University of Twente, The Netherlands
Universitas Gadjah Mada, Indonesia

The development of a pedotransfer function predicting the hydraulic conductivity for the Bogowonto river basin, Java.

Annet Both s1213555
18-8-2014

Preface

After three years of study, this thesis is my final project for the Bachelor Civil Engineering at the University of Twente. I will start with the master 'Water engineering and Management' after finishing this bachelor. For this reason, I searched for a thesis related to water. I am also interested in mathematics, GIS and exploring different cultures. The opportunity to go to Indonesia and taking field measurements in combination with developing a pedotransfer function really appealed to me. Therefore I am really passionate about this thesis.

For this thesis the effect of land use on the hydraulic conductivity was researched. This is done by obtaining samples in the Bogowonto river basin, at Sumbing Mountain. These results were processed in a soil lab. Then a pedotransfer function was developed based on the measured values to describe the relationship between hydraulic conductivity and the slope.

I would like to thank all the people helped me accomplish this thesis. Martijn Booij for arranging this project and giving very good feedback and advice. I would like to thank Mister Oka for managing the fieldtrips and providing me with the necessary tools. Then I would like to thank Mister Makruf from the Faculty of Agriculture for helping me with the laboratory work. Finally I would like to thank Diko, the technical assistant, for the excellent help and the pleasant times in the field.

Annet Both
July 2014, Yogyakarta

Summary

In the field of water engineering it is very important to develop hydrological models to be able to predict the effect of changes in water flows. An important parameter in such a model is the hydraulic conductivity which is affected by many factors. The purpose of this thesis was to develop a pedotransfer function (PTF) to predict the hydraulic conductivity considering different land use types for the Bogowonto river basin, central Java. This PTF should describe the relationship between the hydraulic conductivity and the slope.

The data have been collected at Sumbing Mountain in the north of the river basin. The hydraulic conductivity and slope were measured at 153 point on different plots. Three pinus forest, three acacia forest, three puspa forest and eight agriculture plots were investigated. A significant difference between agriculture and all forest types was found. The hydraulic conductivity was higher on agricultural sites, which is different from the results found in other studies. The top layer was very loose at the agricultural sides which might have caused the difference. However, more research should be done before any conclusions can be drawn. A very weak relationship between slope and hydraulic conductivity was found on forest, so it is recommended to use the mean of the obtained values as predictor in hydrological models. A linear relationship has been found between the hydraulic conductivity and the slope on agricultural sites.

Content

1. Introduction

Section 1.1 provides background information; section 1.2 describes the research framework, then the objective and the research question are given in section 1.3. Finally, the report structure is given in section 1.4.

1.1. Background

On Java, Indonesia, droughts often occur in the dry season and floods frequently occur in the monsoon season (November to March). This will cause not only social damage, but also high economical damage since Java is the centre of the economy of Indonesia. Therefore, it is desired that the water flows can be controlled in a better way. A possible solution for preventing the floods and droughts is a different distribution of land use. For instance planting trees can cause an increase in water storage, so the rivers have less water to process. Due to irrigation, agriculture upstream normally uses so much water that the cities downstream have a lack of water. On a local scale, a lot of water is lost in irrigation channels through evaporation or through infiltration into the ground.

To estimate the effects of possible measures, like the change of land use types, hydrological models have to be made to assess the water flow in the river basin. One of the fundamental laws in hydrology is Darcy's Law, a law that estimates the volume of water flowing across a unit area per unit time. Hydraulic conductivity, K [m/day], is an important parameter in Darcy's law and therefore an interesting characteristic of a river basin when creating a model. The hydraulic conductivity describes how easily water can move through the ground given a certain driven force (USGS, 2010). The hydraulic conductivity has an effect on the amount of surface runoff, groundwater recharge, water supply for plants, nutrient cycling and spreading of pollution (Napolitano, 2011; USGS, 2010). This thesis will focus on the unsaturated hydraulic conductivity because the tools for measuring this parameter are available. Unsaturated hydraulic conductivity is the hydraulic conductivity in the unsaturated soil layer where only the smaller pores are filled with water, the larger pores are filled with air (Napolitano, 2011). Hydraulic conductivity is strongly related to the volumetric water content (θ). The volumetric water content is the volume of water per bulk volume of the soil (USGS, 2010). When the volumetric water content decreases, the unsaturated hydraulic conductivity also decreases (Tindall et al., 1999). The volumetric water content is related to the matric pressure (Ψ) which is the relative pressure of the water in the pores compared to the air pressure (USGS, 2010). Therefore the hydraulic conductivity also depends on the matric potential. The hydraulic conductivity will be different in dissimilar soil types due to different bulk densities. The hydraulic conductivity can also be influenced by change in pore conductivity, porosity, tortuosity and the season (Tindall et al., 1999). The hydraulic conductivity in clay can be changed by swelling of the soil, this occurs when the water content decreases and the suction increases what makes the soil shrink and pore sizes decreases, and therefore reduces the hydraulic conductivity. The hydraulic conductivity can locally be affected by the amount of litter on the ground, slope and the root depth of trees (Tindall et al., 1999).

To be able to use the hydraulic conductivity in hydrological models, data are required. The hydraulic conductivity can be measured in the field or in a laboratory but this is expensive and very time-consuming. Hence, data for estimating hydraulic conductivity are scarce in tropical areas. Pedotransfer functions (PTFs) can be an useful alternative for measurements. These are analytical equations that are developed to define the relationship between geographical data (e.g. soil type, slope, land use) and hydraulic parameters of a certain area. Many PTFs have been developed to predict different hydraulic parameters (water retention curve, infiltration, etc.) using different predictors (bulk density, soil type, etc.).
The first PTFs were created for temperate soils in Europe and the USA. These soils normally contain 5-60% clay or 5-70% sand, however tropical soils can consist of 70-90% clay (Hodnett & Tomasella, 2002). Consequently the original PTFs created for temperate soils are not useable for tropical regions (Hodnett & Tomasella, 2002). The first very simple PTF for tropical soils was created by Stirk in 1957

(Minasny & Hartemink, 2011). Since then more PTFs have been formulated for tropical regions, as a result, many PTFs for tropical regions are now available. The variety of PTFs is large, since the PTFs are based on different predicted properties, predictors, soil types and countries. None of the developed PTFs were created for Indonesia; hence it is questionable if these PTFs are actually assessing the hydraulic parameters correctly for areas in Indonesia. Digital Elevation Models (DEMs) are available for Indonesia, and therefore this a usable predictor for a PTF. For this study a PTF will be developed with the slope rate as predictor and hydraulic conductivity as hydraulic parameter.

It is important to know whether the land use type can predict the hydraulic conductivity since land use change is one of the possible solutions for preventing floods and droughts. This was researched for this thesis, where the land use type was represented by the amount of litter. The results can be found in Appendix A. No relationship was found between the amount of litter and the hydraulic conductivity. So the amount of litter is not usable as a predicator for the hydraulic conductivity.

1.2. Research framework

This thesis is part of a project carried out by the University of Twente and Universitas Gadjah Mada (UGM), researching the effects of land use changes on spatial and temporal water availability in the Bogowonto river basin. To be able to analyse the effect of different land cover types on hydraulic conductivity, the hydraulic conductivity and slope will be measured in the Bogowonto river basin, Central Java. This river basin is part of the 'Balai Besar Wilayah Sungai Serayu-Opak' water authority, what supervises all the water flows and is located in Yogyakarta. The Bogowonto River basin covers in total 597,25 km^2 (Kisworo et al., 2013).

1.3. Objective and research questions

The objective of this thesis is to develop one or more PTFs predicting the hydraulic conductivity for the Bogowonto river basin, considering different land use types. The PTF(s) will describe the relationship between the slope and the hydraulic conductivity on different land use types, based on field measurements in the Bogowonto river basin. The following questions will be answered:

1) <u>What are the measuring points in the river basin?</u>
    a) Which soil types are present in the river basin?
    b) Which land use classes are present in the river basin?
    c) Which slope rates are present in the river basin?
    d) Which categories can be determined from an overlay of question 1a, 1b and 1c?

2) <u>What are the unknown characteristics at the measuring points?</u>
    a) What is the slope in the different research areas, based on measurements?
    b) What is the hydraulic conductivity in the different research areas?

3) <u>Is there a significant difference in hydraulic conductivity given different land uses?</u>

4) <u>Can one or more PTFs predict the hydraulic conductivity given the slope rate?</u>
    a) Which PTFs can be drawn from the collected data?
    b) How well predicts the PTF the hydraulic conductivity, using validation techniques?

1.4. Report structure

An introduction on the subject has been given in chapter 1 and in chapter 2 the river basin is described. The methodology of the fieldwork and developing the pedotransfer functions is given in chapter 3. The results can be found in chapter 4 and will be discussed in chapter 5. Finally, the conclusions and recommendations are given in chapter 6.

2. Study area and data

This chapter will provide an overview of the study area. First a general introduction to the area will be given in section 2.1. Then maps of soil type, land use and slope will be presented in section 2.2. In section 2.3 the results of overlaying slope, soil type and land use types will be presented. Finally, detailed information of the measuring location will be given in section 2.4.

2.1. Bogowonto river basin

The measuring points are located in the Bogowonto river basin. This is a river basin in central Java, Indonesia. Figure 2.1 gives an overview of Indonesia, and the black box shows the location of the Bogowonto in central Java. The river basin is located 7°023' – 7°054' South and 109°056' – 109°010' East and has a total area around 597,25 km^2. The north contains mountains and the south is located at the Indian Ocean. Since the area is located in a tropical region close to the equator, there are only two seasons; a monsoon season from November to March when very high intense rainfall occurs and a dry season from April to December. From June to September there is almost no rain at all. However, the rain season last longer in the mountains resulting in spatial difference of the amount of rainfall in the river basin. The amount of rain per year differs from 1.500-2.000 mm per year in the lower areas to 3.500-4.000 mm per year in the mountains, see Figure 2.2. The mean temperature is around 26 °C. (Marhaento, 2014)

Figure 2.1: Map op Indonesia, with the black box showing the location of the Bogowonto river basin. (Google, 2014)

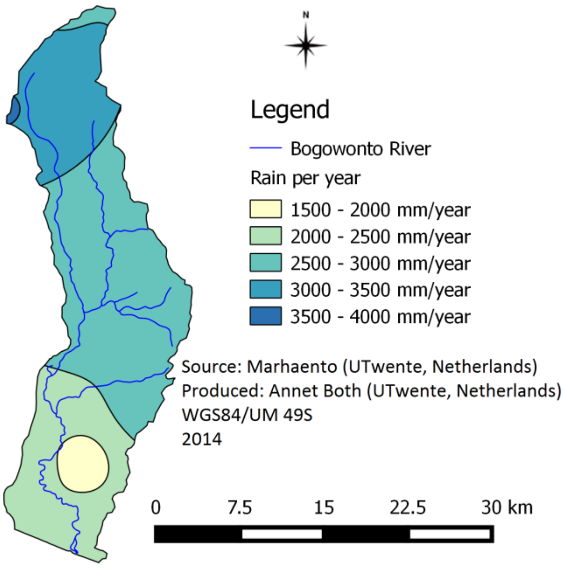


Figure 2.2: Rainfall in mm per year, measured in the period 2002-2011, in the Bogowonto river basin.

2.2. Geographical characteristics

Figure 2.3 shows that seven soil types are present in the river basin area. Latasol covers 60,7% of the river basin. Regosol is only present close to the coast, where also alluvial covers the regions closer to the coast. The different land uses are shown in Figure 2.4. About 54,8% of the area is covered by forest, tillage covers 25% and settlements 12,9%. Figure 2.5 shows that there is a big slope difference in the region. In the south, the ground is flat and high slopes rates can be found in the north and east. It can be concluded that the area has a big diversity in soil type, land use and slope. (Marhaento, 2014)

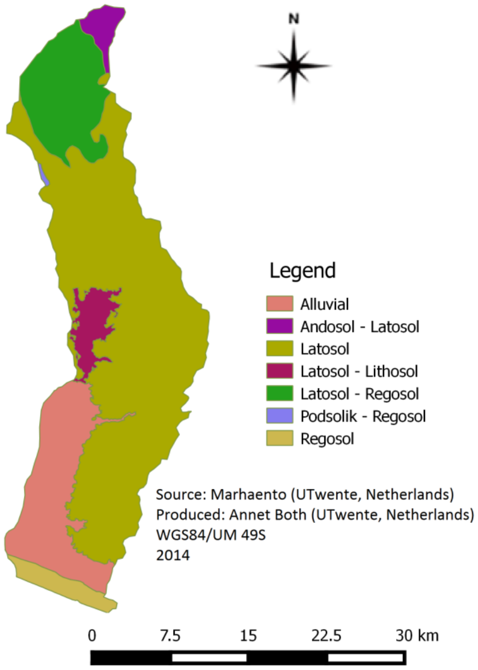


Figure 2.3: Soil types in the Bogowonto river basin.

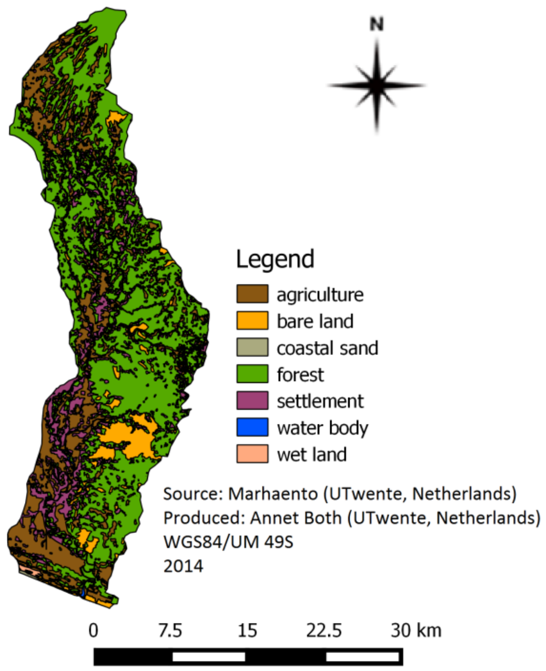


Figure 2.4: Land use types in the Bogowonto river basin.

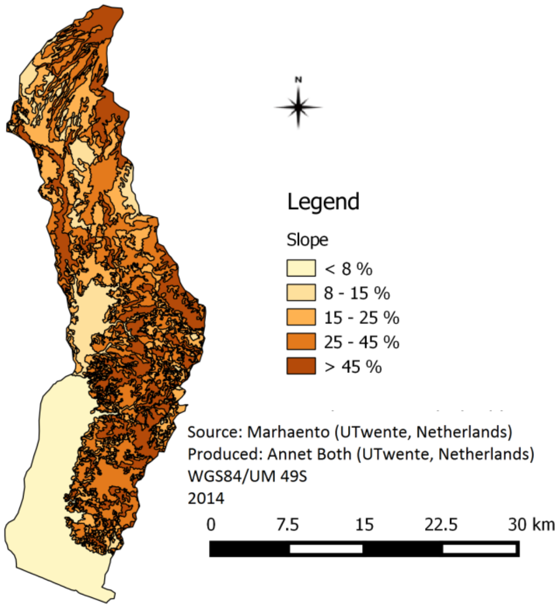


Figure 2.5: Slope rates in the Bogowonto river basin.

2.3. Common combinations of land use, soil type and slope rates

The following overlays (intersect) with QGIS 2.2.0 were made; soil type with slope, soil type with land use, land use with slope and all three categories together. This was done to analyse which combinations are the most common in the Bogowonto River basin. The results are maps with many very small areas containing different combinations. This does not give a clear overview of the results and therefore the results are summarised in the following tables. The tables give the percentage of the ten most common classes per overlay.

The overlay of soil type and land use results in total 34 different areas, of which the ten most common are presented in Table 2.1. The combination of forest and latosol covers 42.0% of the area, and is therefore the most common combination. This is a remarkable high percentage compared to the other combinations, second most common combination is alluvial with agriculture with only 8,7%.

Table 2.1: Results overlay of soil type and land use, using QGIS 2.2.0.

Soil type	Land use	Percentage of occurrence [%]
Latosol	Forest	42,0
Alluvial	Agriculture	8,7
Latosol	Agriculture	7,6
Latosol - Regosol	Forest	6,4
Latosol	Settlement	5,7
Latosol - Regosol	Agriculture	5,6
Latosol	Bare land	5,1
Alluvial	settlement	4,8
Alluvial	Forest	2,7
Andosol - Latosol	Forest	1,9

The result from the overlay of land use with slope is presented in Table 2.2. Unlike the combination of land use and soil, there is no dominant combination. It is remarkable that only forest occurs as land use type in of top three combinations. This can be explained by the fact that forest is the most common land use type. Agriculture mainly occurs on land with a maximum of 25% slope. No dominating slope rate was found.

Table 2.2: Results overlay of land use and slope using QGIS 2.2.0.

Land use	Slope [%]	Percentage of occurrence [%]
Forest	25 - 45	22,5
Forest	> 45	14,4
Forest	15 - 25	12,0
Agriculture	< 8	10,0
Agriculture	15 - 25	6,1
Settlement	< 8	5,0
Agriculture	8 - 15	3,8
Settlement	15 - 25	3,6
Agriculture	25 - 45	3,5
Forest	< 8	3,5

In Table 2.3, the ten most common combinations from the overlay slope and soil type are presented. The overlay gives four combinations that occur very often. Latosol is often present since this is the most common soil type, and it covers land with all slope rates. Alluvial covers a large area with a low slope (< 8%); this can be explained by the fact that alluvial covers the land close to the sea, which is usually flat.

Table 2.3: Results overlay of slope with soil type, using QGIS 2.2.0.

Slope [%]	Soil type	Percentage of occurrence [%]
25 - 45	Latosol	25,7
< 8	Alluvial	16,6
15 - 25	Latosol	16,3
> 45	Latosol	16,0
15 - 25	Latosol - Regosol	5,5
8 - 15	Latosol - Lithosol	3,8
25 - 45	Latosol - Regosol	3,7
< 8	Regosol	3,0
8 - 15	Latosol	2,6
8 - 15	Latosol - Regosol	2,2

Finally an overlay of all the three characteristics was performed. The ten most common combinations are presented in Table 2.4. Outstanding is the land use forest, which is by far the most common land use and is present in the three most common combinations, this in combination with soil type latosol. This can be explained by the fact that this combination is present in 42,0% of the region. It is also remarkable that bare land is present in this list while this land use type in not present in the other overlays. This is probably due to the fact that bare land occurs on latosol, which is a common soil type.

Table 2.4: Results of overlay of the three characteristics using QGIS 2.2.0.

Slope [%]	Land use	Soil type	Percentage of occurrence [%]
25 - 45	Forest	Latosol	19,5
> 45	Forest	Latosol	11,4
15 - 25	Forest	Latosol	9,7
< 8	Agriculture	Alluvial	8,6
< 8	Settlement	Alluvial	4,8
15 - 25	Agriculture	Latosol	3,1
15 - 25	Settlement	Latosol	3,0
15 - 25	Agriculture	Latosol - Regosol	2,9
> 45	Bare land	Latosol	2,9
< 8	Forest	Alluvial	2,6

2.4. Location of measurements

From the results found in section 2.3, the soil type latosol should be the soil type of interest because this soil type occurs in most combinations. However, UGM requested to carry this project out at Sumbing Mountain. UGM is performing a research project at Sumbing Mountain and this project would add information to their database. UGM has seventeen research plots at Sumbing Mountain, which are plots of 30*30 meters. Sumbing Mountain is an inactive volcano with a height of 2.577m in the north of the Bogwononto river basin. All plots are covered with the soil type andosol. The land use types which occur the most at Sumbing Mountain were investigated, these are:

- **Pinus forest (Plot 1 to 3).**

This is a slow growing forest type. Ferns grow between the trees.

- **Acacia forest (Plot 4 to 6).**

This is a fast growing forest type. There is hardly any vegetation between the trees at plot 4. At plot 5 ferns and moss grow between the trees. Many bushes grow at plot 6, which makes it hard to calculate the slope and locate the exact points for the measurements.

- **Agriculture (Plot 7 to 14).**

One chili field, six tobacco fields and one mixed field of onions, tobacco and cauliflower were investigated. These types of agriculture were chosen because they are easy to work in and very common at Sumbing Mountain. Some other agricultural sites were partly covered with plastic to prevent tare from growing between the plants, and therefore these plots were less suitable as a measuring plot. No litter or leaves were found on the ground. At the tobacco fields, the plants were recently planted and therefore only approximately 30 centimeters high. Only at plot 14, the tobacco was around 70 centimeters at one side of the field, and therefore the roots are deeper what has an effect on the hydraulic conductivity (Lampurlanés & Cantero-Martínez, 2006).

- **Puspa forest (Plot 15 to 17).**

This is native forest. The forest was very dense with many bushes between the trees. It was hard to work on, especially on plot 17 which was so steep that sand slipped from under your feet as you walked.

Figure 2.6 contains a map of the Bogowonto river basin with the locations of the seventeen plots.

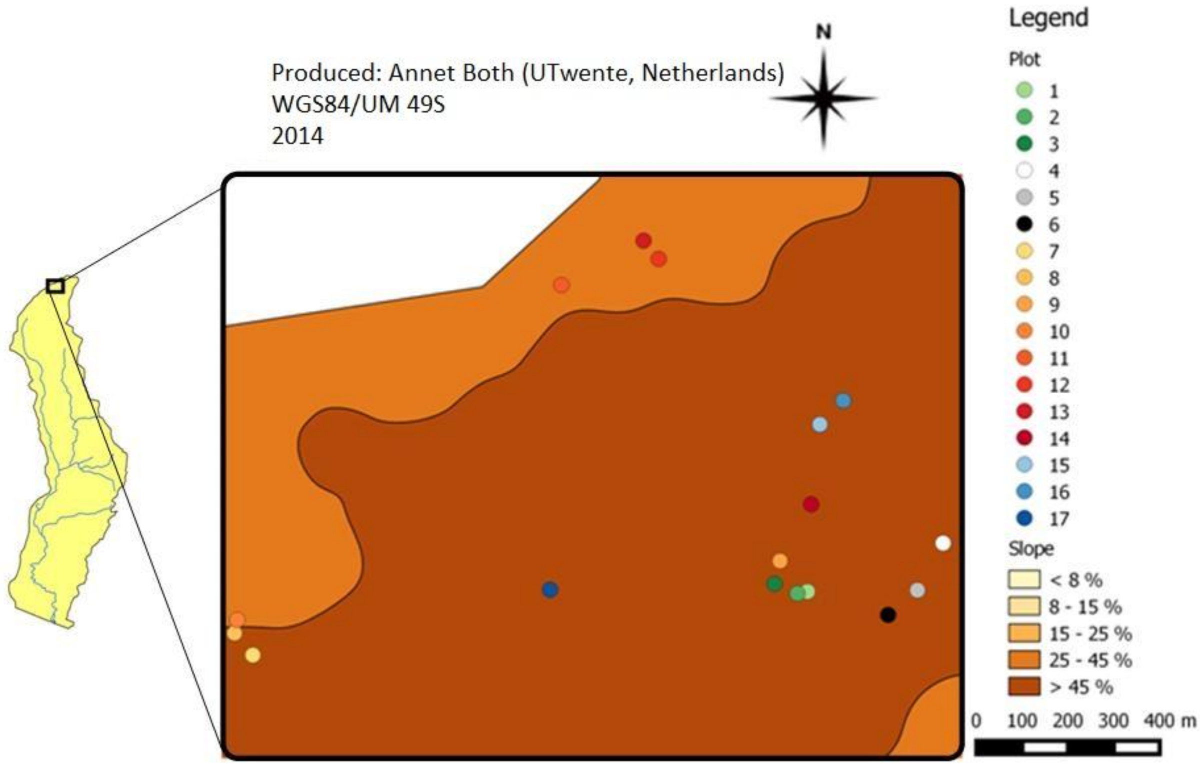


Figure 2.6: Location of plots in Bogowonot river basin, using QGIS 2.2.0.

3. Methodology

In this chapter the methodology of the field measurements will be described. The methods for the slope measurements and the hydraulic conductivity measurements are presented in section 3.1 and 3.2 respectively. Section 3.3 describes the functions used the investigate the effect of land use on the hydraulic conductivity. Section 3.4 will give the calibration and validation process of the PTFs.

3.1. Slope measurements

The slope has been measured with a clinometer; a picture of a clinometer in use can be seen in Figure 3.1. This is a small device; two persons are standing approximately five meters from the point of interest in line with the aspect, one with the clinometer at the highest point and one at the lowest point in a straight line. A schematic representation can be found in Figure 3.2. When looking through the tool and looking at the head of the other person, the slope can be measured. However it is only accurate when the two people have approximately the same length. There is a instrumental error of 0,25° (Suunto, 2014) and an unknown systematic error in the measurements due to the position point of measuring, so where the persons were standing, and the interpretation of the clinometer.
Trying to get representative data of the plot, nine samples were taken in a grid form. An image of the plot and its measuring points is shown Figure 3.3. Point 1/2/3 are located at the highest side of the plot. The slope was measured per measuring point resulting in nine slope rates per plot.

Figure 3.1: Measuring slope with a clinometer.

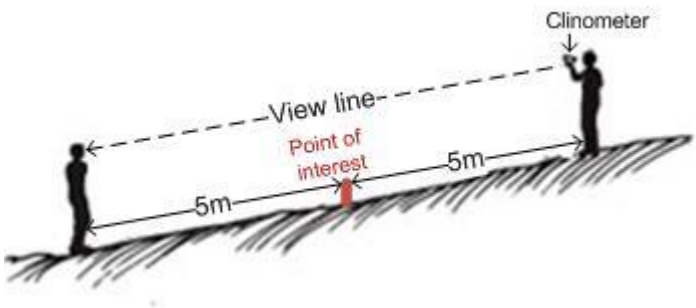


Figure 3.2: Schematic representation of measuring slope.

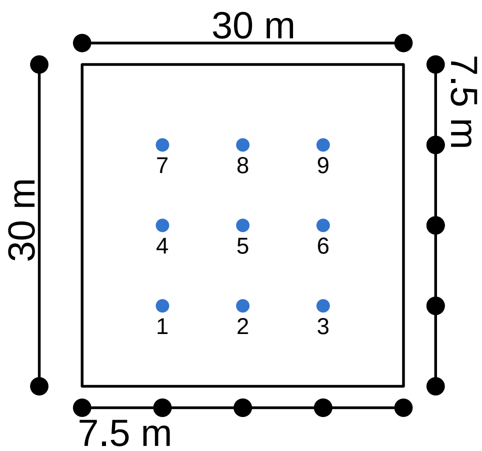


Figure 3.3: Overview measuring point per plot.

3.2. Hydraulic conductivity measurements

The unsaturated hydraulic conductivity can be measured with a tension infiltrometer in the field or with a ring infiltrometer in the lab. A tension infiltrometer is easier to use because the tool is very small and light. In comparison, taking ring samples is more difficult and heavy and one should bring

all the samples to the laboratory. With a tension infiltrometer the hydraulic conductivity can be determined quicker than with a ring infiltrometer and therefore more samples can be obtained in the same time. The tension infiltrometer was first designed and used in the 1970s. (Jarvis et al., 2013)
Because the mini infiltrometer DECANGON TM is available at UGM, this method is preferred over a ring infiltrometer. A schematic representation of the used infiltrometer can be found in Figure 3.4. At all measuring points, every minute the difference in water volume in the 'water reservoir' was measured for fifteen minutes in total. After the first results, the total measuring time was reduced to five minute because the hydraulic conductivity was stable after five minutes. By reducing the measuring time, more points could be taken. With the water in the 'bubble chamber' and the 'suction control tube', the suction rate could be set. The suction rate will make the water only move due to the hydraulic forces, and therefore preventing it from going into cracks or wormholes. A suction rate of -2 mBar has the best result on sands (Decagon Devices, 2007-2012). Andosol is sand and for that reason a suction rate of -2 mBar was used. This value is equivalent to a pF of 0,301 [-], this is very close to the saturated hydraulic conductivity. With the use of a water retention curve, the saturated hydraulic conductivity can be calculated.

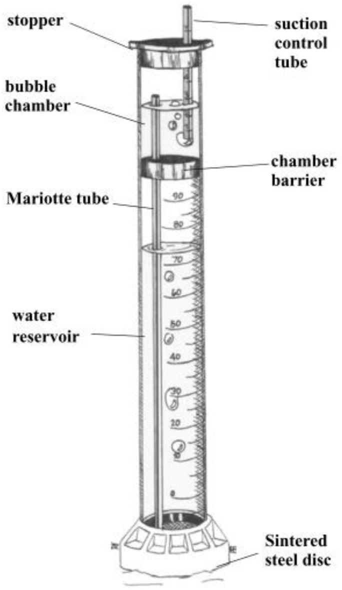


Figure 3.4: Schematic representation of the infiltrometer (Decagon Devices, 2007-2012).

3.3. Effect of land use on hydraulic conductivity

A Tukey-test is performed to find whether there is a significant difference in hydraulic conductivity given a different land use type. It is not necessary to perform an ANOVA-test before performing a Tukey-test, but producing an ANOVA-table is part of the process of performing the Tukey-test. The hypotheses for an one-way ANOVA test are also drawn, because in case the null hypothesis from the ANOVA-test is accepted, a Tukey-test is no longer necessary. Then the Tukey-test will not be performed and therefore the process will speed up. A more detailed explanation of the Tukey-test is given in Appendix C.

3.4. Developed pedotransfer functions

This section will first describe how the functions were set up, and then which validation techniques were used.

Set-up of functions

The 'curve fitting tool' from MATLAB was used to find the best fitting pedotransfer function. The preparation for drawing the PTF was done as follows. First the dataset was divided into two groups; 50% of the data for calibration and 50 % of the data for validation. After making a list of all measuring point, the calibration group consists of data with odd index numbers (e.g. point 1, 3, 5, etc) and the validation group consists of even index numbers, so each group contains data from every plot.
First it should be investigated if any correlation occurs in the data set. To see if there is a linear relation between the slope and the hydraulic conductivity the Pearson product correlation coefficient was used.

$$r\,[-] = \frac{SS_{xy}}{\sqrt{SS_{xx}SS_{yy}}}$$

With

$$SS_{xy} = \sum_i (X_i - \bar{X})(Y_i - \bar{Y})$$
$$SS_{xx} = \sum_i (X_i - \bar{X})^2$$
$$SS_{yy} = \sum_i (Y_i - \bar{Y})^2$$

X_i= slope [%] value i of dataset
$\bar{X}$= mean of the slope [%]
Y_i= hydraulic conductivity [m/day] value i of dataset
$\bar{Y}$= mean of the hydraulic conductivity [m/day]

A perfect positive correlation will result in a r of +1 [-], a perfect negative correlation in a r of -1 [-]. The weaker the correlation, the more r will go to 0 [-]. Therefore, a r of 0 indicates that there is no linear relationship.

To prevent over-fitting, only simple equations were tested. Therefore the simplest forms of linear regressions were fitted, resulting in equations 1 and 2. Casanova (2000) gives a logarithmical PTF developed for degraded natural prairie in Chile, and this function, equation 3, was also tested on this data set. The following equations were fitted:

$$K = a * slope + b \qquad (1)$$
$$K = a * slope^2 + b * slope + c \qquad (2)$$
$$ln(K) = a * slope + b \qquad (3)$$

K represents the hydraulic conductivity in [m/day] and the slope will be in percentage [%].

The significantly of the PTF can be tested with a t-test. The t-value was calculated as follows:

$$t = r\,\frac{\sqrt{n-2}}{\sqrt{1-r^2}}$$

The critical t-value $t_{2,5}$ can be found with the use of a t-test table. With degrees of freedom n-2 and a significant level of 95%.

Validation pedotransfer function

The following validation statistics were used to test the goodness of fit of the PTF, where:

$\hat{y}$= the calculated hydraulic conductivity [m/day] with the use of the drawn PTF
y = the measured hydraulic conductivity [m/day] value from the validation group
$\overline{y}$ = the mean hydraulic conductivity [m/day] from the validation group.

- Coefficient of determination (r^2)

$$r^2 = 1 - \frac{\sum(y_i - \hat{y_i})^2}{\sum(y_i - \overline{y})^2}$$

The coefficient of determination is also known as the Nash-Sutcliffe coefficient. This measures the total variation of $\overline{y}$, which can be explained by the linear relationship of x and y. In other words, how well the found data fits the developed PTF. r^2should be close to 1 for a good fit.

- Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[y_i - \hat{y_i}]}^{2}$$

Measures the variance of the fit and should be as small as possible.

- Mean Error (ME)

$$ME = \frac{1}{n}\sum_{i=1}^{n}[y_i - \hat{y_i}]$$

This measures the deviation from the mean. This should be close to zero.

The curve fitting tool from Matlab calculates the r^2 and $RMSE$ with fitted equations, therefore the r^2 and $RMSE$ will be used to evaluate the fitted curves in the calibration process.

4. Results

The results from the fieldwork will be presented in this chapter. In section 4.1 the results from the slope measurements will be given; in section 4.2 the results from the hydraulic conductivity are presented. In section 4.3 describes the effect of land use on the hydraulic conductivity. Section 4.4 shows how well the developed PTF fits the data.

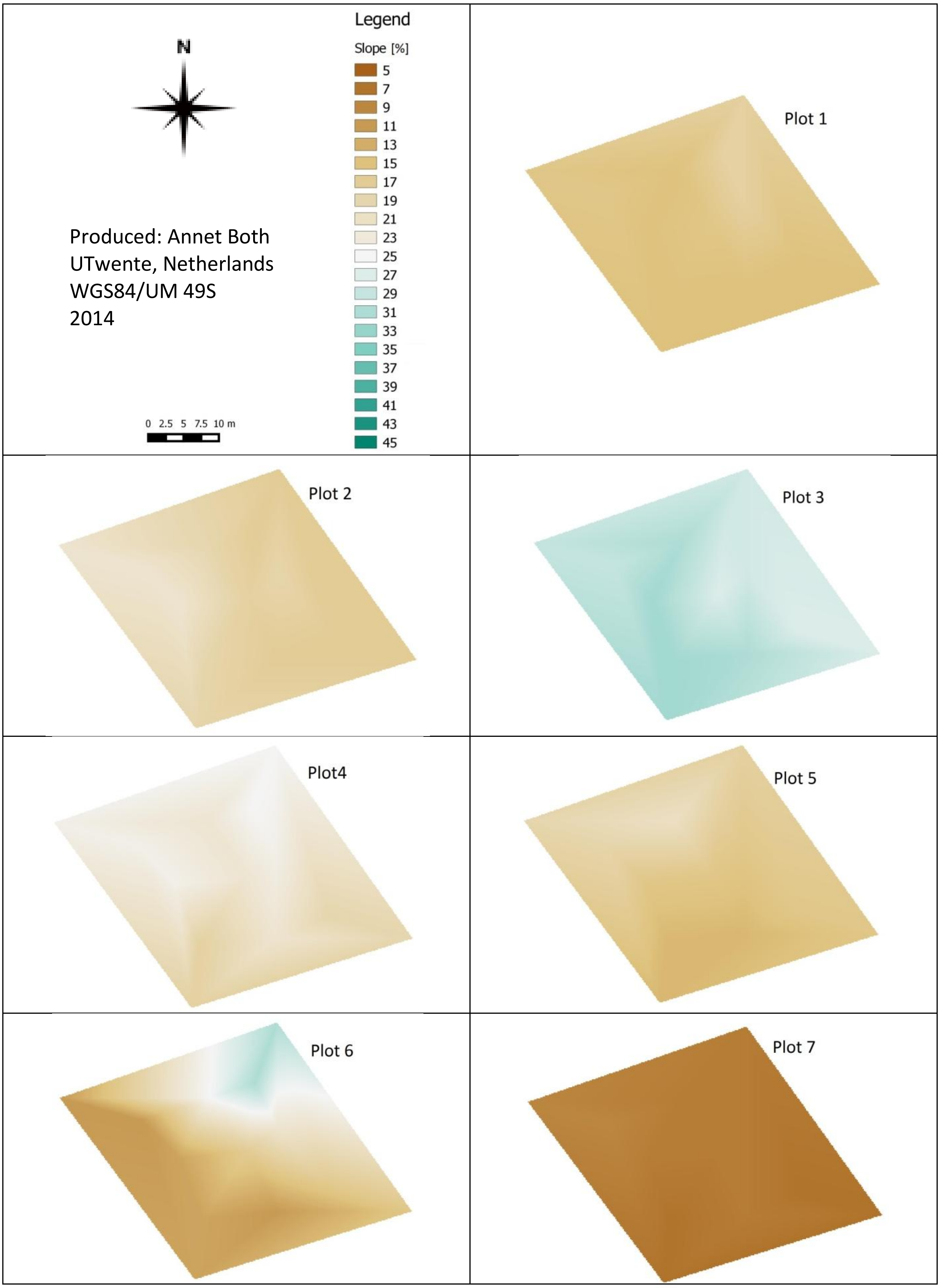
4.1. Slope measurements

In Table 4.1 the slope rates per point are shown. Due to high vegetation, the slope was not always measured five meter apart from the point.
Plot 3, 4, 9, 10 and 14 have a large slope in only one direction. Plot 12 and 17 are the steepest plots. Plot 12 shows no variation in the aspect; however plot 17 shows two opposites aspects what makes this plot different from all other plots. Plot 7 is the flattest plot. Plot 6 and 8 show a variation of slope rates from medium to high. Only medium slope rates were found at plot 1, 2, 5 and 11. Plot 13, 15 and 16 contain low and medium slope rates.
Figure 4.1 shows visual representations of the slope rate per plot. The methodology of making these maps is given in Appendix B.1.

Table 4.1: Slope [%] per plot.

	Land use type and plot number								
Number	**Pinus 1 [%]**	**Pinus 2 [%]**	**Pinus 3 [%]**	**Acacia 4 [%]**	**Acacia 5 [%]**	**Acacia 6 [%]**	**Agriculture 7 [%]**	**Agriculture 8 [%]**	**Agriculture 9 [%]**
1	15	17	27	19	16	16	7	14	31
2	18	19	28	24	16	22	8	14	31
3	18	17	28	25	18	31	8	16	30
4	15	17	31	22	14	11	8	19	27
5	16	18	27	22	16	17	8	19	27
6	19	19	31	22	21	25	8	25	27
7	15	19	32	18	14	12	7	24	28
8	16	22	32	24	16	12	8	25	28
9	15	22	29	24	19	11	9	28	27

	Land use type and plot number							
Number	**Agriculture 10 [%]**	**Agriculture 11 [%]**	**Agriculture 12 [%]**	**Agriculture 13 [%]**	**Agriculture 14 [%]**	**Puspa 15 [%]**	**Puspa 16 [%]**	**Puspa 17 [%]**
1	16	18	33	18	25	17	20	27
2	16	14	34	15	24	5	18	44
3	17	14	32	13	22	15	11	41
4	22	18	38	16	28	18	6	27
5	19	15	38	12	25	18	11	33
6	22	13	37	11	23	7	10	44
7	26	15	35	12	23	13	26	31
8	26	13	35	9	22	12	4	27
9	23	13	36	7	22	26	12	8


Legend
Slope [%]
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
N
Produced: Annet Both
UTwente, Netherlands
WGS84/UM 49S
2014
0 2.5 5 7.5 10 m
Plot 1
Plot 2
Plot 3
Plot4
Plot 5
Plot 6
Plot 7

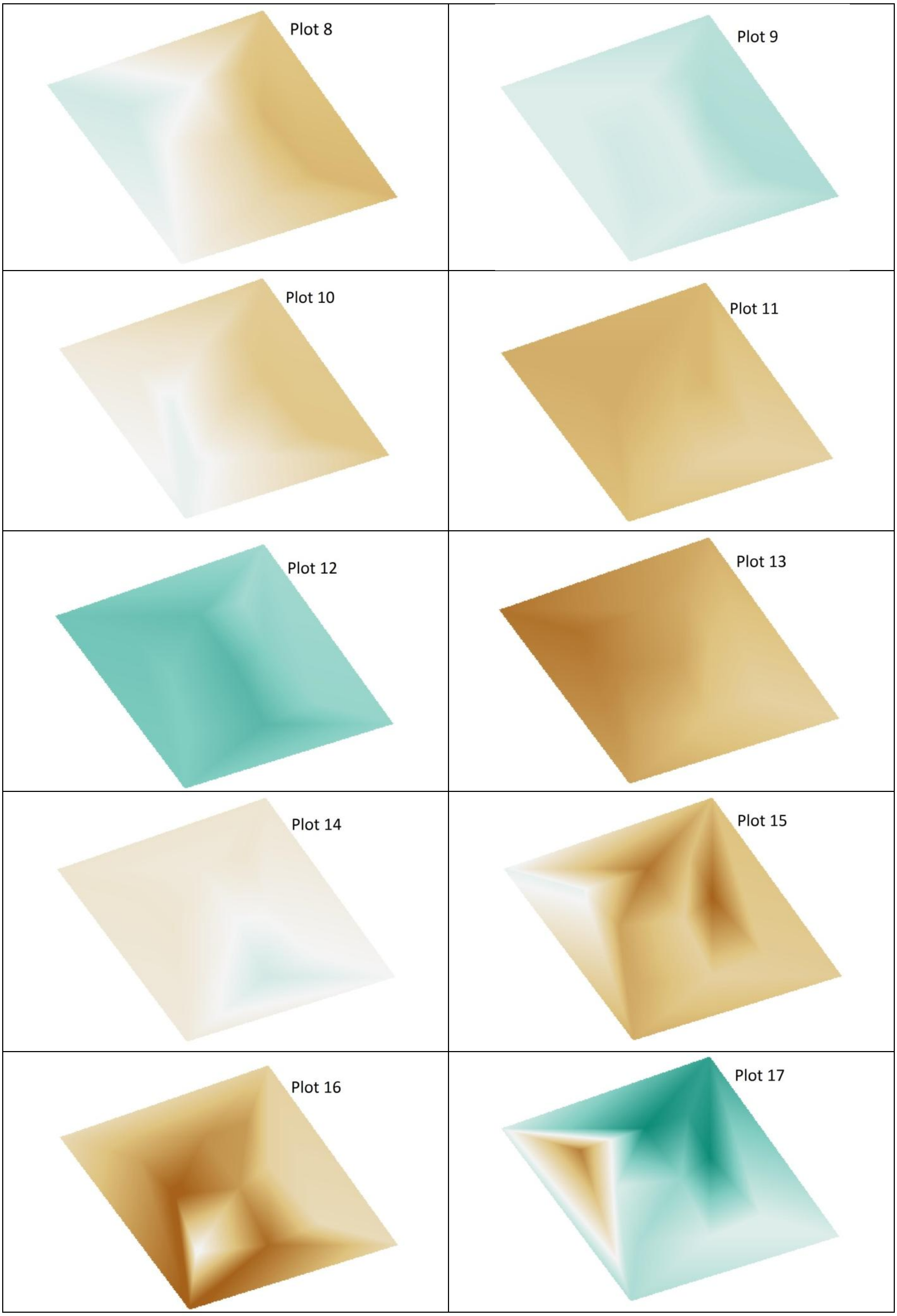


Figure 4.1: Visual image of slope rates per plot.

An overlay was produced in QGIS 2.2.0 between the middle of every plot (point 5) with the average slope of the plot as attribute and the available 30m DEM (Marhaento, 2014). The plots are very small, and therefore it is expected that the middle point will represent the plot accurately. The resolution of the DEM is 1 arc-second (30 m). The overlay makes it possible to visualize the difference between the measurements and the slope rate obtained from the available DEM, obtained with ASTER GDEM. The result of this analysis is presented in Table 4.2. No average slope rates above 35% were found in the field. However, the slope rates given by the DEM are very often bigger than 45%. The slope is overestimated at plot 1 to 9 and 14 to 17. Though, plot 10, 11 and 13 are slightly underestimated. Only plot 12 was estimated correctly by the DEM. The difference between the slope rates can be up to 37%. Therefore, it can be concluded that this DEM is not a good representation of the study area.

Table 4.2: Slope rate measured in the field and obtaind from a 1 arc-second DEM per plot.

Plot	Average slope from field measurements [%]	Slope from DEM [%]
1	16	>45
2	19	>45
3	29	>45
4	22	>45
5	17	>45
6	17	>45
7	8	>45
8	20	>45
9	28	>45
10	21	20-45
11	15	20-45
12	35	20-45
13	13	20-45
14	24	>45
15	15	>45
16	13	>45
17	31	>45

4.2. Hydraulic conductivity measurements

When plots 1 to 9 were measured, there was heavy rainfall in the evening. During the measurement of the other plots there was also rain during the day. The measurements were not taken during or shortly after the rain. The temperature was approximately the same for all plots. The results of measuring the hydraulic conductivity of pinus forest, acacia forest, agriculture and puspa forest are presented in Figure 4.2, 4.3, 4.4 and 4.5 respectively. The method of calculating the hydraulic conductivity can be found in Appendix B.2 and the exact values per measuring point can be found in Appendix B.3. Appendix B.4 shows the results of the statistical outliers tests.

The hydraulic conductivity found on plot 1 and 2 seem to lie in the same range, see Figure 4.2. It appears that plot 2 has 1 or 2 outliers, however the z-scores, presented in Appendix B.4, show that the dataset does not contain any outliers. The variation of plot 3 is higher. This is probably due to difficult measurements conditions. There was also a large variation in vegetation on the plot, which also might have influenced the results. On top of that, the slope was higher in plot 3 which can explain the higher values compared to plot 1 and 2, since higher slope rates will make the unsaturated hydraulic conductivity increase as well (Casanova et al., 2000). Casanova (2000) explained this effect with the appearance of surface sealing, the result of moved soil downhill due to

erosion, and the difference in the vertical and lateral hydraulic conductivity. The differences between the diagnostic soil horizons influence the run-off of the water since the direction and speed of the water flow depends on the amount of anisotropy of the soil. No ANOVA-test was performed to check this hypothesis because there is little data available.
The hydraulic conductivity values are expected to be between $8*10^{-5}$ and 8 m/day (Shevnin et al., 2006), so the values found on pinus forest sites are high but as expected.

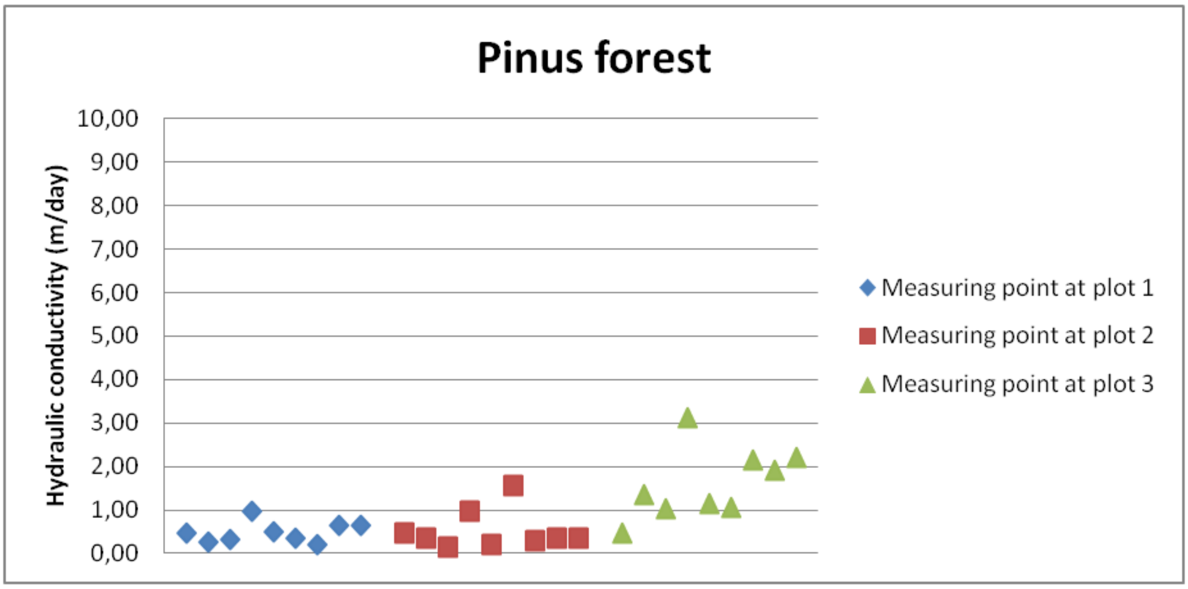


Figure 4.2: The hydraulic conductivity per measuring point on pinus forest plots.

Figure 4.3 shows that plot 6 shows a wider range of hydraulic conductivity than plot 4 and 5. This probably caused by the hard measuring conditions, like in plot 3. On this plot there was also a large diversity of vegetation what made it harder to measure the hydraulic conductivity. Plot 4 had a higher slope than plot 5 and 6, but this cannot be detected visually from Figure 4.3. More data is required to draw meaningful conclusions from an ANOVA-test, so this was not performed on this data. The values lie in the expected range (Shevnin et al., 2006).

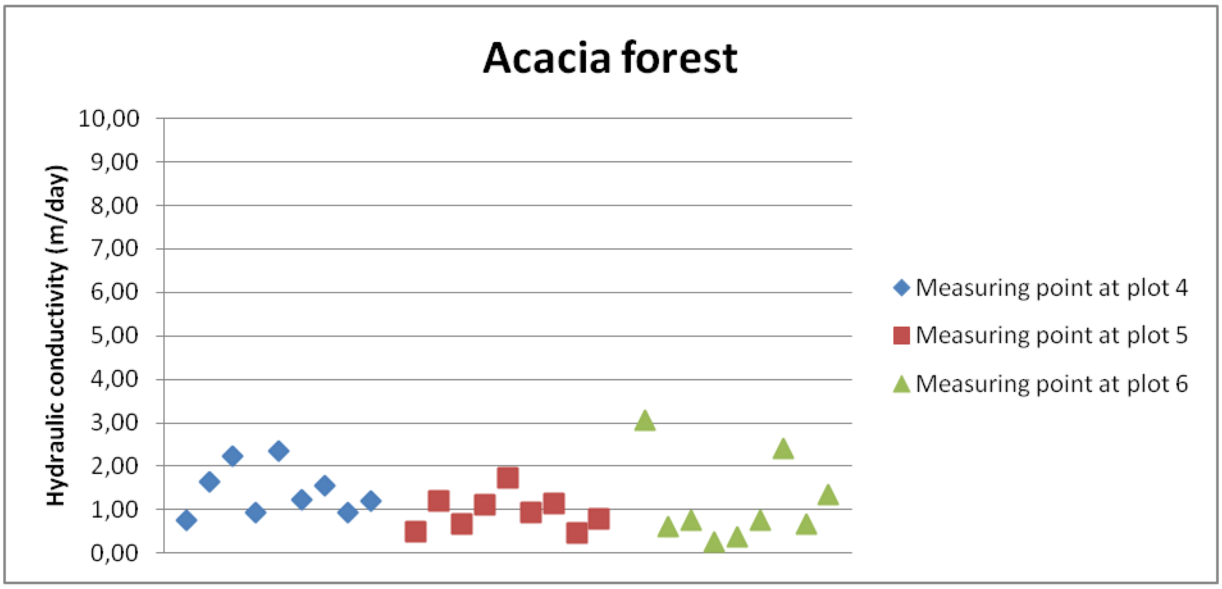


Figure 4.3: The hydraulic conductivity per measuring point on acacia forest plots.

Figure 4.4 shows that plot 12 shows a very high variation in the hydraulic conductivity. This plot has a very high slope rate, which could explain the high values, but the variation cannot be explained. Plot

7 has the lowest slope and therefore the lowest hydraulic conductivity, as expected. There seems little correlation between the eight agriculture plots. The values at plot 12 are high in comparison with the literature values (Shevnin et al., 2006), the values at the other plots are as expected. An ANOVA-test on all agriculture data shows there is a significant difference in hydraulic conductivity given different slope rates, see Appendix B.5.

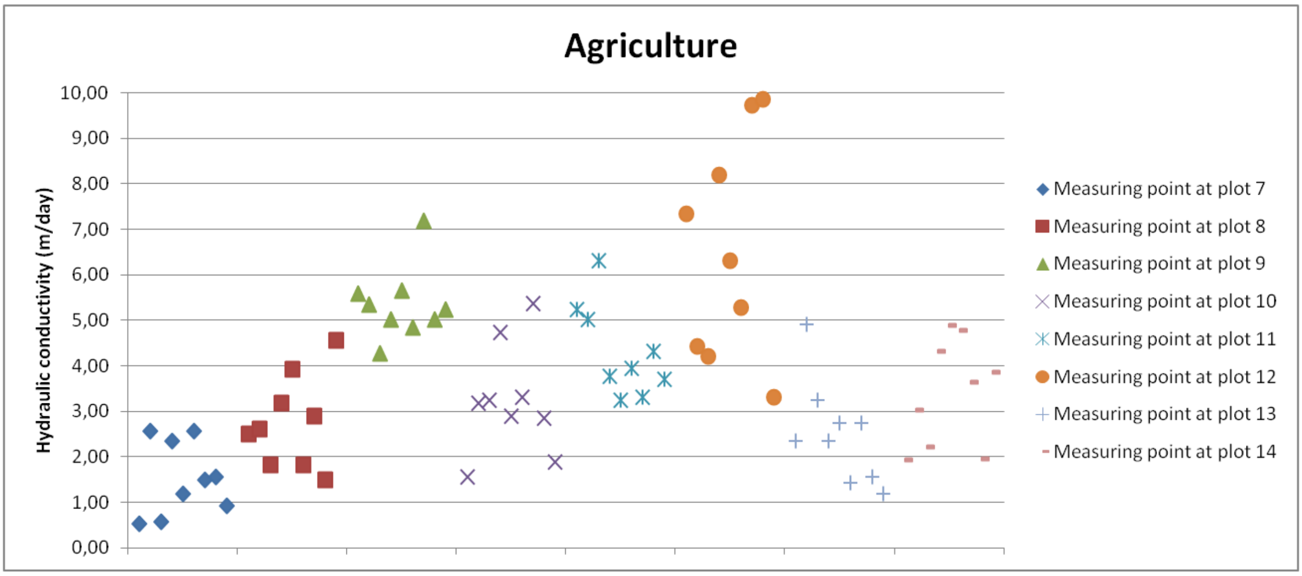


Figure 4.4: The hydraulic conductivity per measuring point on agriculture plots.

The results of the hydraulic conductivity measurements on puspa forest sites are presented in Figure 4.5. The values lie in the expected range (Shevnin et al., 2006). The first point of plot 15 seems to be an outlier, however this was not found as outlier in the outliers test. Furthermore, the hydraulic conductivity results do not show a high variation, but the coefficient of variation, see Table 4.3, is very high. This might be caused by the points 15.1, 16.1 and 17.2 which are higher compared to the other values.

A high coefficient of variation is also found for the pinus forest, this is probably caused by the third plot, which had higher values than plot 1 and 2. The coefficients of variations of agriculture and acacia forest are similar and lower than pinus and puspa forest. The high coefficient of variation for all the plots can probably be explained by the range of the slopes on the different plots. It seems that the slope has a bigger impact on agriculture than on pinus, acacia, and puspa forest, which might be the result of erosion. During heavy rainfall, the water that runs-off on the land takes soil particles downhill with the flow. The particles will be deposited as the slope is decreasing. Therefore the lower slopes can have a denser top layer. The vegetation in the forest slows the erosion process, this makes the effect of slope more visible at the agricultural sites. (Derpsch, 2014)
When looking at the means of the hydraulic conductivity, one can assume that land use has an effect on the hydraulic conductivity. This will be tested in section 4.3.

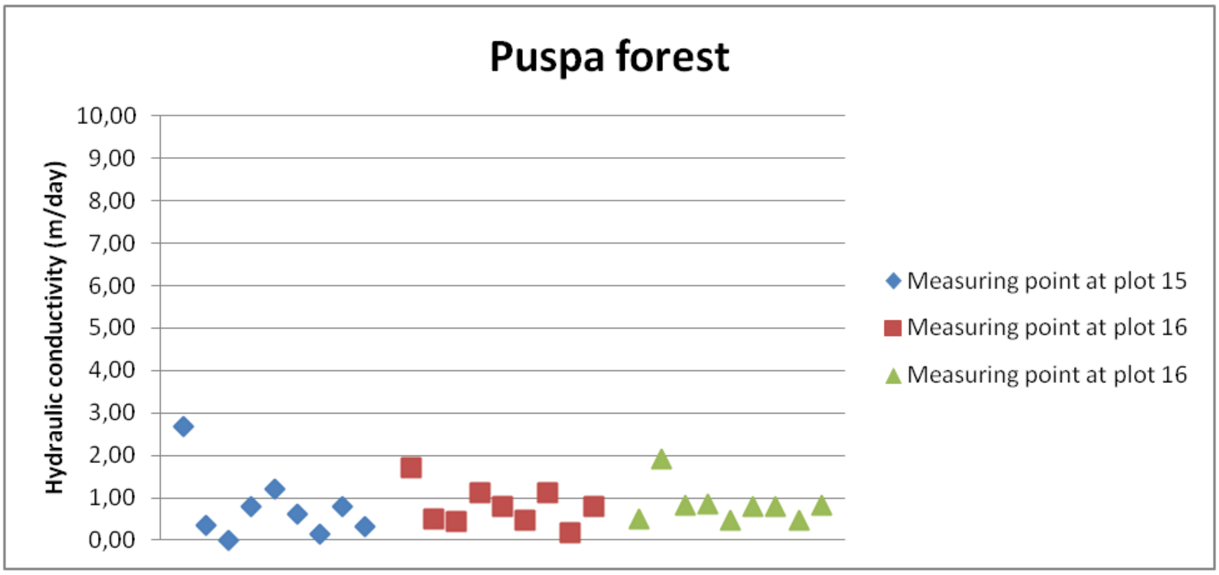


Figure 4.5: The hydraulic conductivity per measuring point on puspa forest plots.

Table 4.3: Mean, standard deviation and coefficient of variation of hydraulic ocnductivity per land use type.

	Pinus forest [m/day]	Acacia forest [m/day]	Agriculture [m/day]	Puspa forest [m/day]
Mean	0,87	1,17	3,70	0,79
Standard Deviation	0,75	0,69	1,96	0,57
Coefficient of Variation	86%	59%	53%	72%

4.3. Effect of land use on hydraulic conductivity

The following null hypothesis is assumed with μ the mean of the data:

$$H_0: \mu_{pinus\ forest} = \mu_{acasica\ forest} = \mu_{agriculture} = \mu_{puspa\ forest}$$
$$H_1: not\ all\ means\ are\ the\ equal$$

The null hypothesis will be rejected when $p_{0.05} > p_{value}$.

The ANOVA-test gives a p_{value} of 5,47 *10^{-20}. This is smaller than $p_{0.05}$ and therefore the null hypothesis is rejected and it can be concluded that not all means are equal. Next, a Tukey-test will be performed to see which land use types show a significant difference. The following null hypothesises are drawn:

$$H_0: \mu_{pinus\ forest} = \mu_{acacia\ forest}; \mu_{pinus\ forest} = \mu_{agriculture}; \mu_{pinus\ forest} = \mu_{puspa\ forest};$$
$$\mu_{agriculture} = \mu_{acacia\ forest}; \mu_{agriculture} = \mu_{puspa\ forest}; \mu_{acacia\ forest} = \mu_{puspa\ forest}$$

$$H_1: \mu_{pinus\ forest} \neq \mu_{acacia\ forest}; \mu_{pinus\ forest} \neq \mu_{agriculture}; \mu_{pinus\ forest} \neq \mu_{puspa\ forest};$$
$$\mu_{agriculture} \neq \mu_{acacia\ forest}; \mu_{agriculture} \neq \mu_{puspa\ forest}; \mu_{acacia\ forest} \neq \mu_{puspa\ forest}$$

The null-hypothesis will be rejected when the difference between two means is higher than the Yartwick number. The amount of input values should be the same for every factor when performing a Tukey-test. Plot 8, 10 and 14 were chosen as representatives for agriculture sites because these plots contain approximately the same slope rate as the forest sites. With the equations used as described in Appendix C, the following Yartwick number was found:

$$Yartwick\ number = 0{,}58\ [\frac{m}{day}]$$

Table 4.4: Difference in means for comparing with the Yartwick number.

	Agriculture [m/day]	Acacia forest [m/day]	Pinus forest [m/day]	Puspa forest [m/day]
Agriculture				
Acacia forest	**1,95**			
Pinus forest	**2,25**	0,30		
Puspa forest	**2,33**	0,38	0,08	

From the Yartwick number and Table 4.4 it can be concluded that there are a significant differences between agriculture and acacia forest, agriculture and pinus forest agriculture and puspa forest. No significant differences were found between the different forest types. This implies that land use does influence the hydraulic conductivity. The hydraulic conductivity is higher at agricultural sites which means that the water flows away slower than on forest sites.

In Indonesia native forest (puspa) are quickly replaced by fast growing forest types like acacia and pinus which can be used for the pulp paper and wood industry. The hypothesis is that the hydraulic conductivity is higher in the native forest because of deeper roots. However, Table 4.4 shows there is no significant difference between native and non native forest. This is not as expected and might be due to measuring mistakes which results in a high variation of the hydraulic conductivity per plot.

4.4. Goodness of fit developed pedotransfer function

In section 4.3 a significant difference between agriculture and forest was found. Consequently, two separate PTFs are developed for forest and agriculture.

Calibration pedotransfer function for forest sites

First the r is calculated, this results in an r of 0,22 [-]. This indicates a weak correlation because it is close to 0. Nonetheless, a PTF is developed to be able to check if a PTF would fit better than the mean. The results of fitting the data can be found in Table 4.5. This table shows the coefficients found for each equation and the coefficient of determination (r^2) and Root-Mean-Squared Error (RMSE).

Table 4.5: Found coefficients after fitting equations 1, 2 and 3 on forest data. Including r2 and RMSE.

Function	a	b	c	r^2 [-]	RMSE [(m/day)^2]
1	0,011	0,63	-	0,020	0,595
2	0,0007	-0,02	0,87	0,029	0,600
3	0,009	-0,37	-	0,021	0,595

The r^2 values indicate that all equations are a very poor fit for the dataset. On top of that, the RMSE values are not good either. It can be concluded that the hydraulic conductivity for forest cannot be predicted based on the slope. Therefore, it is recommended to use the mean of all measured values.

$$K_{forest} = 0{,}95[\frac{m}{day}]$$

Calibration pedotransfer function for agriculture sites

An r of 0,64 [-] was found for agriculture sites. This indicates a relationship between the slope and hydraulic conductivity on agricultural sites and a PTF is therefore developed. The results of fitting can be found in Table 4.6. This table shows the coefficients found for each equation and the coefficient of determination (r^2) and Root-Mean-Squared Error (RMSE).

Table 4.6: Found coefficients after fitting equations 1, 2 and 3 on agriculture data. Including r^2 and RMSE.

Function	a	b	c	r^2 [-]	RMSE [(m/day)^2]
1	0,15	0,75	-	0,415	1,55
2	0,001	0,07	1,45	0,419	1,56
3	0,05	0,82	-	0,421	1,55

The three different equations give very similar results in the r^2 and $RMSE$. The third equation is slightly better than the others, and the first equation gives the lowest r^2. When looking at the $RMSE$, none of the equations gives a very good result because a good fit should be close to 0. The $RMSE$ is high for all fits. Equation 3 gives the best and equation 2 the worst results. Overall, from the r^2 and $RMSE$ none of the equations can be pointed out as remarkably better than the others.
The first coefficient (a) of the second equation is very small, what makes the equation almost linear. To avoid over-fitting, the linear equation is preferred. This makes sense when you look at the distributions of the points in Figure 4.6. One could see a weak linear relationship between the two variables. This makes a linear relationship between slope and hydraulic conductivity the best fit for these data.

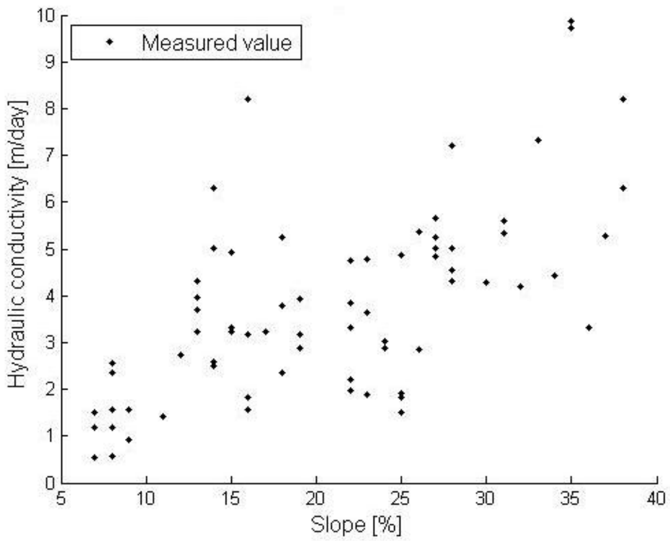


Figure 4.6: Hydraulic conductivity plotted against slope, all measuring points on agriculture sites.

To be able to see if the linear relationship is significant, a two-tailed t-test was performed. First a null hypothesis was defined; there is no correlation between the slope and the hydraulic conductivity.

$$H_o: \rho = 0$$
$$H_1: \rho \neq 0$$

This is tested with the value t.
With the equation given in section 3.4 a t-value of 7,039 [-] was found. A critical t-value of 2,650 [-] was found. Because $t > t_{2,5}$ the null hypothesis is rejected and therefore there is a significant relationship between slope and hydraulic conductivity.

Considering the r^2, $RMSE$, graph and the significant linear relationship between slope and hydraulic conductivity the following PTF was developed for agricultural sites:

$$K_{agriculture}\left[\frac{m}{day}\right] = 0,15 * slope\ [\%] + 0,75$$

However, the low r^2 and high $RMSE$ values indicate that the formula is not a very good predictor of the two variables. This hypothesis will be tested when validating.

Validation of pedotransfer functions

No relation between slope and hydraulic conductivity was found on forest sites, so the mean of the measured values will be used as a predictor. Therefore, in this section only the developed PTF for agriculture will be validated. This was done with the split-sample test (Booij, 2013), different data from the same study area were used as validation data.

The results of these tests can be found in Table 4.7. The r^2 value is low but considering that the values were obtained in the field it shows a medium result, since field measurements often contain a high bias. The RMSE is high, which also indicates a weak predictor. The RMSE is similar to the RMSE calculated after the calibration of the function. The r^2 value decreased what indicates a weaker fit. The ME is low which indicates a medium fit because it should be close to 0.

Table 4.7: Statistical results validation PTF for agriculture.

r^2 [-]	**RMSE [(m/day)^2]**	**ME [m/day]**
0,3037	1,5861	0,0856

The three statistical results show that the developed PTF is a medium predictor of the hydraulic conductivity given the slope. However, it will give a better result than just using the mean.

To be able to see if the r^2 value is significant, a similar two-tailed t-test to calibration process was performed. First a null hypothesis was defined; there is no correlation between the slope and the hydraulic conductivity.

$$H_o: \rho = 0$$
$$H_1: \rho \neq 0$$

With the equation given in section 3.4 a t-value of 5,486 [-] was found. A critical t-value of 2,650 [-] was found. Because $t > t_{2,5}$ the null hypothesis is rejected and therefore there is a significant relationship between slope and hydraulic conductivity.

5. Discussion

First the results of the hydraulic conductivity will be discussed, then the use of the developed PTF.

5.1. Hydraulic conductivity

During the field measurements it was noticed, that especially on agriculture sites, the hydraulic conductivity changed rapidly when moving the tube only 10 cm. This might have caused the high variation in the sample points. A tension meter with more ground contact might give a better result.

Most studies found a larger saturated hydraulic conductivity at forest sites than at agricultural sites (Salemi et al., 2013; Zimmermann et al., 2006). A two to three times larger hydraulic conductivity on forest than on agriculture is not unusual (Jarvis et al., 2013). The bulk density is larger on croplands due to decayed roots and more macropores and mesopores are present. A small percentage of volume in soil are macropores, these pores can transport a significant amount of rainwater quickly into deeper soil layers. At agricultural sites, the land is ploughed which disrupts the macropores and makes it hard for the water to infiltrate into the soil. (Puhlmann & von Wilpert, 2012; Wahren et al., 2009).

However, this study has found a larger hydraulic conductivity on agricultural sites compared to forest sites. This unexpected result is not caused by the method of measuring. There is no significant difference in hydraulic conductivity when using a tension infiltrometer, a ring-infitrometer or laboratory measurements (Jačka et al., 2014).

Furthermore, the method of sampling at the agricultural site was the same as at the forest sites and the weather conditions were also the same. From the results of weight of the litter and leaves, no litter or leaves were present at agricultural sites, it would also be expected that the infiltration rates would be higher in the forest (Neris et al., 2012). The agriculture samples were not taken at the same day, not by the same person and same infiltrometer so it appears to be unlikely that the found results are all measuring mistakes.

The date of measurement during the growing season has an effect on the hydraulic conductivity (Lampurlanés & Cantero-Martínez, 2006). At the beginning of the season agriculture increases the porosity of the soil. The hydraulic conductivity decreases as the plants grow. This is due to the root growth and surface sealing. The measurements on agriculture sites for this study were carried out when the tobacco was recently planted. So the hydraulic conductivity found for this study is higher than when the hydraulic conductivity was measured at the end of the growing season. This increases the difference between the hydraulic conductivity found at agricultural sites and forest sites. However, it does not explain the higher hydraulic conductivity on agriculture sites than on forest sites.

The evaluation method of the raw data has an effect on the results (Fodor et al., 2011). Since the method is the same for all land use types, this seems unlikely to cause the larger hydraulic conductivity on agricultural sites. Although the used method in this thesis by Zhang (1997) overestimates the hydraulic conductivity (Fodor et al., 2011), it is possible that this error is larger on agriculture. This should be investigated before any conclusions can be drawn, however this error should also have been noticed during other studies.

A compact roller reduces the soil roughness rapidly, a factor that influences the depression storage capacity of the soil (Lampurlanés & Cantero-Martínez, 2006). A rougher soil can store more water temporally than a smoother soil and will give a higher infiltration rate (Zobeck & Onstad, 1987). Forests normally contains smoother surfaces than agriculture surfaces. At Sumbing Mountain no heavy machinery or compactor rollers are used. These machines are probably used on the investigated sites in the found studies. This might explain the difference in hydraulic conductivity between this study and other studies however, the magnitude of the impact is unknown. More research should be done to be able to draw conclusion on this hypothesis. The larger hydraulic conductivity on agricultural sites might be explained by the fact that the mini-disk infiltrometer measures the unsaturated hydraulic conductivity and not the saturated hydraulic conductivity which was measured in the other studies. During the fieldwork it was noted that the soil in the top layer at the agriculture sites was very loose. When walking on the soil, you would leave a footmark of around a half a centimetre deep. This could indicate that the bulk density of the top soil is very low, and therefore the hydraulic conductivity also very high. This is only a hypothesis, and therefore more research should be done to be able to explain the increase of hydraulic conductivity on agricultural sites.

5.2. Use of developed PTF

The developed PTF for agriculture can predict the hydraulic conductivity with the use of a Digital Elevation Model (DEM). At this moment, DEMs with a resolution between 5m and 1000m are available. A 5m resolution DEM is not very common and can only be derived from LIDAR (light detection and ranging) (Agarwal P. K. et al., 2006). When using the PTF developed for this thesis, one should consider wisely which DEM resolution should be used as predictor. In section 3.1 it was already concluded that a 30m resolution DEM is very inaccurate for this research area, therefore a 5 or 10m DEM is recommended. DEM's with higher resolution show less curves and become rapidly more linear when using higher resolution (Hancock, 2005). In coarser DEMs the steeper slopes are considered less steep and lower slopes are considered steeper, compared to higher resolution DEMs (Sorensen & Seibert, 2007).
When using a low resolution DEM, one could interpolate towards a higher resolution, e.g. 5 or 10 m resolution, to represent the area more accurate. However, Sørensen and Seibert (2007) found that this will not give the same results as an original high resolution DEM when calculating secondary topographic characteristics, the secondary characteristic is always larger when using a coarser DEM. Secondary topographic characteristic are characteristics that are calculated with the use of the DEM, for instance in this case the hydraulic conductivity. The different results are mainly caused by discretization, this is the effect caused by changed cell-size on the algorithms that are used when calculating the elevation. The discretization decreases the minimum slope on lower resolution DEMs and therefore will influence the outcome when calculating a secondary characteristic. The effect of smoothening of the surface is relatively small compared to the effect of discretization. Smoothening occurs when the cell-size is increased; the smaller cells will be smoothened to form larger cells and therefore detail will be lost. The terrain type, e.g. flat terrains or steep terrains, will not influence the value of the secondary characteristic because flat areas are more affected by discretization and the steep areas are more affected by the terrain-smoothing, a contrary relation. (Wolock & McCabe, 2000)

The developed PTF is a linear equation, consequently the hydraulic conductivity will increase with higher slope and there is no stagnation point. This might not be the case in the field. Therefore, the accuracy of this PTF is unknown for slopes rates above 38%.

This PTF is developed for a tropical region with the soil type andosol, so this PTF can be used on similar regions in and outside Indonesia. However, the measurements were taken at a high attitude of approximately 1.700m where the rain season last longer than downhill. Therefore, this PTF is less suitable for tropical regions with a lower attitude.

6. Conclusion and recommendations

First the conclusions are given in section 6.1 and then the recommendation are given in section 6.2.

6.1. Conclusions

Seven soil types are present in the Bogowonto river basin. Latasol occurs the most and covers 61% of the area. Forest covers 54,8% of the area and is the most comment land use type. There is a big slope difference is the Bogowono river basin, the north and east contain high slope rates where the south is flat. The three characteristics together give a high present of latosol in combination with forest and a variety of slope rates. On request of UGM, the measuring points were taken in the north of the river basin, on andosol soil.

A high variety of slope was found at Sumbing Mountain. Slope rates between 7 and 38% were found, which is different from the slope rate found with the available 30m DEM. The DEM overestimates almost all plots. The found hydraulic conductivity values are as expected considering other studies. There is a significant difference between the hydraulic conductivity at agricultural sites and at forest sites. The hydraulic conductivity is higher at agricultural sites. This is unexpected and could be explained by the fact that the top layer at the agricultural site is very loose, and therefore has a local low bulk density.

At forest sites there is no relation found between the slope and the hydraulic conductivity. Therefore, it is advised to use the mean value of the measuring point as input for hydraulic models, with a constant of 0,95 m/day.

At agricultural sites, a relationship between slope and hydraulic conductivity was found. This is described with a linear pedotransfer function explaining 41% of the data. This PTF was validated, and was found as a medium model for the data. An r^2 of 0,30 [-], $RMSE$ of 1,59 [(m/day)^2] and a ME of 0,09 [m/day] was found.

6.2. Recommendations

A 30m DEM is available for Java, ASTER GDEM, but it shows a big difference with the found slope rates in the field. This is due to linearization of the slope. Therefore, it is preferred to use a 5 or 10m resolution DEM. This PTF is valid for slopes smaller than 38%, so it is recommended not to use this PTF on slopes higher than 38%.

To be able to get a representative presentation of the area, it is recommended to take many samples because the variation of the hydraulic conductivity is very high on every plot. The coefficient of variation differs from 24% to 105% which indicates that it is hard to predict the hydraulic conductivity. Measuring the difference in volume for five minutes is optimal on andosol soils. With preparation time included, one should reserve ten minutes per measuring point. Setting the measuring points in grid form takes a lot of time, especially in dense vegetated plots. Hence, it is recommended to use a different way of sampling that is quicker to set up. The season and the time in the growing season have an impact on the hydraulic conductivity. The measurements for this study were taken in one season and at the beginning of the growing season. It is recommended to spread the measurements over the year, so the result will be more representative. Using a tension infiltrometer is recommended because it is faster than the ring infiltrometer. Therefore, it is relatively easy to obtain data.

The hydraulic conductivity will be different in different soil types. If a hydrological model will be made for the Bogowonto river basin more data are required because the river basin contains different soil types. Therefore it is recommended to measure the hydraulic conductivity in other parts of the Bogowonto river basin as well.

This PTF can be used for other tropical regions covered with andosol in or outside Indonesia. Other regions are not recommended because the hydraulic conductivity strongly relates to the soil type.

Bibliography

Agarwal P. K. , Arge L. , & A., D. (2006). Lidar to DEM. Retrieved 14-8, 2014, from http://web.cs.swarthmore.edu/~adanner/lidar.php

Booij. (2013). *Inleiding Waterbeheer (192240131)*. University of Twente. https://blackboard.utwente.nl/webapps/portal/frameset.jsp.

Casanova, M. P., Messing, I., & Joel, A. (2000). Influence of aspect and slope gradient on hydraulic conductivity measured by tension infiltrometer. *14*(1), 155-164. http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-8-545 doi:10.1002/(SICI)1099-1085(200001)14:1<155::AID-HYP917>3.0.CO;2-J

Decagon Devices. (2007-2012). Mini Disk Infiltrometer, users manual. Retrieved from DecagonDevices website:

Derpsch, R. h. c. (2014, 25.04.2014). Understanding the process of soil erosion and water infiltration. Retrieved 3 June, 2014, from http://www.rolf-derpsch.com/en/erosion/

Eklundh, L. (2013). *Interpolation*. Lund University GIS centre. Lund.

Fodor, N., Sándor, R., Orfanus, T., Lichner, L., & Rajkai, K. (2011). Evaluation method dependency of measured saturated hydraulic conductivity. *Geoderma, 165*(1), 60-68. doi: http://dx.doi.org/10.1016/j.geoderma.2011.07.004

Google (Cartographer). (2014). Kaartgegevens. Retrieved from https://www.google.nl/maps/place/Indonesi%C3%AB/@-2.548926,118.0148634,5z/data=!3m1!4b1!4m2!3m1!1s0x2c4c07d7496404b7:0xe37b4de71badf485

Hancock, G. R. (2005). The use of digital elevation models in the identification and characterization of catchments over different grid scales. *Hydrological Processes, 19*(9), 1727-1749. doi: 10.1002/hyp.5632

Hodnett, M. G., & Tomasella, J. (2002). Marked differences between van Genuchten soil water-retention parameters for temperate and tropical soils: a new water-retention pedo-transfer functions developed for tropical soils. *Geoderma, 108*(3-4), 155-180. doi: 10.1016/s0016-7061(02)00105-2

Jačka, L., Pavlásek, J., Kuráž, V., & Pech, P. (2014). A comparison of three measuring methods for estimating the saturated hydraulic conductivity in the shallow subsurface layer of mountain podzols. *Geoderma, 219–220*(0), 82-88. doi: http://dx.doi.org/10.1016/j.geoderma.2013.12.027

Jarvis, N., Koestel, J., Messing, I., Moeys, J., & Lindahl, A. (2013). Influence of soil, land use and climatic factors on the hydraulic conductivity of soil. *Hydrology and Earth System Sciences, 17*(12), 5185-5195. doi: 10.5194/hess-17-5185-2013

Kisworo, H., Sukardi, S., Sukiyoto, M., & Warsito, B. (2013). *River Management in Indonesia English Edition*

Lampurlanés, J., & Cantero-Martínez, C. (2006). Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. *Soil and Tillage Research, 85*(1–2), 13-26. doi: http://dx.doi.org/10.1016/j.still.2004.11.006

Lane, M. L. (2009). *Introduction to Statistics*

Marhaento, H. (2014). Data Reviews and Water Balance Estimation in Bogowonto Catchment (University of Twente ed.).

Minasny, B., & Hartemink, A. E. (2011). Predicting soil properties in the tropics. *Earth-Science Reviews, 106*(1-2), 52-62. doi: 10.1016/j.earscirev.2011.01.005

Napolitano, A. (2011). Analysis of some parameters related to the hydraulic infiltration of a silty-loam soil subjected to organic and mineral fertilizer systems in Southern Italy. *Italian Journal of Agronomy, 6*(2), 117:125. doi: doi:10.4081/ija.2011.e19

Neris, J., Jiménez, C., Fuentes, J., Morillas, G., & Tejedor, M. (2012). Vegetation and land-use effects on soil properties and water infiltration of Andisols in Tenerife (Canary Islands, Spain). *CATENA, 98*(0), 55-62. doi: http://dx.doi.org/10.1016/j.catena.2012.06.006

Puhlmann, H., & von Wilpert, K. (2012). Pedotransfer functions for water retention and unsaturated hydraulic conductivity of forest soils. *Journal of Plant Nutrition and Soil Science, 175*(2), 221-235. doi: 10.1002/jpln.201100139

Salemi, L. F., Groppo, J. D., Trevisan, R., de Moraes, J. M., de Barros Ferraz, S. F., Villani, J. P., . . . Martinelli, L. A. (2013). Land-use change in the Atlantic rainforest region; consequences for the hydrology of small catchments. *Journal of Hydrology, 499*, 100-109. doi: 10.1016/j.jhydrol.2013.06.049

Shevnin, V., Delgado-Rodríguez, O., Mousatov, A., & Ryjov, A. (2006). Estimation of hydraulic conductivity on clay content in soil determined from resistivity data. *Geofísica internacional, 45*, 195-207.

Sorensen, R., & Seibert, J. (2007). Effects of DEM resolution on the calculation of topographical indices; TWI and its components. *Journal of Hydrology, 347*(1-2), 79-89. doi: 10.1016/j.jhydrol.2007.09.001

Stevens. (1999). Post Hoc Tests in ANOVA.

Suunto. (2014). SUUNTO PM-5/360 PC. Retrieved 11-8, 2014, from http://www.suunto.com/Products/Compasses/Suunto-PM-5/Suunto-PM-5360-PC/

Tindall, J. A., Kundel, J. R., & Anderson, D. E. (1999). *Unsaturated zone hydrology for scientist and engineers* R. A. MacConnin (Ed.) Retrieved from http://wwwbrr.cr.usgs.gov/projects/GW_Unsat/Unsat_Zone_Book/

USGS. (2010, January 2013). Unsaturated Flow Basics. Retrieved 3 June, 2014, from http://wwwrcamnl.wr.usgs.gov/uzf/unsatflow/unsatflow.html

Wahren, A., Feger, K. H., Schwärzel, K., & Münch, A. (2009). Land-use effects on flood generation – considering soil hydraulic measurements in modelling. *Adv. Geosci., 21*, 99-107. doi: 10.5194/adgeo-21-99-2009

Wolock, D. M., & McCabe, G. J. (2000). Differences in topographic characteristics computed from 100- and 1000-m resolution digital elevation model data. *Hydrological Processes, 14*(6), 987-1002. doi: 10.1002/(SICI)1099-1085(20000430)14:6<987::AID-HYP980>3.0.CO;2-A

Zimmermann, B., Elsenbeer, H., & De Moraes, J. M. (2006). The influence of land-use changes on soil hydraulic properties: Implications for runoff generation. *Forest Ecology and Management, 222*(1-3), 29-38. doi: 10.1016/j.foreco.2005.10.070

Zobeck, T. M., & Onstad, C. A. (1987). Tillage and rainfall effects on random roughness: A review. *Soil and Tillage Research, 9*(1), 1-20.

Appendix A: The effect of land use on hydraulic conductivity

In this Appendix the research of the effect of land use, represented by the amount of litter, on the hydraulic conductivity will be given. First the methodology will be presented in section A.1, then the results will be given in section A.2.

A.1 Methodology

The amount of litter this is collected at every measuring point. A spot of 15*15 cm was created. First the leaves on the ground were collected and put in a plastic bag per measuring point. After that the hydraulic conductivity was measured. Finally the litter was removed from the spot with a small shovel. This was also collected in a small plastic bag. The moisture content influences the weight of the sample. To be able to compare the samples, the samples were dried. This was done in a laboratory at UGM, at the Faculty of Agriculture. The samples were dried for two days in an oven at 70°C. This makes the water evaporate and only the dray material will be left. Then the samples were weighted. This gave the amount of litter on every spot. The first result gave no correlation with the hydraulic conductivity, so the litter was not measured at plot 10 to 17.

A.2 Results

The results from the litter measurements are shown in Figure A.1, the exact values are given in Table A.1. The high amount of litter at measuring point 7 at plot 3 is most remarkable. However, it has a z-score of 2,5 [-] and cannot be considered as an outlier. The z-scores of all points can be found in Table A.2. No litter was found at the agriculture sites because there are no trees present on the sites and farmers till the land.

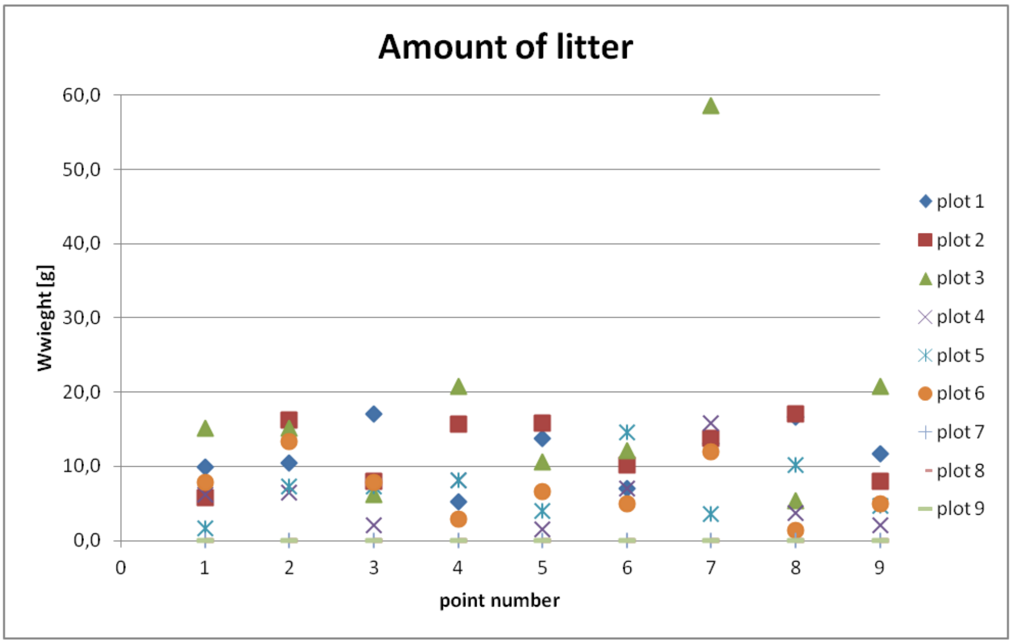


Figure A.1: Amount of litter per measuring point.

Table A.1: Amount of litter per measuring point.

	Pinus forest [g]	Acacia forest [g]
Plot 1.1	9,92	6,14
Plot 1.2	10,49	6,40
Plot 1.3	16,99	2,07
Plot 1.4	5,22	8,04
Plot 1.5	13,74	1,44
Plot 1.6	7,02	6,97
Plot 1.7	13,02	15,81
Plot 1.8	16,68	3,64
Plot 1.9	11,74	2,00
Plot 2.1	5,70	1,61
Plot 2.2	16,27	7,34
Plot 2.3	7,92	7,23
Plot 2.4	15,70	8,12
Plot 2.5	15,87	4,00
Plot 2.6	10,19	14,55
Plot 2.7	13,81	3,58
Plot 2.8	17,00	10,20
Plot 2.9	7,95	4,67
Plot 3.1	15,07	7,89
Plot 3.2	15,09	13,40
Plot 3.3	6,21	7,82
Plot 3.4	20,76	2,90
Plot 3.5	10,60	6,60
Plot 3.6	12,03	5,00
Plot 3.7	58,60	12,00
Plot 3.8	5,30	1,30
Plot 3.9	20,80	4,90

Table A.2: z-score of litter per measurement point.

	Pinus forest [-]	Acacia forest [-]
Plot 1.1	-0,43	0,07
Plot 1.2	-0,29	0,13
Plot 1.3	1,34	-0,84
Plot 1.4	-1,61	0,49
Plot 1.5	0,52	-0,99
Plot 1.6	-1,16	0,25
Plot 1.7	0,34	2,24
Plot 1.8	1,26	-0,49
Plot 1.9	0,02	-0,86
Plot 2.1	-1,51	-1,32
Plot 2.2	0,92	0,13
Plot 2.3	-1,00	0,11
Plot 2.4	0,79	0,33
Plot 2.5	0,83	-0,72
Plot 2.6	-0,48	1,97
Plot 2.7	0,36	-0,82
Plot 2.8	1,09	0,86
Plot 2.9	-1,00	-0,54
Plot 3.1	-0,20	0,26
Plot 3.2	-0,20	1,65
Plot 3.3	-0,75	0,24
Plot 3.4	0,15	-1,00
Plot 3.5	-0,48	-0,07
Plot 3.6	-0,39	-0,47
Plot 3.7	2,51	1,30
Plot 3.8	-0,81	-1,41
Plot 3.9	0,16	-0,50

The mean of the litter per land use type is given in Table A.3. The mean of pinus forest is higher than the mean from acacia forest. The coefficients of variations for both acacia forest and pinus forest are high. This can be explained for pinus forest by the high value of measurment point 7 at plot 3.

Table A.3: mean, standard deviation and coefficient of variation for litter measurements.

	Pinus forest litter [gram]	Acacia forest litter [gram]	Agriculture litter [gram]
Mean	14,06	6,50	0
Standard Deviation	9,98	3,99	0
Coefficient of Variation	71%	61%	

In Figure A.2 the hydraulic conductivity is plotted against the amount of litter found in every measuring point. It is not possible to see any correlation between the two parameters. The amount of litter seems to have no influence on the hydraulic conductivity. This is confirmed by *r* of 0,15 [-] which indicates a very weak linear relationship. Together with the high standard deviations, it seems that the amount of litter cannot be used as a predictor for the PTF.

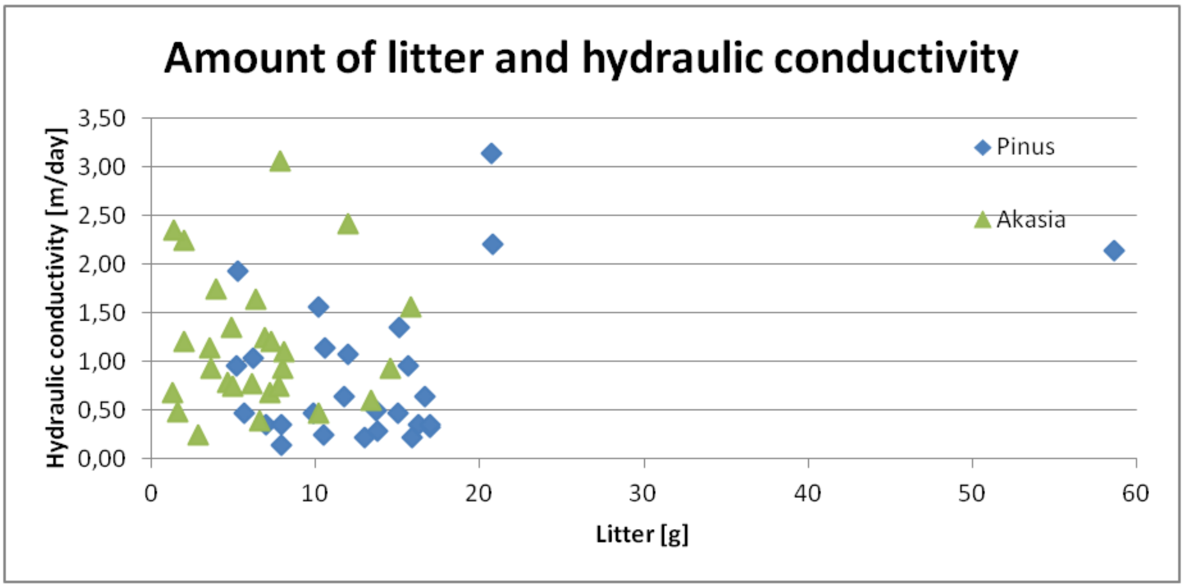


Figure A.2: The hydraulic conductivity as a funcion of the litter amount at ech measuring point.

Appendix B: Results fieldwork

In this appendix first a description of the interpolation process of the slope per plot is given in section B.1. The calculations made with field results, volumes to hydraulic conductivity are described in section B.2. Then all exact values of hydraulic conductivity per measuring point are presented in section A.3. Finally the z-scores of all the measuring points are given in section B.4. The calculations used in section 4.3, effect of slope on agriculture sites, are given in section B.5.

B.1 Methodology slope maps

QGIS 2.2.0 was used to produce a slope map of every plot. To be able to do this, the GPS coordinate of every point was taken. These coordinates were loaded from MS Excel into QGIS with the slope as an attribute. Although the points were taken in grid form, the measured coordinates did not always correspond to the grid. This was probably due to a 3m error in the GPS devices. Furthermore, a GPS only works properly in open fields. Plot 13 shows the most accurate image of a plot and its measuring points and corners, see Figure B.1. Therefore this plot was used as template for all other plots. For every plot the slope was added as attribute.

The interpolation tool was used to find a slope rate for the entire plot. In QGIS only two interpolation methods are available; Triangulated Irregular Network (TIN) and Inverse Distance Weighted (IDW). These are both local interpolation methods. This means that the surface window is limited, only input data that is close to the unknown value will be used to calculate the slope rate for the unknown points. This method will lead to a less smooth surface in comparison to a global method. Though, a local method is less sensitive to outliers. When using a TIN interpolation, triangles will be made between the points. Then the area per triangle will be interpolated. IDW estimates the unknown value by using a circular moving window. The effect of a known point depends on the distance to the unknown point, the further the known point, the less it weights in the calculation of an unknown point. How large the effect of the distance is depends on the weight-factor k, this can be set by the user. A value between one and three is commonly used. A k of one makes all known values equal and a value of three makes the close values more imported. A value of two is standard and very often used. (Eklundh, 2013)

The resulting pictures of the IDW show 'bulls-eyes'. These are locally larger or smaller values around the known points, so this method does not give a good representation of the area. Figure B.2 shows the result of an IDW-interpolation for plot 6 as an example. Though, TIN did not give a 'blocky' image, as expected and therefore this method was used. Plot 15, 16 and 17 show a 'blocky' result, this is because of the large variation in slope rates on those plots.

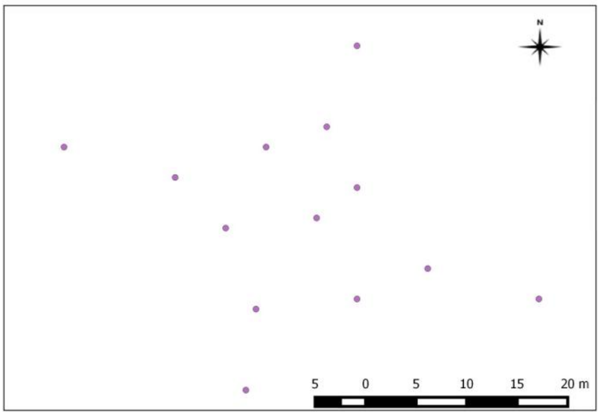


Figure B.1: Point distubution at plot 13, used as template.

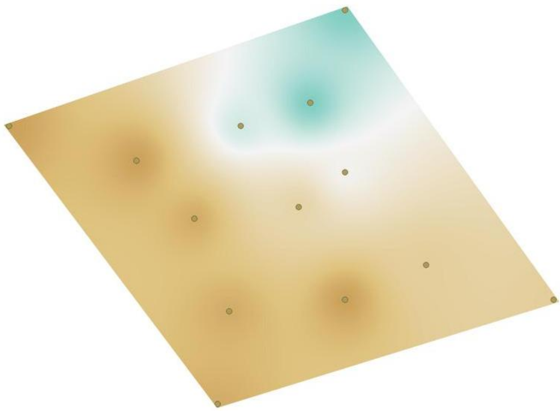


Figure B.2: Example of the 'bulls-eyes' effect, plot 6.

B.2 From measurement volume values to hydraulic conductivity

The volume of water in the infiltrometer was recorded every minute for in total 15 minutes. The results received in the field were therefore 15 volume values in mL per measuring point. After the first results only 5 minutes were measured. Zhang (1997) and Wooding (1968) developed commonly used methods to calculate the hydraulic conductivity from the raw data (Fodor et al., 2011). The method from Zhang (1997) was advised in the manual from Decagon Devices (2007-2012) and was also recommended by Fodor (2011), who compared the two methods. Therefore this method was used, the calculations are as follows. From the volume the infiltration can be calculated per point.

$$Infiltration\ (cm) = \frac{V_{t_0} - V_t}{\pi * r^2}$$

$V_{t_0}$is the volume (mL) at the starting point, V_t the volume (mL) at t time after the starting time and r is the radius of the tube of the infiltrometer, which is 1,55 cm (Decagon Devices, 2007-2012). Then a graph with the cumulative infiltration plotted against the square root of time is produced per plot. A linear trend line is added to the graph to find the parameter C_1 .The first coefficient of the trend line will be the parameter C_1 in the following formula (Decagon Devices, 2007-2012).

$$k = \frac{C_1}{A}$$

k is the hydraulic conductivity (cm/s). Degon Devices (2007-2012) provides a table to find the value A, which depends on the radius of the tube, the chosen suction rate, which is -2 mBar, and the soil type, which is sand. This gives an A of 2,43.

These calculations were done for all the measuring points. The template provided by Degon Devices (2007-2012) was made for a different type of infiltrometer. Therefore this template is adapted, which speeds up the process.

B.3 Exact values per measuring point

In Table B.1, the hydraulic conductivity per measuring point is presented.

Table B.1: Hydraulic conductivity per measuring point including mean, standard deviation and Coefficient of Variation.

Point	Plot																
	Pinus 1 [m/day]	Pinus 2 [m/day]	Pinus 3 [m/day]	Acacia 4 [m/day]	Acacia 5 [m/day]	Acacia 6 [m/day]	Agriculture 7 [m/day]	Agriculture 8 [m/day]	Agriculture 9 [m/day]	Agriculture 10 [m/day]	Agriculture 11 [m/day]	Agriculture 12 [m/day]	Agriculture 13 [m/day]	Agriculture 14 [m/day]	Puspa 15 [m/day]	Puspa 16 [m/day]	Puspa 17 [m/day]
Mean	0,48	0,52	1,61	1,43	0,95	1,14	1,53	2,75	5,35	4,32	4,32	6,51	2,50	3,40	0,76	0,78	0,82
STD	0,24	0,46	0,81	0,57	0,41	0,97	0,81	1,01	0,81	1,02	1,02	2,41	1,14	1,17	0,80	0,47	0,44
CV	49%	88%	51%	40%	43%	85%	53%	37%	15%	24%	24%	37%	45%	34%	105%	60%	54%
1	0,46	0,46	0,46	0,78	0,48	3,06	0,53	2,49	5,59	1,57	5,24	7,34	2,35	1,92	2,67	1,71	0,50
2	0,25	0,36	1,35	1,64	1,21	0,61	2,56	2,60	5,34	3,17	5,02	4,42	4,92	3,03	0,36	0,50	1,92
3	0,32	0,14	1,03	2,24	0,68	0,75	0,57	1,82	4,27	3,24	6,30	4,20	3,24	2,21	0,01	0,43	0,82
4	0,96	0,96	3,13	0,93	1,10	0,25	2,35	3,17	5,02	4,74	3,78	8,19	2,35	4,31	0,78	1,10	0,85
5	0,50	0,21	1,14	2,35	1,75	0,39	1,18	3,92	5,66	2,89	3,24	6,30	2,74	4,88	1,21	0,78	0,46
6	0,36	1,57	1,07	1,25	0,93	0,75	2,56	1,82	4,84	3,31	3,95	5,27	1,42	4,77	0,61	0,46	0,78
7	0,21	0,28	2,14	1,57	1,14	2,42	1,50	2,89	7,20	5,38	3,31	9,72	2,74	3,63	0,14	1,10	0,78
8	0,64	0,36	1,92	0,93	0,46	0,68	1,57	1,50	5,02	2,85	4,31	9,87	1,57	1,96	0,78	0,18	0,46
9	0,64	0,36	2,21	1,21	0,78	1,35	0,93	4,56	5,24	1,89	3,70	3,31	1,18	3,85	0,32	0,78	0,82

B.4 z-scores per measuring point

A test should be performed to check if all the measurements are usable for statistical tests and the calibration of a PTF. A dataset can contain outliers because of measuring errors. Outliers should be removed from the dataset to a give statistical correct result. This can be tested with its 'z-score'. The formula is as follows:

$$z = \frac{x - \mu}{\sigma}$$

Where x is the measured value, μ is the average of the plot and σ is the standard deviation of the plot. It was chosen to calculate the z-score with the mean and standard deviation per plot since the hydraulic conductivity is expected to be similar on one plot. 99,7 % of all measurements will be between z= -3 and z= 3. This means that all measurements with |z|>3 should be removed from the dataset because they are an outlier. The following table shows the z-value per measuring point. Some points are close to |z|>3, however no point exceeds |z|>3.

Table B.2: z-score of hydraulic conductivity per measuring points.

Point	Plot																
	Pinus 1 [-]	Pinus 2 [-]	Pinus 3 [-]	Acacia 4 [-]	Acacia 5 [-]	Acacia 6 [-]	Agriculture 7 [-]	Agriculture 8 [-]	Agriculture 9 [-]	Agriculture 10 [-]	Agriculture 11 [-]	Agriculture 12 [-]	Agriculture 13 [-]	Agriculture 14 [-]	Puspa 15 [-]	Puspa 16 [-]	Puspa 17 [-]
1	-0,08	-0,13	-1,41	-1,15	-1,14	1,98	-1,23	-0,25	0,29	-1,37	0,90	0,34	-0,13	-1,26	2,37	1,99	-0,73
2	-0,99	-0,36	-0,31	0,36	0,65	-0,55	1,28	-0,15	-0,01	-0,05	0,69	-0,87	2,12	-0,31	-0,51	-0,61	2,48
3	-0,68	-0,83	-0,71	1,43	-0,67	-0,40	-1,19	-0,92	-1,34	0,01	1,96	-0,96	0,65	-1,01	-0,94	-0,76	-0,01
4	2,02	0,96	1,88	-0,89	0,38	-0,92	1,02	0,41	-0,41	1,25	-0,53	0,70	-0,13	0,78	0,02	0,69	0,07
5	0,07	-0,68	-0,57	1,62	1,96	-0,77	-0,44	1,15	0,38	-0,28	-1,06	-0,09	0,21	1,27	0,55	0,00	-0,81
6	-0,53	2,29	-0,66	-0,33	-0,05	-0,40	1,28	-0,92	-0,63	0,07	-0,36	-0,51	-0,95	1,18	-0,20	-0,69	-0,09
7	-1,14	-0,52	0,65	0,24	0,47	1,32	-0,04	0,13	2,28	1,78	-0,99	1,33	0,21	0,20	-0,77	0,69	-0,09
8	0,67	-0,36	0,39	-0,89	-1,20	-0,48	0,05	-1,24	-0,41	-0,31	-0,01	1,39	-0,82	-1,23	0,02	-1,30	-0,81
9	0,67	-0,36	0,74	-0,39	-0,41	0,22	-0,74	1,78	-0,15	-1,10	-0,60	-1,33	-1,17	0,39	-0,55	0,00	-0,01

B.5 Effect of the slope on hydraulic conductivity on agriculture sites

To check if there is a significant difference in the hydraulic conductivity for different slope rates, ANOVA test was performed. Three classes were made: 0-15%, 16-25% and >26% slope rate. A more detailed explanation of the Tukey-test is given in Appendix B. The following null hypothesis was drawn:

$$H_0: \mu_{0-15\%} = \mu_{16-25\%} = \mu_{>26\%}$$
$$H_1: not\ all\ means\ are\ the\ equal$$

The null hypothesis will be rejected when $p_{0.05} > p_{value}$.

The ANOVA-test gives a p-value of $3{,}47 \cdot 10^{-9}$. This is smaller than $p_{0.05}$ and therefore the null hypothesis is rejected. The following null hypothesises were drawn for the Tukey-test:

$$H_0: \mu_{0-15\%} = \mu_{16-25\%};\ \mu_{0-15\%} = \mu_{>26\%};\ \mu_{16-25\%} = \mu_{>26\%};$$
$$H_1: \mu_{0-15\%} \neq \mu_{16-25\%};\ \mu_{0-15\%} \neq \mu_{>26\%};\ \mu_{16-25\%} \neq \mu_{>26\%};$$

With the equations used as described in Appendix B, the following Yartwick number was found:

$$Yartwick\ number = 1{,}11\ [\frac{m}{day}]$$

Table B.3: Difference in means per slope class for comparing with the Yartwick number.

	26%> [m/day]	16%-25% [m/day]	0%-15% [m/day]
26%>			
16%-25%	**2,06**		
0%-15%	**3,10**	1,04	

From the Yartwick number and Table B.3 it can be concluded that there is a significant difference between the biggest slope rate and the medium and small slope. This indicates that the slope rate has an effect on the hydraulic conductivity. Drawing a PTF with the slope rate as indicator is therefore meaningful.

Appendix C: ANOVA- test

This appendix includes a general explanation of the calculations used in the ANOVA-test. An ANOVA-test works like a t-test, however it is possible to analyze more than two groups. The following assumptions should apply on the dataset; there is normality and homogeneity of variance and the observations are independent. One can see if there is a significant difference somewhere in the land use with an ANOVA- test. (Lane, 2009) An ANOVA- test can be performed with MS Excel, which is used for this study. As input, the values of the hydraulic conductivity per plot are presented in a table per land use type.

It is chosen to perform the ANOVA with *p=0.05* and *α=0.05*. The following null hypotheses are drawn:

$$H_0: \mu_{land\ use\ y1} = \mu_{land\ use\ y2} = \mu_{land\ use\ yi}$$
$$H_1: not\ all\ means\ are\ the\ equal$$

MS Excel gives the following table as an output when performing the ANOVA.

Table C.1: Output Excel for a one-way ANOVA.

Groups	*Count*	*Sum*	*Mean*	*Variance*		
Pinus forest						
Akasia forest						
Agriculture						
Puspa forest						
Variation analyses						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F-crit*
Between groups						
Within groups						
TOTAL						

The null hypothesize will be rejected when:

$$p_{0.05} > p_{value}$$

This means that the variance cannot be explained by chance and therefore one or more of the land use types are not equal to the mean. However, it is unknown to which land use type this applies.

Therefore a Tukey-test will be performed if the previous null hypothesis is rejected. A Tukey-test is chosen instead of a LSD or Steffe-test because in this case all means have to be compared (Stevens, 1999). Again the following assumptions have to be met; normality and homogeneity of variance and independent observations. A Tukey-test can show where the significant differences in the rejected land use type factors are. The following hypotheses are drawn:

$$H_0: \mu_i = \mu_j$$
$$H_1: \mu_i \neq \mu_j$$

To be able to accept or reject the null hypothesis the so-called 'Yartwick-number" should be computed:

$$Yartwick\ number\ [\frac{m}{day}] = q * \sqrt{\frac{MSE_{within}}{n}}$$

Here MSE_{within} is the Mean Square Error within groups and can be obtained by the excel output table (marked in orange in Table C.1) and q is a number which can be obtained from so-called q-table for Tukey-test. In this table, the numerator is the amount of land use types and the denominator is the degrees of freedom within groups (marked in blue in Table C.1). The value n is the amount of measured values per land use type. The following table will be produced sorting the means from large to small and then by subtracting the means.

Table C.2: Table Tukey-test, required to test null hypothesis.

	Agriculture [m/day]	Acacia forest [m/day]	Pinus forest [m/day]	Puspa forest [m/day]
Agriculture				
Acacia forest	$\mu_{agriculture} - \mu_{\mathrm{akasia}}$			
Pinus forest	$\mu_{agriculture} - \mu_{\mathrm{pinus}}$	$\mu_{\mathrm{akasia}} - \mu_{\mathrm{pinus}}$		
Puspa forest	$\mu_{agriculture} - \mu_{\mathrm{puspa}}$	$\mu_{\mathrm{akasia}} - \mu_{\mathrm{puspa}}$	$\mu_{\mathrm{pinus}} - \mu_{\mathrm{puspa}}$	

The null-hypothesis will be rejected when the difference between two means is higher than the Yartwick number.