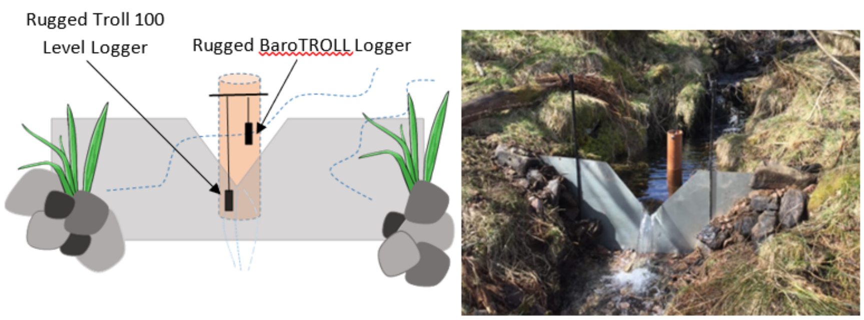
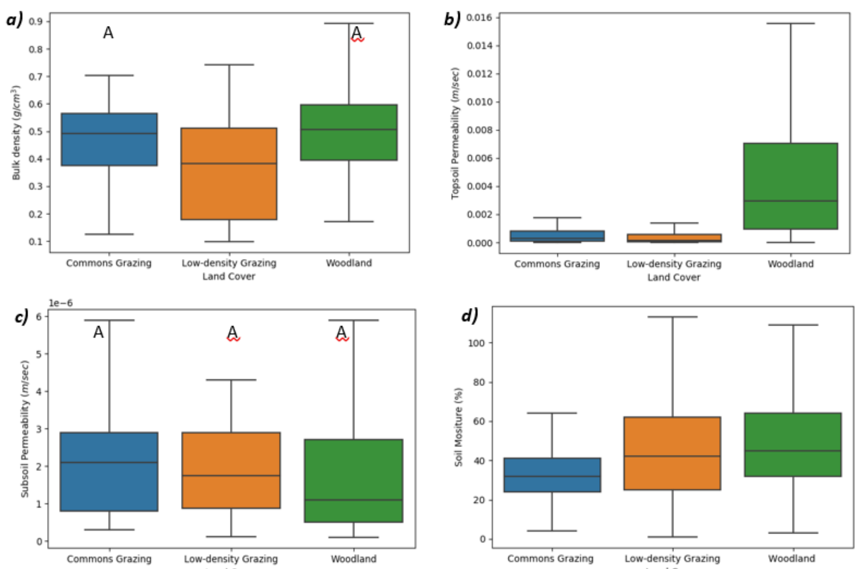
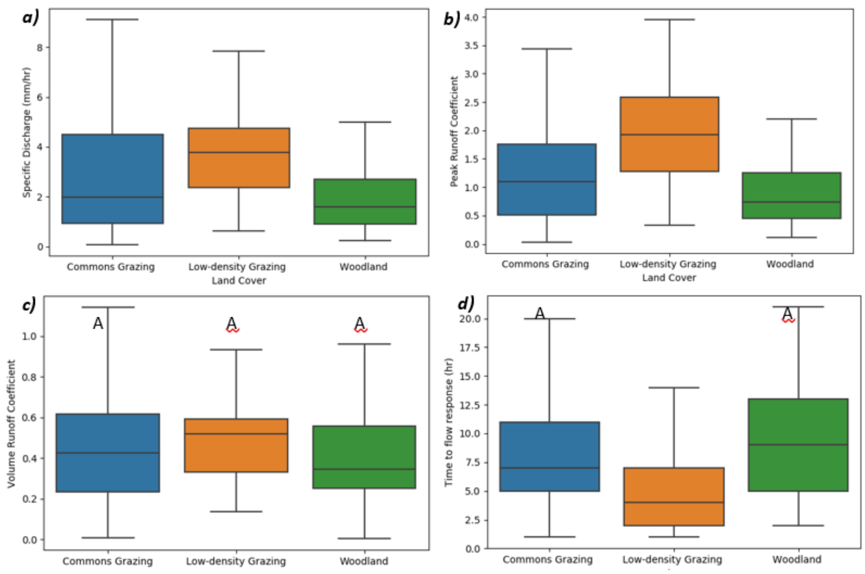

Carlisle
Maryport
Workington
Whitehaven
Keswick
Penrith
Lake District National Park
Windermere
Kendal
1Km
Legend:
Commons Grazing (CG)
Semi-natural Woodland (W)
Low-Density Grazing (LG)
CG1
CG2
CG3
Burn Banks
RSPB Naddle Farm
W1
W2
W3
LG1
LG2
LG3
Rain Gauge
Haweswater Reservoir


Rugged Troll 100
Level Logger
Rugged BaroTROLL Logger


a)
b)
c)
d)
Bulk density (g/cm³)
Topsoil Permeability (m/sec)
Subsoil Permeability (m/sec)
Soil Moisture (%)
Commons Grazing
Low-density Grazing
Woodland
Land Cover
A
1e−6



Field Site	Site ID	Catchment Size (km^2)	Elevation (AOD)	GPS	Ground Vegetation Cover (Dominant species)	Land Management
Commons Grazing	CG1	0.08	260	54°32'19 N 002°45'58 W	*Nardus stricta, Molinia caerulea, Pteridium aquilium, Ulex europaeus, Ranunculus sp.*	Commons Grazing all year round at a maximum intensity of 0.12 LU/ha.
	CG2	0.12	260	54°32'90 N 002°47'40 W	*Nardus stricta, Molinia caerulea, Pteridium aquilium, Ulex europaeus, Ranunculus sp., Sphagnum sp.*	
	CG3	0.08	270	54°32'14 N 002°46'44 W	*Galium saxatile, Rubus sp., Potentilla erecta, Digitalis sp., Pteridium aquilium, Deschampsia flexuosa*	
Low-density Grazing	LG1	0.03	360	54°31'12 N 002°46'12 W	*Nardus stricta, Molinia caerulea, Deschampsia flexuosa, Sphagnum sp., Pteridium aquilium, Ranunculus sp.*	Predominately grazed during 1st May - 30th September with up to 70 ewes, plus lambs. From 1st October- 31st October this is decreased to 40 ewes, plus lambs which are then removed from 1st November until 30th April. Maximum ewe intensity of 0.10LU/ha.
	LG2	0.06	370	54°31'20 N 002°46'39 W	*Nardus stricta, Molinia caerulea, Deschampsia flexuosa, Sphagnum sp., Pteridium aquilium, Ranunculus sp., Cirsium vulgare*	Two grazing regimes; Part of catchment, i) all year-round grazing, the other ii) grazing during 1st May- 30th September with up to 70 ewes plus lambs. Which is decreased on 1st October- 31st October to 40 ewes, plus lambs which are then removed from 1st November until 30th April. Maximum intensity of 0.10LU/ha.
	LG3	0.09	390	54°321'30 N 002°46'28 W	*Nardus stricta, Molinia caerulea, Potentilla erecta, Equisetum arvense, Carduus sp., Veronica sp., Juncus sp*	Predominately no grazing with an area of all-year round grazing, max 161 ewes + lambs. Maximum intensity of 0.10LU/ha.
Woodland	W1	0.03	280	54°31'33 N 002°45'39 W	*Deschampsia flexuosa, Nardus stricta, Sphagnum sp., Pteridium aquilium, Trifolium repens*	Semi-natural upland woodland designated as a site of special scientific interest (SSSI). The NVC classification is for W7, W9, W11 – upland mixed woodland and wet woodland. The woodlands are fenced to exclude livestock.
	W2	0.03	310	54°31'30 N 002°45'44 W	*Nardus stricta, Molinia caerulea, Pteridium aquilium, Sphagnum sp., Trifolium repens, Euphrasia sp.*	
	W3	0.03	270	54°31'40 N 002°45'33 W	*Mercurialis perennis, Deschampsia flexuosa, Sphagnum sp.*	

			Land cover		
			Commons Grazing	Low-density Grazing	Woodland
Streamflow properties	Specific Peak Discharge (mm/hr)	η	1.96	3.76	1.52
		μ	2.71	3.72	1.80
		SEM	0.26	0.21	0.16
	Peak runoff coefficient	η	1.03	1.82	0.72
		μ	1.27	1.83	0.87
		SEM	0.12	0.10	0.08
	Volume runoff coefficient	η	0.43	0.52	0.34
		μ	0.46	0.51	0.40
		SEM	0.04	0.03	0.03
	Time to peak flow (hr)	η	7	4	8
		μ	8	5	9
		SEM	0.5	0.5	0.7
Soil properties	Bulk density (g/cm^3)	η	0.49	0.39	0.50
		μ	0.46	0.36	0.50
		SEM	0.02	0.02	0.02
	Topsoil permeability (m/s)	η	2.78E-04	1.47E-04	2.94E-03
		μ	1.33E-03	6.68E-04	4.58E-03
		SEM	3.01E-04	1.29E-04	5.12E-04
	Subsoil permeability (m/s)	η	2.10E-06	1.75E-06	1.10E-06
		μ	2.47E-06	2.25E-06	2.21E-06
		SEM	3.65E-07	3.51E-07	3.74E-07
	Soil moisture (%)	η	32.3	47.0	50.0
		μ	32.7	45.6	49.1
		SEM	0.5	1.0	1.0

Land Cover	Cumulative flow (mm)	
	1 mm/hr	2 mm/hr
Commons Grazing	283	102
Low-density Grazing	270	189
Woodland	131	21

Reference	Vegetation	Ratio of Kfs woodland compared grazed land	Depth (cm)
Agnese et al. (2011)	40-50-year-old Broadleaf	3.4	10-20
N. A. L. Archer et al. (2013)	180-year-old Broadleaf 500-year-old Broadleaf	6 5	4-15 4-15
Mawdsley et al. (2017)	18-month-old Saplings	2.3	10-30
Marshall et al. (2009)	7-year-old Broadleaf	2.4	18-30
Murphy, Hanley, Ellis, and Lunt 2020)	7-15-year-old Broadleaf	1.8	6
Zimmermann et al. (2006)	Rainforest	4 8	12.5 20
This Study	Broadleaf	4.6 -	5 15