Investigations into the effect of different land use on field-saturated hydraulic conductivity in the Eddleston Water catchment

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Soil infiltration constant head test using a Guelph Permeameter in rough grazing field. Jack Brickell, British Geological Survey © UKRI 2024

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Keyworth, Nottingham British Geological Survey 2024

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Summary

Land use and management have an impact on the infiltration capacity of soil. It is thought that by changing the way we use and manage land we can increase infiltration into the soil, slow the flow of water through the catchment and reduce flood peaks. However, there are few observational data that directly measure changes in soil permeability in different land uses. This report describes field investigations into the role of land cover on soil permeability in part of the Eddleston catchment in the Scottish Borders as a pilot for a larger study in the future.

Investigations were carried out at Wester Deans Farm on a range of land use types: coniferous woodland, improved grassland, a ten year old broadleaved transverse strip and rough grazing grassland. Experiments to measure the hydraulic conductivity (K_{fs}) of soils underlying these land uses were conducted using a constant head well permeameter (Guelph permeameter). In total there were 129 infiltration tests conducted for this study; 41 in coniferous woodland, 33 in improved grassland, 24 in a broadleaved transverse strip and 31 in rough grazing grassland.

Results indicate that median K_{fs} rates were highest in soils under rough grazing, and medians statistically similar to the coniferous woodland and 10 year old transverse strip woodlands. Highest individual results, and overall range, were obtained under woodlands where root systems are able to create pathways for water flow. The lowest K_{fs} rates were under improved grasslands where dense animal grazing is known to increase compaction of the surface. Statistical analysis showed K_{fs} under improved grasslands to be statistically lower than the three other land uses tested. This study illustrates the role that areas of rough grazing may play in increasing soil infiltration and storage, and may have a similar impact to tree planting. Further study is planned on extending the surveys, and using these data to help plan soil restoration strategies.

1 Introduction

1.1 SETTING

The Eddleston Water project has been ongoing since 2009 with the primary aim to investigate the possibility of reducing the risk of flooding to the communities of Eddleston and Peebles through the implementation of natural flood management (NFM) features (Spray et al., 2021).

It is generally accepted that forest-covered soils have higher field-saturated hydraulic conductivities (K_{fs}) than non-forested soils (Chandler et al., 2018). Increasing soil infiltration is seen as a potential form of NFM, as it is thought to slow water flow through the catchment by increasing water storage and reducing surface runoff.

Previous research in the Eddleston catchment (Archer et al., 2013) considered the role of land cover on soil permeability. The study considered three ages, and types, of woodland and found that soil permeabilities under broadleaf woodlands were greater than grassland areas, and that older woodlands had higher soil permeability. The impact of coniferous plantations was less, with soil permeabilities not much higher than adjacent grassland. They concluded that improved grazed grassland hinders rainfall infiltration, and protecting older woodland areas was a priority.

This study was undertaken to build upon the work by Archer et al, 2013 through field study on a land use (grazed rough grassland) not considered in their work, and to repeat measurements in woodland and improved grassland in another part of the catchment. Field work was undertaken in several stages through university staff investigations, supervised student projects at Edinburgh and Dundee Universities and targeted fieldwork from BGS staff members to complete the study.

1.2 SITE

For this project a field site within the Eddleston catchment area was selected at Wester Deans Farm. This site contains a mixture of land uses including: grazed improved grassland, grazed rough grassland, coniferous woodland and broadleaf woodland. The ages of woodland are approximately c. 55 years for the coniferous plantation, and c. 10 years for the mixed broadleaved shelter belt (transverse strip).

Table 1 Approximate total areas of each land use within the field site.

Land use	Size	Area	Location (approximate grid reference)
Conifer	200 x 30 m	6000 m^2	NT 21169 51741, NT 21278 51695
Improved grassland	590 x 280 m	$1.65x10^5$ m^2	NT 21159 51718, NT 21271 51673
Rough grazing	700 x 660 m	$4.62x10^5$ m^2	NT 21084 51774, NT 21026 51745
Transverse strip	330 x 4 m	1320 m^2	NT 21276 51637, NT 21180 51502*

It was hypothesised that the highest K_{fs} rates would be under coniferous woodlands when compared to the immature broadleaf woodland strip. This was due to the age difference, allowing root systems to develop, and the result of the smaller size of the broadleaf woodland shelter belt. It was also hypothesised that grazed rough grasslands would provide higher soil infiltration rates than grazed improved grassland, where there is likely a higher degree of compaction (Greenwood and McKenzie, 2001).

1.3 SOIL AND GEOLOGY

The superficial geology of the Eddleston catchment, as outlined in Ó Dochartaigh et al. (2018), is described to be a mix of fluvioglacial tills, gravel-sized colluvium and thick floodplain alluvium comprised of sand and gravel. Soils mapped are likely to be either gleys (poorly drained) or brown soils (freely drained) formed during the last glacial retreat c. 13,000 years ago (Environment Scotland, 2024). Although both soils are derived from Silurian and Ordovician greywackes and shales, infiltration rates in the brown soils are likely to be higher due to their free flowing characteristics and lower till content.

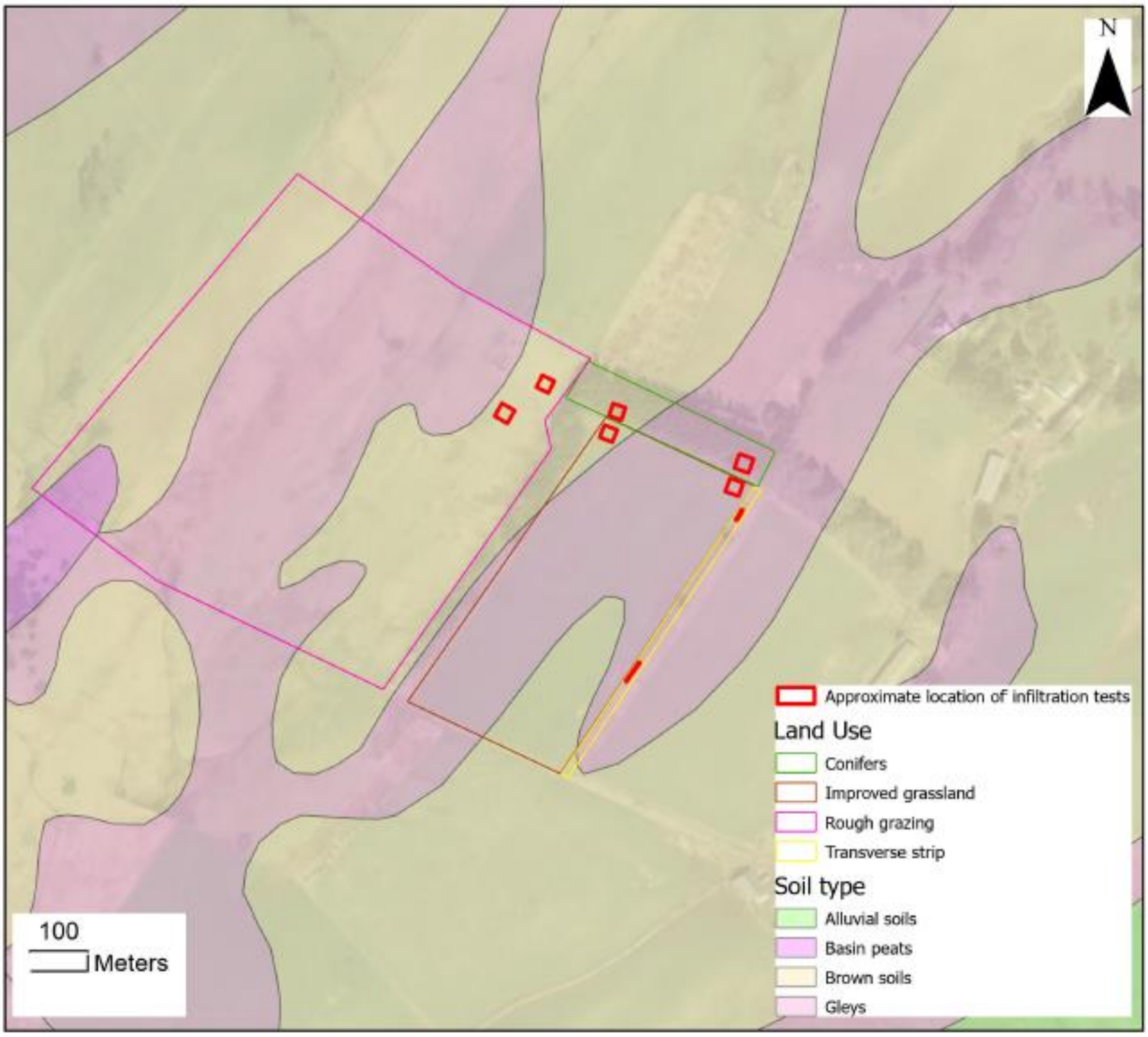

Figure 1 Map of soil types at Wester Deans Farm with field test locations highlighted in red. Map data ©2023 Maxar, Microsoft.

2 Methodology

2.1 FIELD CAMPAIGNS

To gain an understanding of how land use impacts soil K_{fs} rates, a range of sites across land uses were selected to obtain data. The land uses investigated were grazed improved grassland, grazed rough grassland and coniferous woodland.

There have been several stages of fieldwork carried out at Wester Deans Farm looking at soil infiltration capacity. This report collates and presents data from each of these. Fieldwork was carried out in three phases through collaboration with University of Dundee and Heriot Watt University staff members and Master's students. Additional fieldwork was completed by staff at the BGS. A summary of fieldwork is given in Table 2. Table 3 summarises the number of soil infiltration tests completed for each land use type and the approximate centre point of test locations. Land use types and test locations are also shown in Figure 2.

Table 2 Timeline of fieldwork for the project

When	Who	Land use
21st & 22nd July 2021	T Ball Staff research into NFM at Eddleston	Improved grassland, broadleaved transverse strip, conifer plantation
October and November 2021	A McCleave (MA) and G Kane (MEarthSci) dissertation projects*	Conifer plantation, improved grassland
24th to 27th July 2023	J Brickell (BGS)	Rough grazing (acidic grassland)

*Fieldwork conducted together and separate dissertations written.

Table 3 Test locations

Land use	Number of results	Location (approximate grid reference)
Conifer	41	NT 21169 51741, NT 21278 51695
Improved grassland	33	NT 21159 51718, NT 21271 51673
Rough grazing	31	NT 21084 51774, NT 21026 51745
Transverse strip	24	NT 21276 51637, NT 21180 51502*

A systematic sampling strategy was used for the study with measurements taken in a 4 by 4 grid where practical. For the transverse strip, there was not room to implement a grid system, instead a random sampling strategy was implemented with tests being completed at differing distances from fence posts.

Figure 2 Locations of field sites. Map data ©2023 Maxar, Microsoft.

2.2 EQUIPMENT AND EXPERIMENTAL PROCEDURE

All field saturated hydraulic conductivity (K_{fs}) testing was completed using a constant head well permeameter (Guelph Permeameter). Figure 3 shows a Guelph Permeameter during a constant head test in rough grazing land. Two permeameters were used simultaneously on most visits in the interests of making efficient use of time.

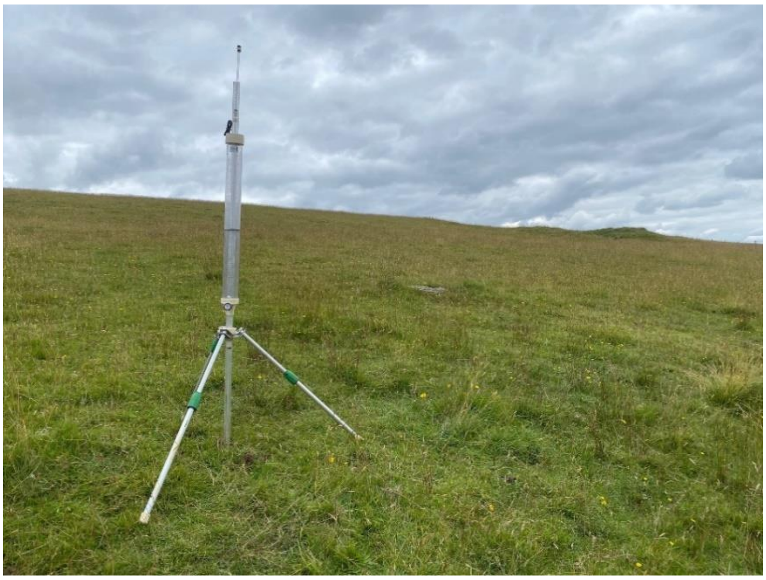

Figure 3 Guelph permeameter mid test in rough grazing field.

The use of a constant well head permeameter is described in detail in the instructions provided by Soil Moisture (Soil Moisture, 2012a) and by MacDonald et al. (2012). The same approach was used at all sites, with each field working undertaking the same training. A summary of the standardised methodology used to measure K_{fs} of soils beneath each target land use for these fieldwork campaigns is given below:

- Two areas were selected for testing within each target land use.
- Each site was gridded and a hole augered at regular intervals within each grid cell.
- Each hole was augered to as consistent a depth (c. 0.15m) and diameter (c. 7cm) as possible.
- The holes were brushed using a stiff nylon brush to reduce any problems associated with smearing (McKay et al., 1993).
- A small volume of pea gravel was added to each hole to reduce any potential for collapse during tests.
- Constant well head (Guelph) permeameter was used.
- Constant head falling test set to either 5 or 10 cm head with the latter selected if infiltration rate was anticipated to be low.
- Tests were conducted for a minimum of 30 minutes with readings taken at regular intervals to capture steady state changes in water level.

As the constant head test is reliant upon saturating the soil with water, overall weather conditions during experiments are not an important factor, so long as not frozen or the soil fully saturated beforehand. No fieldwork was conducted during these periods.

3 Analysis

3.1 PROCEDURE

Field results were initially compiled in a spreadsheet and graphed to assess the steady state of water level change (cm/min). These were plotted as water level change through time showing the steady infiltration rate of water during tests (MacDonald et al., 2012). Further analysis was completed to calculate K_{fs} utilising a single head method spreadsheet provided by Soil Moisture (Soil Moisture, 2012b). This method calculates K_{fs} based on the steady state rate of water level change (R) during each experiment and through the application of a shape factor (C), see Appendix 1, based on the soil characteristics encountered. Other inputs for the calculation are which reservoir in the Guelph permeameter is used (inner or outer), the constant head of water applied and the radius of the borehole in cm. Results are given in the section 3.2.

To assess confidence in results, summary box plots and statistics have been produced using the R programming language. These are given below in sections 3.2 and 3.3 respectively.

3.2 RESULTS

A summary of results is given in Table 4.

Table 4 Summary of the results of K_{fs} testing under each land use

Land use	No of tests	Median (mm hr^{-1})	10th percentile (mm hr^{-1})	90th percentile (mm hr^{-1})
Conifer plantation	41	11.5	3.85	137.40
Improved grassland	33	0.29	0.10	3.99
Rough grazing	31	19.10	10.62	34.85
Broadleaved transverse strip	24	7.68	2.37	76.01

Results indicate that median K_{fs} is highest for soils underlying rough grazing land and are lowest under improved grassland. Tree cover, both conifer plantation and broadleaved transverse strip, give a higher range in K_{fs} results than rough grazing but with a slightly lower median result. Infiltration rates under improved grassland are lower than all other land uses. Summary box plots of test K_{fs} values are given in Figure 4, with K_{fs} plotted on a log scale. The boxplots above summarise the infiltration test data set into the median (green line), upper and lower quartile (blue box) and the maximum and minimum data points. Outliers are represented by dots. Variability within the results is highest in both of the forested locations.

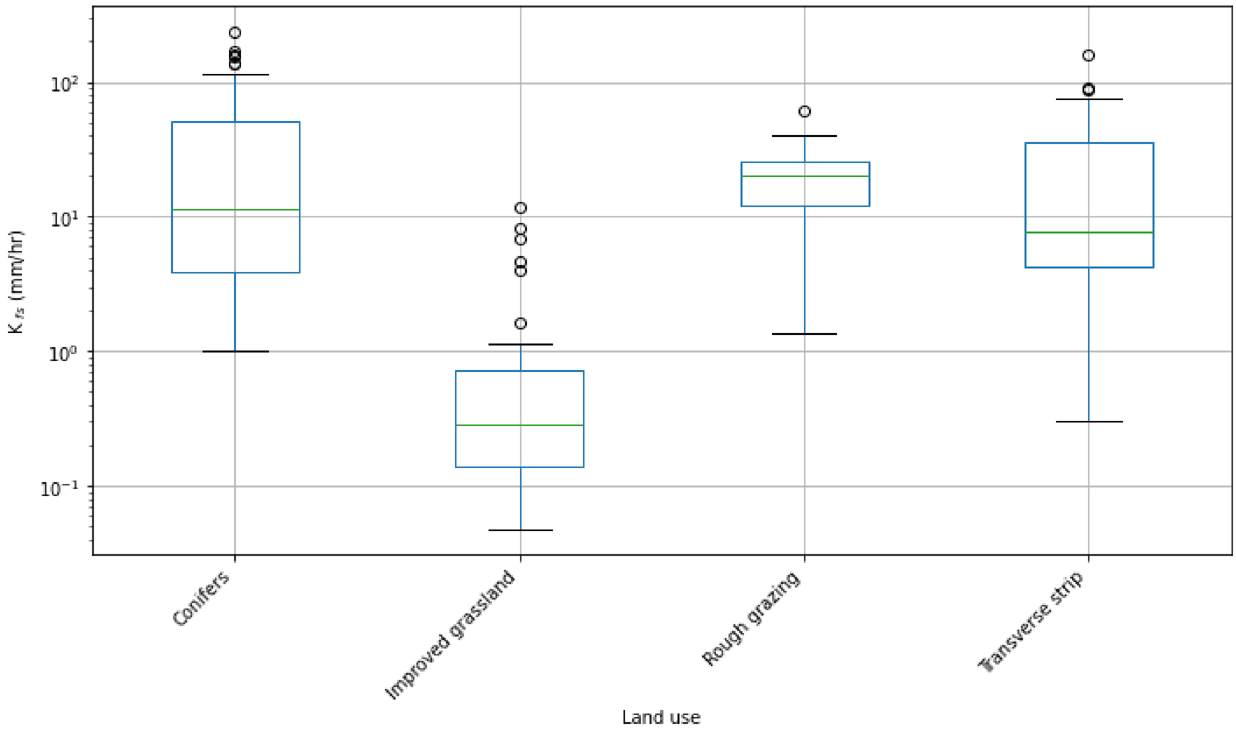

Figure 4 Box plots of field saturated hydraulic conductivity results. Y-axis is a log scale.

3.3 STATISTICAL TESTING

To allow for statistical comparison between different sites Welch's t-tests have been applied to the data to understand relationships between the different land uses. This was completed using R. The results are shown in Table 5, and an empirical cumulative distribution function shown in Figure 5 to help visual comparison of the datasets.

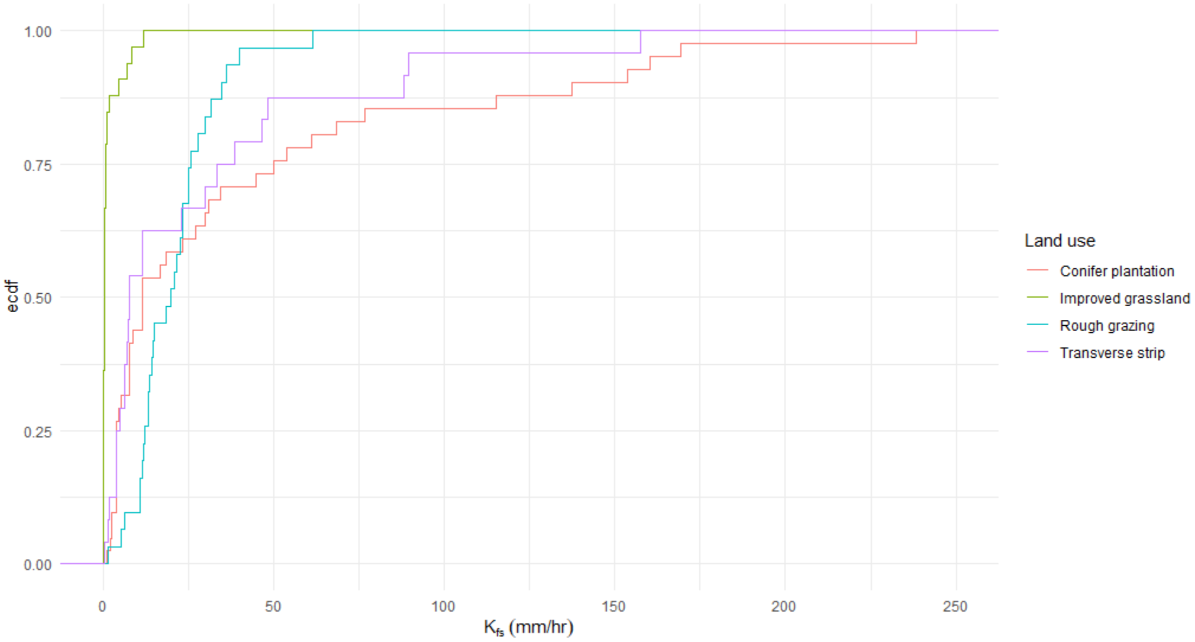

Figure 5 Empirical cumulative distribution function (ECDF) plot for all land uses.

Table 5 T-test results for infiltration tests (Log) using Welch's t-test with the null hypothesis that the means of the two samples are different

Land use 1	Land use 2	P-value
Conifer	Improved grassland	<0.0001
Conifer	Transverse strip	0.35
Conifer	Rough grazing	0.71
Improved	Transverse strip	<0.0001
Improved	Rough grazing	<0.0001
Transverse	Rough grazing	0.18
Conifer	Improved grassland	<0.0001

As seen in Figure 5, the cumulative probabilities for the conifer plantation and the transverse strip indicate that the two data sets are comparable. The T-test results above indicate that the mean infiltration rates for the majority of land uses are statistically comparable (>0.05). The exception being Improved grassland, which is significantly different to all other landcovers.

4 Discussion

There is considerable variability in the hydraulic conductivity results obtained across the different land uses at Wester Deans Farm. The variability is thought to be caused by both the different underlying soil types and the land uses.

Variability within each of the land use groups is highest in the forested areas. This is likely to be the result of heterogeneity within the soils under forests, where root systems are unpredictable and may form preferential flow pathways (Noguchi et al., 1999).

Hydraulic conductivity (K_{fs}) is higher in rough grazing than in improved grassland. Statistically the results from rough grazing are comparable to the two forested areas and not to the improved grassland. The improved grassland is subject to more intensive animal grazing, which is known to increase compaction (Greenwood and McKenzie, 2001) and may result in the generation of a lower permeability shallow layer (Anderson, 2011). The conifer plantation and the transverse strip, in formerly improved grassland areas, both show increased K_{fs} values which are comparable to those obtained on rough grazing. These data indicate the important function of rough grazing land in preserving higher permeability soils, and suggest that there may be more impact from restoring improved grassland areas than tree planting in areas already used for rough grazing. The differences in hydraulic conductivity between a 10 year old narrow, broadleaved, transverse strip and a 55 year old conifer plantation are minimal, although it is unclear whether the improved infiltration in the young transverse strip is due to the tree planting or the exclusion of grazing animals.

Further work is planned in Eddleston to investigate these findings further and study the potential for soil restoration techniques.

Appendix 1

CALCULATION FORMULAS RELATED TO SHAPE FACTOR (C)

Formulas from (Soil Moisture, 2012b).

Soil Texture-Structure Category	α^*(cm^{-1})	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_1/a}{2.102 + 0.118(H_1/a)}\right)^{0.655}$ $C_2 = \left(\frac{H_2/a}{2.102 + 0.118(H_2/a)}\right)^{0.655}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

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