The Impact of Tree Planting on Infiltration Dependent on Tree Proximity and Maturity at a Clay Site in Warwickshire, England

Revell, N, Lashford, C, Rubinato, M & Blackett, M

Original citation:
Revell, N, Lashford, C, Rubinato, M & Blackett, M 2022, 'The Impact of Tree Planting on Infiltration Dependent on Tree Proximity and Maturity at a Clay Site in Warwickshire, England', Water, vol. 14, no. 6, 892.
https://dx.doi.org/10.3390/w14060892

DOI 10.3390/w14060892
ISSN 2073-4441

Publisher: MDPI

water

MDPI

Article

The Impact of Tree Planting on Infiltration Dependent on Tree Proximity and Maturity at a Clay Site in Warwickshire, England

Nathaniel Revell [1,*], Craig Lashford [1,2], Matteo Rubinato [1,2,3] and Matthew Blackett [1,2]

1 Centre for Agroecology, Water and Resilience, Coventry University, Coventry CV8 3LG, UK; ab0874@coventry.ac.uk (C.L.); ad2323@coventry.ac.uk (M.R.); aa8533@coventry.ac.uk (M.B.)
2 Faculty of Engineering, Environment & Computing, School of Energy, Construction and Environment, Coventry University, Coventry CV1 5FB, UK
3 IKT-Institute for Underground Infrastructure, Exterbruch 1, 45886 Gelsenkirchen, Germany
* Correspondence: revelln@uni.coventry.ac.uk

Abstract: Urbanisation and the replacement of previously vegetated areas with impermeable surfaces reduces the lag times of overland flow and increases peak flows to receiving watercourses; the magnitude of this will increase as a result of climate change. Tree planting is gaining momentum as a potential method of natural flood management (NFM) due to its ability to break up soil and increase infiltration and water storage. In this study, a 2.2 km^2 clay-textured area in Warwickshire, England, planted with trees every year from 2006 to 2012 was sampled to investigate how infiltration varies dependent on season and tree proximity and maturity. Infiltration data was collected from 10 and 200 cm away from selected sample trees from November 2019 to August 2021 using a Mini Disk infiltrometer (MDI). The results show that mean infiltration is higher at the 10 cm proximity compared with the 200 cm proximity by 75.87% in winter and 25.19% in summer. Further to this, mean 10 cm infiltration is 192% higher in summer compared with winter, and mean 200 cm infiltration is 310% higher in summer compared with winter. There is little evidence to suggest a relationship between infiltration and tree maturity at the study site.

Keywords: tree planting; tree proximity; infiltration; flood risk management; natural flood management (NFM)

Citation: Revell, N.; Lashford, C.; Rubinato, M.; Blackett, M. The Impact of Tree Planting on Infiltration Dependent on Tree Proximity and Maturity at a Clay Site in Warwickshire, England. *Water* **2022**, *14*, 892. https://doi.org/10.3390/w14060892

Academic Editor: Chang Huang

Received: 15 February 2022
Accepted: 11 March 2022
Published: 12 March 2022

1. Introduction

The global climate is predicted to change in ways unseen in recorded history [1,2]. Climate predictions show that across the UK, the frequency and severity of extreme weather events will increase, sea levels will rise, summers will become warmer and drier, and winters will be warmer and wetter [1,3]. Urbanisation and the replacement of previously vegetated areas with impermeable surfaces, such as asphalt and concrete, reduces the lag times of overland flow and increases peak flows to receiving watercourses; the magnitude of this will increase as a result of climate change [4–8]. Conventional methods of flood management prioritise moving flood waters downstream as quickly as possible [5,9]; however, the recent increase in flood frequency has led to increased investigations into more sustainable methods of managing flood risk, namely, Natural Flood Management (NFM) methods [5,10,11].

NFM methods aim to replicate pre-development catchment hydrology and encourage infiltration, interception, and evapo(transpi)ration, with the aim of storing and slowing precipitation before reaching the receiving watercourse [4,12,13]. Common examples include vegetation planting to increase infiltration and interception (and subsequent evapotranspiration), reducing soil compaction by changing farming and animal grazing routines, and 'roughening' and obstructing watercourse channels and overland flow pathways to slow the flow of water downstream during high-rainfall events [14–17]. Tree planting is often considered a valuable method of NFM as tree roots can enhance soil macro-porosity, connect flow pathways, reduce compaction, and improve soil structure, which increases infiltration and water storage capacity [18–23]. The value of tree planting has been acknowledged by the UK Government, who have allocated GBP 4 million to organizations aiming to increase UK woodland coverage; and GBP 1.4 million to the Environment Agency (England) for the same purpose [24]. Additionally, Government grants have been introduced to encourage farmers to convert arable land to woodland via the 'Woodland for Water' scheme, run in coalition with the Environment Agency and the Forestry Commission [25]. Furthermore, the UK Government have pledged to plant 30,000 ha of trees per year until 2024 (the end of the current Government), which highlights their acknowledgement of the benefits of tree planting [26].

However, regardless of funding allocations and the increased investment in tree planting, few studies have assessed the impacts of tree planting on infiltration, and contextualised this with regard to flood risk mitigation and the use of tree planting as a method of NFM [3,27–31]. Therefore, the aim of this study is to investigate the impacts of tree planting on infiltration dependent on tree maturity and tree proximity.

This work is the precursor to another study previously conducted by the same authors [31], which focused on the hydrological modelling of the collected infiltration data (used for this work and listed in Section 3) and the analysis and variations in peak flow and total discharge from the study site as a result of changing land cover. Therefore, the same sample site and infiltration data collection methods (presented in Section 2) are used in both studies. However, this study focuses solely on the variations in infiltration data, and the influence of tree proximity and tree maturity on infiltration—in addition to undertaking statistical testing on such data. Developing an understanding of the influences of tree planting on infiltration, and contextualising these findings in the context of the wider implementation of NFM and existing policy, will aid in the justification and subsequent uptake of NFM methods [15,32]. This will allow for enhanced flood risk reduction both at present, and in the future, considering the predicted impacts of climate change and continued urbanisation [1,3–5].

2. Materials and Methods

2.1. The Heart of England Forest

The Heart of England (HofE) Forest charity have planted 1,883,928 trees across 2832 hectares of Warwickshire and Worcestershire, England. The charity aim to eventually plant and maintain 12,140 hectares of forest across the English Midlands for the benefit CO_2 mitigation, public amenity, habitat creation, wildlife, and biodiversity [33]. The HofE forest began planting trees across the study site in 2006, and continued annually until 2012, when the trees were left to grow with very little human interference. The HofE forest plant saplings in line with National Vegetation Classification (NVC) guidelines [34,35] to ensure that newly forested areas correspond with exiting native species for the area, defined as 'mature lowland broadleaved woodland'.

2.2. Sample Area and Infiltration Data Collection

The study site is a 2.2 km^2 area in Warwickshire, UK (52.1511° N, 1.5139° W), owned by the HofE forest, and was defined by generating a watershed boundary using a 1 m digital terrain model of the area [36] (Figure 1). Infiltration data were collected every other week from specific sample trees planted in 2006 (*Betula pendula*), 2008 (*Populus tremula*), 2010 (*Betula pendula*) and 2012 (*Populus tremula*). In addition, infiltration data were collected from a plot of pre-existing woodland planted in *cc.* 1900 (*Quercus petraea*), and a grassland control site. The data collected from the grassland control were used in comparison with the wooded areas, and the samples taken from the *cc.* 1900 area provided information regarding the infiltration characteristics of mature trees and were used for comparison. Figure 1 shows the locations of the infiltration sample plots and sampling locations.

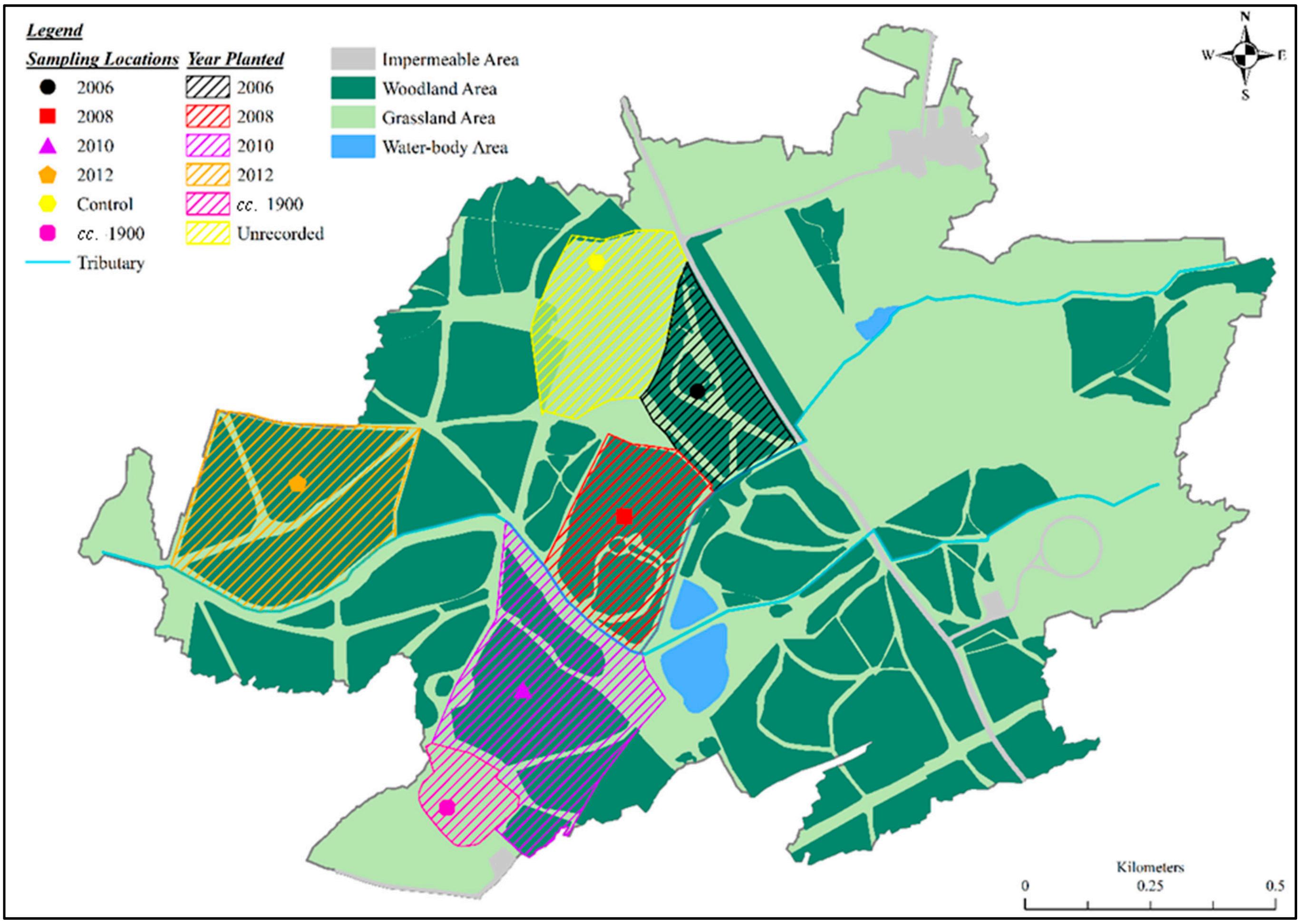

Figure 1. Sample sites and sampling locations with land cover highlighted [37]. Data is reproduced under the open government license.

As this study aims to determine the variation in infiltration dependent on proximity, infiltration measurements were taken from 10 cm and 200 cm away from the base of the sample trees. The 10 cm proximity was as close as any measurement instrument could get to the base of the tree without interference from the root system or growths around the base. The 200 cm proximity was defined using literature specific to the tree species sampled throughout the fieldwork [38–40], suggesting that the lateral root spread of all trees would surpass the 200 cm measuring distance by the time the tree matured. The 200 cm proximity would also act as a comparison for the 10 cm proximity, allowing for the influence of tree proximity on infiltration to be delineated.

The Mini Disk Infiltrometer (MDI) was chosen for infiltration data collection due to its portability, low water usage (in comparison to ring-infiltrometer methods), replicability, ease of individual operation, and durability [41–43]. Relevant literature indicates that the tension setting of the MDI is altered from study to study [41,44–46]; therefore, a tension setting of 2 cm was selected following the suggestion of the MDI user manual [47]. It is acknowledged that recent advancements in infiltration models are inclusive of plant-root water uptake such as the Feddes reduction function [48], the compensated non-linear uptake model [49], and methods involving Python [50]. However, this work utilised the infiltration-time model due to the study scope outlining the influence of tree roots on soil porosity and subsequent infiltration as the primary focus (see Section 1).

It is well regarded in the literature that field infiltration measurements inherit high spatial variability, and that replication is imperative for attaining accurate results [51–53]. Therefore, every MDI measurement was replicated twice (in addition to the first measurement) and all replicates were averaged to give a mean average total for that site. As the MDI required a watertight seal with the sample soil, vegetation was removed from the surface of the soil before infiltration measurement proceeded. Figure 2a,b show the method by which infiltration measurements were taken in proximity to the tree.

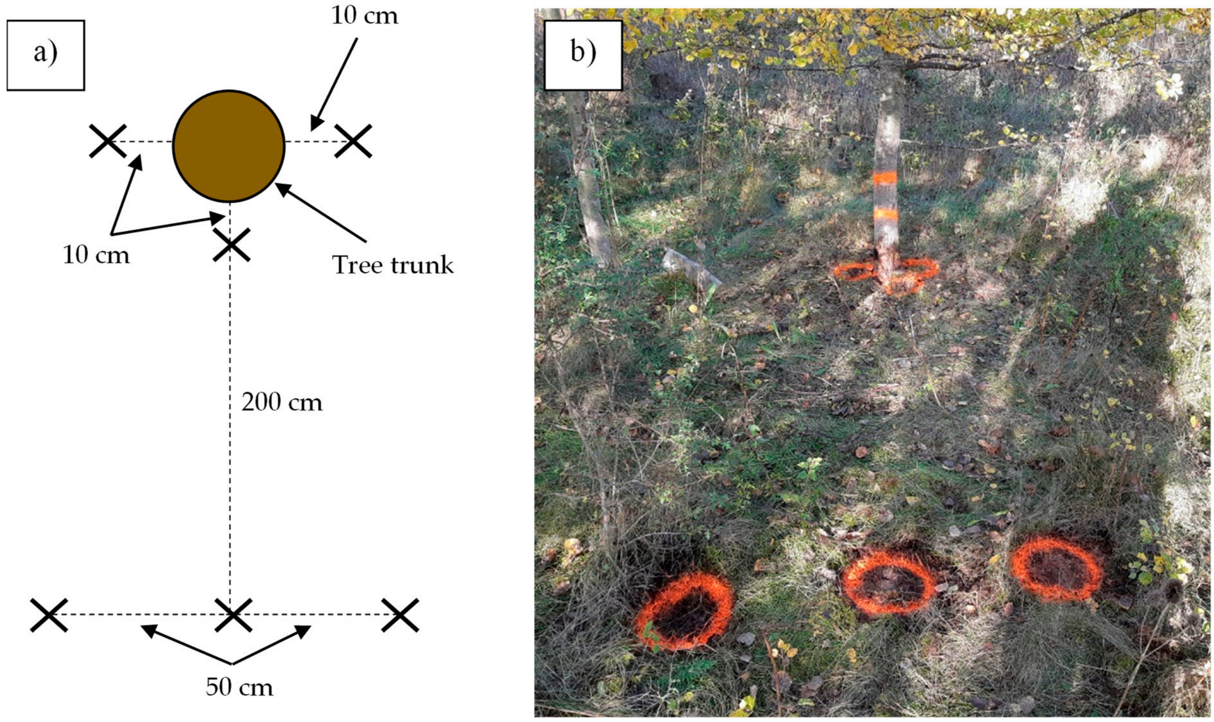

Figure 2. (**a**) Diagram of MDI measurement location in proximity to the sample tree. Black crosses (X) indicate MDI measurement location. (**b**) MDI measurement locations represented at the 2008 sample site.

The 10 cm datums were identified, and a line was measured from the base of the tree in the direction of least obstruction (i.e., no other trees, undergrowth, or shrubbery intruding the area) to mark the location of the 200 cm measurement locations; 50 cm was measured either side of the line to identify replica locations. Replication could not take place in the exact same location as the initial infiltration measurement, as any measurements would be skewed due to previous saturation of the soil; so, 50 cm was chosen to avoid lateral seepage (leading to the overestimation of infiltration values) [54–56]. The control site measurements were collected in a triangular pattern, with each replication being 50 cm from the last to avoid lateral seepage (Figure 3a,b).

A total of 1287 individual infiltration measurements were collected from November 2019–August 2021; 702 from the 10 cm proximity (including the grassland control), and 585 from the 200 cm proximity. Infiltration data was not collected from March 2020 to July 2020 due to the UK national COVID-19 lockdown.

2.3. Soil Texture Analysis and Seasonal Variation

Soil texture influences infiltration characteristics (rate, capacity) [43,57,58]. To understand the influence that varying soil textures across the study site may have on the collected infiltration data, soil samples were extracted from the surface (~5 cm depth) of the soil surrounding the area of MDI measurement using a trowel. A LaMotte [59] soil texture test kit was used to determine the percentiles of sand, silt, and clay for each infiltration sample-area soil, and this information was compared against the UK soil texture triangle to determine the classification name of each sample soil. The percentiles and soil texture classifications of the sample area are shown in Table 1.

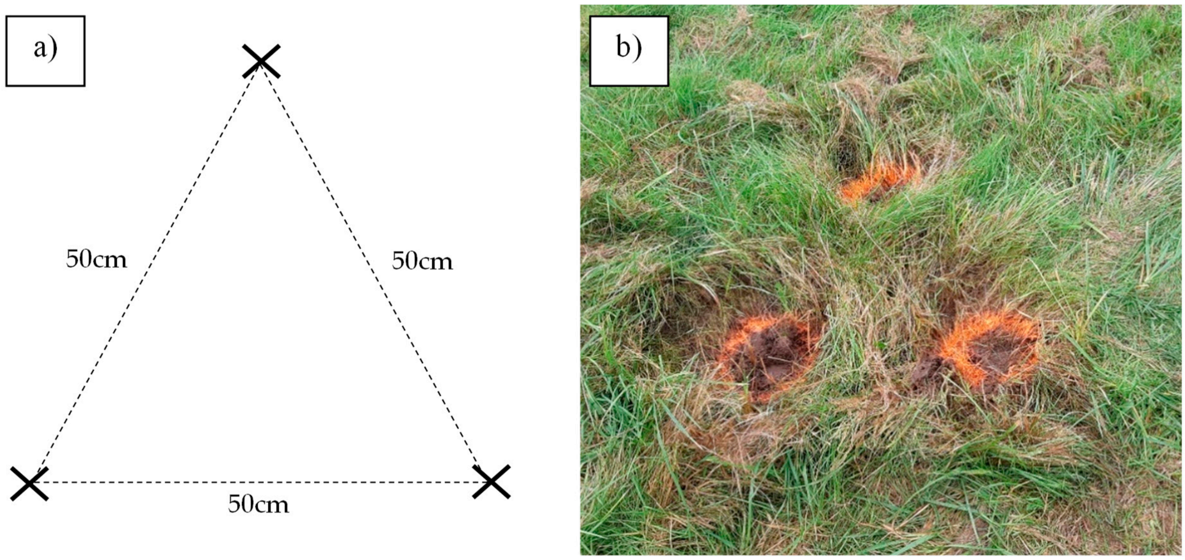

Figure 3. (**a**) Diagram of MDI measurement locations at the controls sample site. Black crosses (X) indicate MDI measurement location. (**b**) MDI measurement locations represented at the control sample site.

Table 1. Soil percentiles and texture classification of each sample site.

Sample Site	Sand %	Silt %	Clay %	UK Soil Classification	
Control	53	20	27	SaCL	Sandy clay loam
cc. 1900	47	40	13	SSL	Sandy silt loam
2006	20	20	60	C	Clay
2008	13	20	67	C	Clay
2010	53	33	14	SaL	Sandy Loam
2012	33	13	54	C	Clay

The 2006, 2008, and 2012 sites are comprised of a clay-heavy soil texture, meaning that they are naturally less permeable compared to other soil textures [55]. The grassland control, *cc*. 1900 and 2010 sites are comprised of a sandier soil texture, indicating that these areas are more permeable compared with other soil textures [55,60]. Due to the varying soil texture, the study site varied hydrologically between summer and winter—particularly across the clay-heavy soils. Throughout the summer, the clay-heavy soils began to crack, creating macropores; this is the opposite to winter, where the soil was bare and often completely saturated due to the inability of infiltration to take place (see Figure 4).

These changes influenced the collected infiltration data and as such, it was decided that the collected infiltration data would be separated to represent soil conditions across the site in both wet and dry periods. This approach also allowed for the trends in infiltration change as a result of changing proximity to be compared through winter and summer, allowing an in-depth analysis of the influence of tree planting on infiltration seasonally across the site. Metrologically, December, January, and February are defined as winter, and June, July, and August are defined as summer by the UK met office [61,62]. However, as this collected data is the precursor to the development of a hydrological model (see Revell et al., (2021)); winter is defined as October to March, and summer is defined as April to September. These timeframes are based on UK average annual temperature and rainfall data, provided by the Met Office [63].

Figure 4. (**a**,**b**) saturation of the 2006 sample site throughout winter, (**c**,**d**) cracking of the 2006 and 2008 sample sites throughout summer.

3. Results

3.1. Tree Proximity and Infiltration

Table 2 shows the average infiltration values for each sample site throughout winter and summer 2019/20 and 2020/21.

Table 2. Average infiltration for 10 and 200 cm proximities throughout both winter and summer sample periods.

	Winter (mL)						Averages
	Control	***cc.* 1900**	**2006**	**2008**	**2010**	**2012**	
2019/20 10 cm	3.4	9.96	0.67	7.04	4.85	3.07	5.42
2020/21 10 cm		5.64	2.17	1.98	2.80	2.31	2.80
10 cm average		7.80	1.42	4.51	3.83	2.69	4.11
2019/20 200 cm		4.22	0.37	2.56	4.70	2.30	3.16
2020/21 200 cm		3.78	0.83	1.36	1.50	1.69	1.51
200 cm average		4.00	0.60	1.96	3.10	2.00	2.34
	Summer (mL)						
2019/20 10 cm	12.35	20.81	14.62	17.95	17.62	18.14	17.19
2020/21 10 cm		11.54	5.06	5.85	9.73	6.70	6.83
10 cm average		16.18	9.84	11.90	13.68	12.42	12.01
2019/20 200 cm		11.38	9.48	16.14	15.19	14.90	14.14
2020/21 200 cm		9.21	3.27	4.45	6.45	4.94	5.04
200 cm average		10.30	6.38	10.30	10.82	9.92	9.60

Mean 10 cm and 200 cm infiltration was 192% and 310% higher in summer compared with winter. In winter, the mean 10 cm infiltration was 75.87% higher than the mean 200 cm infiltration over both sample years; in summer, the mean 10 cm infiltration was 25.19% higher than 200 cm over both years. Throughout winter 2019/20, the mean 10 cm infiltration was 71.38% higher than the 200 cm proximity; in winter 2020/21, the infiltration at 10 cm was on average 85.26% higher than the infiltration at 200 cm across all sites. Summer 2019/20 showed the mean 10 cm infiltration to be 21.55% higher than the 200 cm infiltration, and the mean 10 cm infiltration data was 35.48% higher than the 200 cm proximity values throughout 2020/21. These results show that infiltration varies more between the 10 and 200 cm proximities in winter (71.38% and 85.26% for 2019/20 and 2020/20, respectively) compared with summer; however, the summer 10 cm infiltration was still higher than the 200 cm by 21.55% and 35.48% (in 2019/20 and 2020/21, respectively).

3.2. Tree Maturity and Infiltration

It would be expected that the discrepancy between infiltration at the 10 cm and 200 cm proximity would become greater as tree roots develop, break up the surrounding soil matrix, reduce compaction, and increase porosity [20,21,64,65]. Considering this, it would be expected that the most recently planted HofE trees would show a lower mean infiltration at both proximities compared with older trees across the site; however, this is not the case at the study site. Table 3 shows the two-year mean infiltration of each sample site in winter and summer at both measured proximities, sorted in ascending order.

Table 3. Sample sites in ascending order based on mean infiltration in winter and summer at both 10 and 200 cm proximity.

Winter 10 cm	*cc*. 1900 7.8	2008 4.51	2010 3.83	2012 2.69	2006 1.42
Summer 10 cm	*cc*. 1900 16.18	2010 13.68	2012 12.42	2008 11.9	2006 9.01
Winter 200 cm	*cc*. 1900 4	2010 3.1	2012 2	2008 1.96	2006 0.6
Summer 200 cm	2010 10.82	cc. 1900 10.3	2008 10.3	2012 9.92	2006 6.38

Table 3 shows that, aside from the 2006 site, which consistently showed the lowest mean infiltration regardless of season or proximity, the sorted mean infiltration data did not follow the expected chronological order. The *cc*. 1900 site showed the highest mean infiltration for winter (10 and 200 cm) and for summer at 10 cm; however, it was displaced by 2010 at the summer 200 cm proximity. There was no obvious trend between the highest and lowest infiltration values, with no consistent chronology, as would be expected based on the existing literature [20,21,64,65].

Statistical Analysis: Mann–Whitney Testing

To further test for trends and relationships across the collected infiltration data, statistical analysis was undertaken. Conducting a Kolmogorov–Smirnoff test found the collected data to be non-parametric [66]; therefore, Mann–Whitney tests were undertaken [66–68]. The Mann–Whitney test is the non-parametric equivalent of the independent samples t-test, and is used to deliver a *p*-value indicating to what extent two sets of sample data are statistically significant. Both U_1 and U_2 (Equations (1) and (2)) can be interpreted as the number of observations in a sample that precede or follow observations in the other sample when all samples are ranked in ascending order [69]:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (1)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \quad (2)$$

where n_1 and n_2 are the number of samples in group 1 and 2, respectively, and R_1 and R_2 are the sum of all ranks from the data in groups 1 and 2, respectively. To determine significance (p), the normal approximation equation [70] can be used:

$$P = \frac{\left|U_{min} - \frac{n_1 n_2}{2}\right|}{\sqrt{\frac{n_1 n_2 (n_1 n_2 + 1)}{12}}} \quad (3)$$

where U_{min} is the smallest U value. The Mann–Whitney tests would indicate if there was a significant difference in infiltration between the 10 cm and 200 cm proximities—initially for all winter/summer data, then on a site-by-site basis. If $p \leq 0.05$, then there is a significant difference between the measured variables; if $p > 0.05$, then there is not a significant difference between the two measured variables. The results of the Mann–Whitney test are shown in Table 4.

Table 4. Test criteria, p values and significance levels of Mann–Whitney testing.

Test Criteria	*p*-Value
All 10 cm vs. 200 cm	<0.1
All winter 10 cm vs. 200 cm	<0.1
All summer 10 cm vs. 200 cm	0.02
cc. 1900 10 cm vs. 200 cm winter	0.03
2006 10 cm vs. 200 cm winter	0.02
2008 10 cm vs. 200 cm winter	0.15
2010 10 cm vs. 200 cm winter	0.23
2012 10 cm vs. 200 cm winter	0.07
cc. 1900 10 cm vs. 200 cm summer	0.26
2006 10 cm vs. 200 cm summer	0.07
2008 10 cm vs. 200 cm summer	0.08
2010 10 cm vs. 200 cm summer	0.17
2012 10 cm vs. 200 cm summer	0.17

Table 4 shows that overall, there was a significant difference between the mean infiltration data at the 10 cm tree proximity and the 200 cm tree proximity in both winter and summer. However, whilst the overall trends from the proximity infiltration data showed a significant difference between the 10 cm and 200 cm proximities, this trend was infrequently seen at each individual sample site. In winter, the only sites to show a p-value ≤ 0.05 were *cc*. 1900 and 2006; in summer, no sites showed a significant difference between the 10 cm and 200 cm infiltration data. Whilst only a few values were below the significance threshold (0.05), the p-values can still be used as an indication of how tree maturity may be influencing infiltration across the study site. As discussed, it would be expected that the more recently planted trees would show less discrepancy between infiltration at both proximities, and older planted trees would show more discrepancy. The difference between the sample site p-values (representative of the difference between 10 cm and 200 cm infiltration) are shown in Table 5.

Table 5. Sample sites sorted in ascending order of the relationship between infiltration difference between 10 cm and 200 cm for winter and summer.

Winter	*p*-Value	Summer	*p*-Value
2006	0.02	2006	0.07
cc. 1900	0.03	2008	0.08
2012	0.07	2010	0.17
2008	0.15	2012	0.17
2010	0.23	*cc*. 1900	0.26

The values in Table 5 do not follow the expected chronological increase of the 10 cm and 200 cm infiltration data, as would be expected based on existing literature; however, this trend may be due to varying soil textures, sample days, and antecedent soil saturation. Section 4 discusses and contextualises the presented results in further detail.

4. Discussion

The results of the collected infiltration data show that mean infiltration was higher at the 10 cm proximity compared with the 200 cm proximity by 75.87% in winter and 25.19% in summer. Additionally, the mean 10 cm infiltration was 192% higher in summer compared with winter, and the mean 200 cm infiltration was 310% higher in summer compared with winter. There is no evidence to suggest a correlation between tree maturity and increase infiltration (Section 3.2). Infiltration was highest across both proximities at the *cc.* 1900 site, which supports literature indicating that maturity results in greater infiltration [3,18,71]; however, infiltration was lowest at the 2006 site (the oldest HofE trees), which would be expected to demonstrate the second-highest infiltration rate following chronology. When contextualizing the results of this study, it is important to consider tree maturity, current plating mentality, and antecedent conditions, which are discussed throughout this section.

4.1. Infiltration and Tree Proximity

Th results presented throughout Section 3 indicate that the presence of the tree, and particularly the developing root system, influences infiltration by increasing soil porosity, allowing for soil-water storage and faster infiltration [18,20,58]. Mean infiltration was higher at the 10 cm proximity compared with the 200 cm proximity by 75.87% in winter and 25.19% in summer. It was discussed in Section 1 that tree roots connect flow pathways, reduce compaction, influence porosity, and change soil structure [18–23], and the results of this study support this. Further to this, Section 3.1 highlights the variance between winter and summer infiltration values, showing mean infiltration to be 235% higher in summer compared with winter, and summer 10 cm and 200 cm infiltration being 180% and 290% higher than winter values, respectively. This adds further evidence in support of tree planting, as results show that trees are capable of increasing infiltration at the 10 cm proximity throughout summer and winter, regardless of the naturally low permeability of the sample site soil (Table 1). These results contribute to the knowledge gap regarding both infiltration and proximity, as well as seasonal variations in infiltration, and indicate that tree planting is valuable as a method of NFM.

4.2. Infiltration and Tree Maturity

Regarding the influence of tree maturity on infiltration, there is no evidence to suggest a correlation between tree maturity and increased infiltration at either proximity over time, which has been identified through use of the Mann–Whitney testing presented throughout Section 3. Whilst this finding does predominantly dispute what has been identified regarding tree maturity in the literature [3,71,72], it is important to consider these results in the context of the current ages of sampled trees. Aside from the *cc.* 1900 site, the oldest trees sampled were planted in 2006 and the youngest in 2020. Thus, the 2006 woodland had only been in-situ for 15 years, and the 2012 woodland for 9 years (at the time of analysis). The maturity ages of the sampled tree species were discussed in Section 2.2, concluding that birch and aspen trees can live for 100–120 years, reaching their final heights (where infiltration will be at a maximum) at 60 and 30 years, respectively [38–40]. Considering this, the sample trees are still early in their development and the maturity-relationship results presented throughout Section 3 are only representative of the beginning of the likely effects that the trees will have on infiltration. Whilst there are no obvious trends between infiltration and maturity, Tables 2 and 3 show that the *cc.* 1900 sample site demonstrated the highest infiltration at the 200 cm proximity in the winter, and the 10 cm proximity in both winter and summer. This supports the existing literature regarding infiltration and maturity [18,28,73,74]. According to chronology, and based on the existing literature, it would be expected that the 2006 site would demonstrate the next highest infiltration (after *cc*. 1900); however, this was not the case. Table 3 shows the 2006 site to consistently show the lowest infiltration at both proximities, regardless of seasonality. Referring back to the age of trees planted at the site, particularly in comparison to their discussed maturity age and lifespan, this study has focused primarily on young trees (15 to 1 year old). The results of the infiltration data analysis have highlighted that very mature trees (*cc.* 1900) promote high infiltration, which is an insight into what could potentially be expected from the HofE planted trees across the site.

4.3. Anticedent Conditions

The results regarding tree proximity, maturity, and infiltration can be further contextualised when considering the influence of soil texture across the study site [23,60]. Seen in Table 1, the 2006, 2008, and 2012 sites are clay-textured, meaning they are less permeable compared with the control, *cc*. 1900 and 2010 sites [75,76]. Antecedent moisture, compounded by the less permeable clay-texture, often resulted in surface water pooling during and after rainfall at the aforementioned sites. Infiltration data could not be collected (although it was always attempted) during surface pooling, and it is this phenomenon that may account for the recorded low permeability. Surface pooling was also exaggerated by the winter of 2020 being the fifth wettest on record (329.4 mm/143% higher than the 1981–2010 baseline), and the February of 2020 being the wettest ever recorded, with 155 mm of precipitation (258% higher than the 1981–2010 baseline) [77,78]. It is important to acknowledge the effect that soil texture and moisture may have had on the collected results. However, this study shows that tree planting still increased infiltration at the 10 cm proximity compared with the 200 cm proximity, which is a valuable contribution to the current knowledge regarding the impacts of tree planting on infiltration, and their potential use as a method of NFM.

4.4. Trees and Construction

While this study has demonstrated that there is not a correlation between tree maturity and infiltration at both near and far proximities across the site, it is displayed in Tables 2 and 3 that the *cc*. 1900 sample site showed the highest infiltration at the 200 cm proximity in the winter, and the 10 cm proximity in both winter and summer. This finding is notable when considering the way in which woodland areas are currently managed regarding the felling and (less frequent) translocation of trees to make way for impermeable developments [3,18,79]. Urbanisation can often involve the removal of mature(ing) trees, and this study has shown that trees increase the nearby soil porosity and infiltration rate; so, the removal of established woodlands can alter the hydrology of an area [3,18,30,80]. Aside from the demonstrated improvements to soil porosity and infiltration (Section 3), trees are also proven to contribute to increased interception. Quantifying interception is difficult due to the need for specialised equipment or continuous monitoring [81–83]. However, it is suggested that broadleaf interception loss as a percentage of total precipitation is estimated to be between 10–34% (mean 24.25%) [84,85]. As a comparison, interception loss for grassland is negligible, being <1% [16,86]. In addition to the hydrological implications of mature woodland removal and translocation, it is widely acknowledged that woodlands capture and store significant volumes of CO_2 [72,87,88], and the value of woodland carbon sequestration has been identified by the UK Government as key to aiding in achieving net zero carbon emissions [26]. Furthermore, established woodlands are beneficial from the perspectives of habitat creation and protection [89] and public amenity [16]. Apparent from the benefits of established woodland areas, is that the removal and replacement of mature woodland is mostly detrimental to the surrounding area. Whilst the influences of woodland removal are sometimes 'balanced out' by planting saplings in alternate locations, the newly planted saplings will not have a comparable moderating impact on flood risk (and habitats and amenity) compared with the felled mature trees, as has been demonstrated throughout Section 3 [30,75,90].

4.5. Study Applications

The results of this study have shown that trees (and subsequently woodland) are valuable as a method of NFM as they can increase infiltration at close proximities, and become more capable of doing so with increased maturity; this in addition to the associated benefits regarding carbon sequestration, biodiversity, habitat creation, and public amenity. Referred to in Section 2.3, the HofE site is predominantly clay-textured, which is known to demonstrate low permeability and infiltration [55,60]. This therefore indicates that the derived results are a low-end representation of what the impacts of tree planting could be over a more permeable geology. Area calculations of superficial alluvium, clay, peat, and fluvial deposits throughout the UK show 15% (36,374.25 km^2) to be similar in geology to the HofE site [91]. Therefore, 15% of the UK is likely to demonstrate similar infiltration characteristics to the results of this study (Section 3) if trees were to be planted. However, this statistic can also be interpreted to show that 85% (206,120.75 km^2) of the UK is non-clay textured; indicating that the low-end results derived throughout this study will likely be increased if applied to other areas of the UK [55,89]. Infiltration may be higher, and differing trends may be identified regarding seasonality and tree maturity [20,21]. This highlights the wider applicability of the collected data, emphasising the impact of the study results and proving the applicability of the methodology to other areas across the UK. This also presents an opportunity for this research to be extrapolated and applied to other geologies and soil textures, to potentially aid in justifying the use of tree planting as a method of NFM.

It was discussed throughout Section 4.4 that removing woodland does not only disrupt the ongoing processes of infiltration and interception, but that habitats and carbon sequestration are also influenced—something which the UK Government is trying to alleviate through woodland planting [26]. This is also applicable to planting new saplings to account for the removed established trees—new saplings take time to develop the root systems necessary to influence soil porosity (as has been shown throughout this study), and saplings cannot intercept precipitation to the same extent as an established tree with a larger canopy.

5. Conclusions and Future Work

This study used the MDI to collect 1287 infiltration measurements from 10 cm and 200 cm away from sample trees across a clay-texture site, owned by the HofE forest, in Warwickshire, UK. The results of the study show that mean infiltration was higher at the 10 cm proximity compared with the 200 cm proximity by 75.87% in winter and 25.19% in summer, and that mean infiltration was 180% and 290% higher in summer compared with winter at the 10 cm and 200 cm proximities, respectively. There is little evidence to show a relationship between tree maturity and infiltration; however, the sample trees were still early in their development, and it is likely that infiltration will increase as the root systems of the trees develop [18–23].

The conclusions show that tree planting increases infiltration, even over less-permeable soil textures (see Section 2.3); therefore, is valuable as a method of NFM. The findings of this study also have connotations regarding the way in which woodlands are currently managed, with particular reference to development, construction, and forestry. Trees should be left in-situ wherever possible, and allowed to mature to achieve their maximum infiltration potential. Tree planting is not only beneficial to flood risk management, as Section 4.3 indicates that further benefits include carbon sequestration, public amenity, and habitat creation and preservation. It has been discussed in the literature [30] that published research and case studies reporting the results of long-term woodland infiltration studies are scarce. Shorter-term tree planting and infiltration studies have been undertaken [3,18,30,79]; however, this study has contributed to the wider understanding of the longer-term implications and relationships of tree planting and infiltration with regard to proximity and maturity.

Future work will involve developing a method for projecting the collected infiltration data, and simulating this using a hydrologic model to project the likely future hydrological response of the study site regarding precipitation and baseflow increases in light of climate change. Additionally, future studies could investigate likely variations to the study findings, with specific reference to the impact that climate change will have on woodland growth and rainfall patterns, and how this would influence the effectiveness of tree planting as a method of NFM. Furthermore, further considerations will be made regarding the incorporation of time domain reflectometry (TDR) measurements to compliment the derived infiltration data [92]; TDR instrumentation could be installed at both measurement proximities and the information interpreted to inform infiltration measurements. This would allow for a more robust interpretation of the influence of trees on infiltration characteristics dependent on maturity and proximity at greater depths [93–95].

Author Contributions: Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation N.R.; writing—review and editing, C.L., M.R. and M.B.; visualization, N.R., M.R., C.L. and M.B.; supervision, C.L., M.R. and M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: To access the data collected and analysed in this study, please contact Nathaniel Revell (revelln@uni.coventry.ac.uk).

Acknowledgments: Special thanks are extended to the HofE forest, in particular Stephen Coffey, for their support and assistance throughout the data collection phase of this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lowe, J.A.; Bernie, D.; Bett, P.; Bricheno, L.; Brown, S.; Calvert, D.; Clark, R.; Edwards, T.; Fosser, G.; Fung, F.; et al. *UKCP18 Science Overview Report*; Met Office Hadley Centre: Exeter, UK, 2019.
2. Fowler, H.J.; Ali, H.; Allan, R.P.; Ban, N.; Barbero, R.; Berg, P.; Blenkinsop, S.; Cabi, N.S.; Chan, S.; Dale, M.; et al. Towards advancing scientific knowledge of climate change impacts on short-duration rainfall extremes. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2021**, *379*, 20190542. [CrossRef] [PubMed]
3. Murphy, T.R.; Hanley, M.E.; Ellis, J.S.; Lunt, P.H. Native woodland establishment improves soil hydrological functioning in UK upland pastoral catchments. *Land Degrad. Dev.* **2021**, *32*, 1034–1045. [CrossRef]
4. Ellis, N.; Anderson, K.; Brazier, R. Mainstreaming natural flood management: A proposed research framework derived from a critical evaluation of current knowledge. *Prog. Phys. Geogr. Earth Environ.* **2021**, *45*, 819–841. [CrossRef]
5. Ferguson, C.; Fenner, R. The impact of Natural Flood Management on the performance of surface drainage systems: A case study in the Calder Valley. *J. Hydrol.* **2020**, *590*, 125354. [CrossRef]
6. Kitsikoudis, V.; Erpicum, S.; Rubinato, M.; Shucksmith, J.D.; Archambeau, P.; Pirotton, M.; Dewals, B. Exchange between drainage systems and surface flows during urban flooding: Quasi-steady and dynamic modelling in unsteady flow conditions. *J. Hydrol.* **2021**, *602*, 126628. [CrossRef]
7. Rubinato, M.; Luo, M.; Zheng, X.; Pu, J.H.; Shao, S. *Advances in Modelling and Prediction on the Impact of Human Activities and Extreme Events on Environments*; MDPI: Basel, Switzerland, 2020; Volume 12, ISBN 9783039368020.
8. Rubinato, M.; Nichols, A.; Peng, Y.; Zhang, J.M.; Lashford, C.; Cai, Y.P.; Lin, P.Z.; Tait, S. Urban and river flooding: Comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs. *Water Sci. Eng.* **2019**, *12*, 274–283. [CrossRef]
9. Palla, A.; Colli, M.; Candela, A.; Aronica, G.T.; Lanza, L.G. Pluvial flooding in urban areas: The role of surface drainage efficiency. *J. Flood Risk Manag.* **2018**, *11*, S663–S676. [CrossRef]
10. Wells, J.; Labadz, J.C.; Smith, A.; Islam, M.M. Barriers to the uptake and implementation of natural flood management: A social-ecological analysis. *J. Flood Risk Manag.* **2020**, *13*, e12561. [CrossRef]
11. Bosseler, B.; Salomon, M.; Schlüter, M.; Rubinato, M. Living with Urban Flooding: A Continuous Learning Process for Local Municipalities and Lessons Learnt from the 2021 Events in Germany. *Water* **2021**, *13*, 2769. [CrossRef]
12. Ferguson, C.R.; Fenner, R.A. The potential for natural flood management to maintain free discharge at urban drainage outfalls. *J. Flood Risk Manag.* **2020**, *13*, e12617. [CrossRef]
13. Shuttleworth, E.L.; Evans, M.G.; Pilkington, M.; Spencer, T.; Walker, J.; Milledge, D.; Allott, T.E.H. Restoration of blanket peat moorland delays stormflow from hillslopes and reduces peak discharge. *J. Hydrol. X* **2019**, *2*, 100006. [CrossRef]

14. Dadson, S.J.; Hall, J.W.; Murgatroyd, A.; Acreman, M.; Bates, P.; Beven, K.; Heathwaite, L.; Holden, J.; Holman, I.P.; Lane, S.N.; et al. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *R. Soc. Publ.* **2017**, *473*, 20160706. [CrossRef] [PubMed]
15. Burgess-Gamble, L.; Ngai, R.; Wilkinson, M.; Nisbet, T.; Pontee, N.; Harvey, R.; Kipling, K.; Addy, S.; Rose, S.; Maslen, S.; et al. *Working with Natural Processes—Evidence Directory*; Environment Agency: Bristol, UK, 2018.
16. Ngai, R.; Wilkinson, M.; Nisbet, T.; Harvey, R.; Addy, S.; Burgess-Gamble, L.; Rose, S.; Maslen, S.; Nicholson, A.; Page, T.; et al. *Working with Natural Processes-Evidence Directory Appendix 2: Literature Review*; Environment Agency: Bristol, UK, 2017.
17. Forbes, H.; Ball, K.; McLay, F. *Natural Flood Management Handbook*; Scottish Environment Protection Agency: Stirling, UK, 2016; ISBN 978-0-85759-024-4.
18. Chandler, K.R.; Stevens, C.J.; Binley, A.; Keith, A.M. Influence of tree species and forest land use on soil hydraulic conductivity and implications for surface runoff generation. *Geoderma* **2018**, *310*, 120–127. [CrossRef]
19. Malik, I.; Pawlik, Ł.; Ślęzak, A.; Wistuba, M. A study of the wood anatomy of Picea abies roots and their role in biomechanical weathering of rock cracks. *Catena* **2019**, *173*, 264–275. [CrossRef]
20. Xie, C.; Cai, S.; Yu, B.; Yan, L.; Liang, A.; Che, S. The effects of tree root density on water infiltration in urban soil based on a Ground Penetrating Radar in Shanghai, China. *Urban For. Urban Green.* **2020**, *50*, 126648. [CrossRef]
21. Zhang, D.; Wang, Z.; Guo, Q.; Lian, J.; Chen, L. Increase and Spatial Variation in Soil Infiltration Rates Associated with Fibrous and Tap Tree Roots. *Water* **2019**, *11*, 1700. [CrossRef]
22. Guo, F.X.; Wang, Y.P.; Hou, T.T.; Zhang, L.S.; Mu, Y.; Wu, F.Y. Variation of soil moisture and fine roots distribution adopts rainwater collection, infiltration promoting and soil anti-seepage system (RCIP-SA) in hilly apple orchard on the Loess Plateau of China. *Agric. Water Manag.* **2021**, *244*, 106573. [CrossRef]
23. Leung, A.K.; Boldrin, D.; Liang, T.; Wu, Z.Y.; Kamchoom, V.; Bengough, A.G. Plant age effects on soil infiltration rate during early plant establishment. *Geotechnique* **2018**, *68*, 646–652. [CrossRef]
24. GOV.UK £3.9 Million to Drive Innovative Tree Planting. Available online: https://www.gov.uk/government/news/39-million-to-drive-innovative-tree-planting (accessed on 13 July 2021).
25. GOV.UK; Environment Agency. Forestry Commission Reduce Flood Risk with the Woodland for Water Scheme. Available online: https://www.gov.uk/government/news/reduce-flood-risk-with-the-woodlands-for-water-scheme (accessed on 27 October 2021).
26. UK Government. *The England Trees Action Plan 2021–2024*; APS Group: London, UK, 2021.
27. Waylen, K.A.; Holstead, K.L.; Colley, K.; Hopkins, J. Challenges to enabling and implementing Natural Flood Management in Scotland. *J. Flood Risk Manag.* **2018**, *11*, S1078–S1089. [CrossRef]
28. Xiao, L.; Robinson, M.; O'Connor, M. Woodland's role in natural flood management: Evidence from catchment studies in Britain and Ireland. *Sci. Total Environ.* **2021**, *813*, 151877. [CrossRef]
29. Kay, A.L.; Old, G.H.; Bell, V.A.; Davies, H.N.; Trill, E.J. An assessment of the potential for natural flood management to offset climate change impacts. *Environ. Res. Lett.* **2019**, *14*, 044017. [CrossRef]
30. Cooper, M.M.D.; Patil, S.D.; Nisbet, T.R.; Thomas, H.; Smith, A.R.; McDonald, M.A. Role of forested land for natural flood management in the UK: A review. *Wiley Interdiscip. Rev. Water* **2021**, *8*, e1541. [CrossRef]
31. Revell, N.; Lashford, C.; Blackett, M.; Rubinato, M. Modelling the Hydrological Effects of Woodland Planting on Infiltration and Peak Discharge Using HEC-HMS. *Water* **2021**, *13*, 3039. [CrossRef]
32. McLean, L.; Beevers, L.; Pender, G.; Haynes, H.; Wilkinson, M. Natural Flood Management in the UK: Developing a Conceptual Management Tool. In Proceedings of the 35th IAHR World Congress, Chengdu, China, 8–13 September 2013; p. 12. [CrossRef]
33. The Heart of England Forest Charity The Heart of England Forest. Available online: https://www.heartofenglandforest.com/ (accessed on 13 March 2019).
34. JNCC. *National Vegetation Classification—Ten Years Experience Using the Woodland Section*; Goldberg, E., Ed.; JNCC: Peterborough, UK, 2003.
35. Rodwell, J.S. *National Vegetation Classification: Users Handbook*; JNCC: Peterborough, UK, 2006.
36. Environment Agency LIDAR Composite 1 m DTM. Available online: https://environment.data.gov.uk/DefraDataDownload/?Mode=survey (accessed on 13 October 2018).
37. Ordnance Survey OS VectorMap District. Available online: https://osdatahub.os.uk/downloads/open/VectorMapDistrict (accessed on 14 December 2021).
38. Perry, T.O. Tree Roots: Facts and Fallacies. *J. Arboric.* **1982**, *8*, 197–211.
39. Mauer, O.; Palátová, E. The role of root system in silver birch (*Betula pendula* Roth) dieback in the air-polluted area of Krušné hory Mts. *J. For. Sci.* **2003**, *49*, 191–199. [CrossRef]
40. Hepner, H.; Lutter, R.; Tullus, A.; Kanal, A.; Tullus, T.; Tullus, H. Effect of Early Thinning Treatments on Above-Ground Growth, Biomass Production, Leaf Area Index and Leaf Growth Efficiency in a Hybrid Aspen Coppice Stand. *Bioenergy Res.* **2020**, *13*, 197–209. [CrossRef]
41. Robichaud, P.R.; Lewis, S.A.; Ashmun, L.E. New procedure for sampling infiltration to assess post-fire soil water repellency. *USDA For. Serv.-Res. Note RMRS-RN* **2008**, *14*, 33.
42. Naik, A.P.; Ghosh, B.; Pekkat, S. Estimating soil hydraulic properties using mini disk infiltrometer. *ISH J. Hydraul. Eng.* **2019**, *25*, 62–70. [CrossRef]

43. Bátková, K.; Miháliková, M.; Matula, S. Hydraulic properties of a cultivated soil in temperate continental climate determined by mini disk infiltrometer. *Water* **2020**, *12*, 843. [CrossRef]
44. Nestingen, R.; Asleson, B.C.; Gulliver, J.S.; Hozalski, R.M.; Nieber, J.L. Laboratory Comparison of Field Infiltrometers. *J. Sustain. Water Built Environ.* **2018**, *4*, 04018005. [CrossRef]
45. Fatehnia, M.; Tawfiq, K.; Ye, M. Estimation of saturated hydraulic conductivity from double-ring infiltrometer measurements. *Eur. J. Soil Sci.* **2016**, *67*, 135–147. [CrossRef]
46. Matula, S.; Miháliková, M.; Lufinková, J.; Bátková, K. The role of the initial soil water content in the determination of unsaturated soil hydraulic conductivity using a tension infiltrometer. *Plant Soil Environ.* **2015**, *62*, 515–521. [CrossRef]
47. METER Group Inc. *Mini Disk Infiltrometer User's Manual*; METER Group, Inc.: Pullman, WA, USA, 2020.
48. de Melo, M.L.A.; de Jong van Lier, Q. Revisiting the Feddes reduction function for modeling root water uptake and crop transpiration. *J. Hydrol.* **2021**, *603*, 126952. [CrossRef]
49. Sonkar, I.; Sudesan, S.; Suryanarayana Rao Kotnoor, H.P. Compensated non-linear root water uptake model and identification of soil hydraulic and root water uptake parameters. *Irrig. Drain.* **2022**, *71*, 157–174. [CrossRef]
50. Difonzo, F.V.; Masciopinto, C.; Vurro, M.; Berardi, M. Shooting the Numerical Solution of Moisture Flow Equation with Root Water Uptake Models: A Python Tool. *Water Resour. Manag.* **2021**, *35*, 2553–2567. [CrossRef]
51. Logsdon, S.D.; Jaynes, D.B. Spatial variability of hydraulic conductivity in a cultivated field at different times. *Soil Sci. Soc. Am. J.* **1996**, *60*, 703–709. [CrossRef]
52. Prieksat, M.A.; Kaspar, T.C.; Ankeny, M.D. Positional and temporal changes in ponded infiltration in a corn field. *Soil Sci. Soc. Am. J.* **1994**, *58*, 181–184. [CrossRef]
53. Khodaverdiloo, H.; Khani Cheraghabdal, H.; Bagarello, V.; Iovino, M.; Asgarzadeh, H.; Ghorbani Dashtaki, S. Ring diameter effects on determination of field-saturated hydraulic conductivity of different loam soils. *Geoderma* **2017**, *303*, 60–69. [CrossRef]
54. Rönnqvist, H. Double-Ring Infiltrometer for In-Situ Permeability Determination of Dam Material. *Engineering* **2018**, *10*, 320–328. [CrossRef]
55. Folorunso, O.; Aribisala, J. Effect of Soil Texture on Soil Infiltration Rate. *Arch. Curr. Res. Int.* **2018**, *14*, 1–8. [CrossRef]
56. Muneer, A.S.; Sayl, K.N.; Kamal, A.H. A Comparative Study to Assess the Suitable Models for Predicting the Infiltration Rate in an Arid Region. *Iraqi J. Civ. Eng.* **2020**, *14*, 29–38.
57. Ren, X.; Hong, N.; Li, L.; Kang, J.; Li, J. Effect of infiltration rate changes in urban soils on stormwater runoff process. *Geoderma* **2020**, *363*, 114158. [CrossRef]
58. Rahman, M.A.; Moser, A.; Anderson, M.; Zhang, C.; Rötzer, T.; Pauleit, S. Comparing the infiltration potentials of soils beneath the canopies of two contrasting urban tree species. *Urban For. Urban Green.* **2019**, *38*, 22–32. [CrossRef]
59. LaMotte Soil Texture Test Kit. Available online: https://lamotte.com/products/soil/individual-soil-plant-tissue-test-kits/soil-texture-test-1067 (accessed on 15 October 2020).
60. Groenendyk, D.G.; Ferré, T.P.A.; Thorp, K.R.; Rice, A.K. Hydrologic-process-based soil texture classifications for improved visualization of landscape function. *PLoS ONE* **2015**, *10*, e0131299. [CrossRef]
61. The Met Office When Does Summer Start? Available online: https://www.metoffice.gov.uk/weather/learn-about/weather/seasons/summer/when-does-summer-start (accessed on 2 February 2022).
62. The Met Office When Does Winter Start? Available online: https://www.metoffice.gov.uk/weather/learn-about/weather/seasons/winter/when-does-winter-start (accessed on 12 December 2021).
63. Met Office UK Climate Averages. Available online: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcq89t680 (accessed on 13 November 2021).
64. Martinez, P.; Buurman, P.; do Nascimento, D.L.; Almquist, V.; Vidal-Torrado, P. Substantial changes in podzol morphology after tree-roots modify soil porosity and hydrology in a tropical coastal rainforest. *Plant Soil* **2021**, *463*, 77–95. [CrossRef]
65. Mölder, A.; Sennhenn-Reulen, H.; Fischer, C.; Rumpf, H.; Schönfelder, E.; Stockmann, J.; Nagel, R.V. Success factors for high-quality oak forest (*Quercus robur*, *Q. petraea*) regeneration. *For. Ecosyst.* **2019**, *6*, 49. [CrossRef]
66. Mishra, P.; Pandey, C.; Singh, U.; Keshri, A.; Sabaretnam, M. Selection of appropriate statistical methods for data analysis. *Ann. Card. Anaesth.* **2019**, *22*, 297–301. [CrossRef]
67. Kamis, A.S.; Ahmad Fuad, A.F.; Ashaari, A.; Mohd Noor, C.W. Development of WOP mathematical model for efficient course alteration: LNG tanker manoeuvring analysis and Mann-Whitney U test. *Ocean Eng.* **2021**, *239*, 109768. [CrossRef]
68. Fay, M.P.; Proschan, M.A. Wilcoxon-Mann-Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules. *Stat. Surv.* **2010**, *4*, 1–37. [CrossRef]
69. Nachar, N. The Mann-Whitney U: A Test for Assessing Whether Two Independent Samples Come from the Same Distribution. *Tutor. Quant. Methods Psychol.* **2008**, *4*, 13–20. [CrossRef]
70. Mann, H.B.; Whitney, D.R. On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other. *Ann. Math. Stat.* **1947**, *18*, 50–60. [CrossRef]
71. Dittrich, R.; Ball, T.; Wreford, A.; Moran, D.; Spray, C.J. A cost-benefit analysis of afforestation as a climate change adaptation measure to reduce flood risk. *J. Flood Risk Manag.* **2019**, *12*, e12482. [CrossRef]
72. Lacob, O.; Rowan, J.S.; Brown, I.; Ellis, C. Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. *Hydrol. Res.* **2014**, *45*, 774–787. [CrossRef]

73. Lacob, O.; Brown, I.; Rowan, J. Natural flood management, land use and climate change trade-offs: The case of Tarland catchment, Scotland. *Hydrol. Sci. J.* **2017**, *62*, 1931–1948. [CrossRef]
74. Birkinshaw, S.J.; Bathurst, J.C.; Robinson, M. 45 years of non-stationary hydrology over a forest plantation growth cycle, Coalburn catchment, Northern England. *J. Hydrol.* **2014**, *519*, 559–573. [CrossRef]
75. Archer, N.A.L.; Bonell, M.; Coles, N.; MacDonald, A.M.; Auton, C.A.; Stevenson, R. Soil characteristics and landcover relationships on soil hydraulic conductivity at a hillslope scale: A view towards local flood management. *J. Hydrol.* **2013**, *497*, 208–222. [CrossRef]
76. Rabot, E.; Wiesmeier, M.; Schlüter, S.; Vogel, H.J. Soil structure as an indicator of soil functions: A review. *Geoderma* **2018**, *314*, 122–137. [CrossRef]
77. The Met Office Record Breaking Rainfall. Available online: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2020/2020-winter-february-stats (accessed on 11 June 2021).
78. Davies, P.A.; McCarthy, M.; Christidis, N.; Dunstone, N.; Fereday, D.; Kendon, M.; Knight, J.R.; Scaife, A.A.; Sexton, D. The wet and stormy UK winter of 2019/2020. *Weather* **2021**, *76*, 396–402. [CrossRef]
79. Thomas, H.; Nisbet, T.R. Slowing the Flow In Pickering: Quantifying the Effect of Catchment Woodland Planting on Flooding Using the Soil Conservation Service Curve Number Method. In *International Journal of Safety and Security Engineering*; WIT Press: Southampton, UK, 2016; Volume 6, pp. 12–20.
80. Hankin, B.; Chappell, N.; Page, T.; Whitling, M.; Burgess-gamble, L. *Mapping the potential for Working with Natural Processes: User Guide*; Environment Agency: Bristol, UK, 2017.
81. Klamerus-Iwan, A. Different views on tree interception process and its determinants. *For. Res. Pap.* **2014**, *75*, 291–300. [CrossRef]
82. Rahman, M.; Ennos, R. *What We Know and Don't Know about the Surface Runoff Reduction Potential of Urban Trees*; School of Biological, Biomedical and Environmental Sciences, University of Hull: Kingston-upon-Hull, UK, 2016.
83. Komatsu, H.; Kume, T.; Otsuki, K. Increasing annual runoff-broadleaf or coniferous forests? *Hydrol. Process.* **2011**, *25*, 302–318. [CrossRef]
84. Calder, I.R. Assessing the water use of short vegetation and forests: Development of the Hydrological Land Use Change (HYLUC) model. *Water Resour. Res.* **2003**, *39*, 1–8. [CrossRef]
85. Lunka, P.; Patil, S.D. Impact of tree planting configuration and grazing restriction on canopy interception and soil hydrological properties: Implications for flood mitigation in silvopastoral systems. *Hydrol. Process.* **2016**, *30*, 945–958. [CrossRef]
86. Nisbet, T. *Water Use by Trees—Forestry Commission Information Note FCIN065*; Forestry Commission: Aylesbury, UK, 2005; pp. 1–8.
87. Forestry Commission. *Forestry Statistics 2018*; Forestry Commission: Aylesbury, UK, 2018.
88. Ellison, D.; Morris, C.E.; Locatelli, B.; Sheil, D.; Cohen, J.; Murdiyarso, D.; Gutierrez, V.; van Noordwijk, M.; Creed, I.F.; Pokorny, J.; et al. Trees, forests and water: Cool insights for a hot world. *Glob. Environ. Chang.* **2017**, *43*, 51–61. [CrossRef]
89. Anderson, R.L.; Brye, K.R.; Wood, L.S. Landuse and soil property effects on infiltration into Alfisols in the Lower Mississippi River Valley, USA. *Geoderma Reg.* **2020**, *22*, e00297. [CrossRef]
90. Hynynen, J.; Niemisto, P.; Vihera-Aarnio, A.; Brunner, A.; Hein, S.; Velling, P. Silviculture of birch (Betula pendula Roth and Betula pubescens Ehrh.) in northern Europe. *Forestry* **2010**, *83*, 103–119. [CrossRef]
91. British Geological Survey 1:625k Bedrock and Superficial UK Geology. Available online: https://www.bgs.ac.uk/datasets/bgs-geology-625k-digmapgb/ (accessed on 15 June 2021).
92. He, H.; Aogu, K.; Li, M.; Xu, J.; Sheng, W.; Jones, S.B.; González-Teruel, J.D.; Robinson, D.A.; Horton, R.; Bristow, K.; et al. *A Review of Time Domain Reflectometry (TDR) Applications in Porous Media*, 1st ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2021; Volume 168, ISBN 9780128245897.
93. Cataldo, A.; De Benedetto, E.; Masciullo, A.; Cannazza, G. A new measurement algorithm for TDR-based localization of large dielectric permittivity variations in long-distance cable systems. *Meas. J. Int. Meas. Confed.* **2021**, *174*, 109066. [CrossRef]
94. Ahmed, F.; Borst, M. Monitoring infiltration rates with time domain reflectometers. *Water Environ. Res.* **2019**, *91*, 1638–1649. [CrossRef] [PubMed]
95. Samimi, S.; Marshall, S.J.; Vandecrux, B.; MacFerrin, M. Time-Domain Reflectometry Measurements and Modeling of Firn Meltwater Infiltration at DYE-2, Greenland. *J. Geophys. Res. Earth Surf.* **2021**, *126*, e2021JF006295. [CrossRef]