Hydrological change on Tebay Common following fencing and tree planting: A preliminary dataset

by Tom Mawdsley, Nick A Chappell and Elliot Swallow

Lancaster Environment Centre
Lancaster University
Lancaster LA1 4YQ
n.chappell@lancaster.ac.uk

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Rationale and research location

Measurements were undertaken on Tebay Common over 12-16 July 2016 period to see if hydrological change pertinent to flood mitigation had resulted from fencing an area of the sheep-grazed moorland and subsequent planting with Hawthorn (*Crataegus monogyna*), Blackthorn (*Prunus spinosa*) and Alder (*Alnus glutinosa*) tree saplings. Tebay Common (Fig 1) is in the headwaters of the River Lune catchment, close to Tebay village, Cumbria (UK).

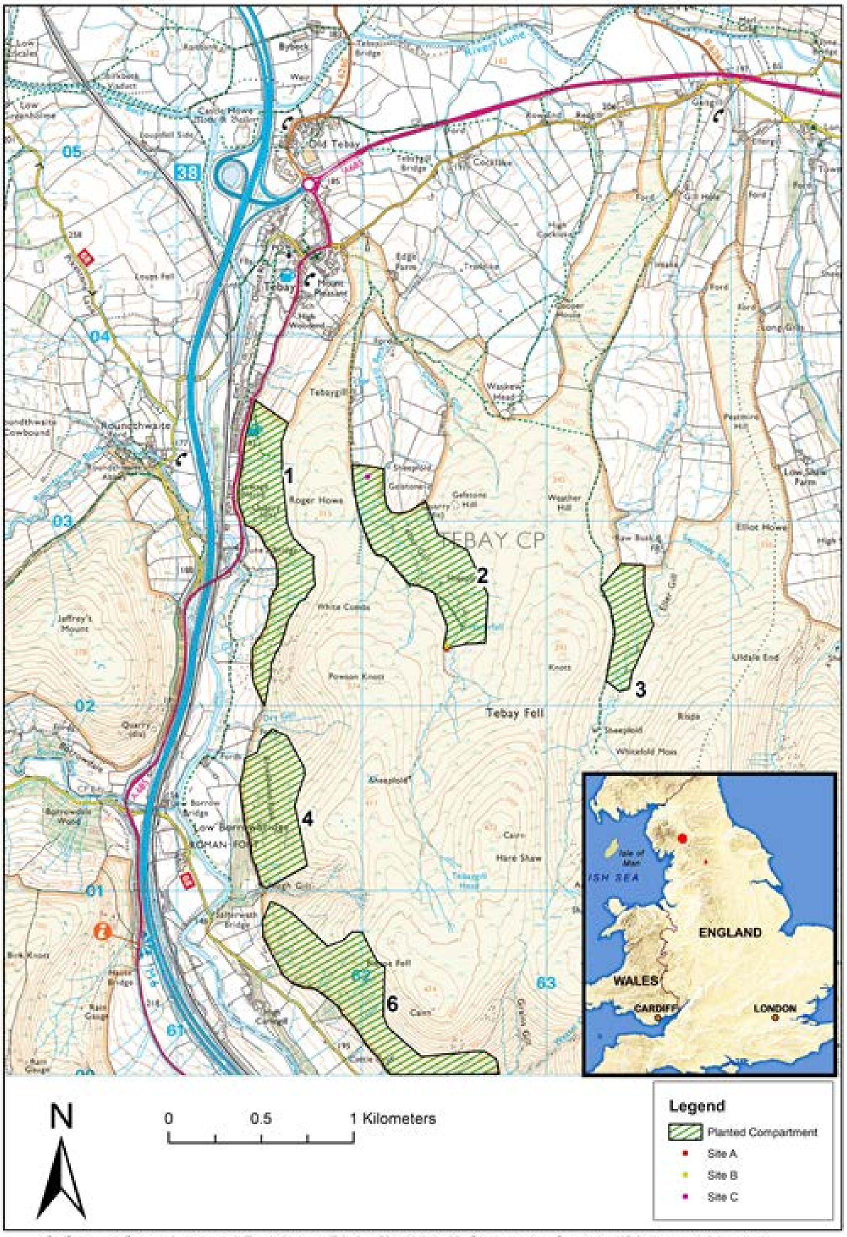


Fig 1. Location of Tebay Fell, that is largely common land, near to Tebay village in Cumbria, Northwest England (UK). Planting compartment '2' was the focus for this study.

Experimental design and methods

A preliminary programme of measurements of subsoil permeability was taken at 100 to 300 mm depth within 50 mm of individual tree saplings and at the same depth but 500 mm away from the same saplings. These permeability measurements were taken with a 'well permeameter' (Talsma and Hallam, 1980) modified for use with slowly permeable soils (Chappell and Lancaster, 2007). The modified well permeameter has a greater vertical displacement of water-level in the reservoir for a unit change in soil permeability by using an outer tube with an i.d. of 23 mm, and an inner tube with an o.d. of 15 mm. This design has been used within previous studies quantifying tree effects on subsoil permeability (e.g., Chappell et al., 1996; Chandler and Chappell, 2008). A total of 20 tests were undertaken, ten at 50 mm from each tree, and ten at 500 mm from the same trees. All tests were undertaken around Alder saplings (ranging in height from 1.73 to 2.12 m) in Plot C shown in Fig 3. The soils in these plots exhibit gleying and are likely to be a Dystric Stagnosol (713e-Brickfield-1). Measured reservoir level changes took between 5 and 85 minutes per test.

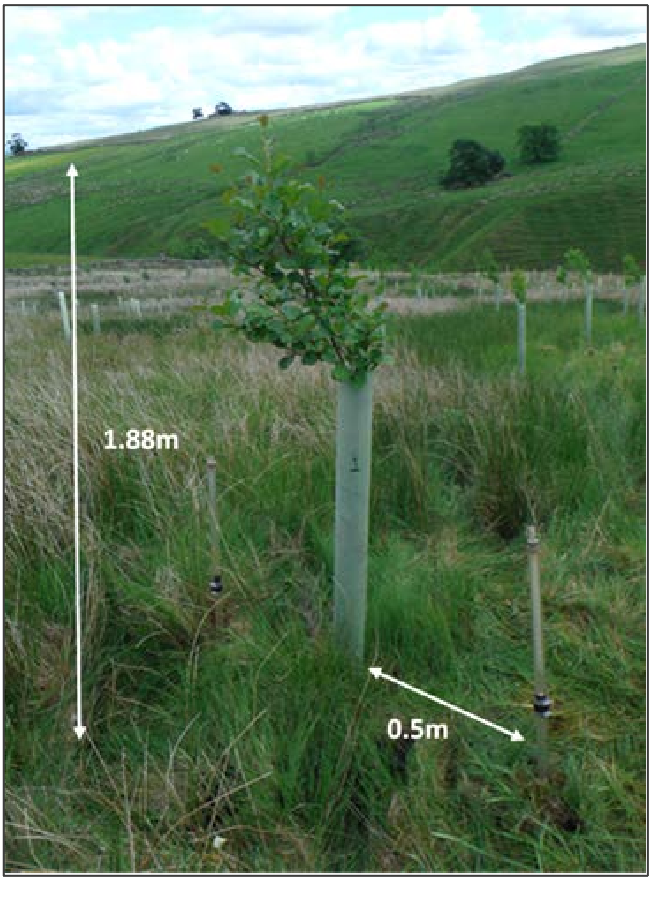


Fig 2. A modified well permeameter in use at 500 mm (0.50 m) away from an Alder sapling in Plot C (see Fig. 3) of planting compartment '2' (see Fig. 1).

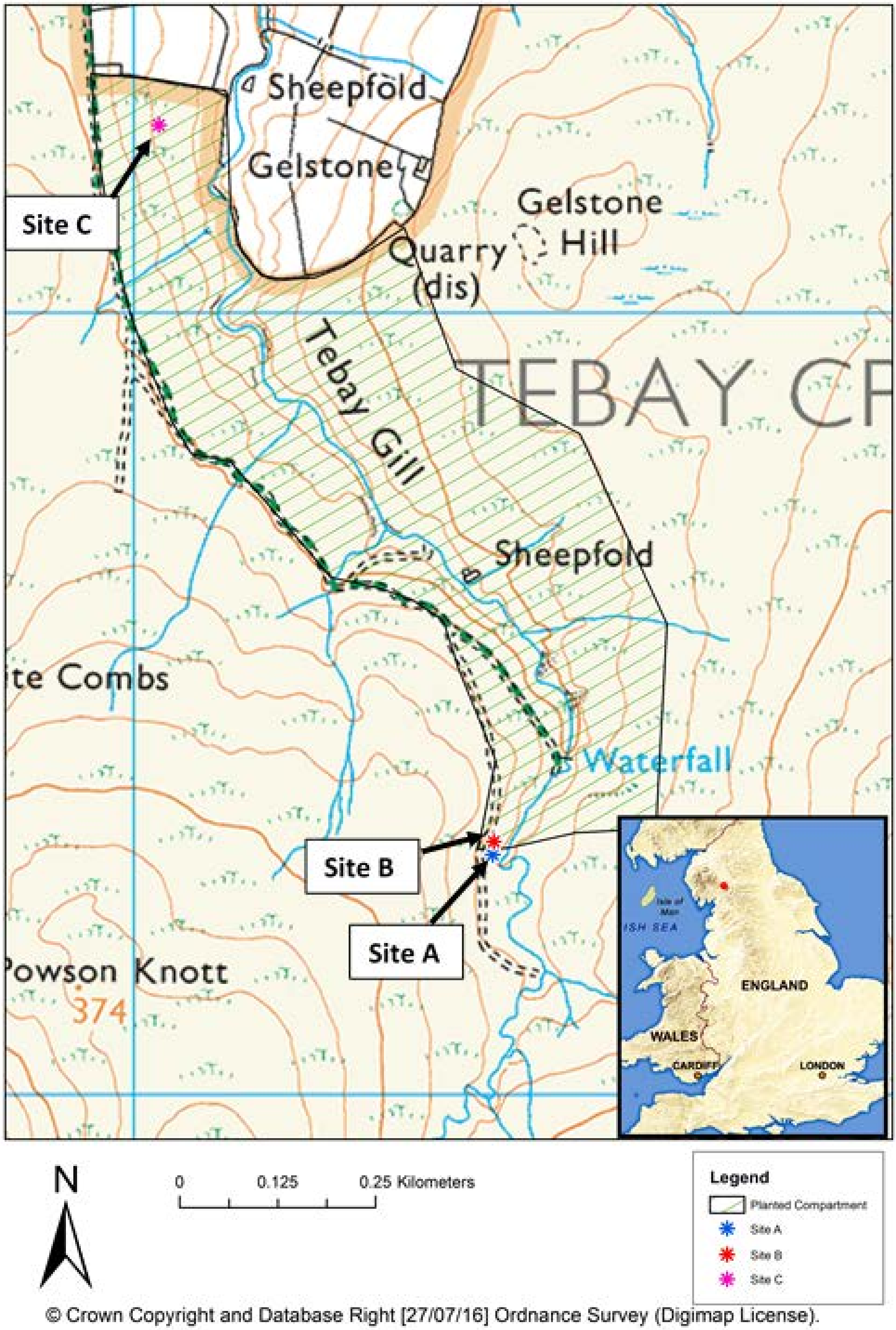


Fig 3. Location of the three research plots (Site A, B and C) in planting compartment '2' (shaded area) on Tebay Fell, Cumbria (see Fig. 1).

A preliminary programme of measurements of volumetric moisture content of the surface 0-60 mm of topsoil was also undertaken in Plot A (sheep-grazed moorland), Plot B (adjacent slope where sheep were excluded and the area planted with Hawthorn and one Blackthorn), and Plot C (2.4 km further north in the Alder planting area). Each plot was 10 x 10 m in area, with plots A and B located next to each other (Fig 4).

Fig 4. Arrows showing the approximate locations of the tapes marking out the 10 x 10 m Plot A (upper photograph) and Plot B (lower photograph), that were adjacent to each other.

A Delta-T Ltd 'theta probe' was used to undertake the soil moisture measurements. It uses a simplified Time-Domain Reflectometry (TDR) technique to derive values of volumetric moisture content (Gaskin and Miller, 1996; Miller *et al*., 1997; Shaw *et al.*, 2010). Measurements were taken at every 1 m interval within each plot to give a dataset of 121 values per plot, and

363 values over the three plots. The readings on the theta probe in millivolts were recorded, and then later converted to volumetric moisture content (m^3/m^3) following Gaskin and Miller (1996) and Miller et al. (1997).

Results

An example of the measurements recorded with well permeameter tests and all the derived saturated hydraulic conductivity (or 'coefficient of permeability') values are given in Appendix 1, while all the geo-located volumetric moisture content (m^3/m^3) values for each plot are given in Appendix 2.

Saturated hydraulic conductivity of subsoil at 50 & 500 mm away from saplings

The measured saturated hydraulic conductivity ranged from 0.014 cm/hr to 0.610 cm/hr across the whole dataset, and within the range 0.050-0.610 cm/hr at 50 mm from the saplings and 0.014-0.261 cm/hr at 500 mm from the same saplings. Table 1 summarises the basic statistical properties of both datasets.

Table 1. Summary descriptive statistics of saturated hydraulic conductivity (K_S) of subsoil (100-300 mm depth) at 50 and 500 mm away from Alder saplings (in cm/hr)

Distance from sapling	50 mm	500 mm
Number of separate tests	10	10
Arithmetic mean K_S	0.266	0.106
Geometric mean K_S	0.180	0.079
Median K_S	0.155	0.071
Standard deviation	0.234	0.084
Coefficient of variation (%)	87.9	79.2

Given that saturated hydraulic conductivity is typically lognormally distributed, the geometric mean (see Table 1) is often considered a more representative value of the centroid of the data distribution (e.g., Chappell *et al.*, 1998). Moreover, if a lognormal transformation of the data is able to normalise the data distribution, then it is the geometric mean that should be used with statistical tests requiring normally distributed data. The normality of the data following a lognormal transformation is not tested here, given the small size of the dataset, however, the very preliminary interpretative statistics undertaken, use this value of the centroid. Using a 2-tailed paired t-test a p-value of 0.044 was reported by the MS Excel T.TEST function. This value is smaller than 0.050, and so the **subsoil close to the saplings may be considered statistically different to that at 500 mm away from the saplings. The geometric mean subsoil permeability is a <u>factor of 2.30 larger</u> beneath Alder saplings planted 18-months previously.**

Soil moisture content of the surface in sheep-grazed versus fenced moorland

The volumetric moisture content measurements range from a very dry 0.209 m^3/m^3 to a very wet (likely saturated) value of 0.611 m^3/m^3 across the plot network. Plot C is particularly wet with an arithmetic mean wetness of 0.584 m^3/m^3 and a minimum recorded wetness of 0.507 m^3/m^3. More importantly, the fenced and tree-planted plot next to the southern boundary of compartment 2 (Plot B) is considerably wetter than the adjacent plot that is sheep-grazed (Plot A).

Table 2. Summary descriptive statistics of the volumetric moisture content, θ (m^3/m^3) of the 0-60 mm of the soil surface in the sheep-grazed plot (Plot A; see Fig. 2) and adjacent fenced and Hawthorn/Blackthorn planted plot (Plot B).

	Plot A	Plot B
Number of readings	121	121
Arithmetic mean K_S	0.393	0.527
Geometric mean K_S	0.384	0.524
Median K_S	0.399	0.540
Standard deviation	0.084	0.049
Coefficient of variation (%)	21.30	9.255

Volumetric soil moisture content is typically normally distributed. Using a 1-tailed or 2-tailed paired t-test on the untransformed data a p-value of much less than 0.001 was reported by the MS Excel T.TEST function, indicating that the **moisture content of the ground-surface and upper topsoil of the fenced area is statistically different to that of the adjacent sheep-grazed moorland. The arithmetic mean surface moisture content is a <u>factor of 1.34 wetter in</u>**

the fenced area, some 18 months after fencing. The contrasting surface wetness of the adjacent plots is even visible if the spatial patterns are presented as an interpolated plot (Fig. 5). The individual plots are presented in Appendix 3, where the colours are scaled to show variations within the plot, rather than contrasts between the plots.

Implications of observed hydrological changes for flood mitigation

The geometric mean subsoil permeability was shown to be a factor of 2.30 larger beneath Alder saplings planted 18-months previously. If further data collection, permitting a more robust statistical analysis, produces a similar result, then it provides some evidence that even young trees may affect the permeability of the soil close to their roots.

This would mean that tree planting on the gley soils of Tebay Common, and in similar settings, are likely to exhibit the first signs of improved drainage during flood events within a few months of the planting episode. Improved drainage takes water from the topsoil so that very fast flowing overland flows are less likely to be produced.

The arithmetic mean surface moisture content was shown to be a factor of 1.34 wetter in the fenced area, some 18 months after fencing. The sparse 'scrub' planting of Hawthorn and Blackthorn saplings (see Fig. 4) would be expected to have a *very local* effect on soil drying close to each sapling due to: (1) enhanced transpiration and wet-canopy evaporation effects and (2) increased infiltration capacity and drainage/percolation (see subsoil K_S data). Consequently, the wetter surface of fenced area must be related to the growth of the grass (following sheep exclusion) that traps more overland flow to add into the topsoil during rains. While the contrasting moisture is clear either side of the fence within Plots A and B, the experiment needs to be repeated either side of many fence boundaries on slopes across the wider landscape.

If the findings are seen across many 'plot pairs', then allowing the moorland grass to grow long may have significant benefits for trapping overland flow, and thereby reduce this flood-producing pathway.

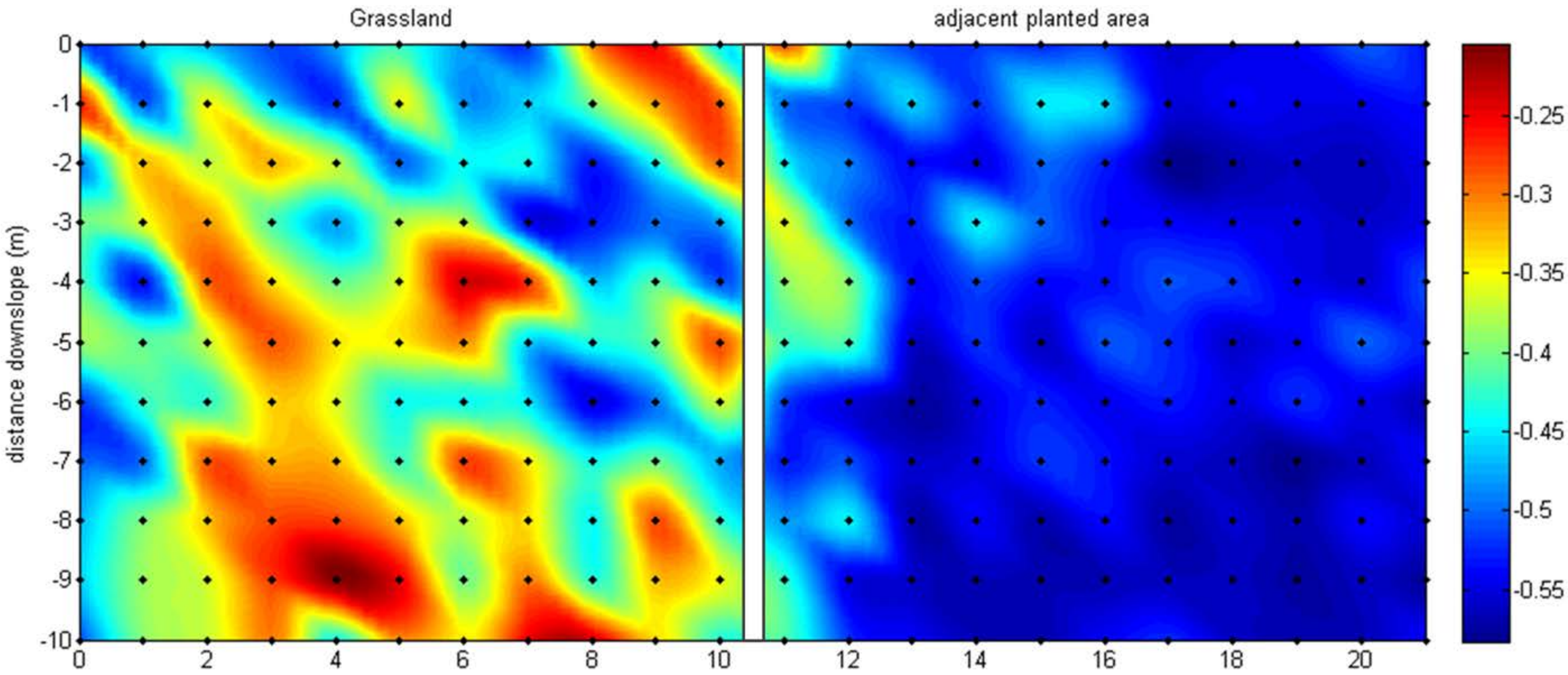


Fig 5. Patterns in volumetric moisture content at the ground surface (0-60 mm in m^3/m^3) either side of a fence. The 'grassland' area (Plot A) is grazed and has short grass, while the 'adjacent planted area' (Plot B) the fence has excluded grazing and allowed grass to grow long (see Fig. 4)

References cited

Chandler, K.R. and Chappell, N.A. 2008. Influence of individual oak (Quercus robur) trees on saturated hydraulic conductivity. *Forest Ecology and Management* 256: 1222-1229.

Chappell, N.A., Stobbs, A., Ternan, J.L. and Williams, A. 1996. Localised impact of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on soil permeability. *Plant and Soil* 182: 157-169.

Chappell, N.A., Franks, S.W., and Larenus, J. 1998. Multi-scale permeability estimation for a tropical catchment. *Hydrological Processes* 12: 1507–1523.

Chappell, N.A. and Lancaster, J.W. 2007. Comparison of methodological uncertainty within permeability measurements. *Hydrological Processes* 21: 2504-2514.

Gaskin, G.J. and Miller, J.D. 1996. Measurement of Soil Water Content Using a Simplified Impedance Measuring. Technique. *J. Agric. Engng. Res.* 63, 153–160.

Miller, J.D., Gaskin, G.J. and Anderson, H.A. 1997. From drought to flood: catchment responses revealed using novel soil water probes. *Hydrological Processes* 11: 533-541.

Shaw, E.M., Beven, K.J., Chappell, N.A. and Lamb, R. 2010. *Hydrology in Practice*. Fourth Edition. Taylor and Francis, Abingdon

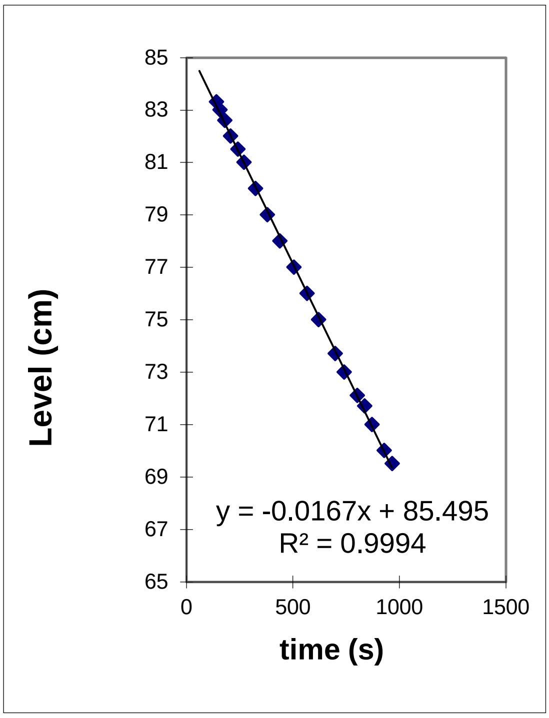
Talsma, T. and Hallam, P.M. 1980. Hydraulic conductivity measurements of forest conductivity. *Aust. J. Soil Res.* 12: 15-26.

Appendix 1: Saturated hydraulic conductivity test data

Well permeametry solver

Tree 1: sample 1 @ 500 mm

	Unst level	hrs	m	s	Time sec	Level cm
1	84		1	0	60	
2			2	21	141	83.3
3			2	37	157	83
4			3	0	180	82.6
5			3	27	207	82
6			4	2	242	81.5
7			4	30	270	81
8			5	24	324	80
9			6	20	380	79
10			7	18	438	78
11			8	24	504	77
12			9	26	566	76
13			10	21	621	75
14			11	38	698	73.7
15			12	21	741	73
16			13	22	802	72.1
17			13	57	837	71.7
18			14	31	871	71
19			15	29	929	70
20			16	6	966	69.5



Specific Discharge (in cm/sec) =		**0.0166**	
Auger Hole radius (cm) =		**3**	
Auger Hole depth (cm) =		**30**	
Depth of reservoir base below ground surface (cm) =		**10**	
Head (cm) =	20		
Reservoir (ID outer pipe, in cm) =	2.4		
Reservoir (OD inner pipe, in cm) =	1.6		
Volumetric discharge (cm3/s) =	0.04172		
Volumetric discharge (cm3/hr) =	150.1936		
Water temperature (deg. C) =		**26**	
Viscosity at 20 deg. C correction factor =			0.868716
Ks (cm/hr) =		**0.0952**	
Ks at 20 deg C (cm/hr) =		**0.0827**	
k (sq cm) =		2.34E-06	
k (darcys) =		23.90329	

The derived saturated hydraulic conductivity values (cm/hr, standardised at 20 ^{o}C) in the subsoil (100-300 mm depth) close to a sapling (50 mm distance from stem) and at 500 mm from an Alder stem.

50 mm	**500 mm**
0.096	0.083
0.119	0.060
0.109	0.075
0.057	0.046
0.191	0.067
0.610	0.173
0.050	0.055
0.597	0.014
0.572	0.230
0.261	0.261

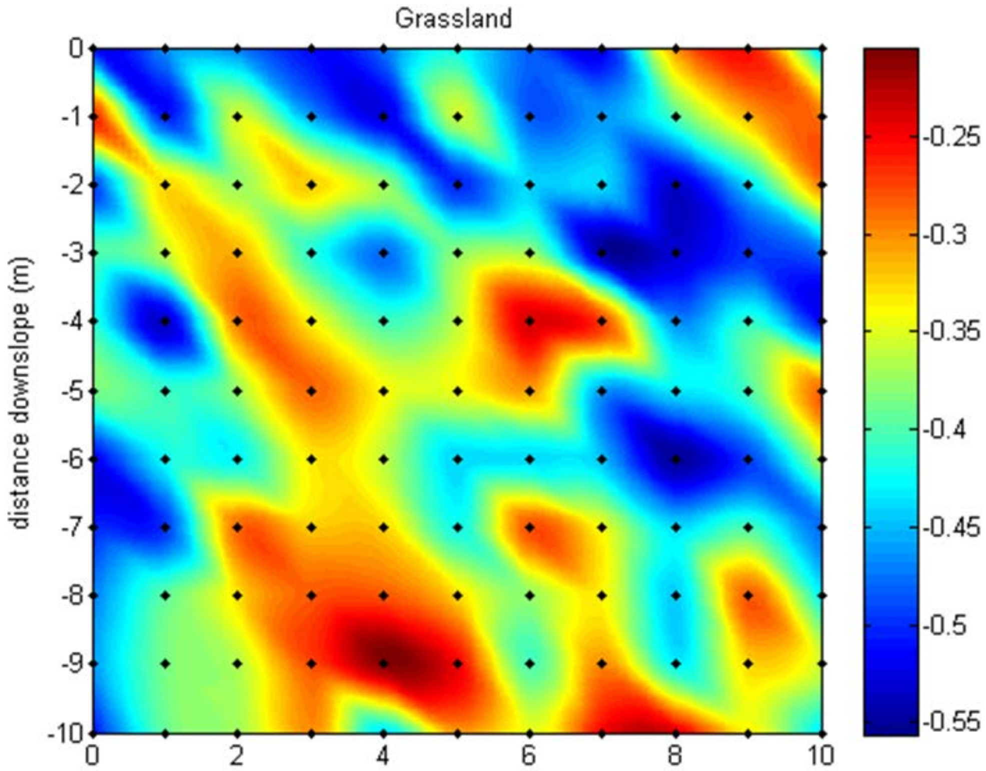
Appendix 2: Volumetric moisture content data (in m^3/m^3 with distances in metres)

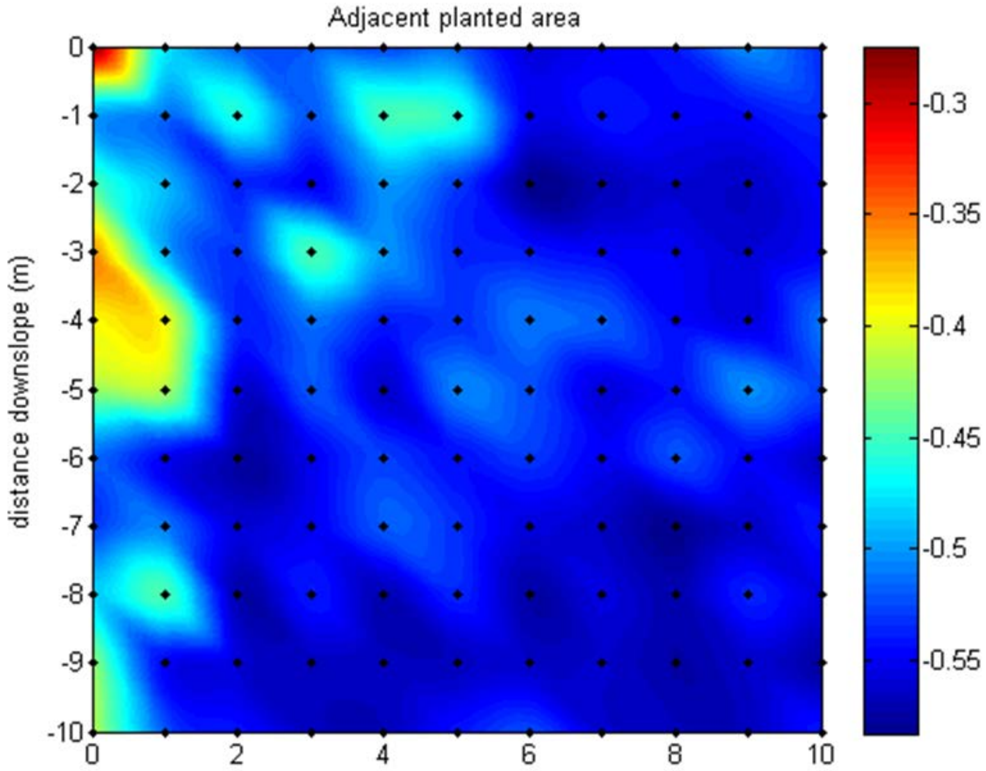
Downslope	Across-slope	Plot A	Plot B	Plot C
0	0	0.511	0.275	0.597
1	0	0.260	0.498	0.588
2	0	0.495	0.445	0.591
3	0	0.399	0.358	0.588
4	0	0.411	0.392	0.590
5	0	0.386	0.422	0.582
6	0	0.519	0.515	0.587
7	0	0.505	0.530	0.573
8	0	0.471	0.482	0.581
9	0	0.463	0.426	0.579
10	0	0.510	0.415	0.582
0	1	0.468	0.477	0.582
1	1	0.508	0.514	0.583
2	1	0.326	0.491	0.577
3	1	0.359	0.495	0.591
4	1	0.535	0.397	0.582
5	1	0.407	0.417	0.591
6	1	0.423	0.549	0.568
7	1	0.496	0.510	0.566
8	1	0.394	0.448	0.579
9	1	0.386	0.549	0.573
10	1	0.392	0.522	0.562
0	2	0.475	0.518	0.599
1	2	0.353	0.461	0.592
2	2	0.374	0.537	0.590
3	2	0.312	0.531	0.605
4	2	0.289	0.537	0.593
5	2	0.372	0.559	0.601
6	2	0.426	0.574	0.572
7	2	0.286	0.558	0.563
8	2	0.327	0.572	0.579
9	2	0.364	0.559	0.564
10	2	0.370	0.542	0.557
0	3	0.513	0.520	0.589
1	3	0.461	0.521	0.603
2	3	0.321	0.549	0.600
3	3	0.414	0.448	0.602
4	3	0.337	0.512	0.583
5	3	0.286	0.521	0.566
6	3	0.332	0.551	0.598
7	3	0.321	0.550	0.597
8	3	0.282	0.540	0.585

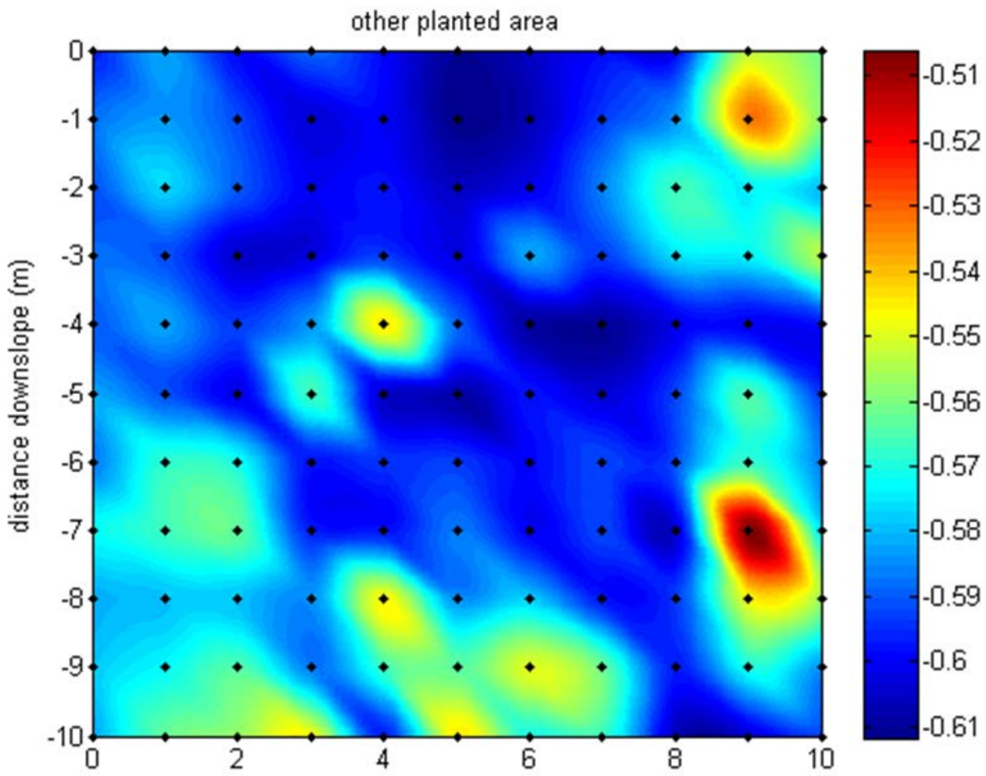
9	3	0.276	0.565	0.587
10	3	0.300	0.566	0.547
0	4	0.477	0.528	0.599
1	4	0.525	0.450	0.600
2	4	0.373	0.501	0.598
3	4	0.478	0.500	0.593
4	4	0.404	0.539	0.545
5	4	0.340	0.561	0.605
6	4	0.361	0.529	0.594
7	4	0.325	0.520	0.598
8	4	0.281	0.570	0.547
9	4	0.209	0.567	0.566
10	4	0.441	0.568	0.597
0	5	0.425	0.519	0.610
1	5	0.357	0.460	0.611
2	5	0.503	0.529	0.606
3	5	0.378	0.536	0.602
4	5	0.360	0.533	0.589
5	5	0.344	0.508	0.608
6	5	0.441	0.544	0.593
7	5	0.421	0.534	0.587
8	5	0.326	0.537	0.585
9	5	0.248	0.566	0.563
10	5	0.307	0.542	0.545
0	6	0.483	0.557	0.606
1	6	0.485	0.551	0.607
2	6	0.441	0.580	0.601
3	6	0.372	0.540	0.582
4	6	0.237	0.510	0.609
5	6	0.306	0.524	0.598
6	6	0.438	0.531	0.599
7	6	0.278	0.557	0.600
8	6	0.376	0.574	0.578
9	6	0.402	0.563	0.550
10	6	0.347	0.525	0.571
0	7	0.518	0.549	0.599
1	7	0.461	0.541	0.593
2	7	0.440	0.567	0.586
3	7	0.545	0.547	0.593
4	7	0.274	0.519	0.610
5	7	0.462	0.557	0.603
6	7	0.450	0.550	0.592
7	7	0.346	0.564	0.592
8	7	0.337	0.557	0.598
9	7	0.298	0.563	0.562
10	7	0.247	0.561	0.567

0	8	0.300	0.539	0.600
1	8	0.399	0.547	0.583
2	8	0.531	0.559	0.566
3	8	0.531	0.550	0.576
4	8	0.466	0.546	0.601
5	8	0.433	0.543	0.592
6	8	0.551	0.524	0.591
7	8	0.439	0.580	0.603
8	8	0.444	0.571	0.593
9	8	0.429	0.574	0.597
10	8	0.236	0.567	0.607
0	9	0.257	0.504	0.554
1	9	0.312	0.545	0.533
2	9	0.437	0.563	0.574
3	9	0.497	0.559	0.574
4	9	0.411	0.556	0.600
5	9	0.402	0.504	0.565
6	9	0.493	0.547	0.567
7	9	0.404	0.562	0.507
8	9	0.282	0.538	0.547
9	9	0.325	0.562	0.571
10	9	0.335	0.566	0.605
0	10	0.451	0.534	0.561
1	10	0.291	0.535	0.559
2	10	0.292	0.546	0.580
3	10	0.476	0.547	0.554
4	10	0.513	0.512	0.598
5	10	0.285	0.527	0.594
6	10	0.362	0.566	0.587
7	10	0.477	0.540	0.576
8	10	0.428	0.556	0.557
9	10	0.357	0.576	0.585
10	10	0.433	0.541	0.593

Appendix 3: Interpolated surfaces of volumetric moisture content data for Plots A ('Grassland'), B ('Adjacent planted area') and C ('other planted area') respectively (using Matlab GRIDDATA function with a triangular-based cubic interpolator). Coordinate data for the corners of the plots are also given.




Adjacent planted area
distance downslope (m)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
2
4
6
8
10
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55


other planted area
distance downslope (m)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
2
4
6
8
10
-0.51
-0.52
-0.53
-0.54
-0.55
-0.56
-0.57
-0.58
-0.59
-0.6
-0.61

Tebay Common Sites	**GPS Coordinate Data**		
	N Coordinates	**W Coordinates**	**Accuracy (ft)**
Site A	N 54°24.908’	W 002°34.808’	10
	N 54°24.910'	W 002°34.802'	10
	N 54°24.902'	W 002°34.806'	12
	N 54°24.905'	W 002°34.797'	10
Site B	N 54°24.911'	W 002°34.800	12
	N 54°24.912'	W 002°34.790	12
	N 54°24.904'	W 002°34.796'	12
	N 54°24.905'	W 002°34.787'	13
Site C	N 54°25.398'	W 002°35.199'	10
	N 54°25.402'	W 002°35.200'	10
	N 54°25.396'	W 002°35.189'	10
	N 54°25.400'	W 002°35.189	10