Master Thesis

The Design of Contour Trenches in Vietnam

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October 2007

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Abstract

During the last years, drought, water shortages, and in combination with flood are serious problems in Ninh Thuan province, Vietnam. These situations need to be encountered to improve the livelihood of this region community. Royal Haskoning and Westerveld Conservation Trust suggested the implementation of contour trenching as the appropriate solution. In water harvesting technique, this method is identified as a catch runoff, following with the infiltration, and eventually retains water subsurface. However, this process, from rain water into the unsaturated zone and how to design a contour trench from the hydrological point of view are less studied.

Therefore, the approach here is to demonstrate the hydrological modeling part and furthermore study the factors that affect the implementation of these contour trenches. The rainfall-runoff correlation is calculated using rational method. Afterwards, water flow and storage are simulated using Hydrus 2-D. However, the main limitation in these modeling is that there is no measured data for the calibration. In this case, it is more like testing the probable factors in several scenarios. Since the water flow process from rainfall to the unsaturated zone is quite complicated, maximum events are taken.

Subsequently, the results of the simulations show some important findings. First, the design of a contour trench should start with the goal. If it is to maximize the groundwater recharge, then runoff should be chosen at a reasonable probability. However, if the goal is on vegetation growth, then runoff accumulation is necessary to meet the water demand of the vegetation. Second, since the local soil property is loamy sand, the distribution of water content below the trench is almost only in vertical direction. Third, regarding the infiltration process, slope and spacing have minor effects. On the other hand, soil properties will distinguish a lot between storage capacities, both temporal and spatial. Fourth, water availability in contour trenches is relatively short, about 2 weeks. A maximum additional storage of 4 m^3/m is equal to 27% soil moisture increase compared to the condition without contour trench.

These results are used as the inputs for further hydrological measurements. The measurements need to be conducted are soil hydraulic properties, infiltration capacity, vegetation growth, rainfall-runoff, groundwater level, and evaporation.

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Chapter 1
Introduction

1.1 Background

Drought is identified as a very serious problem in semi-arid regions. This problem has been experienced more intense in South province of Vietnam, Ninh Thuan during the last years. In addition, low river flows during the dry season which causes saline intrusion and water shortages for domestic and agricultural use also occurs frequently in this region. Even in the wet season, it gets flooded. These situations have to be encountered and moreover to be solved to improve the livelihood of this region community.

To overcome these multiple threat, Royal Haskoning and Westerveld Conservation Trust suggested the implementation of water harvesting techniques. It is contour trenching chosen to be as the solution. The hydrological processes of this method are a simple catch runoff and infiltration process, which eventually retains water subsurface. Nowadays, contour trenches have not been carried out in Vietnam since this technique is unknown there.

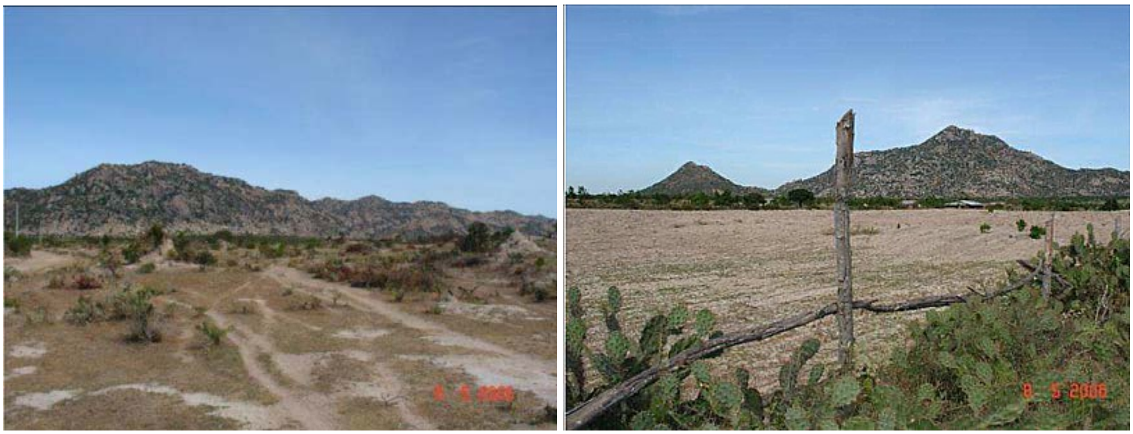
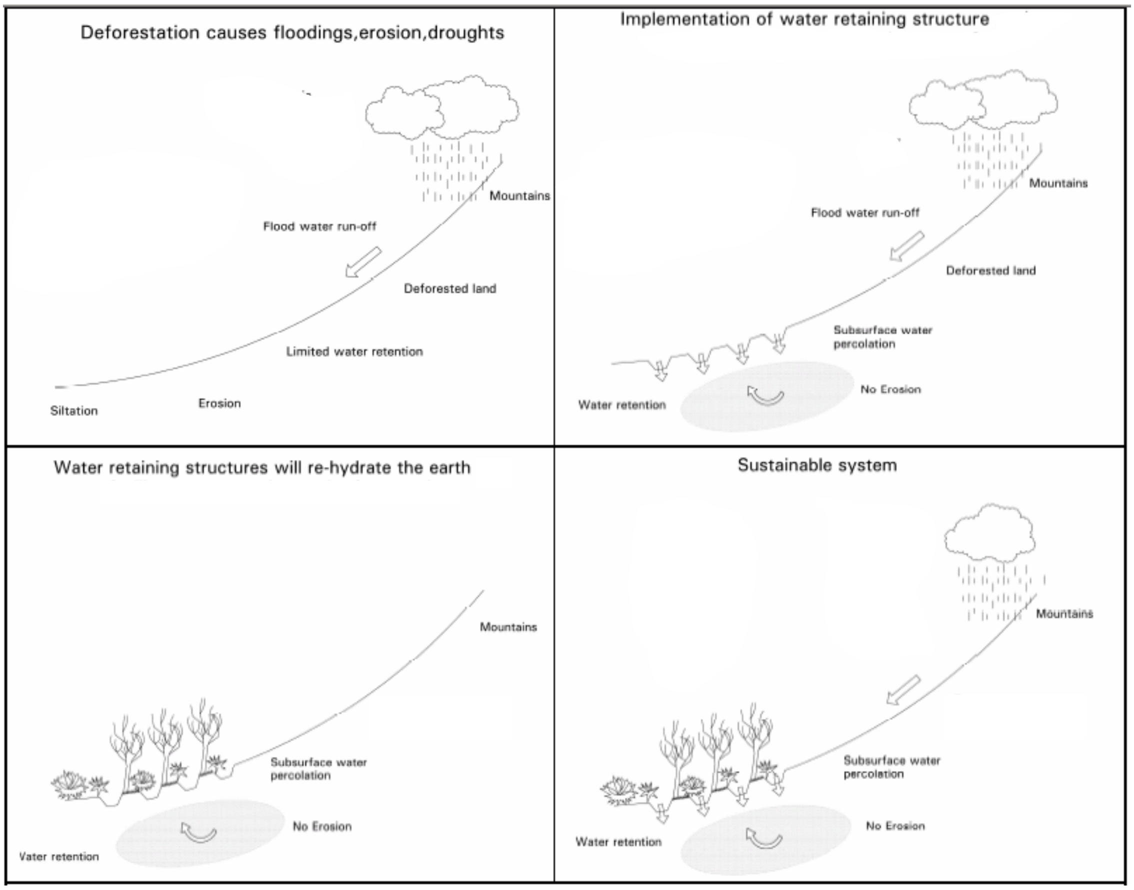


Figure 1.1 Site area at Ninh Thuan Province.
Source: Royal Haskoning

In summary, the concept of proposed contour trench is re-hydrating the earth by sustainable, small-scale sub-surface water retention technique (Royal Haskoning report, 2006). This can be seen in **Figure 1.2**.

Currently, previous implementation on contour trench by Westerveld Conservation Trust has already shown promising results in Kitenden, Amboseli, Kenya. Basically, in hydrological point of view, the design of this contour trench itself uses the peak rainfall event. However, what happen with the rain water during its process into the unsaturated zone is unknown yet. Now, what is apparent physically is that the area covered by vegetation both inside and near the trench after 2 years of implementation. Implicitly, this condition is believed also as an indication of storing more water in the unsaturated zone. In the future, it is expected that vegetation growth increases continuously proportional to the available soil moisture.



Deforestation causes floodings,erosion,droughts

Implementation of water retaining structure

Water retaining structures will re-hydrate the earth

Sustainable system

Figure 1.2 Concept of the contour trench.
Source: Westerveld Conservation Trust, modified.

Therefore, since there is a deficiency in contour trench design, more hydrological research needs to be conducted to ascertain the effects of contour trench. The first approach here is to explore the modeling part and study the factors that affect the implementation of these contour trenches. Hydrological modeling will be applied in order to demonstrate the effect of contour trenching on water flow and storage. In this study, however, the modeling condition is more to testing factors without any calibration. Afterwards, the results will be used as the inputs for further hydrological measurements and determine the important parameters when designing the contour trenches.

1.2 Objective

The general objective of this study is to examine the factors that affect the implementation of contour trenches. In order to achieve this, the objectives are set as follow:

- To develop step by step scenarios of probable conditions in the unsaturated zone as an impact of a contour trench
- To investigate the water flow and its distribution in the vicinity of the contour trench
- To quantify the additional water storage of the contour trench
- To formulate the design steps of contour trenches
- To give recommendation on measurements, how to attain the utmost results in implementation of contour trenches

1.3 Outline of Study

This thesis comprises of 6 chapters.

The first chapter begins with the main introduction to the thesis subject where the background and its problem, research question with the objectives, and outline of this study are explained.

The description of the study area is described in the second chapter. The topography, meteorological condition variability, the groundwater level and soil properties on several points in the catchment area are highlighted.

In the third chapter, the methodology of this study is explored. In particular, the run off formulation, infiltration process and the method to approach the case study using the available data are described.

The main work of this thesis is explained in chapter four and five. First, the rainfall-runoff formula is calculated. Afterwards, the modeling of unsaturated zone due to implemented water retention techniques is developed with step by step scenarios using the application of HYDRUS 2-D. The results are mainly demonstrated on both water content distribution and water storage.

The last chapter, Chapter 6, summarizes the findings of previous chapters in conclusions and recommendations. This chapter presents the formulation of measuring plans and design of the contour trench.

Chapter 2
Description of the Case Study Area

2.1 Geography

The central region coastal area of Vietnam (**Figure 2.1**) is a narrow plain over 1,000 km long and is transected by many small to medium-sized rivers flowing eastwards from the highlands to the South China Sea. Ninh Thuan Province is enclosed by mountains and is characterized by three kinds of terrain, mountain (63,2%), hill (14,4%) and coastal delta (22,4%). The specific study area is at Phuoc Nam Commune, Ninh Phoc district and is a dry area, located precisely at 11^{o} 31’ - 11^{o} 27’ N to 108^{o} 51’ - 108^{o} 56’ E with elevation range about 13.5 to 437 m above sea level. Moreover, it is located about 10 km from the coastal area. The project site can be seen in **Figure 2.2**.

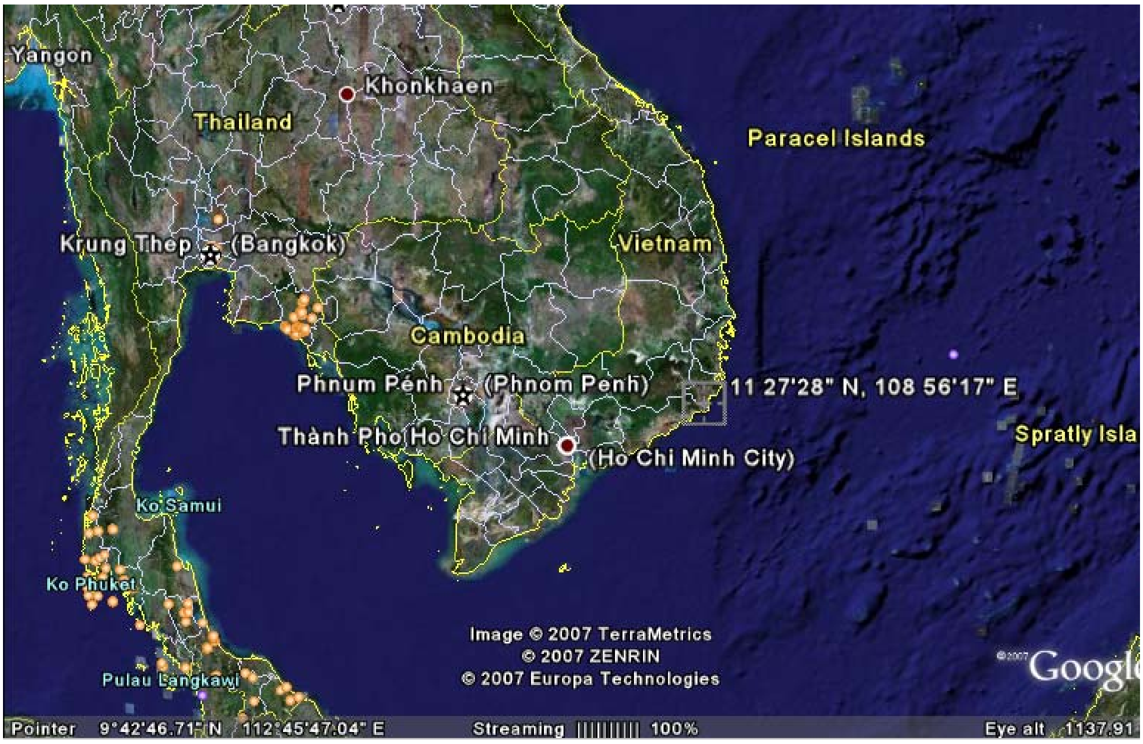


Figure 2.1 Location of case study (grey square).
Source: Google Earth.

2.2 Climate

Generally, the climate in Vietnam is controlled by the monsoon, the warm, moist tropical maritime air mass from the South China Sea to the south eastern of the region. However, in the

Ninh Thuan province, the climate differs from the rest of the provinces in Vietnam which is dry. Below are the meteorological data available from Phan Rang station which is the nearest meteorological station from the study area (see **Figure 2.2**).

Table 2.1 Monthly Average Meteorological Data at Phan Rang Station (1999-2005)

Data	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	2	0	10	24	46	63	48	55	123	158	140	86
Evaporation (mm)	155	156	181	164	156	142	170	176	103	78	103	140
Humidity (%)	72	72	74	75	75	75	75	75	79	80	76	75
Temperature (^{0}C)	25	25	27	28	29	29	29	29	29	27	26	25

Figure 2.2 Location of station Phan Rang and the study area (the black square).
Source: Google Earth.

The average rainfall is 756 mm, but very unevenly distributed throughout a year period. In this area, rainfall varies remarkably in a year, from January to April accounts for 5% and from May to August 28%, while from September to December accounts for 67%. Significant rainfall events occur from September to December, with its peak in October, and dry season from January to April. Potential evaporation in the region is provided by an annual total data of 1722 mm. It represents monthly average exceeds 5 mm/day, while in September and November about 3.3 mm/day. Lowest potential evaporation rate is found only in October of 2.5 mm/day. The average temperature is 27^{o}C where the peak reaches to 37^{o}C (Oxfam GB, 2005). Monthly average humidity is almost stable at 75%.

In addition to rainfall data, daily data are found in the internet from 1997 to 2002. It is also based on Phan Rang station measurement and available at University of Tokyo website. One remark on this data is, however, that the monthly data in 1999 is totally different to the data provided by the project. From the University of Tokyo, the annual rainfall reaches to 1041 mm, whereas from the project data is only 754 mm.

After the field visit, daily rainfall data from 4 different stations were available. Those are from station:

- Phuoc Hu: 10 years data, annual average of 646 mm.
- Phuoc Ha: 11 years data, annual average of 975 mm.
- Nhi Ha: 22 years data, annual average of 858 mm.
- Mua Quan The: 28 years data, annual average of 715 mm.

Although the stations have different annual average value, the monthly rainfall distribution per year shows about the same trend. Below is the average rainfall of all 5 stations. The complete details of data can be seen in **Appendixes B**.

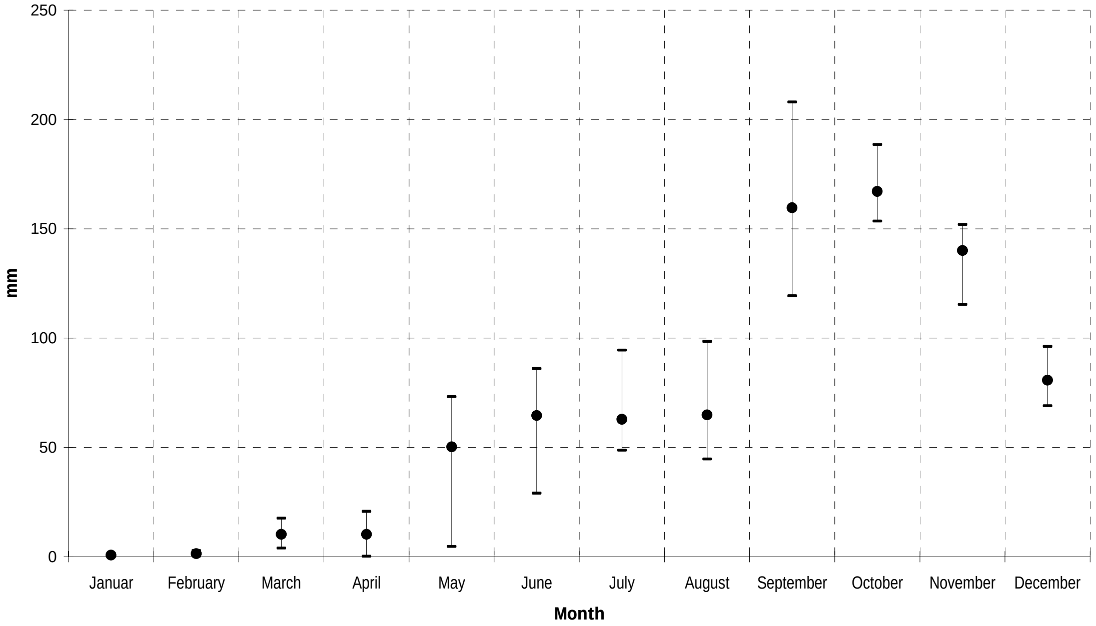


Figure 2.3 Average annual precipitation of 5 stations near the project area.

2.3 Soil Profile

In the area of Ninh Phoc district, soil profile data are collected from the field. Most of the samples refer to silty sand and coarse sand. The first layers that form the unsaturated zone are silty sand which is from the soil surface to 3 or 4 m deep. Below the first layer, there is fine sand to coarse sand layers to a depth of ten's meter. Furthermore, lime sandstone layer exists below the silty sand. Most of the soil profile have good conductivity and are suitable for drain. Only at location LKPN02, silty clay is found. Here, the silty clay layer ranges from the soil surface to a depth of 5.5 m. In summary, 6 soil data out of 12, which are near to the project area can be seen in **Figure 2.4**.

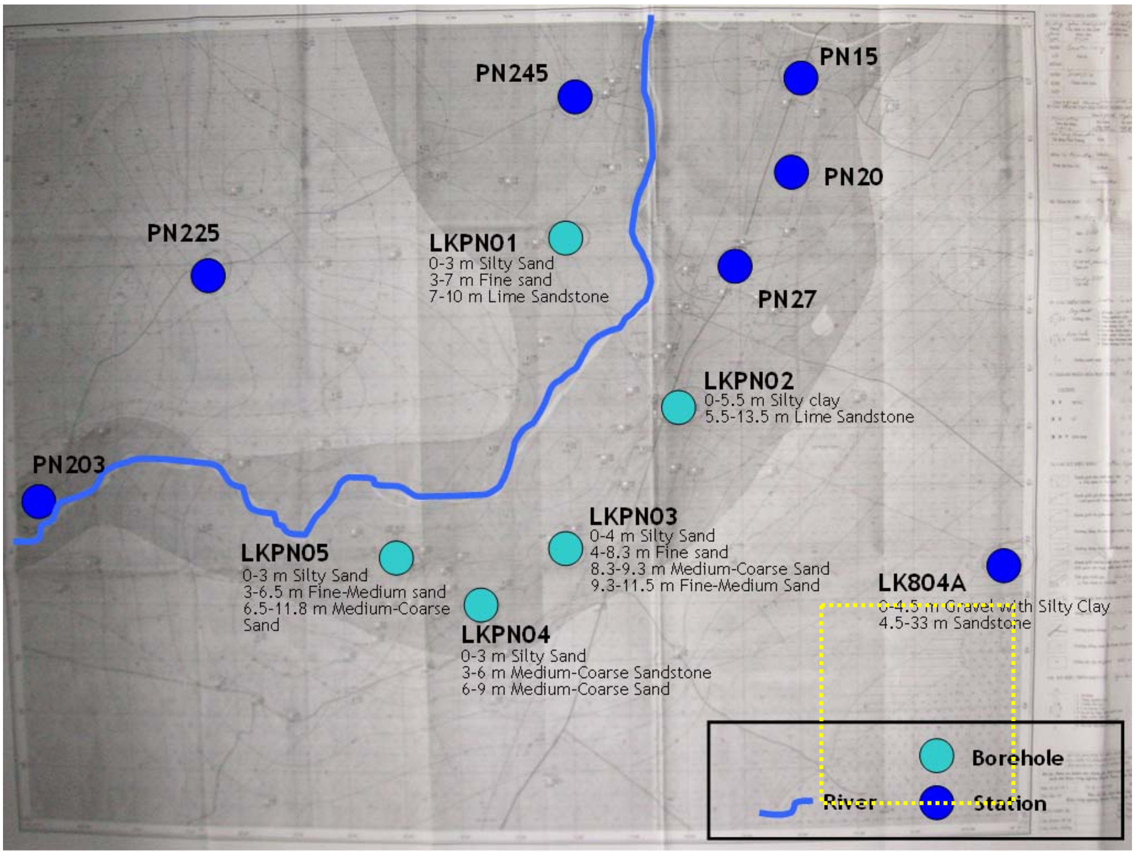


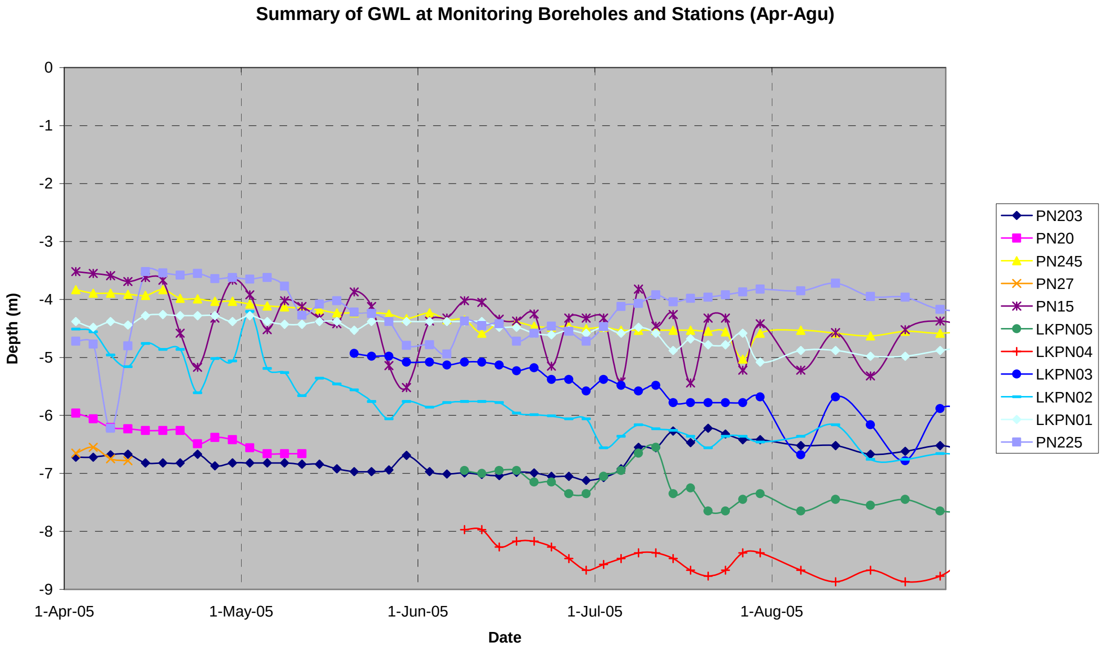
Figure 2.4 Locations and soil profiles of 6 samples in near the project (yellow square).

2.4 Geo-hydrology

The groundwater levels in this study area were measured from 3 April 2005 to 30 November 2005. There are 5 boreholes and 7 stations. Each of them were measured every 3 days from April to July, October, and November, while in August and September, measurements were done every 6 days. The results of those measurements are presented in **Figure 2.5**.

Looking at both graph, the groundwater level can be divided into dry season and wet season. Interventions such as abstraction from locals or industries are unknown. However, when there is a rapid fluctuation, it might be caused by some local abstractions or sudden rainfall events.

Most of the groundwater level between April and August (dry season), ranges from -3.5 to -9 m below the soil surface. The fluctuation itself indeed varies from point to point, but the trend shows more or less a gentle decrease towards the end of the dry season. On the other hand, From September to November, groundwater level increases due to rainfall events, especially at the downstream part of the project. LKPN02 shows the greatest increase, which almost reaches the soil surface. Only LKPN05 and LKPN04 do not affected by rainfall events.



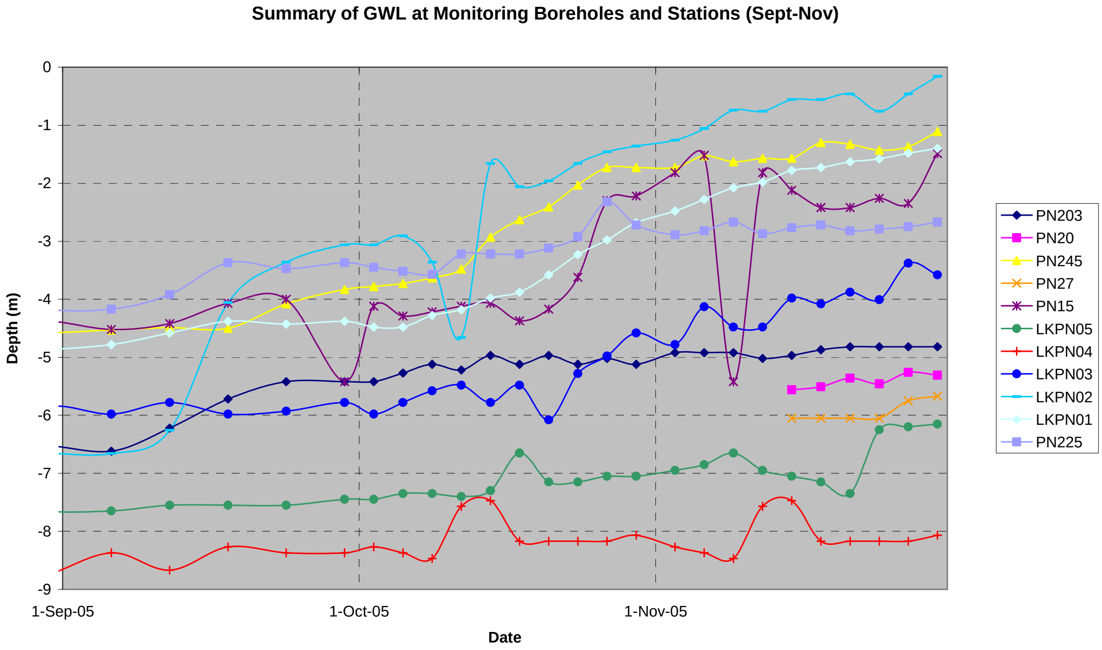


Figure 2.5 Groundwater level measurements from 3 April 2005 to 30 November 2005.

2.5 Water Stream

There are two seasonal water streams identified on the provided geo-hydrological map and Google Earth map (see **Figure 2.6**). Water streams can be used as a potential runoff accumulation in wet season to fill up the contour trenches besides using its spacing area. To be able to do it, one may divert the seasonal creek by constructing a dam so that it may overflow to the trenches site. Similarly to the seasonal creeks, temporary roads are beneficial to accumulate runoff although in a smaller scale and in a shorter period compare to the creeks. Besides, gullies might also increase surface runoff in small scale. Therefore, these water streams are highly to be considered.

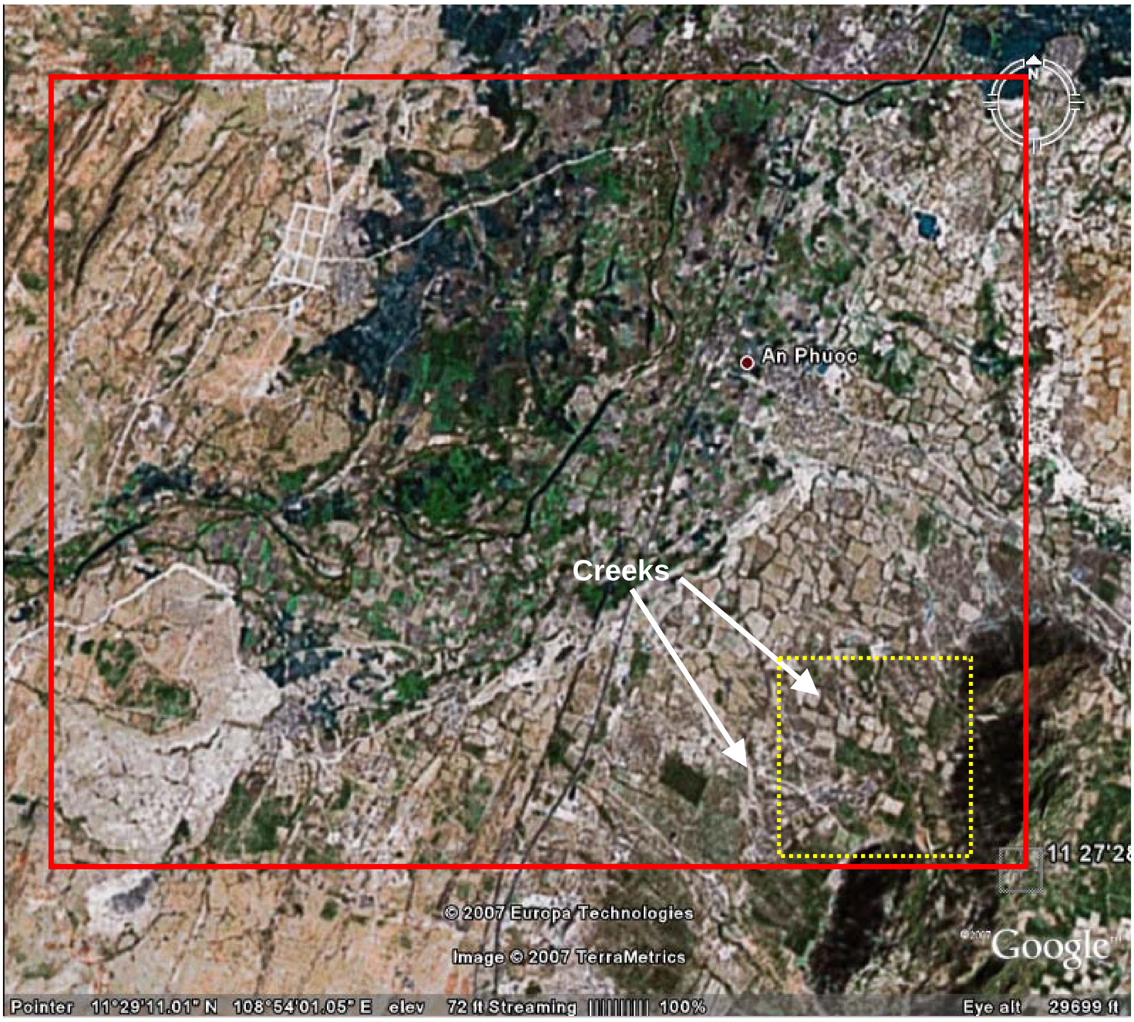


Figure 2.6 Available water streams in the vicinity of the project.

2.6 Impact of Drought to Socio-Economic

The study area is a poor commune. In the dry season people do not have enough water for both consumption and irrigation.

The main economic sector of the province is agriculture. In this areas, commonly there are 3 rice crop pattern in irrigated areas, first, from early December to early April, from late April to early August, and the main cropping season from September to early December. The main sources of water in dry season are river water and well water.

Based on the report of Oxfam GB, the impact of drought to the agriculture reduces 60-70% in rice production 2004. From December 2004 to April 2005, only 7,372 ha of rice and corn areas were cultivated, whereas in 2004 it was to 17,398 ha. In 2005, some areas had to postpone or even cancel this rice crop because of water shortage. As a result, locals experienced 3 times of crop losses.

Figure 2.7 Groundwater exploitation by local community.

Source: Report by Oxfam GB, Assessment of the Impact of Drought In Ninh Thuan Province, Vietnam, 2005.

Chapter 3
Methodology

3.1 Water Harvesting Technique

The principle of water harvesting techniques (**Figure 3.1**) according to ICARDA 2001 and SIWI 2001 consists of three main components. First, the catchment area is where the part of the land contributes its share of rainwater. Second, the storage is the place where runoff water is held or collected. Third, the target or cultivated area is where the harvested water is used.

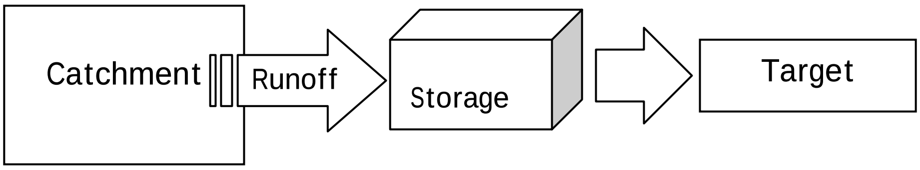


Figure 3.1 Components of water harvesting technique.

In this study, the water harvesting technique is limited to the combination of contour trenches and stone lines. The contour trenches, from the time span and water use point of view, are short term storage and for crop production purposes. Stone lines are used to slow down runoff and filter the water.

Regarding to the components, the catchment areas here are creeks, gullies, roads and the spacing between trenches. Runoff is collected temporary in the trenches. Following, the next storage is as soil moisture. Finally, it is aimed to provide sufficient moisture for vegetation growth and trees.

Apart from that, due to uneven distribution of runoff and soil erosion, it is suggested to conduct water harvesting with maximum slopes of 5% (SIWI, 2001).

3.2 Furrow Irrigation

The water flow mechanism of contour trenches can be approached with a furrow irrigation system. An understanding therefore of what happens in furrow irrigation is of interest. Looking at its construction, it similarly has to be excavated, although for contour trenches like in this study are in a bigger scale and will need the help of a bulldozer or grader. The water flow, in general, after filling up the trench is mainly an infiltration process. It shows the same pattern as in furrow irrigation. **Figure 3.2** below shows three typical wetting pattern on furrow irrigation.

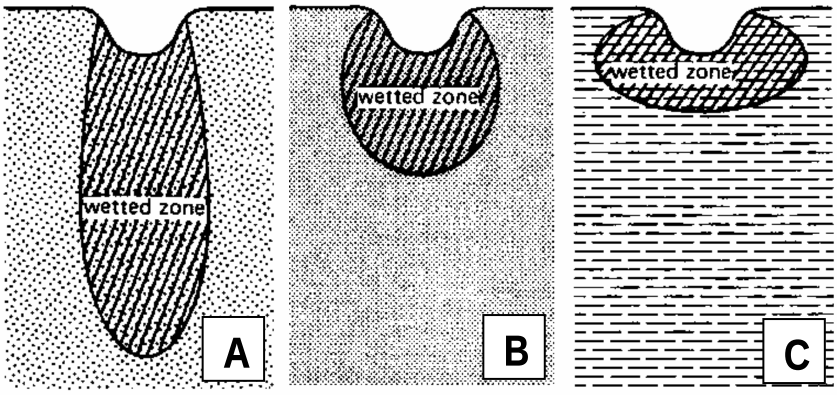


Figure 3.2 Different wetting patterns in furrows. Soil type: A-Sand, B-loam, C-Clay.
Source: www.fao.org

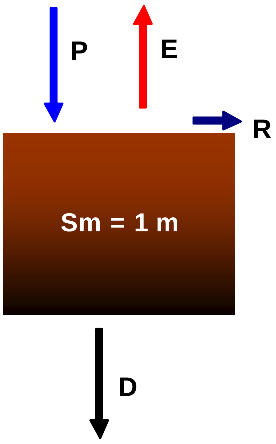
Wetting patterns here is described based on the soil properties. It yields to downward and lateral movement. Clay soil, which has lower permeability than loam and sand, will have more lateral movement compare to the others.

This wetting pattern can be poor because of several conditions. It first can be caused by several unfavorable natural conditions such as compacted layer, different soil types, and uneven slope. Another thing is too wide spacing furrow might lessen the moisture between two trenches. Furthermore, poor management like supplying water from various stream dimensions and stopping the inflow too soon will affect the wetting pattern as well. Related to trenches, the dimension has to be optimal and runoff must be match to accumulate water in the trenches.

Other important aspects in furrow irrigation are the spacing between furrows and suitable slope. The spacing is related wetting patterns which might overlap each other. For furrow irrigation, the suitable slope should not exceed 0,5 % or preferable gentle slope with spacing relatively small since the dimension of furrows are small as well. Here, the term slope of furrow irrigation is different to slope of contour trenches. In furrow irrigation, the slope is the flow direction in the furrow, whereas in contour trench, the slope is parallel to the contour of the landscape. Since the suggested slope for water harvesting technique by SIWI is maximum 5 %, in this study, the slope varies from 0 up to 10 %.

3.3 Water Balance

A water balance at the first layer in the unsaturated zone is made. Generally, the calculated water balance depends on the amount of water entering the soil (inflow) and leaving the soil (outflow). Inflow and outflow are divided into four parameters which affect the water balance. Those parts are precipitation, evaporation, runoff, and percolation. The change in water storage is based on a schematic water balance shown in **Figure 3.3**.



Where:

P = Precipitation
E = Evaporation
R = Runoff
Sm = Soil water storage
D = Percolation

Figure 3.3 Water balance components.

It is assumed to be a simplified water balance model. In general, the model neglects soil water dynamics, no water uptake to the root zone occurs, and interception is insignificant. It mainly provides information of one month time step. The soil is taken as fine sand with moisture holding capacity of 150 mm per 1 m soil depth. It is defined that 90% of monthly rainfall enters the soil and the rest becomes runoff. First month estimation stipulates the condition where soil moisture storage is zero, which can be taken in the middle of the dry season. The monthly average evaporation is set to 2 mm per day in wet season and 2.5 mm/day in dry season.

Table 3.1 Water Balance

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Precepitation (P)	46.1	62.9	48.4	54.6	122.9	158.4	140.2	85.7	1.8	0.2	10.2	24.3	755.7
Potential Evaporation (ET)	156.4	141.5	169.8	175.6	102.7	77.7	102.7	140.0	154.8	156.3	180.8	164.0	1722.3
Actual Evaporation (E)	41.5	56.6	43.5	49.1	60.0	62.0	60.0	62.0	77.5	70.0	13.5	21.9	617.6
Run-off (Ro)	4.6	6.3	4.8	5.5	12.3	15.8	14.0	8.6	0.2	0.0	1.0	2.4	
Acc. of Soil Moisture (Sm)	0	0	0	0	50.6	131.2	150.0	150.0	74.1	4.3	0.0	0.0	
Percolation (D)	0	0	0	0	0	0	47.4	15.1	0	0	0	0	62.5

Based on the results, some remarks on the calculated water balance can be made. Compared to potential evaporation data by existing meteorological station, about 36% is predicted to occur in the field as the field is dry and has not sufficient moisture to be supplied to the atmosphere. The first water storage occurs in September, at the beginning of a significant rainfall event and yield to 50.6 mm. In November and December, the maximum soil moisture capacity is exceeded, with a total of 62.5 mm.

Additionally, if the water balance is developed at a small scale, it is apparently difficult to estimate the process due to heterogeneity and uncertainties on the field. Thus, this calculation result may be accepted for larger scales.

3.4 Rainfall-Runoff

To fill up the trench, rainfall is the main source. At the upstream catchment area, rainwater flows as runoff into the trench. Consequently, a relationship between rainfall and runoff events should be determined. Factors that are affecting runoff are quite complex such as infiltration capacity, rainfall intensity, rainfall duration, antecedent soil moisture, soil type, vegetation, slope, and catchment size. However, these variables are simplified in this study using the rational method.

This rational method is commonly used to calculate peak runoff. However, here it is utilized in cases where only spacing is considered and no waterstream is available at the vicinity of the trench. Thus runoff is generated by the available catchment area at the upstream part of the trench. In general, rational method results are very sensitive to the coefficient and rainfall intensity selected. The rational method equation is shown below.

$Q = c\ i\ A$

Where:
Q = peak discharge [L^3/T]
c = rational method runoff coefficient
i = rainfall intensity [L/T]
A = drainage area [L^2]

3.5 Unsaturated Zone

In the hydrological cycle, the unsaturated zone often functions as a transmission of water falling or ponded on the soil surface to the underlying groundwater or as temporary storage for plant use. The thickness of unsaturated zone may vary from less than 1 to 10's m. It can be divided into three zones, the root zone, the intermediate zone, and the capillary zone (or fringe) above water table. The root zone is where the roots of plants are found, which can be to a depth of more than 10 m from the soil surface. The capillary zone is where the capillary force takes water upward from the saturated zone. Thus this zone will be wetter than the intermediate zone. A column of an unsaturated zone is shown in **Figure 3.4**.

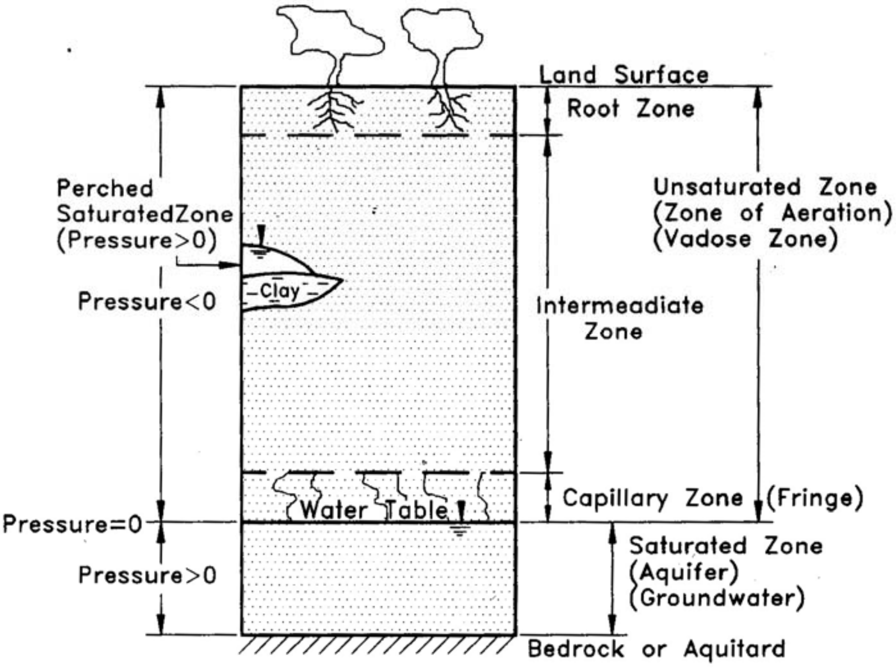


Figure 3.4 Classification of the unsaturated zone.
Source: Guymon, 1995, pg. 4

In the unsaturated zone, water is held by absorption, adsorption, osmotic and capillary forces. Absorption refers to an uptake into a body. Adsorption describes a water film held by the grain surface due to electrical charges. Osmotic forces occur when water is drawn into soil aggregates by differences of salt concentrations with the water in the pores. Capillary forces are due to surface tension in small pores.

There are three important notes for unsaturated zone condition. First, the hydraulic conductivity is a function of $\psi(\theta)$ and $K(\theta)$ which can be approximated by using analytical relation from Genuchten, [1980]. This is further explained in the next sub chapter about Hydrus 2-D. Second, the pressure (ψ) is always negative with respect of the atmosphere, while in terms of water tension or suction is $|\psi|$. Third, the soil moisture content can be a function of the water tension ($\psi = \psi(\theta)$) or vice versa ($\theta = \theta(\psi)$). This is usually expressed in form of moisture retention curve.

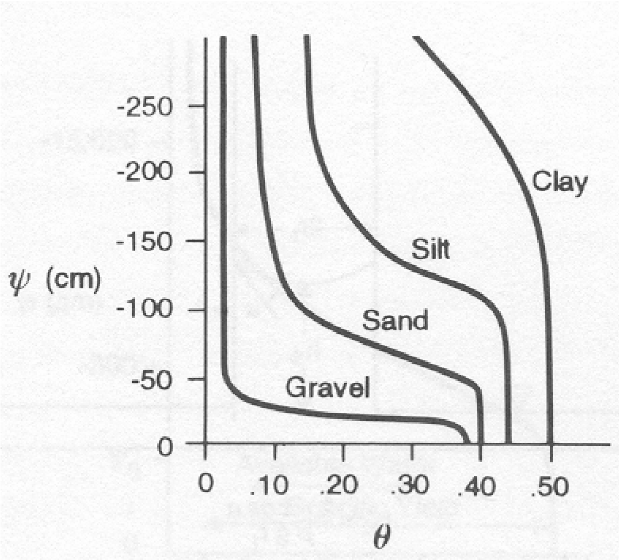


Figure 3.5 An example of moisture retention curve.

3.6 Hydrus 2-D

To examine the distribution and quantify the water storage below the trench in response to meteorological condition and groundwater fluctuation unsaturated-saturated zone model is performed. The software chosen in this study is Hydrus 2-D. This program is developed by Simunek, J., M. Th. van Genuchten and M. Sejna. The latest version, 1.01 of Hydrus-2D was released in March 2007.

HYDRUS 2-D consists of the computational computer program and interactive graphics-based user interface. It numerically solves the Richards equation for variably saturated water flow. The flow equation incorporates a sink term to account for water uptake by plant roots.

HYDRUS 2-D may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The program can handle flow regions delineated by irregular boundaries. The flow region itself may be composed of non uniform soils having an arbitrary degree of local anisotropy.

The governing flow equation is:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[K\left(K^A_{ij}\frac{\partial h}{\partial x_j} + K^A_{iz}\right)\right] - S$$

$$K(h,x,y,z) = K_s(x,y,z)\,K_r(h,x,y,z)$$

Where:
θ = soil volumetric water moisture [$L^3\ L^{-3}$]
h = pressure head [L]

S = sink term [T^{-1}]
x_i = spatial coordinate[L]
t = the time [T]
K_{ij}^{A} = components of a dimensionless anisotropy tensor K^{A} [LT^{-1}]
K_r = unsaturated hydraulic conductivity function [LT^{-1}]
K_s = saturated hydraulic conductivity function [LT^{-1}]

In this study, the van Genuchten [1980] soil-hydraulic equation is used. This predictive equation for the unsaturated hydraulic conductivity function in terms of soil water retention parameters is derived from the statistical pore-size distribution model of Mualem [1976]. The formulas are presented as follow:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^{n}]^{m}} & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

$$K(h) = K_s S_e^{l}[1-(1-S_e^{1/m})^{m}]^{2}$$

$$m = 1 - 1/n\ , \quad n > 1$$

Where:
θ = water content [-]
θ_r = residual water content [-]
θ_s = saturated water content [-]
h = pressure head [L]
α = inverse of the air-entry value [L^{-1}]
Se = effective water content [-]
α , m, n = empirical coefficient

3.6.1 Input

The Hydrus 2-D parameters needed are:

- Basic Information; the time information of the simulation, processes, iteration criteria
- Domain geometry; the dimension information of the case study and further to mesh generation
- Domain properties; soil hydraulic model
- Initial condition; in pressure head or water content
- Boundary condition; include flux, variable head, variable flux, free drainage, deep drainage, seepage face, and atmospheric boundary.

3.6.2 Output

The output of Hydrus 2-D used in this study is expressed in water content distribution per time step.

Chapter 4
Scenarios and Analyses

In this chapter, the contour trench scenarios and its analyses are discussed in detail. The first step is to describe the whole water flow process included in the simulation. Starting from rainfall that reaches the soil surface, rainfall-runoff relationships have to be determined. Afterwards runoff accumulation yields the amount of water that can be retained in the trench. Later on, the water flow continues to the infiltration process, from ponding to falling head in the trench into the unsaturated zone.

4.1 Description of Hydrological Processes

The planned trench may vary in dimension. This is due to the fact that runoff also varies in time. Furthermore, runoff will fill up the trench to a certain amount of water. In this case, it is not known yet to what extent it will reach an optimum result with respect to available runoff. For the test and the sake of simplicity, the case study of contour trenches in Kitenden, Amboseli (see **Figure 4.1**) will further be used in the modeling part. The mentioned contour trench is 3.5 meters wide with respect to a bulldozer capacity in excavating the surface soil, 1 meter deep due to the removal of presume compacted soil surface layer and 150 meters long, which was freely defined. Thus the total usable volume for retaining water in a trench yields to 525 m^3. The distance between contour trenches may also vary, since it catches the rainfall and eventually affects the amount of runoff.

However, actual runoff that flows into the trench is cumbersome to simulate in combination with the infiltration model. Therefore, it will be calculated separately. In general, runoff will strongly depend on several factors such as slope gradient, rainfall intensity, rainfall duration, initial subsurface moisture, and soil properties. First, the higher the slope the more runoff occurs. Second, the intensity of rainfall events need to be taken into account since this will relate to the infiltration rate of the soil condition. Third, the duration may exceed the infiltration and thus creates ponding surface. Fourth, the initial condition in the field related to water content may vary in time. The initial subsurface condition in the wet season is almost saturated where it will apparently create higher runoff than in the dry season. Fifth, runoff also depends on the soil properties, for example sand layer will infiltrate faster than silt layers.

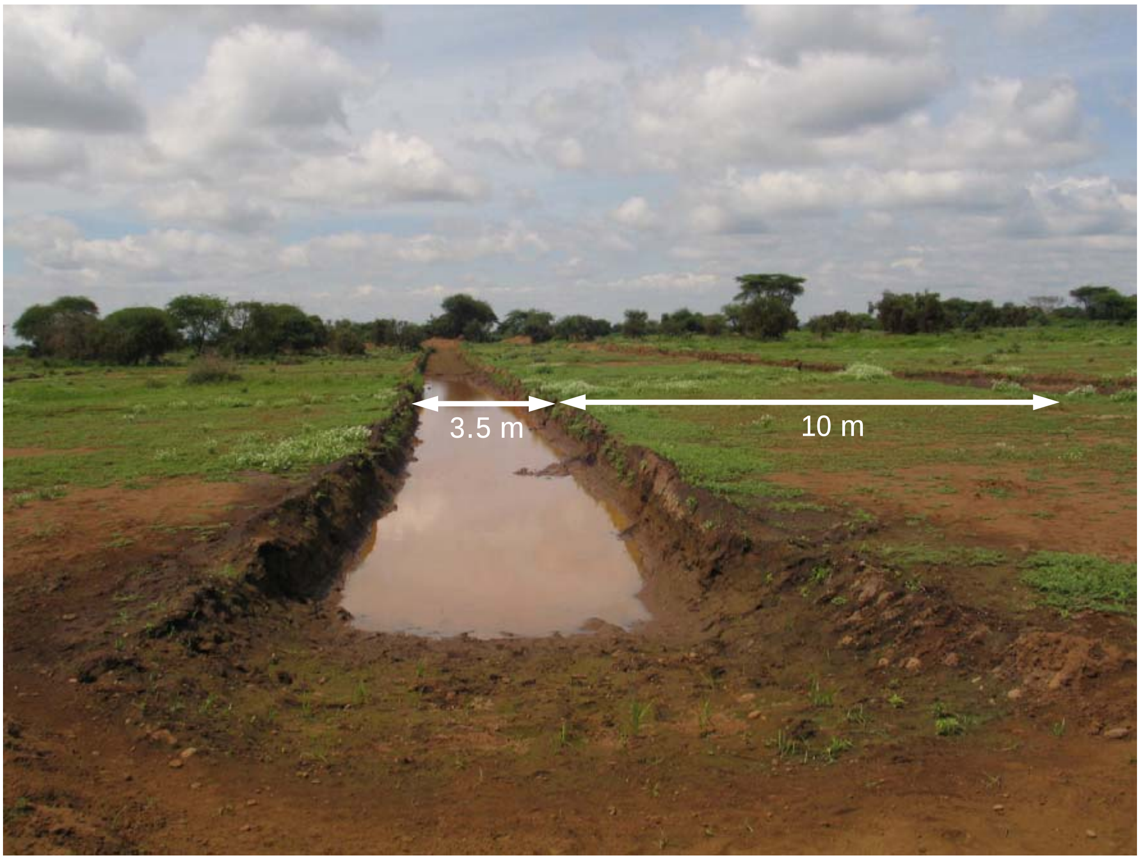


Figure 4.1 An example of contour trench in Kitenden.
Source: Westerveld Conservation Trust

Excavating the trenches in run-off area will lead to a certain fill up. The area which will accumulate the runoff is the upstream side of the first trench and the areas between trenches. The larger the distance between those excavated trenches, the higher runoff one may expect. In other words, the runoff will eventually be proportional to the size of the catchment area. Despite this statement, there are also several studies on surface runoff which shows that the longer the slope, the less runoff per unit length compared to short slopes will be available (van de Giesen et al, 2005). In this study, runoff calculation will not go into detail such as specified by van de Giesen, since it concerns more to reasonable probability and not validation.

A trench is expected to retain runoff water and afterwards subsurface for a certain period. This is known as the infiltration process. However, the question remains how long these trenches are able to store a certain amount of runoff and how can these be used. As a hypothesis, this condition depends strongly on the initial soil moisture conditions and subsurface soil properties and moreover the available vegetation.

Another important aspect to be considered in the study of contour trenches is siltation. Runoff occurs on a slope and will cause erosion. Therefore, runoff may convey eroded soil surface towards the trench. The stone line indeed functions as a filter to avoid those small particles entering the trench. However, it might come to a condition where the sediments overflow the stone lines and finally trap in the trench. Subsequently, during the infiltration process, when water is forced to infiltrate in the subsurface, it allows the sediments to settle. When the trenches are filled with sediment (see **Figure 4.2**) it will reduce the infiltration capacity and eventually block the downwards water flow. This condition would retain water longer above the surface. After some time, it can be seen that the area siltation is dried out and reduced.

Figure 4.2 Siltation at the bottom of the contour trench.
Source: Westerveld Conservation Trust

4.2 Rainfall-Runoff

The rainfall-runoff model as described in the previous chapter uses a rational method. It is a simplified runoff calculation of a complicated process, which can be taken as the first step in predicting the peak event. It gives an indication of a maximum value without any time distribution of runoff. However, for the design of the contour trench which has less failure, this runoff estimation is sufficient enough. One may expect that the dimensions of the trench and the spacing should be optimized in such a way that they suit the runoff occurrence. However, the question remains to which runoff?

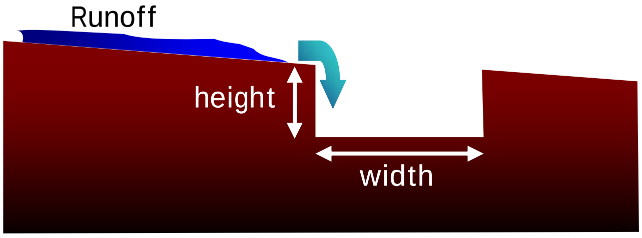


Figure 4.3 Runoff uncertainties at a trench.

Despite of the variability in rainfall intensity, infiltration capacity, soil type, and antecedent soil moisture, assumptions have to be made. The available meteorological data from 5 stations near the study area are provided as daily rainfall data, although it is believed that runoff occurs in hours of rainfall events. The soil data shows sand as the main local surface. Thus, this condition causes rainfall easily to infiltrate, although it might also covered by compacted surface. Based on ICARDA study, the runoff coefficient of a compacted soil ranges from 0.4 to 0.6. In correlation to the antecedent soil moisture, it is investigated that before high intensity rainfall occurs, most of the time it has already been rained for at least a day.

According to this fact, the antecedent soil moisture can be assumed to be close to saturation. As a result of complex process above, several assumptions of runoff coefficient are selected. Moreover, to give a number of possible conditions where the soil surface is in impermeable condition, a runoff coefficient of 1 is tested as well.

Rainfall intensity used in this calculation is based on daily data which is further assumed to be in an hour. It is found that the extreme rainfall located near to the study area occurred in November 2003, with 280 mm. The assumed lower threshold as a trench fill up is 50 mm per day. This number is exceeded zero to ten times a year with dominantly ranges from 50 to 70 mm per day. Therefore, a moderate scenario uses the middle value of 60 mm per day.

The scenarios refer to the planned condition and additionally to two smaller alternatives of trench dimensions. Trench alternative 1 has a dimension of 1 m in width and depth. Trench alternative 2 is 1.5 m wide and 1.5 deep. The last one, trench alternative 3 is the planned condition, with a width of 3.5 m and depth of 1 m. Besides, the spacing between trenches that represents the drainage area may vary as well. The selected numbers are based on the planned condition, which is 20 m and one smaller number, 10 m.

Calculations here are more to some trial of different variables. First, increasing rainfall intensity from dominant to extreme rainfall is to include both, the daily situation which might occur frequently and the extreme one which might occur because of the climate change. This gives a range of probable runoff accumulation in the trenches. Besides, the study of van de Giesen indicate that longer spacing tend to have less runoff. Thus the runoff coefficient for 20 m is less than the 10 m spacing. Another thing is that the calculations do not the infiltration rate. The results can be seen on the table below.

Table 4.1 Rainfall-Runoff Calculations

Scenario	c	i (mm/hr)	Drain. Area	Q (m^3/hr)	in 3.5 m^2 Tr. (m)	in 2.25 m^2 Tr. (m)	in 1 m^2 Tr. (m)
1	**0.3**	**60**	**23.5**	**0.42**	**0.12**		
2	0.3	60	21.5	0.39		0.17	
3	0.3	60	21	0.38			0.38
4	0.8	280	23.5	5.26	1.50		
5	0.8	280	21.5	4.82		2.14	
6	0.8	280	21	4.70			4.70
7	0.4	60	13.5	0.32	0.09		
8	0.4	60	11.5	0.28		0.12	
9	0.4	60	11	0.26			0.26
10	0.9	280	13.5	3.40	0.97		
11	0.9	280	11.5	2.90		1.29	
12	0.9	280	11	2.77			2.77

From the result of 12 scenarios, it can be concluded that none of the 3.5 m wide trench will be fully fill up, except on the extreme event. A trench with of 3.5 m and spacing of 20 m will be filled only with 12 cm height of water in condition where common 60 mm rainfall occurs. At a storm event of 280 mm per hour, the water in the trench may overflow. The other smaller dimensions than 3.5 will also overflow when it comes to extreme condition. On the other hand, those trenches will never fully fill up with moderate rainfall event.

Based on this rough calculation above, one may conclude that it is still very difficult to fully fill up the trench using the planned dimension and spacing. Thus, there should be some extra water supply to increase the volume of water in the trench which can be done by utilizing the existing water stream upstream the trench area. However, the need to fully fill up the trench is not yet important, and thus only if crop water requirements are set.

Practically, there are some considerations on selecting the dimension of the trench. First, the available heavy machine e.g. bulldozer, grader, that excavates the trench in the field has a certain width capacity. This means, for the ease, the width depends on these heavy machines. Therefore, when it comes to a fix width, then the variable which can be modified is only the depth. The depth will surely need attention since the presumed compacted soil surface has to be removed. At the end, the combination of the available heavy machine in the study area and soil condition in regard to compaction removal has to be taken into account to attain the suitable trench dimension.

4.3 Infiltration

The following research is to study the infiltration process in the trenches. For this, the Hydrus 2-D model is used. To see the effect of different inputs on the infiltration process modeling, several scenarios are developed. In each scenario, the simulations are performed three times. The first one is where the simulation reaches the equilibrium of the existing condition. To check whether the domain has already reached the equilibrium, the monthly water storage volume in one year is compared. Afterwards, the condition without any intervention is simulated for one month and the last one continues by a simulation where the planned condition is implemented. Stone lines are neglected in the model since their function is merely to filter runoff in order to decrease the sediment content. The assumption is that runoff passes the stone lines towards the trench without diminishing its quantity.

The last infiltration model deals with the planned condition. This model is basically a combination of several scenarios done previously. In addition, it simulates three trenches with fill up condition as a consequence of probable runoff condition.

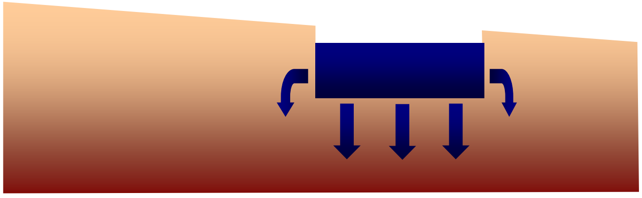


Figure 4.4 Flow direction of infiltration process of a trench.

4.3.1 Geometry and Mesh

The geometry of the model has to include at least one trench which can be duplicated for the whole area. Looking at the assumed slopes, there are 3 different geometries. The first one is a simple square area for no slope condition, whereas the second and third one has a trapezium shape due to slope condition. Each of the geometry comprises of half a trench on both upper edges with the remaining area as soil. A trench, in accordance to planned conditions, has a dimension of 3.5 m wide and 1 m deep. The spacing is fixed to 10 m. Therefore, the length of the domain is 13.5 m. The depth is divided into two areas, the unsaturated and saturated area. Selected groundwater fluctuates around 3 m from the bottom boundary. Thus the first 4 m from the upper boundary is the unsaturated zone. The main meshes are provided in **Figure 4.5a - 4.5c**.

Additionally, there are also other created geometries and meshes due to different scenarios with respect to spacing and trench dimensions. The two other spacings of 15 m and 20 m are developed for a slope of 5%. Next, two other probable trench dimensions of cube shape are also created. The first one has a width of 1 m and second one of 1.5 m. These dimensions are applied for all slope alternatives.

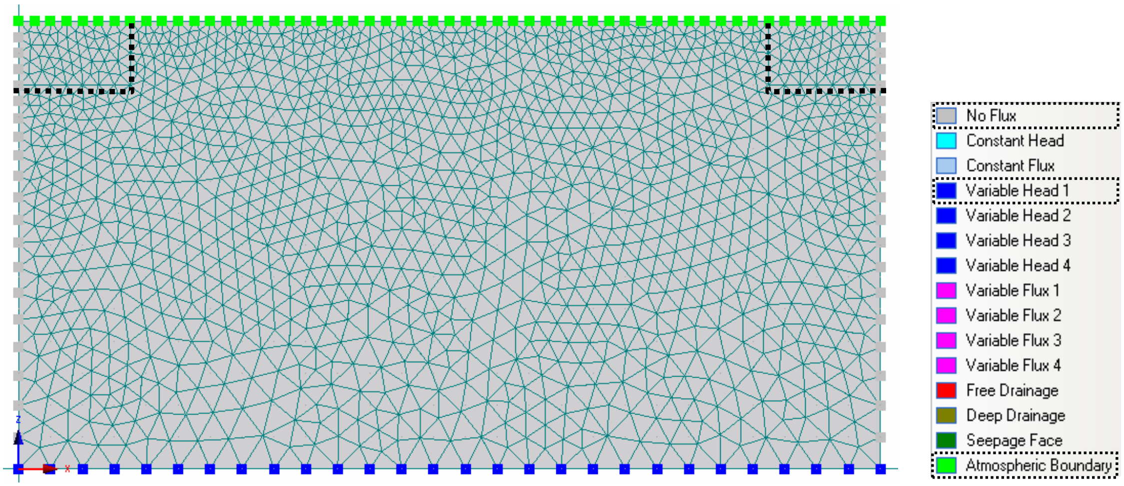


Figure 4.5a Mesh with no slope (dimension 1350 cm x 700 cm).

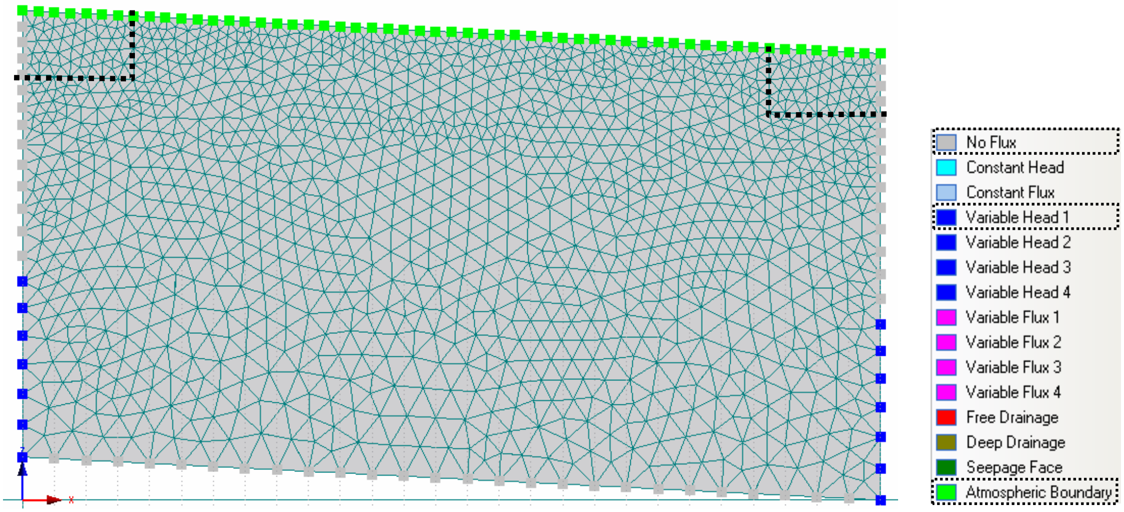


Figure 4.5b Mesh with slope of 5%.

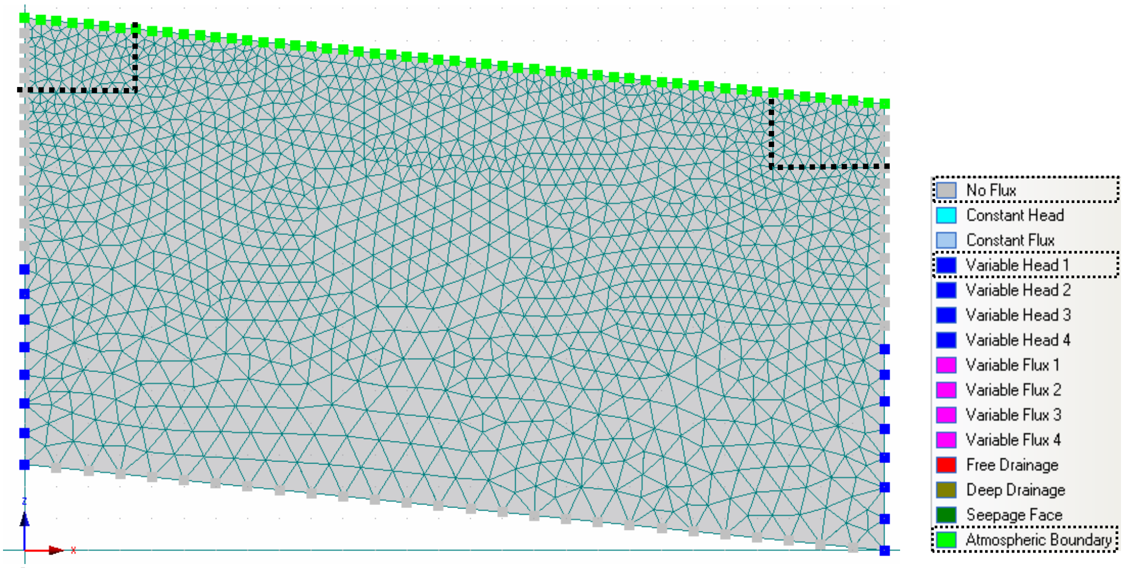


Figure 4.5c Mesh with slope of 10%.

4.3.2 Input Data

The main input data can be divided into three parts, the domain properties, initial condition and boundary condition. These parameters may vary as they differ in scenarios. Domain properties describe the soil characteristic and distribution. The initial condition either head or water content has to be assumed evenly in the first simulation and then using its results to simulate the second one. The boundary condition comprises of fluxes, heads, drainage, seepage, and atmospheric boundary.

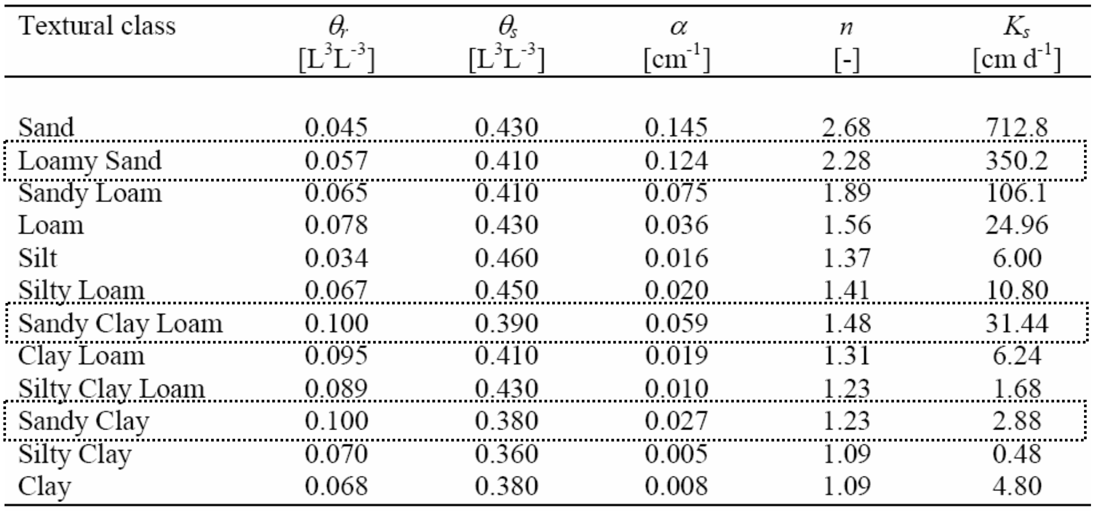
Domain Properties

In general, soil properties that are used in the scenario are sandy clay loam. This type of soil is selected as an assumption of the overall scenarios. The soil hydraulic parameters are based on analytical functions of van Genuchten [1980] for twelve textural classes of the USDA soil textural triangle according the Carsel and Parrish [1988].

There are also simulations on different soil properties. This is done in the last scenario. For a comparison of several default soil property parameters, they are summarized in **Table 4.2**. Those marked dot boxes are the selected soil property parameter which is used in the further modeling.

For the planned situation, soil properties found in the field are mostly silty sand, at LKPN03, LKPN04, and LKPN05. The apparent location can be seen in the summary of the soil profile map in **Chapter 2**. These are points that are considered to be the nearest one to the study area. However, since the available sand soil data are limited to the vertical distribution without any soil hydraulic characteristic, it has to be assumed comparable to a default soil property. Thus, in accordance to the soil catalog, silty sand is believed to have similarities to loamy sand. Loamy sand hydraulic parameters can be found in detail in the default soil catalog provided by the software.

Table 4.2 Default Soil Hydraulic Catalog



Textural class	θ_r [L^3L^{-3}]	θ_s [L^3L^{-3}]	α [cm^{-1}]	n [-]	K_s [$cm\ d^{-1}$]
Sand	0.045	0.430	0.145	2.68	712.8
Loamy Sand	0.057	0.410	0.124	2.28	350.2
Sandy Loam	0.065	0.410	0.075	1.89	106.1
Loam	0.078	0.430	0.036	1.56	24.96
Silt	0.034	0.460	0.016	1.37	6.00
Silty Loam	0.067	0.450	0.020	1.41	10.80
Sandy Clay Loam	0.100	0.390	0.059	1.48	31.44
Clay Loam	0.095	0.410	0.019	1.31	6.24
Silty Clay Loam	0.089	0.430	0.010	1.23	1.68
Sandy Clay	0.100	0.380	0.027	1.23	2.88
Silty Clay	0.070	0.360	0.005	1.09	0.48
Clay	0.068	0.380	0.008	1.09	4.80

Source: User Manual Hydrus (2D/3D)

Initial Condition

To solve the unsaturated flow equation, an initial condition is required. The initial condition here is very difficult to determine, since there has not been any investigation done at the study area regarding head and/or water content. Thus, the spatial data remains unknown. Therefore, it is assumed to be evenly distributed, which is suggested at the discussion forum of Hydrus 2-D software. The value used for each first simulation is applying a head of -100 cm for the whole domain. After the equilibrium is reached, the second simulation uses the last time step result on head.

Boundary Condition

Three boundary conditions are assigned in the model (see **Figure 4.5a - 4.5c** in color). First is the atmospheric boundary. It represents the regional daily precipitation and evaporation. Precipitation data are taken from the monthly average data divided by days per month. Evaporation data are acquired from the water balance results which differ on monthly basis. This boundary condition is placed on the top surface of the domain. Second is the variable head boundary, which represents the fluctuation in the saturated zone. The groundwater level data is chosen from a near planned location which in this case is LPKN03. In addition, based on the geo-hydrological map, the planned location has about the same groundwater depth as LKPN03. The local measured groundwater level, however, is not annually complete. Therefore, interpolation is done to connect the lack data. For no slope condition, these data are assigned on the bottom of the domain whereas with slope scenarios, this boundary is set at the right and left side. Third is the no flux boundary. For no slope scenarios, this boundary is assigned at the right and left side, while in slope scenarios this boundary is specified at the bottom of the domain and at the upper right and left side. The annual graphs of the boundary conditions are presented in **Figure 4.6a - 4.6c**.

This model is presenting bare soil. It means that vegetation is absent and thus no water uptake is simulated. It also avoids sink terms in the model.

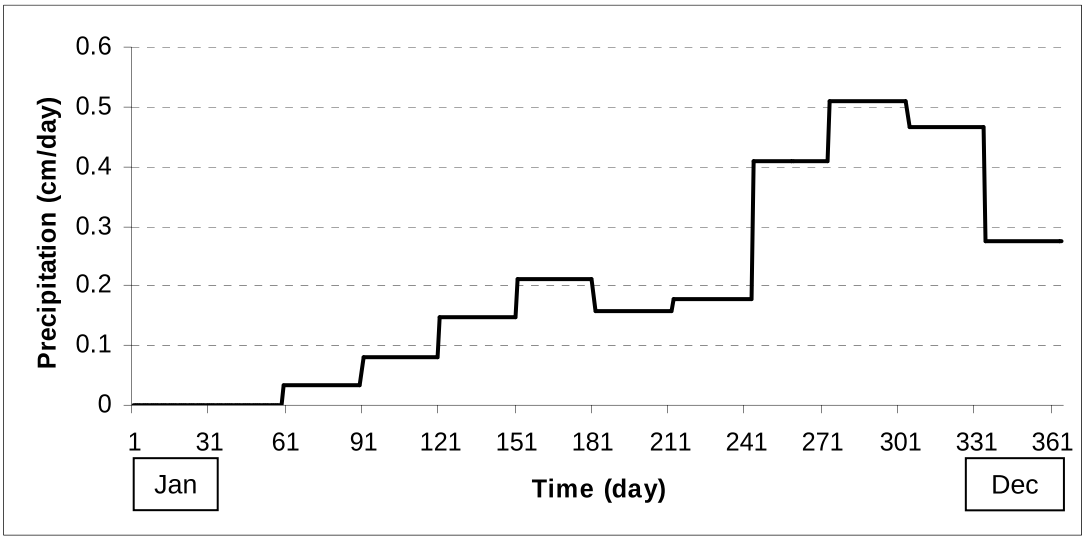


Figure 4.6a Monthly average precipitation data.

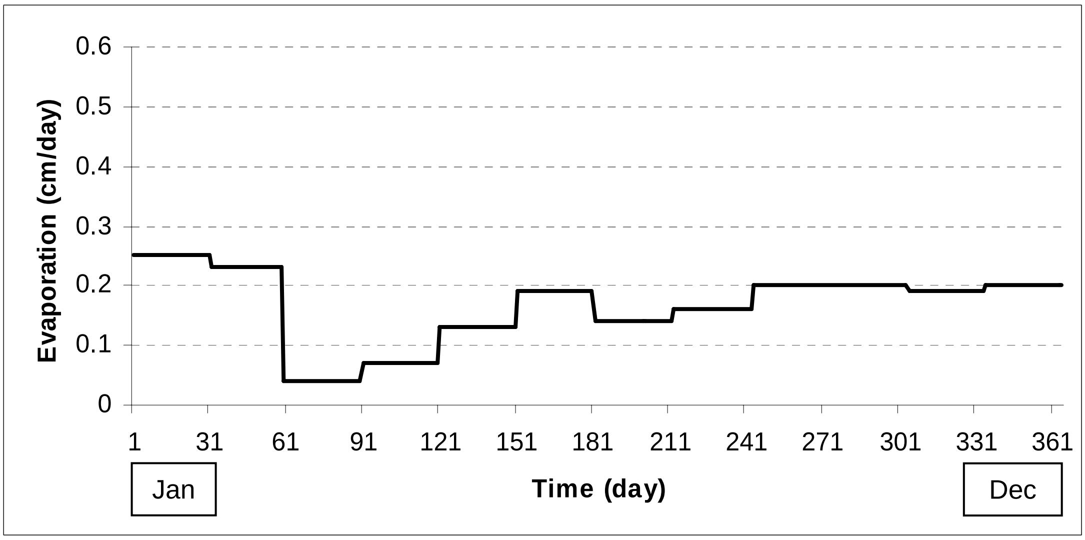


Figure 4.6b Monthly average evaporation data.

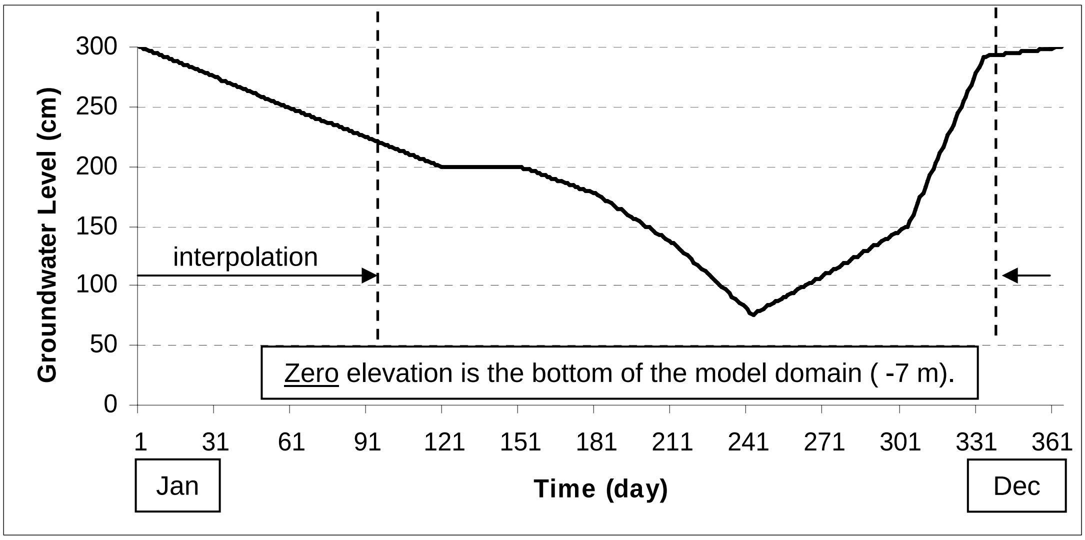


Figure 4.6c Monthly average evaporation data.

4.4 Scenarios

The scenarios compasses of step by step simulations, establishing possible conditions which might occur in the field. It starts from the probable different slope and geometry as an application of an uneven topography and various trench dimensions. Following the spacing at a slope of 5% is to see whether water flow affect one trench to another. Furthermore the ponding effect is conducted to represent conditions when there is less rainfall or events which will result too little runoff accumulation in the trench. Different soil properties are simulated since the existing of apparently different soil layers in the field. All of these simulations are not connected directly to rainfall-runoff calculation, but rather more to view the infiltration process and the storage possibility. Therefore, the condition compared is limited to with and without trench.

Each scenario begins with a simulation that is expected to reach the equilibrium condition of water storage and avoid the effect of initial conditions. This is established in order to have stabilized water content distribution for the whole domain caused by the atmosphere input. After the equilibrium is achieved, it is ensured that the last time step result can be used as the initial condition for the main simulation, the comparison between with and without a trench. The first simulation can be seen in **Figure 4.7a - 4.7c**. These equilibrium reach are for simulation trench with a width of 3.5 m. It means that each different geometry have their specific mesh and thus its own water storage. In the graphs, it shows that for every type of soil, the equilibrium is already found after the third year. Another important aspect is the differences in subsurface storage volume. This subject will be discussed in further sub chapter related to different soil properties. The unit of the subsurface storage is in cm^2. It represents the volume per 1 m wide.

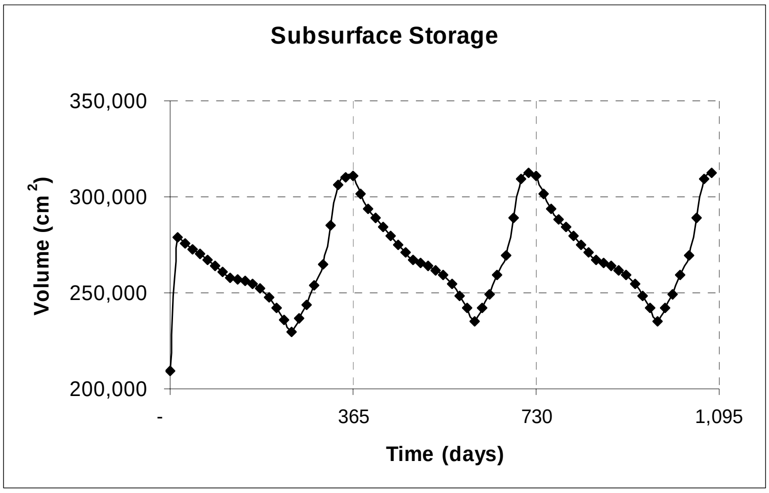


Figure 4.7a Equilibrium reach of sandy clay loam properties.

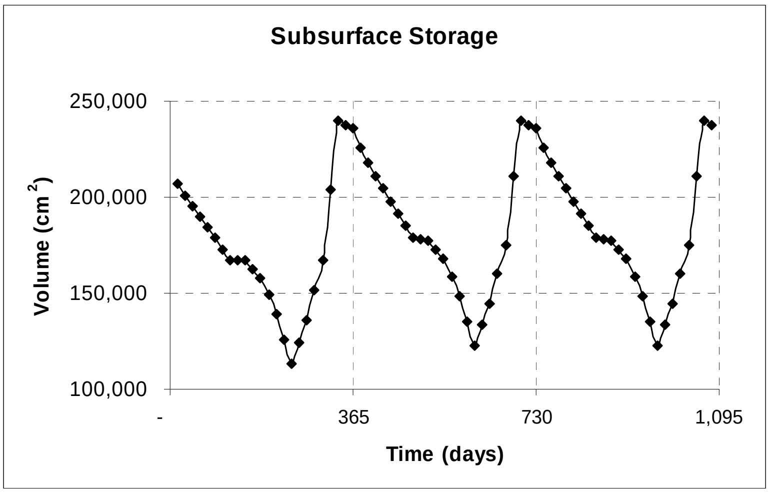


Figure 4.7b Equilibrium reach of loamy sand properties.

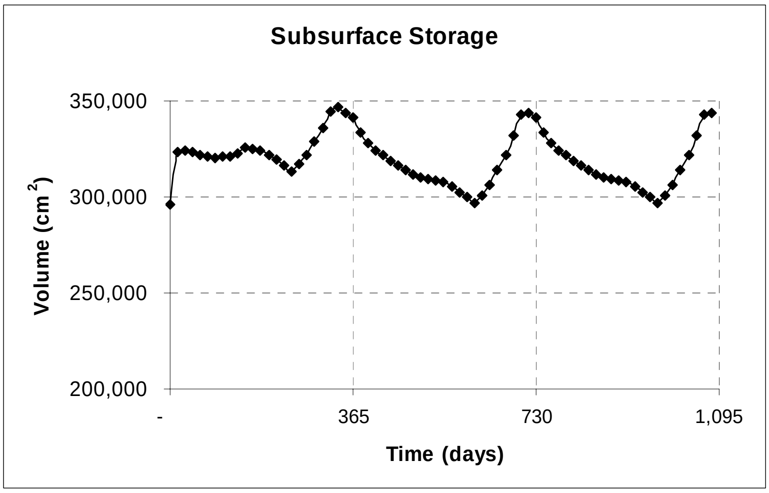


Figure 4.7c Equilibrium reach of sandy clay properties.

Next, the trench is assumed to be full at the beginning of January when the wet season ends and the dry season starts. In this period, condition is at the point where no precipitation occurs, except the remaining ponding water in the trench. To see the distribution of water flow, the trench is simulated for two months. Moreover, this condition also gives an indication of the time needed and the distribution of infiltration process until the trench is dried out.

4.4.1 Dimension and Slope

The first scenario is looking at the topography and the possible dimension of the trench. Contour trenches as a water harvesting technique can be applied in various topography, although there is a certain limit of slope to avoid erosion. In this study, the slope may range from 0 (zero) to 10%. The areas, where there is almost no slope represent flat areas. Increasing the slope to a maximum of 5% is recommended by SIWI 2001. Moreover, 10% is selected based on Peter Westerveld justification where topography is quite steep and sensitive to erosion.

Trench dimensions are considered to be varying since there is a relationship between runoff accumulation and the optimum capacity of the trench. Indeed, technically it is suggested to construct trenches that correspond to the available runoff in order to avoid too little ponding water in the trench. In this case, three different trench dimensions are selected. The first is using the trench dimension already applied in Kitenden, a width of 3.5 m and 1 m depth. Following, a cube shape of 1.5 m wide and deep is to represent a smaller but deeper trench. Lastly, the dimension decreases to a smaller cube shape with a width and depth of 1 m.

In total, scenarios for this section are divided into 9 single simulations with 3 different slope and 3 different trench dimensions. Below are the simulated scenarios:

1. Without slope, trench dimension:
    - 3.5 m wide and 1 m deep
    - 1.5 m wide and 1.5 m deep
    - 1 m wide and 1 m deep
2. With slope 5%, trench dimension:
    - 3.5 m wide and 1 m deep
    - 1.5 m wide and 1.5 m deep
    - 1 m wide and 1 m deep
3. With slope 10%, trench dimension:
    - 3.5 m wide and 1 m deep
    - 1.5 m wide and 1.5 m deep
    - 1 m wide and 1 m deep

In this report, the results do not include all simulations, but rather taking the maximum and minimum constraint of assumed slope and trench dimension. Therefore, the discussion will emphasize only on 4 scenarios. Each simulation has a sandy clay loam soil property, duration of 2 months, and specifically observing the water distribution either horizontal or vertical. Observation can be done to nodes or cross sections. Nodes will be useful in time where measured data are available. This report is simply looking at a certain cross section with its water content fluctuations.

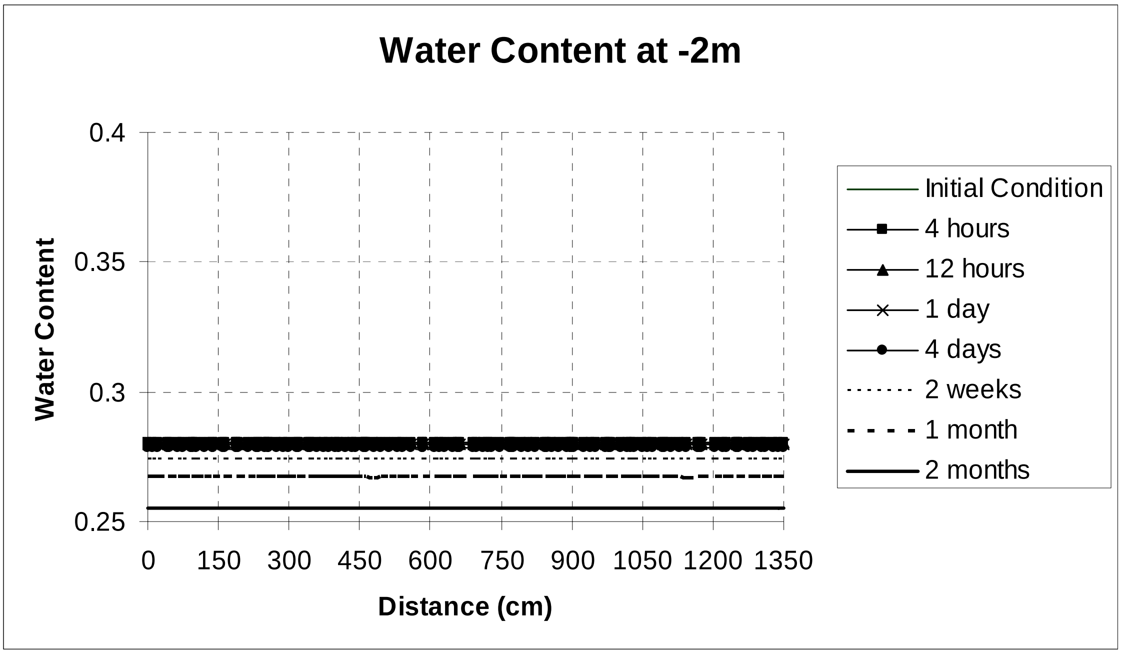


Figure 4.8a Horizontal distribution of water content without trench (3.5mx1m), no slope.

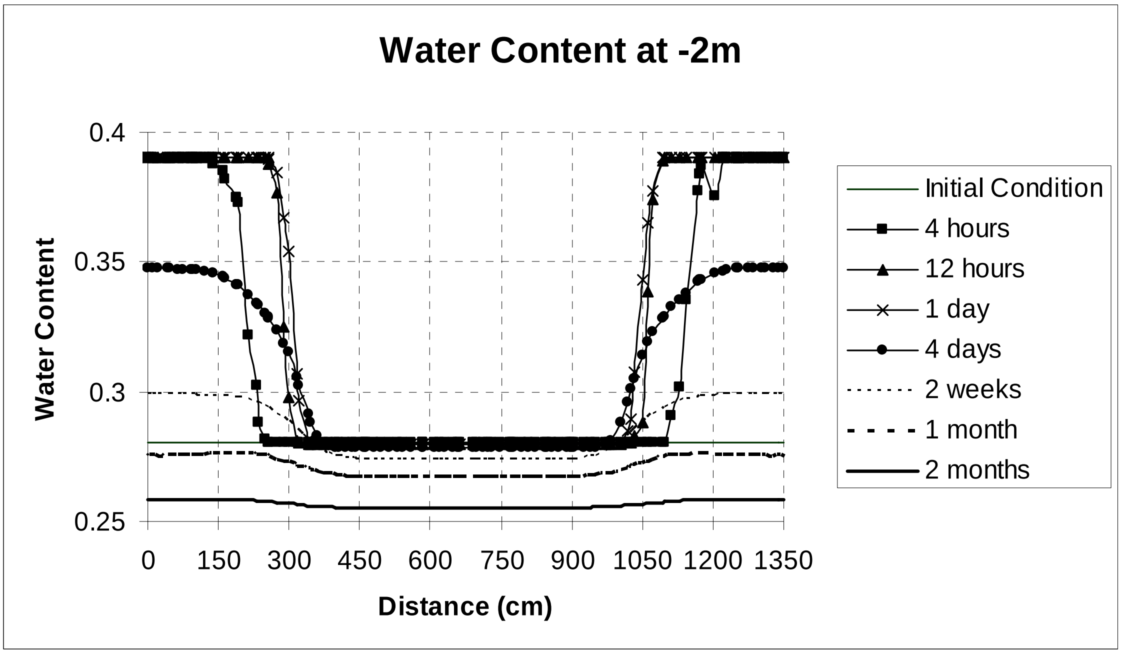


Figure 4.8b Horizontal distribution of water content with trench (3.5mx1m), no slope.

The first discussion is on the difference between with and without trench (3.5mx1m) and no slope. Observations are limited to horizontal distribution at a depth of 2 m. From **Figure 4.8a**, it can be seen that the initial condition starts from 0.28 and decreases to 0.26 in 2 months. This reduction is due to 2 possible effects, the groundwater which falls of 50 cm in this 2 months and evaporation. In the first two dry months without rainfall, there is no significant reduction of water content. When the trench is implemented (see **Figure 4.8b**), the water content obviously increases 0.11, to the maximum after 1 day due to water flow downwards. It describes the porosity being fully filled with water at 0.39 and reaches the distance of about 260 cm from the middle of both half trenches. After 4 days, the water content 1 m below the trench lessen to 0.35 till it attain the normal condition as it is without trench. From 1 to 2 months of infiltration process, there is no substantial difference in water flow.

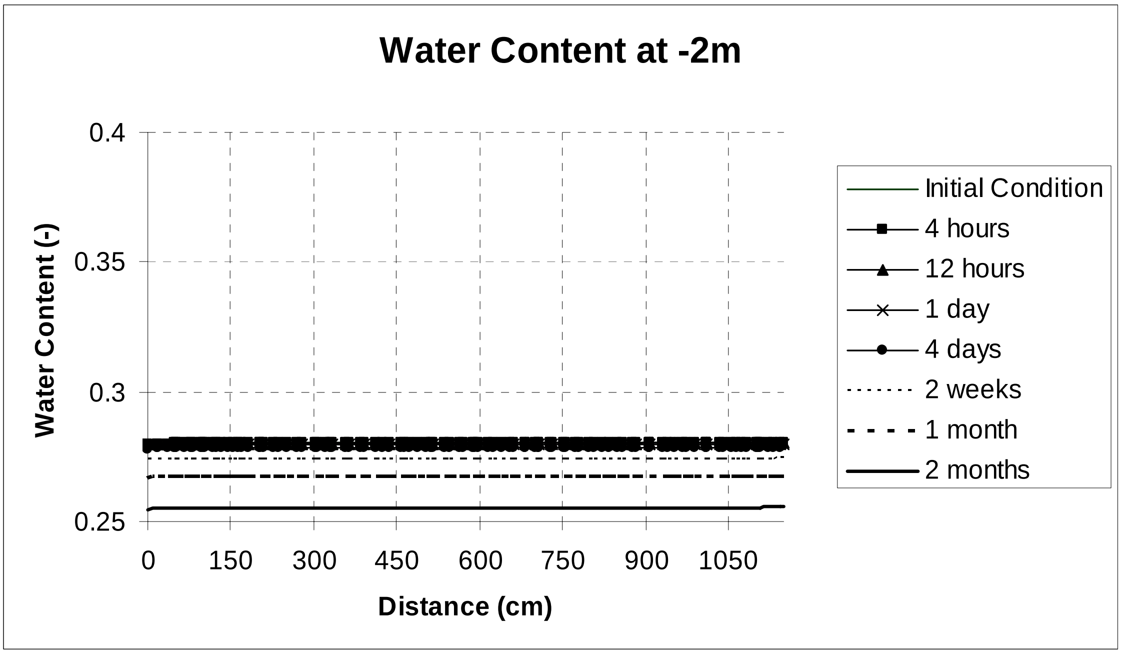


Figure 4.9a Horizontal distribution of water content without trench (1.5mx1.5m), slope 5%.

The second discussion is on the difference between with and without trench on a smaller dimension, 1.5mx1.5m, and slope of 5% (**Figure 4.9a** and **4.9b**). Here, the observation is done horizontally at a depth of 2 m parallel to the slope of the soil surface. The water content without trench decreases from 0.28 to 0.26 in 2 months. This pattern shows similarity to the previous simulation on no slope condition. Compared to with trench condition, after 12 hours, the soil moisture increased 0.11. The porosity is fully filled with water at 0.39 and reaches the distance of 163 cm from the middle of both half trenches. After 4 days, the water content 0.5 m below the trench lessens to 0.34. Furthermore, after 2 months of infiltration process, the soil moisture is at about the same condition as without trench.

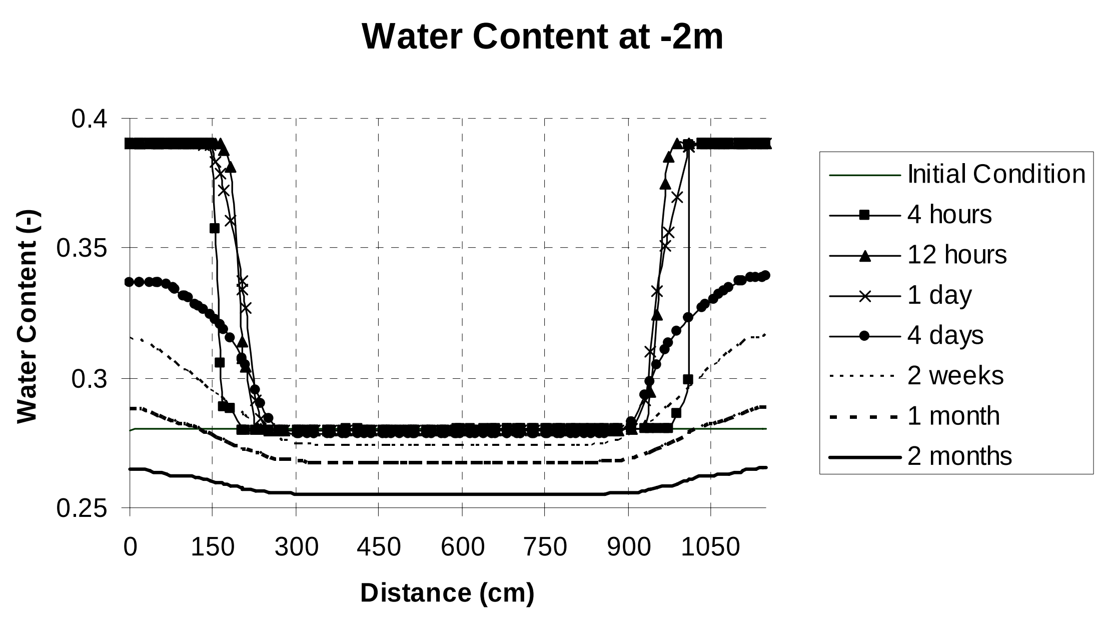


Figure 4.9b Horizontal distribution of water content with trench (1.5mx1.5m), slope 5%.

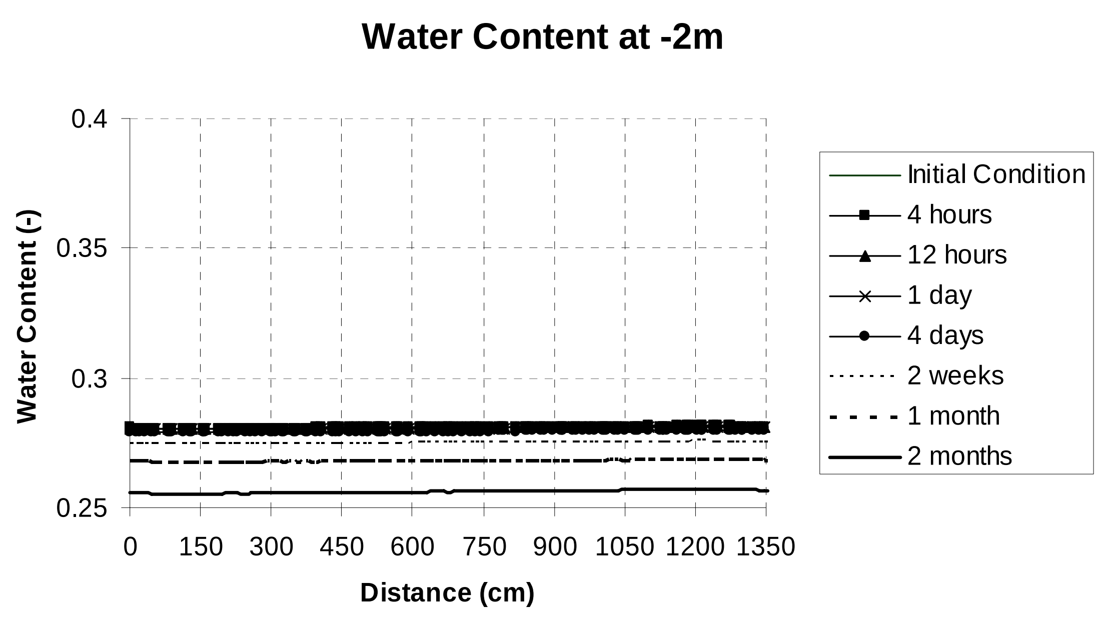


Figure 4.10a Horizontal distribution of water content without trench (3.5mx1m), slope 10%.

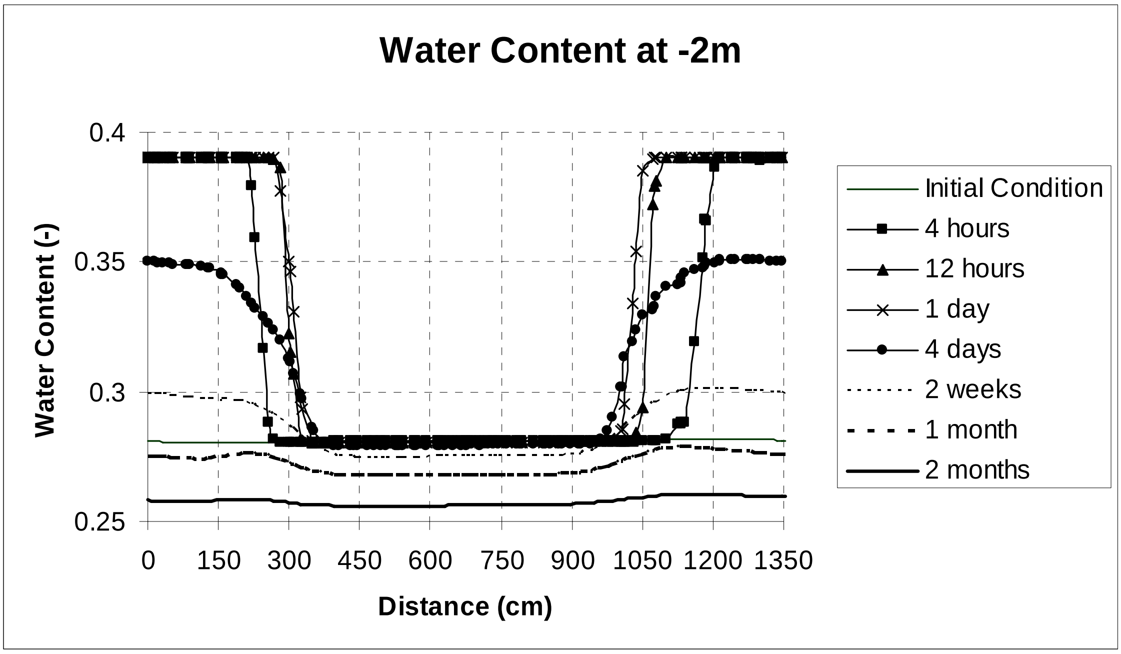


Figure 4.10b Horizontal distribution of water content with trench (3.5mx1m), slope 10%.

The third discussion is again almost the same as the first and second one. The difference lies only at the slope. Here, the slope is set to 10%. Observations are done at horizontal distributions; at a depth of 2 m parallel to the soil surface. **Figure 4.10a** and **Figure 4.10b** show the condition without trench and with trench respectively, where those graphs are more or less similar to **Figure 4.8a** and **Figure 4.8b**. Comparing the horizontal distribution on scenario with no slope, it seems to be no difference at all. However, one might questions that slope ranges from 0 to 10% should give an indication of horizontal moisture distribution. This can be checked by comparing water content at a point after some time for both, no slope and slope of 10%. For example, the water content 300 cm from the middle of the trench is almost the same for no slope and slope of 10%, which is 0.35. Thus, this proves that there is not much different in horizontal water flow.

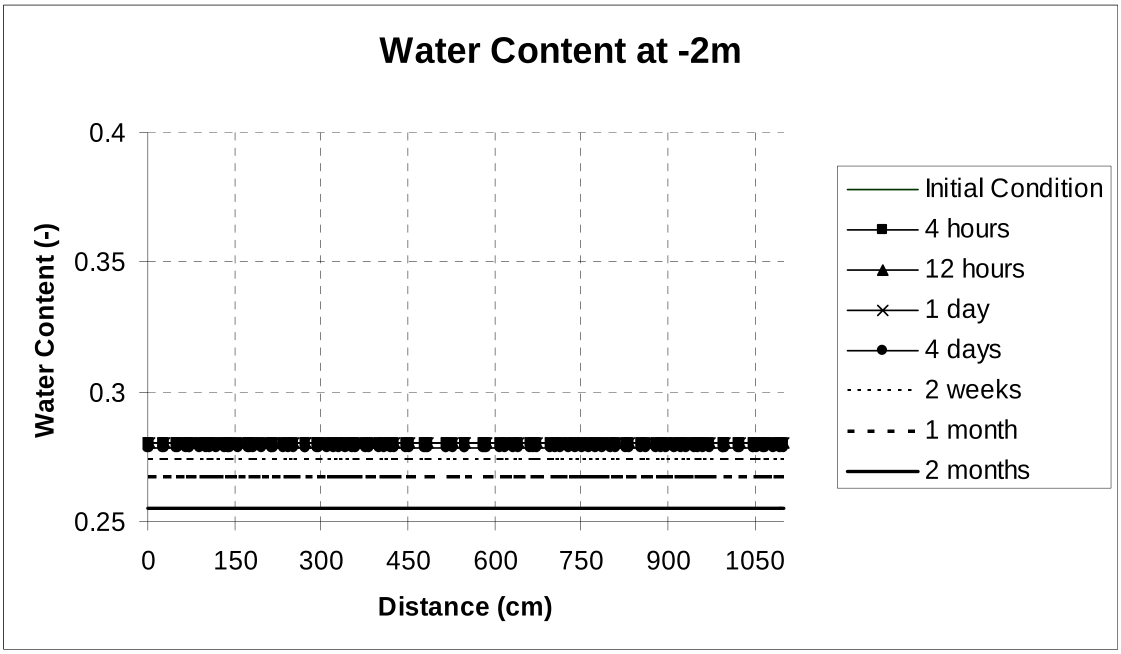


Figure 4.11a Horizontal distribution of water content without trench (1mx1m), no slope.

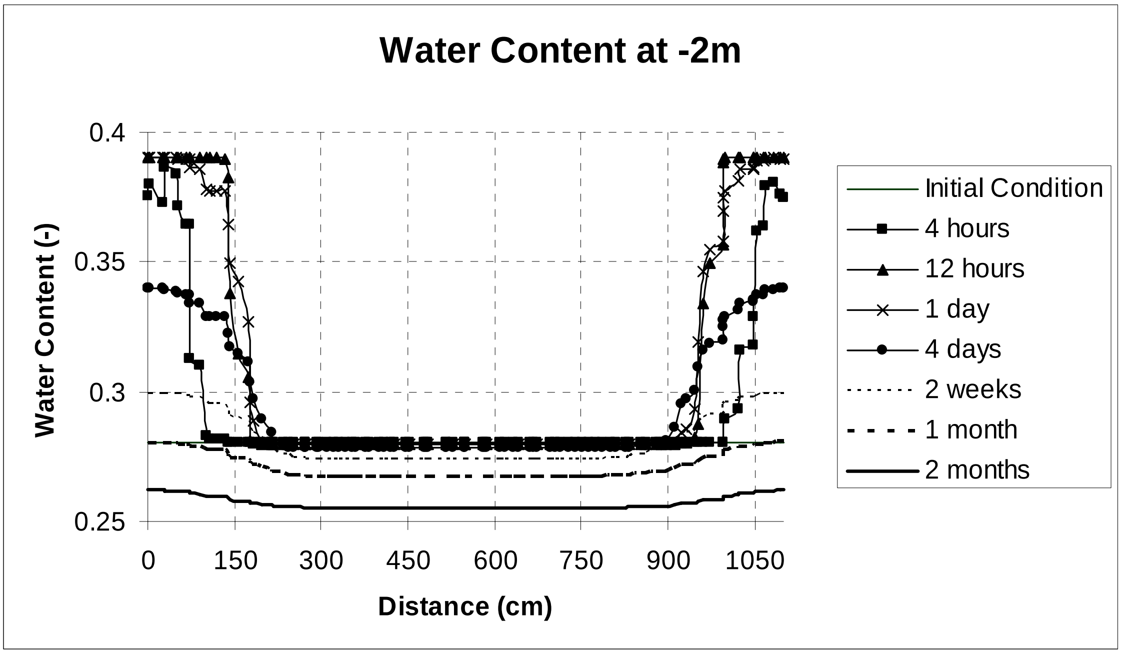


Figure 4.11b Horizontal distribution of water content with trench (1mx1m), no slope.

The forth discussion is looking at a smaller size of a trench, 1x1m, but still observing at the depth of 2 m. Like the previous scenarios, the distribution of the water content is focused on the area below the trench and the influence to horizontal distribution. For the existing condition (**Figure 4.11a**), the water content will decrease in time, continuously to evenly water content of 0.26. If the trench is applied (see **Figure 4.11b** and **Figure 4.1c**) then the water content increases to a maximum with a distance of 124 cm from the middle of the trench. Both no slope and slope of 10% have similar trend in drawdown. This is also comparable with the 3.5mx1m trench, which also leaves the spacing subsurface dry.

Furthermore, it gives an indication that slope on bare soils does not matter to infiltration process and the different in trench dimension is merely a subject of available volume that can be stored in the trench. Eventually, these different dimensions will store water subsurface for a particular time period.

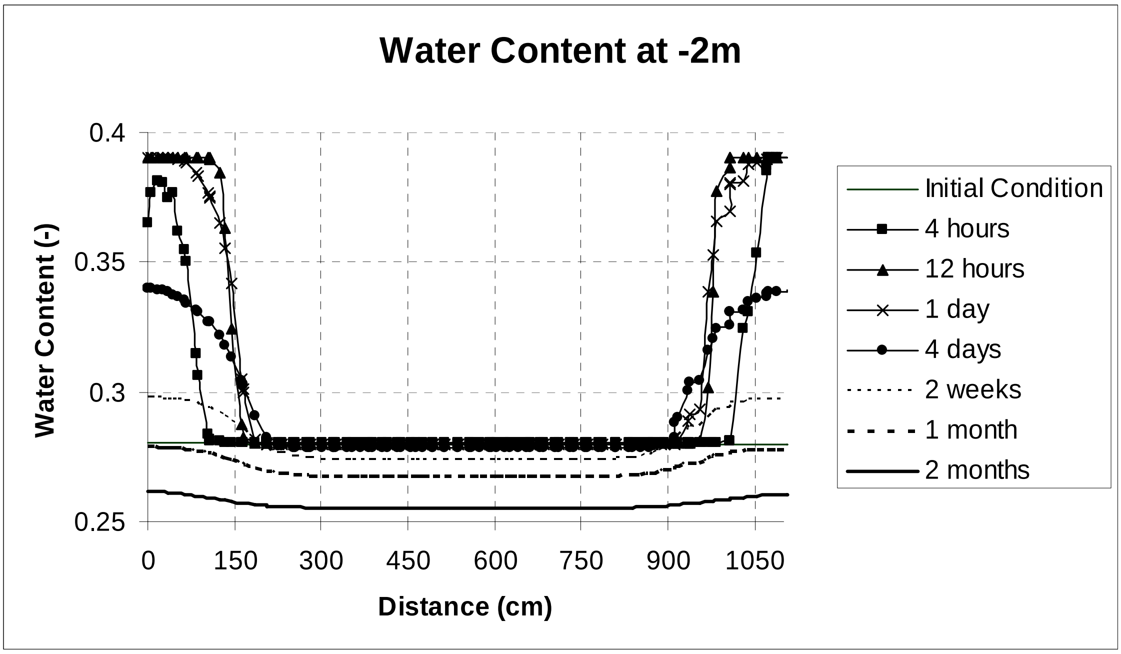


Figure 4.11c Horizontal distribution of water content with trench (1mx1m), slope 10%.

4.4.2 Spacing at Slope 5%

The spacing scenario is only done at a slope of 5%. The simulation is using sandy clay loam soil property as well. As discussed previously taking either no slope or 10% slope will not make any differences in water drawdown distribution. The focus here is on horizontal flow whether there is any overlapping water flow between 2 trenches. This means that the water flow from the side of the trench is something important to be considered. With slope 5%, three different spacing taken are 10 m, 15 m, 20 m.

Three simulation results will be observed on the middle profile of the spacing. The 10 m spacing is presented in **Figure 4.12a** and spacing 20 m in **Figure 4.12b**. 15 m spacing is not included in this report, since it can be interpolated between the 10 m and 20 m spacing.

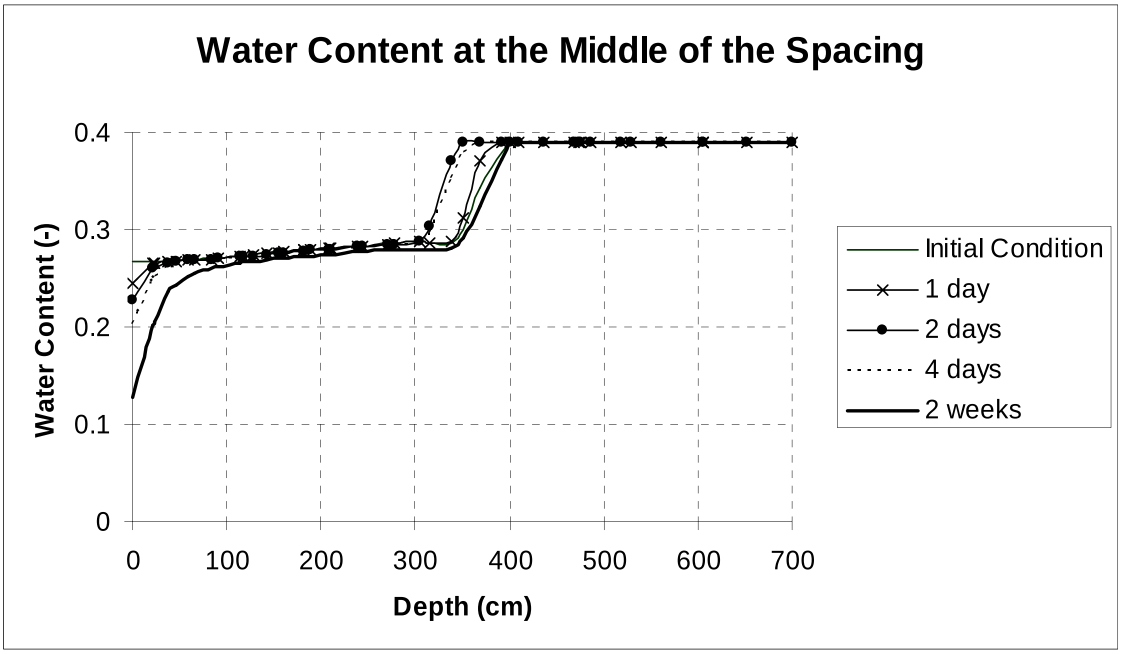


Figure 4.12a Vertical distribution of water content with trench spacing of 10 m, slope 5%.

As seen on the graph above, the water content at the middle of the trench fluctuates during 2 weeks of infiltration process. In this period of time, however, the groundwater decreases 11 cm. Despite of this condition, significant effect of the water drawdown is on the second day. Water that infiltrates below the trench affects the rising of groundwater level. It is shown after 2 days simulations; the increment of saturated soil is about 50 cm. Afterwards the water content cease and follows the groundwater fluctuation. Additionally, the upper part slowly becomes dry due to evaporation.

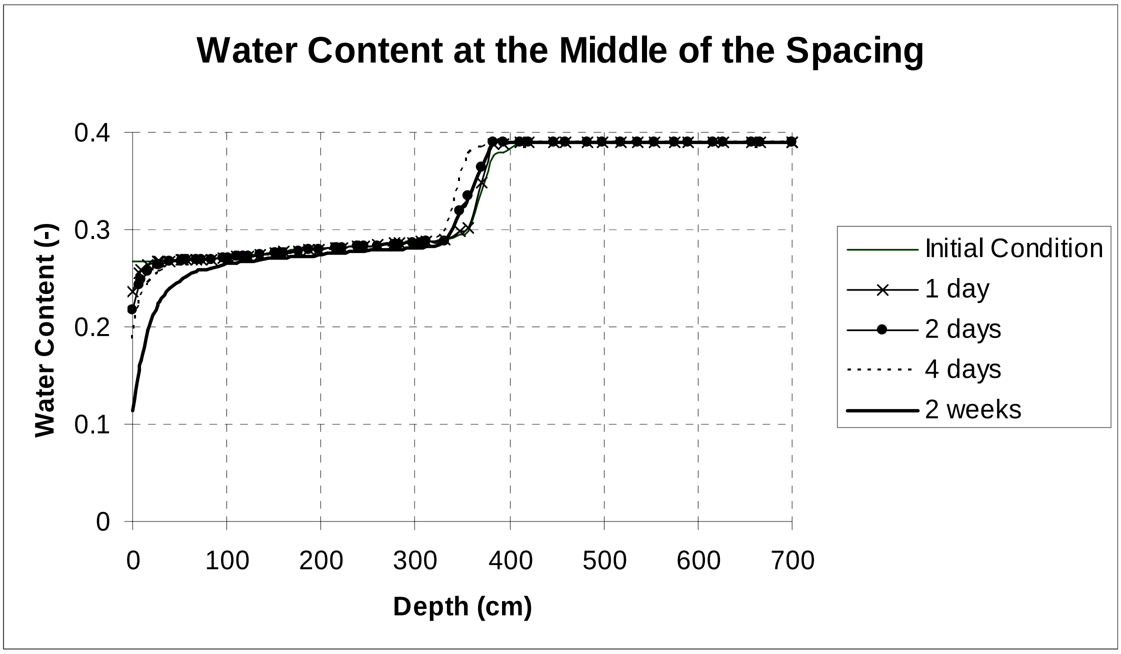


Figure 4.12b Vertical distribution of water content with trench spacing of 20 m, slope 5%.

On **Figure 4.12b**, where the spacing is 20 m, it can be seen that the infiltration has still a little effect at the middle of spacing. In other words, the effect of water drawdown may influence to a distance of 10 m from the trench side. The initial condition is about the same as after the first day. The increase of about 15 cm at the middle of the spacing occurs after 2 days.

Therefore, using sandy clay loam property and shallow groundwater, there is an increase in soil moisture at the spacing of 10 and 20 m.

4.4.3 Ponding

This scenario assumed that water runoff accumulation due to precipitation can be less than the whole trench volume. Therefore, two random numbers, 1/2 and 1/5 are selected. For 1/2 volume, the result is shown in **Figure 4.13a** and 1/5 volume in **Figure 4.13b**. Both graphs show the horizontal distribution at a depth of 2 m and no slope condition. These can also be compared to the existing condition, without trench as it is presented previously in **Figure 4.8a**, and with trench but with a full ponding in **Figure 4.8b**.

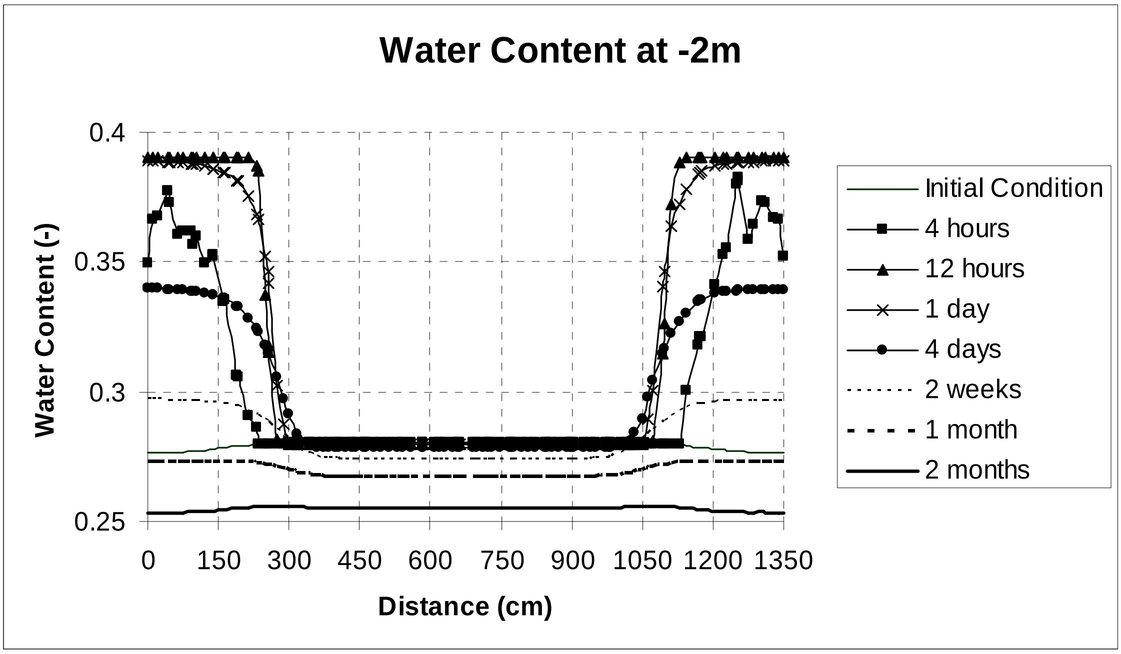


Figure 4.13a Horizontal distribution of water content with 1/2 ponding, no slope.

Generally, when ponding water in the trench is less, then dry out process will be faster. Here, for 1/2 ponding simulation, the maximum reach to horizontal direction is 213 cm from the middle of the trench. This condition occurs after 12 hours. Following the 1/5 ponding, the maximum reach to horizontal direction is 141 cm after 12 hours. A part from the above results, looking to the full ponding, then the time needed to reach the maximum horizontal direction is 260 cm after 1 day. Thus, it is obvious that the amount of water in the trench will effect the horizontal distribution. Afterwards, the decrease in water content stays likely the normal pattern as it is in the existing condition.

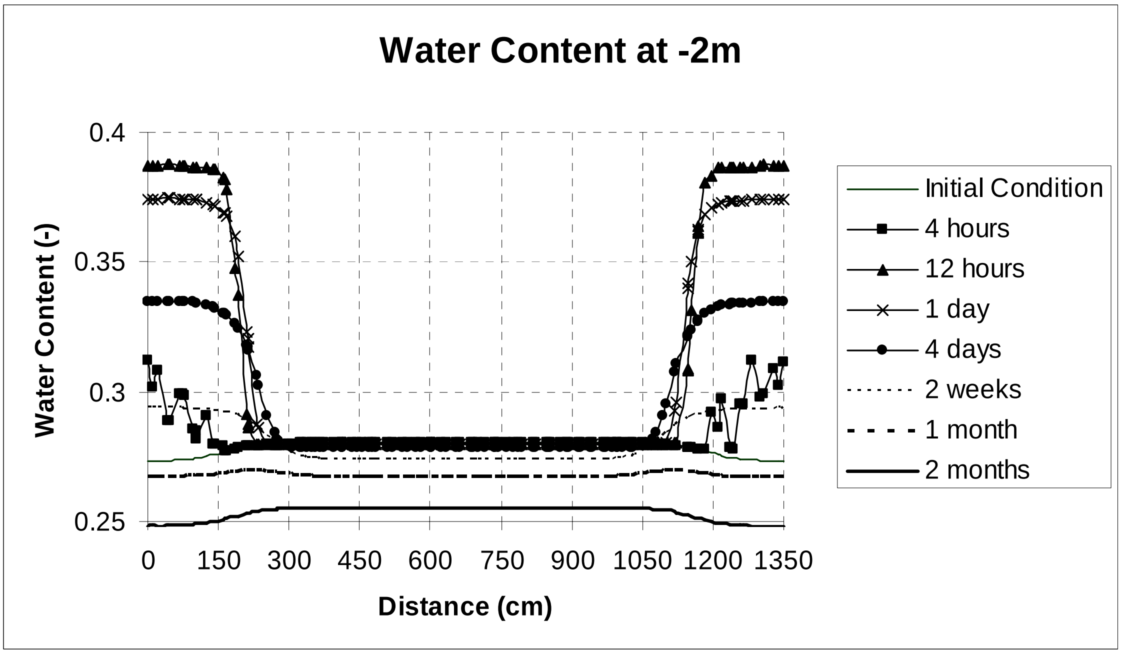


Figure 4.13b Horizontal distribution of water content with 1/5 ponding, no slope.

4.4.4 Soil Properties

Soil properties are parameters which strongly affect the infiltration process. Based on the water storage equilibrium reach, there is a significant range difference to what extent soil may store water. The area of the modeled unsaturated and saturated zone is 945,000 cm^2. The water storage of each soil property yield:

- Loamy sand: 122,750 – 239,920 cm^2 (with range of: 117,170 cm^2)
- Sandy Clay Loam: 235,000 – 312,500 cm^2 (with range of: 77,500 cm^2)
- Sandy Clay: 296,770 – 343,680 cm^2 (with range of: 46,910 cm^2)

Looking to the range of available water storage, loamy sand has the highest capacity. Therefore, Loamy sand has the largest pore space to be filled with water.

Therefore, the next scenarios will vary on these soil properties. For sandy clay loam property, the simulation can be found in the scenario about slope and trench dimension. As an initial remark, the value of saturated conductivity (Ks) for each soil property is:

- Loamy sand: 350 cm/day
- Sandy Clay Loam: 31.44 cm/day
- Sandy Clay: 2.88 cm/day

The first simulation is on loamy sand property. The graphs are presented in **Figure 4.14a** and **4.14b.** These results are mainly observing the horizontal profile of water content. Infiltration process without trench due to average atmospheric condition will be evenly distributed over the whole domain as it is presented in one column. Over the horizontal profile, at a depth of 2 m, it shows a decrease of constant water content from 0.12 at the beginning of the dry season to almost 0.1 after 2 months. Such graph looks alike to previous simulation, where sandy clay loam is applied; only the value is lower now. The next graph, with trench, seems to have a quicker response to water drawdown in the trench. This is indeed proportional to the hydraulic conductivity value. After 4 hours, it already reached the maximum water content of 0.39, 1 m below the trench. Since the porosity of loamy sand is equal to 0.41, it means that the water content which passed this depth has reduced. Besides, there is less water flow to the horizontal direction from the side of the trench. Furthermore, from time step from 4 hours to 2 months, the water content just diminished in time to the point of existing condition equilibrium.

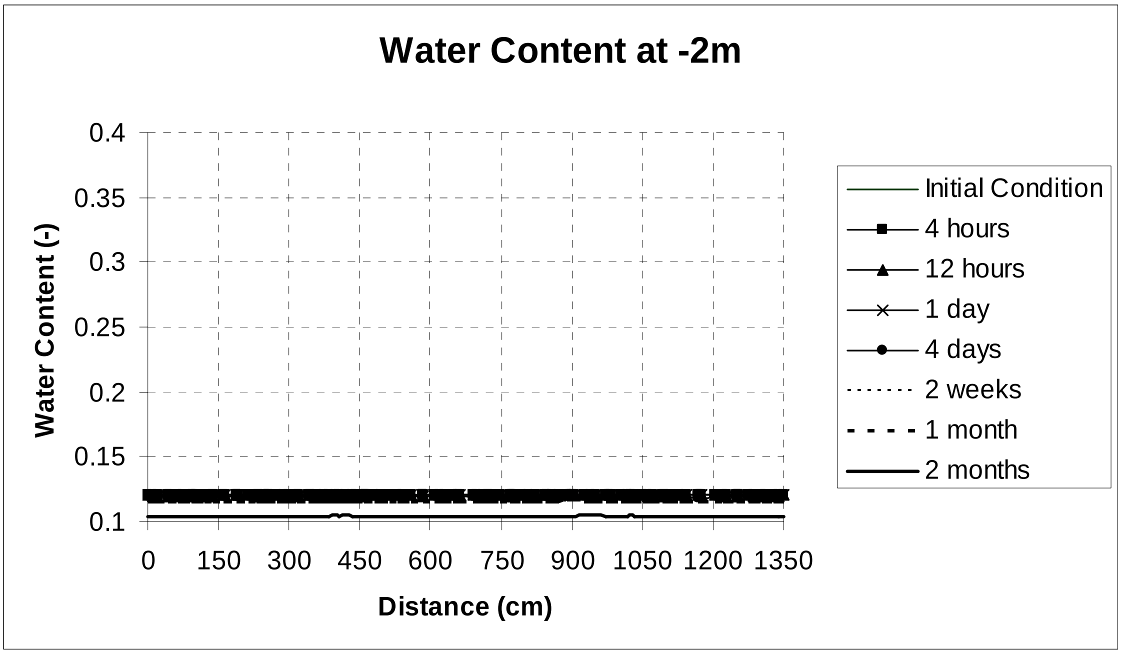


Figure 4.14a Horizontal distribution of water content with loamy sand property, without trench no slope.

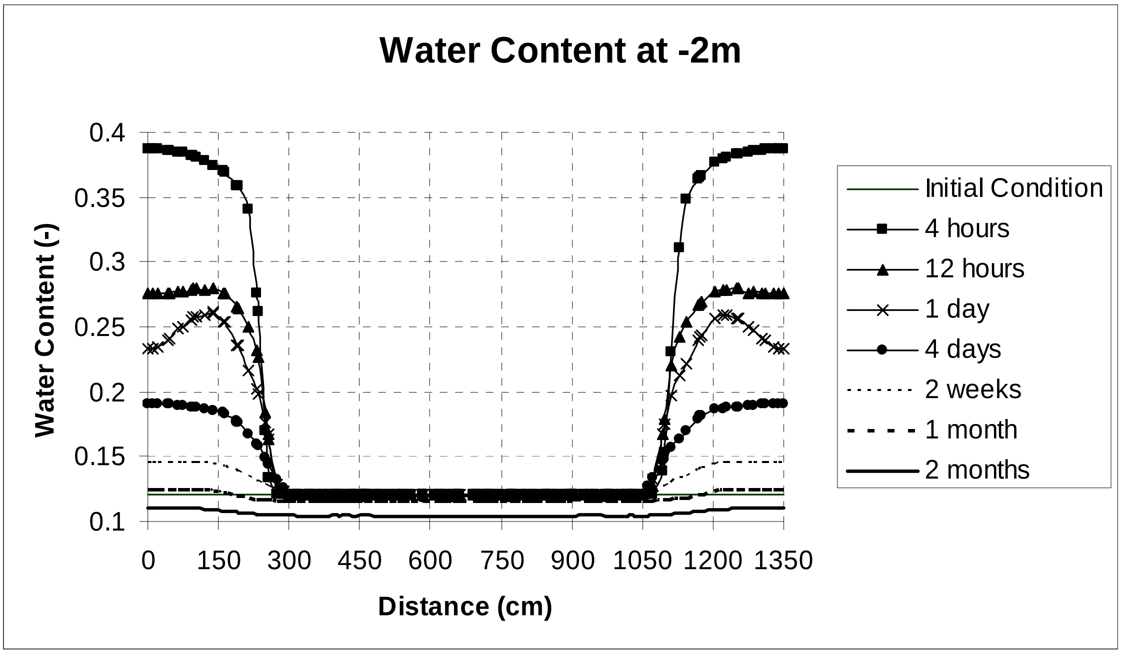


Figure 4.14b Horizontal distribution of water content with loamy sand property, with trench no slope.

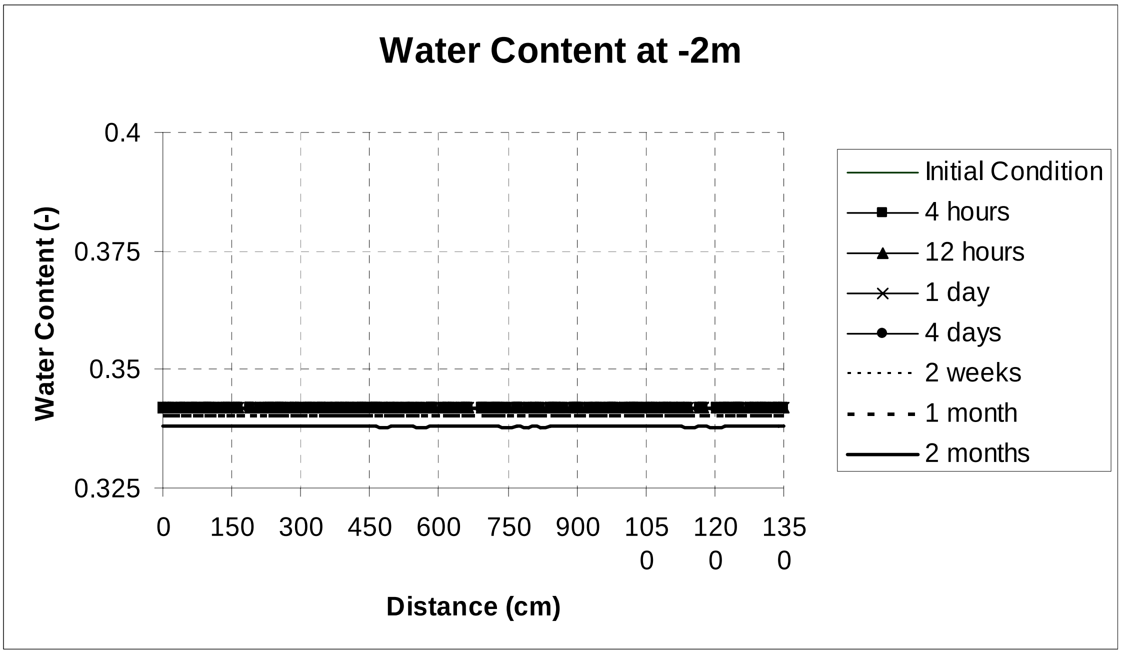


Figure 4.15a Horizontal distribution of water content with sandy clay property, without trench, no slope.

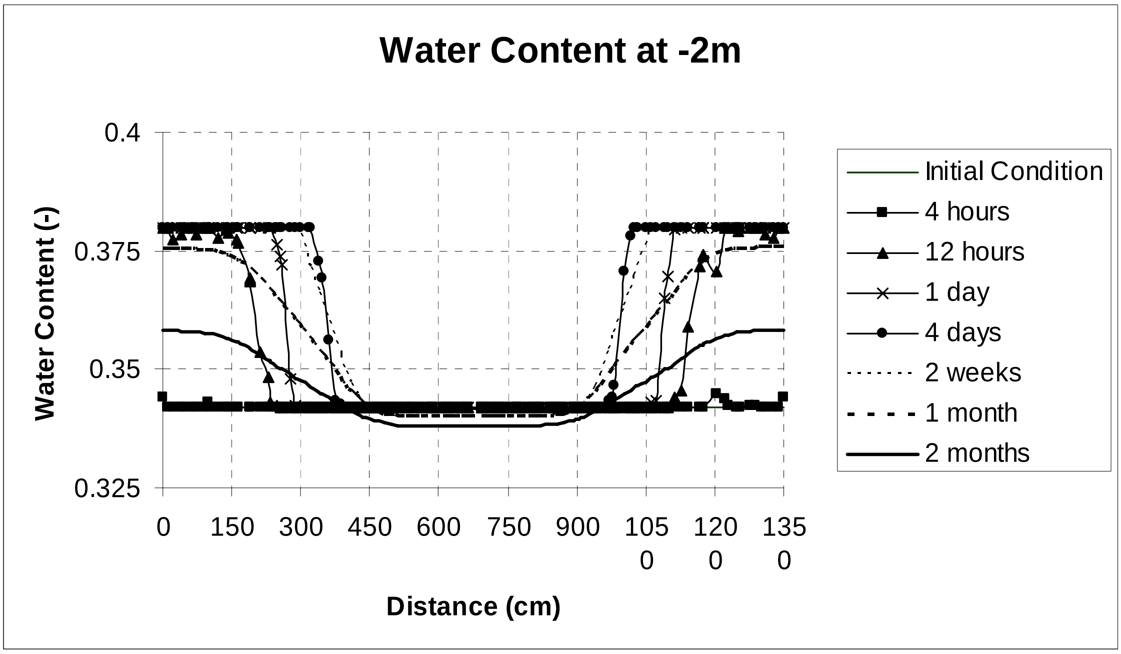


Figure 4.15b Horizontal distribution of water content with sandy clay property, with trench, no slope.

The second infiltration process is on sandy clay soil property. The horizontal profile for existing condition (**Figure 4.15a**) keeps to a constant of 0.34. It stays at this value till the end of the second month. In other words, no meaningful fluctuation occurs. Note that the saturation is at 0.38, which is only 0.04 from the initial condition. **Figure 4.15b** shows that saturation condition can be easily reached. Additionally, although at the depth of 2m, it has a horizontal distribution to 322 cm from the middle of the trench. This value is bigger than the one using sandy clay loam property. Another important point is the slow infiltration process. This can be seen that after 2 weeks, it still maintain the saturated condition although the horizontal distribution becomes less. After a month, the water content below the trench starts to diminish and at the end of the second month, it does not reach the equilibrium yet. Thus, the infiltrated water is still flowing.

4.4.5 Deep Groundwater

In case of groundwater uncertainties or deep groundwater, the next scenario is trying to simulate the infiltration process. The previous scenarios took into account groundwater at a specific monitoring location. However, when it comes to a condition where the groundwater table is assumed to be unknown or very deep, then the previous scenarios would not be valid anymore.

Thus, the simulation on a deep groundwater assumption takes first a domain of no slope. Besides, it still uses atmospheric condition at the upper domain boundary, but now neglecting groundwater fluctuation. Therefore, at the lower boundary, free drainage is assigned. For this, an example of sandy clay loam soil property is used. As usual, the simulation has to reach the equilibrium water storage first. Following the equilibrium reach, the simulation on existing condition and comparing with the implementation of the trench is done. Here, only the vertical distribution result at the middle of the trench is presented, since the existing condition is comparable with the first scenario about slope and trench dimension.

The result is shown in **Figure 4.16**. The Initial condition is at fully filled with water of 1 m in the trench and unsaturated condition below it with water content range from 0.24 to 0.28.

After 1 day, the water in the trench has already infiltrated about two third. At this point saturated condition occurs from a depth of 100 cm to 444 cm and the remaining depth, water content is at 0.24. Next, after 4 days the trench has already dried out and the water content below it starts slowly decreasing its moisture. The distribution of vertical profile eventually has a gentle increasing slope of moisture with respect to the depth. An interesting remark here is that the water in the trench does not totally dry out when water infiltrates the soil. It is caused by the coarse mesh and the retention curve assigned in the simulation. When it comes to the end of the first month and furthermore to the second month, water content returns more or less to the condition as without trench.

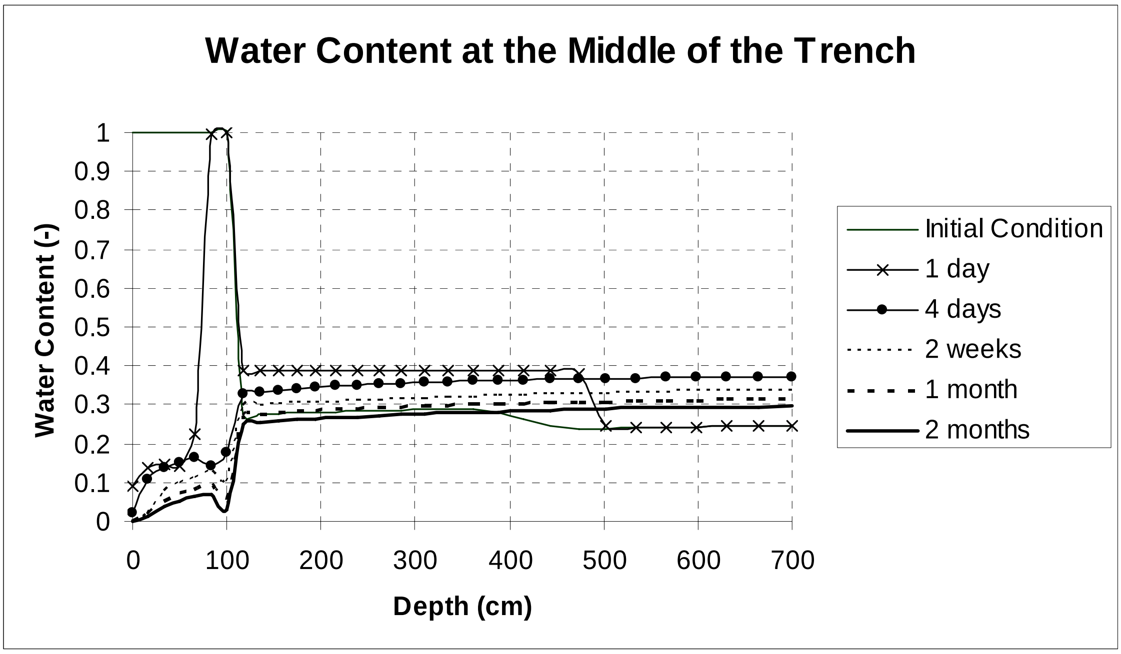


Figure 4.16 Vertical distribution of water content with sandy clay property, no slope.

Chapter 5
Planned Condition

5.1 Planned Condition

The last simulation is the planned condition which simulates the most probable implementation of contour trenches in the study area. It reflects the integration of different scenarios discussed previously. Combining all different provided scenarios, a new model is made. The parameters used here are slope and trenches dimension, spacing, ponding water, soil characteristics and thickness. To see the long term effect of contour trenches, the model is simulated for 10 years.

The first parameter is the slope of the planned area. There are 3 possible locations (see **Figure 5.1**) proposed where the contour trenches may be built. Each area has its own water stream where runoff accumulation is expected to fill up the trenches easily in wet season, adding an extra volume of water. Besides, slopes found are relatively small, 1% at location A and 2% at location B and C.

The trenches which are going to be modeled are 3.5 m wide and 1 m deep. There will be 3 trenches with the spacing of 10 m.

Ponding in the trench is a result of runoff accumulation. Since it varies in time, according to rainfall events and the antecedent condition of soil moisture, ponding is assigned to be fully filled and sometimes assumed to be about 3/4 or 1/2 of the total volume. These random number is applied when the wet season end or 1 month before, which are between December and January. The ponding water can be assigned once or two times annually. Simulation of sedimentation condition is also included in the fifth and ninth year. It is assumed that for the whole year, the sediment stays and is cleaned for the following year. The summary of scenarios of the planned condition is presented below:

- Year 1: once, with all trench full
- Year 2: once, with 2 trench full and 1 trench half full
- Year 3: once, with 2 trench full and 1 trench half full
- Year 4: once, with 2 trench full and 1 trench three forth full
- Year 5: once, sedimentation included, with all trench full
- Year 6: twice, with all trench full
- Year 7: twice, first with all trench full and second with 2 trench full and 1 trench three forth full
- Year 8: once, with 2 trench full and 1 trench three forth full
- Year 9: once, sedimentation included, with all trench full
- Year 10: once, with all trench full

Soil characteristics are based on available soil data. As explained in the description of the study area, most locations have an upper soil layer of silty sand (0-4 m) and below it coarse sand properties (4-7 m).

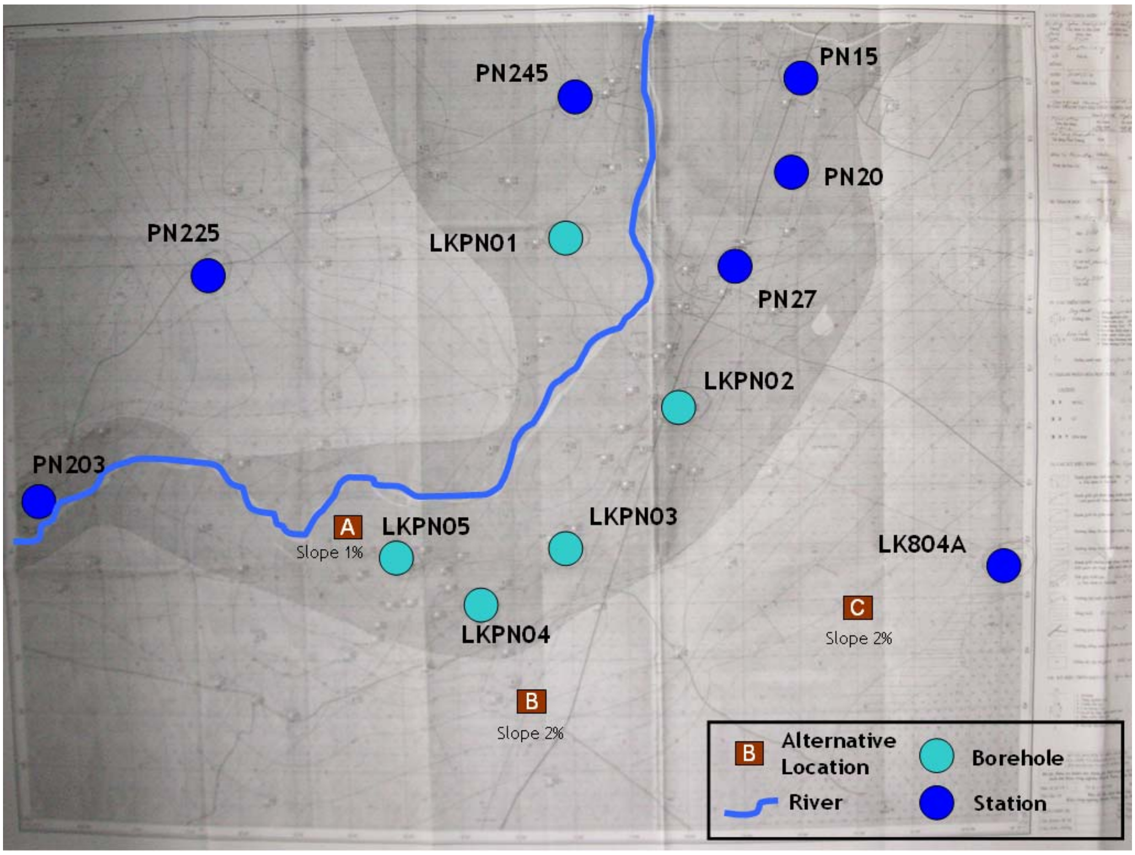


Figure 5.1 Alternative location of contour trench implementation.

The model with the dimensions and observation points is presented in **Figure 5.2**. The domain area has a length of 40.5 m and depths of 7 m. Observation points are added in order to check point to point fluctuation. There are 5 observation point made:

1. At the bottom of the trench
2. 50 cm below the trench
3. 125 cm below the trench
4. 100 cm downstream the trench bottom
5. 75 cm below observation point 4

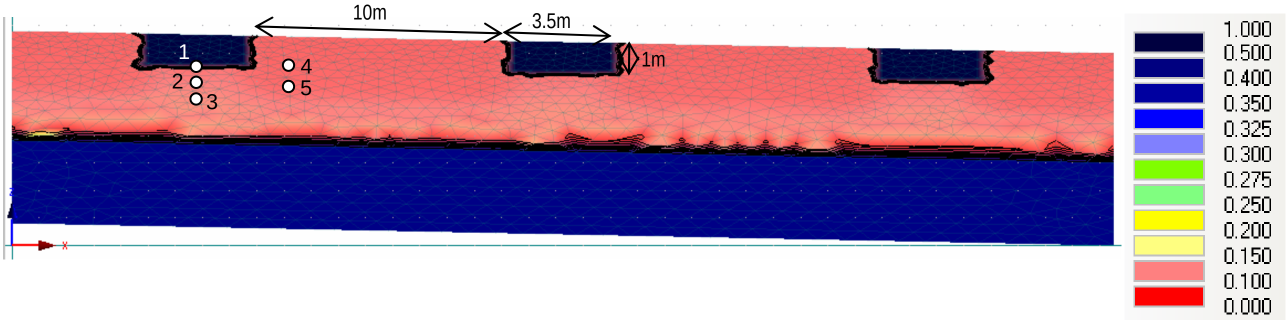


Figure 5.2 The domain with its initial condition and observation points.

5.1.1 Moisture Distribution

Unlike the previous scenario results, which shows only one certain profile, either horizontal or vertical, now the moisture distribution is presented for the whole domain. This gives an overall interactive illustration of the process. **Figure 5.3** shows three trenches and their effects for 1 month simulation. Based on the scenario, it starts with all trenches fully filled up of water.

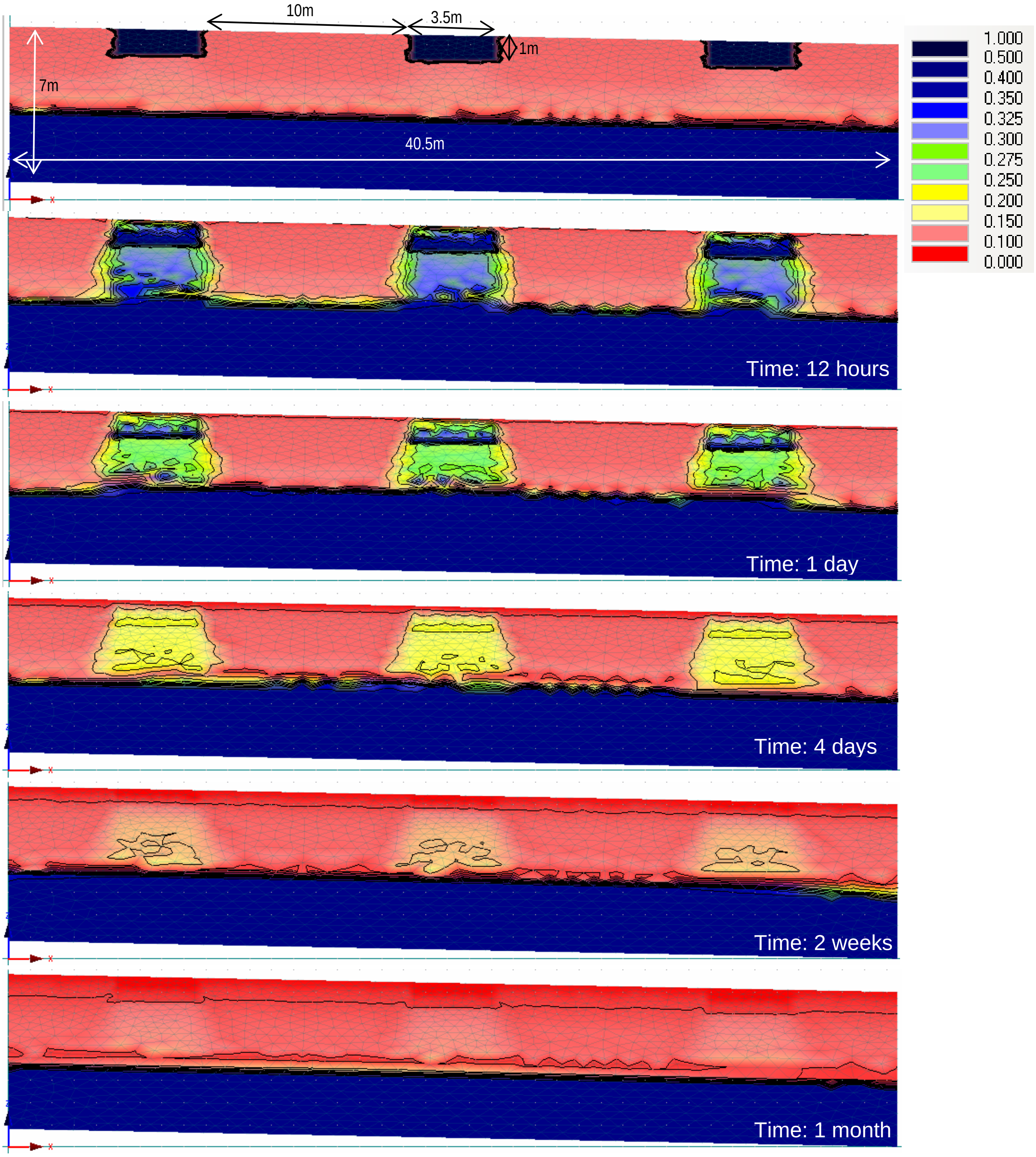


Figure 5.3 1 month moisture distribution.

As shown in the graph above, after 2 hours, water that infiltrates below the trench has already reached a wetting front of about 2 m below the bottom of the trench. The observation of the trench bottom shows that infiltrated water decreases after 2 hours. In reality, the water has been dried out in the trench for such a short time. It is believed that the initial condition has a big influence to it. Looking at the initial condition itself, one may conclude that it is quite dry. Although the simulation is at the end of wet season, and expected to have retained water, however, rainfall inputs seem to drain water rapidly. Silty sand is very suitable for drain and has a big pore space. Water will flow through such layer easily. Therefore, it is obviously that the infiltration process occurs rapidly. And after 1 month, it returns to a fully dry condition.

Besides, there is not much horizontal flow. Both graphs indicate almost only vertical flows. This is explained by observation point number 4 and 5, which is 1 m next to the trench. These keep constant water content of about 0.11. Since the infiltration process occurs rapidly, this gives also an indication of local recharge. It can be seen that at time step 1 day, the groundwater level increases (see **Figure 5.3**). And after 1 month of simulation, the effect of infiltration ceases.

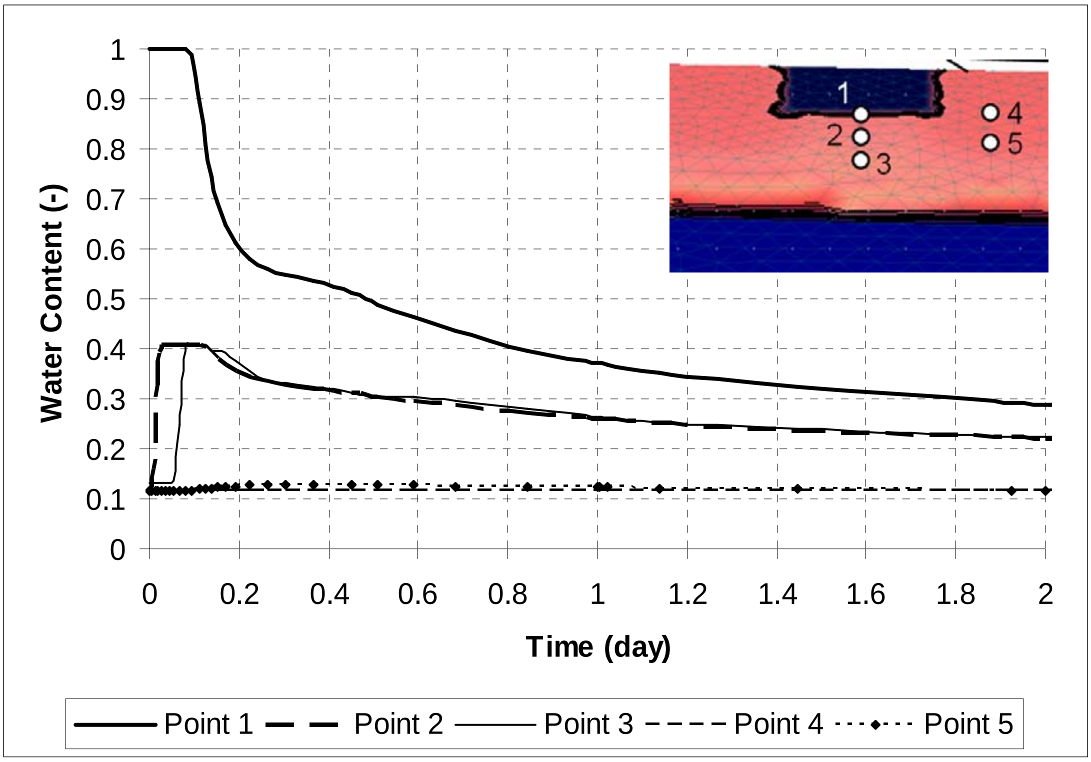


Figure 5.4 5 selected observation points.

5.1.2 Sedimentation

In case when sedimentation occurs in the trench, a scenario is established for the fifth and ninth year. The condition assumed that once there is a thin clay layer accumulated at the bottom of the trench due to unfiltered runoff. Since the drawdown is mainly in vertical direction, now water flows to the side of the trench which remains sand. Therefore, it is believed that the vertical flow reduces, instead of horizontal flow. This is described in **Figure 5.5**, when after 2 hours, the wetting front shifted to the side of the trench. However, afterwards it returns to the same condition, where at time step 12 hours, the moisture distribution is spread out below the trenches.

Moreover, **Figure 5.5** describes delays in infiltration process, retention layer, and the wetting front reach. It can be seen that the vertical water flow through the clay layer causes a delay. In other words, water flows indeed more difficult through a clay layer. At observation point 2 (below the trench), the wetting front now reaches to approximately 6 hours compared to a less than 1 hour without sedimentation,. Furthermore, clay keeps its water content to saturated condition. For 2 days, it is shown that water content does not decrease. It can also be seen clearly in **Figure 5.6**, when it comes to 1 month of simulation, the bottom of the trench may still retain water. About the wetting front, now that the flow from the trench side is higher than without sedimentation, observation point number 5 shows an increase in water content. This means that sedimentation apparently affect the horizontal flow.

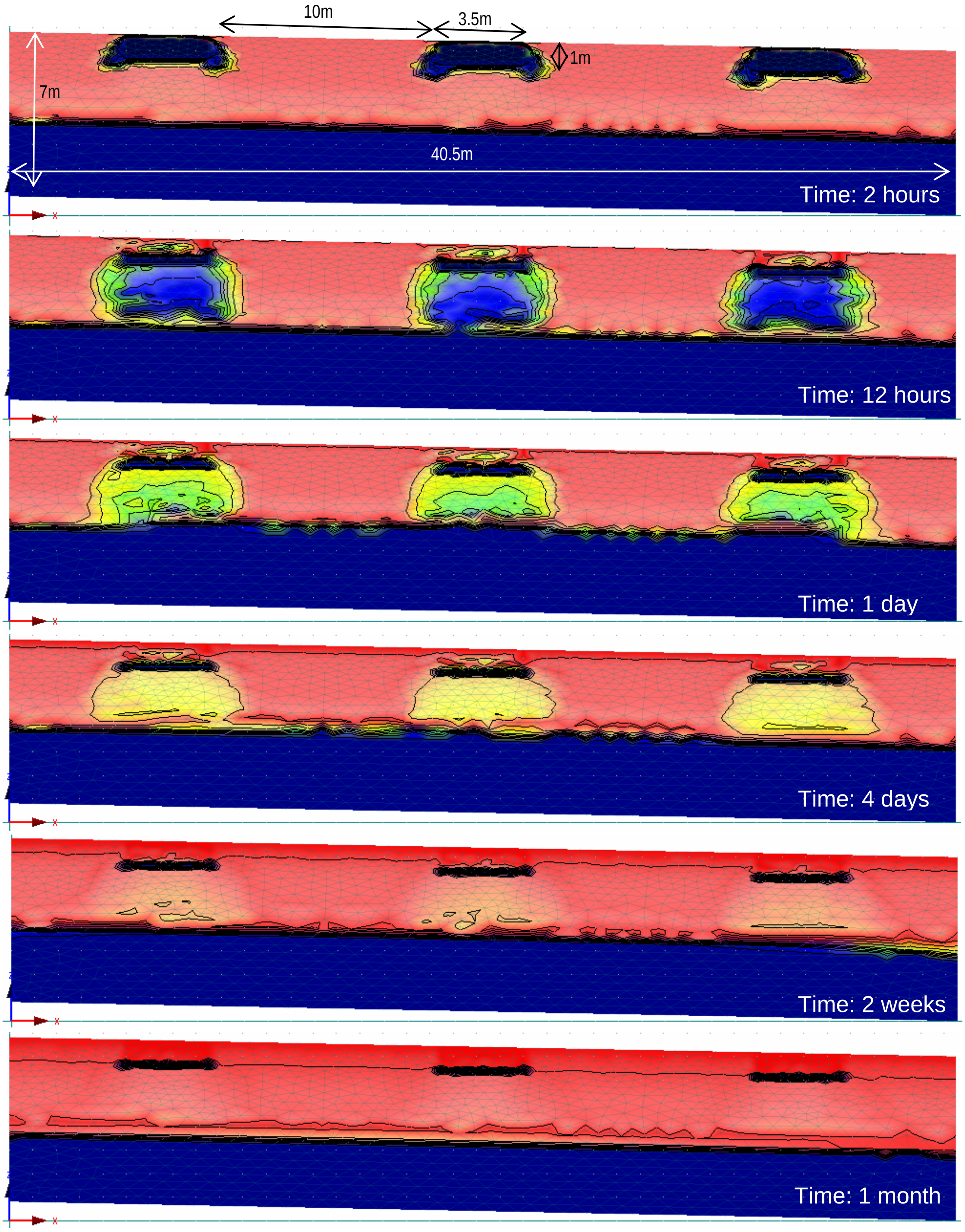


Figure 5.5 1 month moisture distribution include sedimentation.

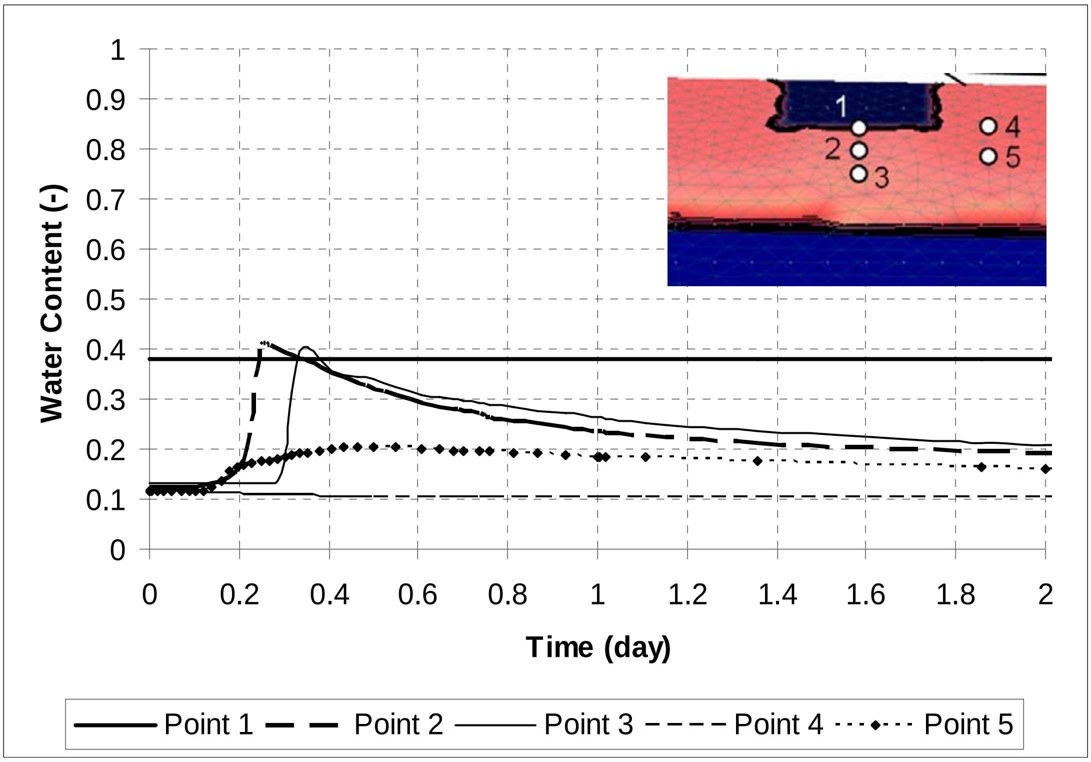


Figure 5.6 5 selected observation points, include sedimentation.

5.1.3 Storage Capacity

Previously, the discussions were more to water flow and moisture distribution. Now, the benefit of excavating trenches is quantified in water storage below the trenches. This is explained by comparing the soil water storage between an existing condition and with implementation of contour trench. It is expected that at the end contour trenching will store water of the wet season and retain it through the dry season.

As shown in **Figure 5.7**, comparing between scenarios without and with trench, it can be seen how the infiltration process in a trench merely affects a short period of time. At first, the peak of the ponding water is applied in the beginning of the year. Exactly at this time period, the water content increases drastically. However, afterwards it comes to the existing condition again where simulated scenarios without and with trench are alike. The water held in the soil after infiltration is unable to be maintained for the rest of the year. Therefore, in dry season with trench, the water storage remains the same as it is without trench. At the end of a dry season, rainfall events occur and additional water accumulation is applied as well. Eventually, these events repeat over the year without creating subsurface storage.

For the modeled 3 trenches, the peak average which occurs at the end of the year is about 110,000 m^2. This is equal to 15 % of the total volume. It means that for every year of runoff accumulation, an extra 15% water storage can be used.

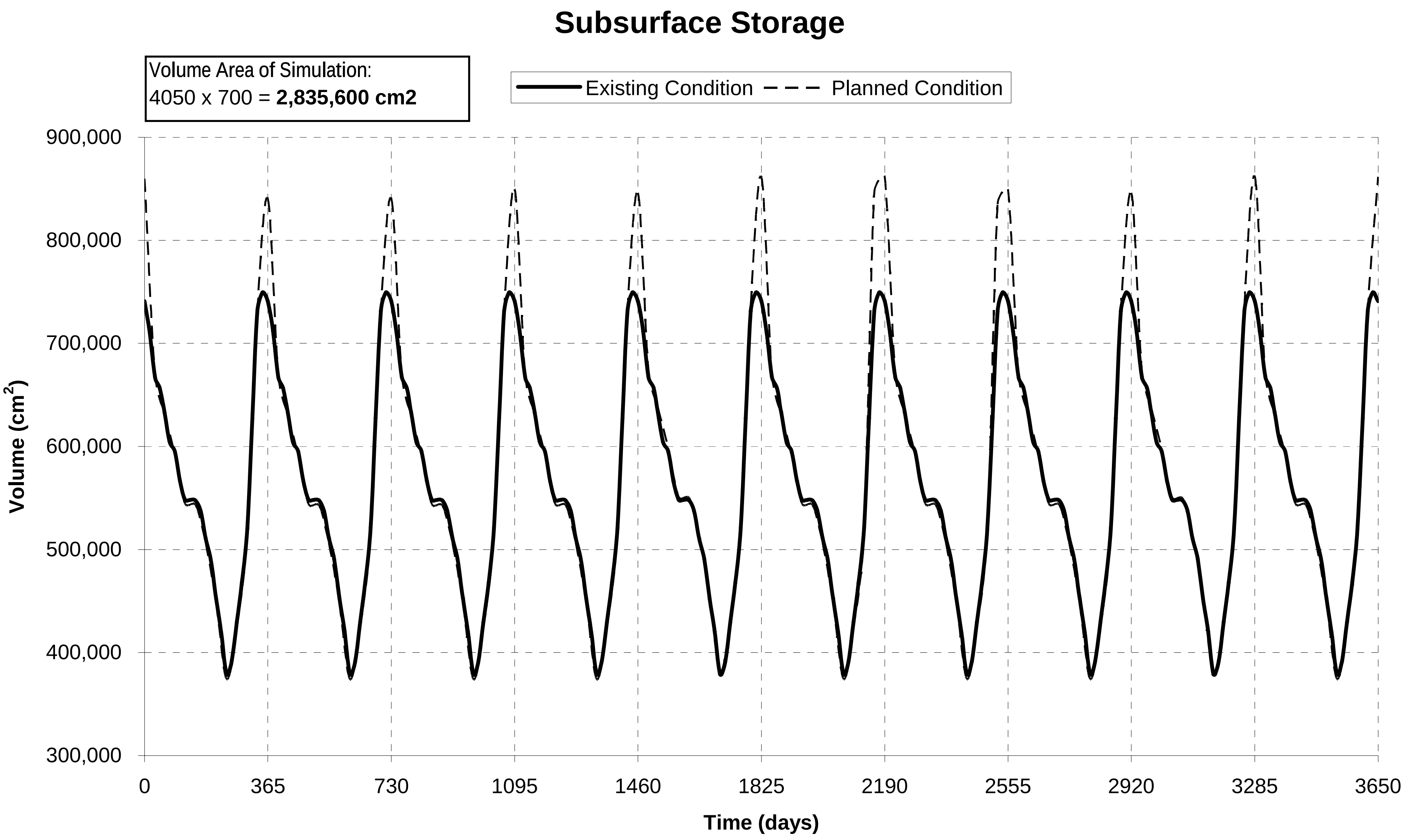


Figure 5.7 Storage capacity after 10 years simulation.

5.2 Up-to-date Data

In this section, the up-to-date data use for Hydrus 2-D simulation is will be explained. The data were collected during the field visit from 21 to 24 of August 2007. The detail activity in the field visit is explained in **Appendixes D**.

5.2.1 Rainfall Data

The latest available rainfall data is explained in **Chapter 2**. The nearest station which is about 4 km to the study area is Mua Quan The station. Compared to the other stations, it provides the longest data series, 28 years. Data on year 1980 is excluded since the value (2374 mm) seemed not to match to the annual trend. Furthermore, one (year 1986) out of 28 years daily data will be use for the Hydrus 2-D input.

The occurrence of rainfall that exceed 50 mm per year ranges from 0 (2002) to 10 times (1998). The significant rainfall events itself is dominantly from September to December with average range of 50 to 70 mm. Looking at the day of occurrence per year, the most probable number is 1 day to 2 days. This will be considered as the number of filling up the trench events per year in the Hydrus simulation.

Table 5.1 Rainfall Exceed 50 mm per Year

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979											121, 91, *254*	
1980												
1981											79, 71	
1982			90									
1983									70	78	55	
1984											59, 52	
1985									59	79		
1986												118
1987									73		58	
1988										51, 58	56	
1989					76							
1990								99				
1991			70			98			73, 72	54		
1992										131		
1993									57			58
1994						68				51		
1995							63		65, 96			
1996					63, 80					82		75
1997							55		56			
1998						76, 88		70	58, 97, 59		134, 83	54, 52
1999				52						101, 85	78	51
2000										76, 51	217	194
2001					110							
2002												
2003											91, 273	
2004						51, 54						
2005												120
2006										63		

5.2.2 Infiltration Rate

To gain an overview of the saturated hydraulic conductivity in the field, infiltration test at 3 different points were conducted. The first measurement took only 6 minutes, merely to indicate the initial infiltration rate value, which was in average of 4000 mm/hr or about 9.5 m/day. Afterwards, 2 measurements were conducted, digging 5 holes in series at several depths (20, 40, 60, 80, and 100 cm). The complete drawing of dig holes and results can be found in **Appendixes E**. It can be concluded from this measurement that the soil found in the field has typically the same infiltration rate. The infiltration rate for the first 40 cm below soil surface after almost 1 hour is about 200 mm/hr or 4.8 m/day. From 40 to 60 cm below, the range is from 300 mm/hr to 1600 mm/hr and from 60 cm to 100 cm, more than 750 mm/hr 18 m/day.

For the Hydrus simulation, the saturated hydraulic conductivity (Ks) is set per layer according to the known infiltration rate. Since the infiltration capacity was not reached, a smaller value from the above mentioned number is assumed. Therefore, the top layer till 60 cm deep, Ks is set 350 cm/day. From 60 cm to 4 m deep, Ks is set 713 cm/day and from 4 m below, Ks is set 1500 cm/day.

5.2.3 Runoff

Based on the relation of infiltration capacity and rainfall intensity analysis, the scenario here is using the moderate (60 mm/hr) and maximum rainfall event (280 mm/hr). To determine how much water would fill up the trench for both 60 mm/hr and 280 mm/hr, first assumption has to be made. The trench dimension is 4 m wide, 1 m deep and has a spacing of 25 m. Second, the infiltration capacity equal to those measured depth of 100 cm, which is about 750 mm/hr. Third, the infiltration capacity at the sand surface is set to be 10 mm/hr. Then the rain of 60 mm/hr will not be retained. In other words, the trench will dry out during one hour infiltration process. On the other hand, when 280 mm/hr rainfall occurs, then water will overflow. Therefore, a fully filled up trench seems fairly to be simulated.

5.2.4 Contour Trench Design

The final design is still based on the peak rainfall event. It results to a trench dimension of 4 m wide and 1 m deep. Again, the 4 m is taken from the capacity of a bulldozer in the field and 1 m is determined because the compacted layer of the soil surface that has to be removed to ease the infiltration process. Besides, the spacing is determined to be 25 m.

5.3 Hydrus 2-D Simulation

Now that some latest data were collected in the field, the simulation can be fine tuned. The result of planned contour trench can be seen in **Figure 5.8**. The new parameters in the following simulation are saturated hydraulic conductivity, layer thickness, and boundary conditions.

The end result shows more or less the same pattern of water flow. These include water content observations and the occurrence of siltation which can be seen at the beginning of this chapter. Besides, water will dry out after about 2 hours and the flow is dominantly in downwards direction. However, now the maximum increase of water content is 27%.

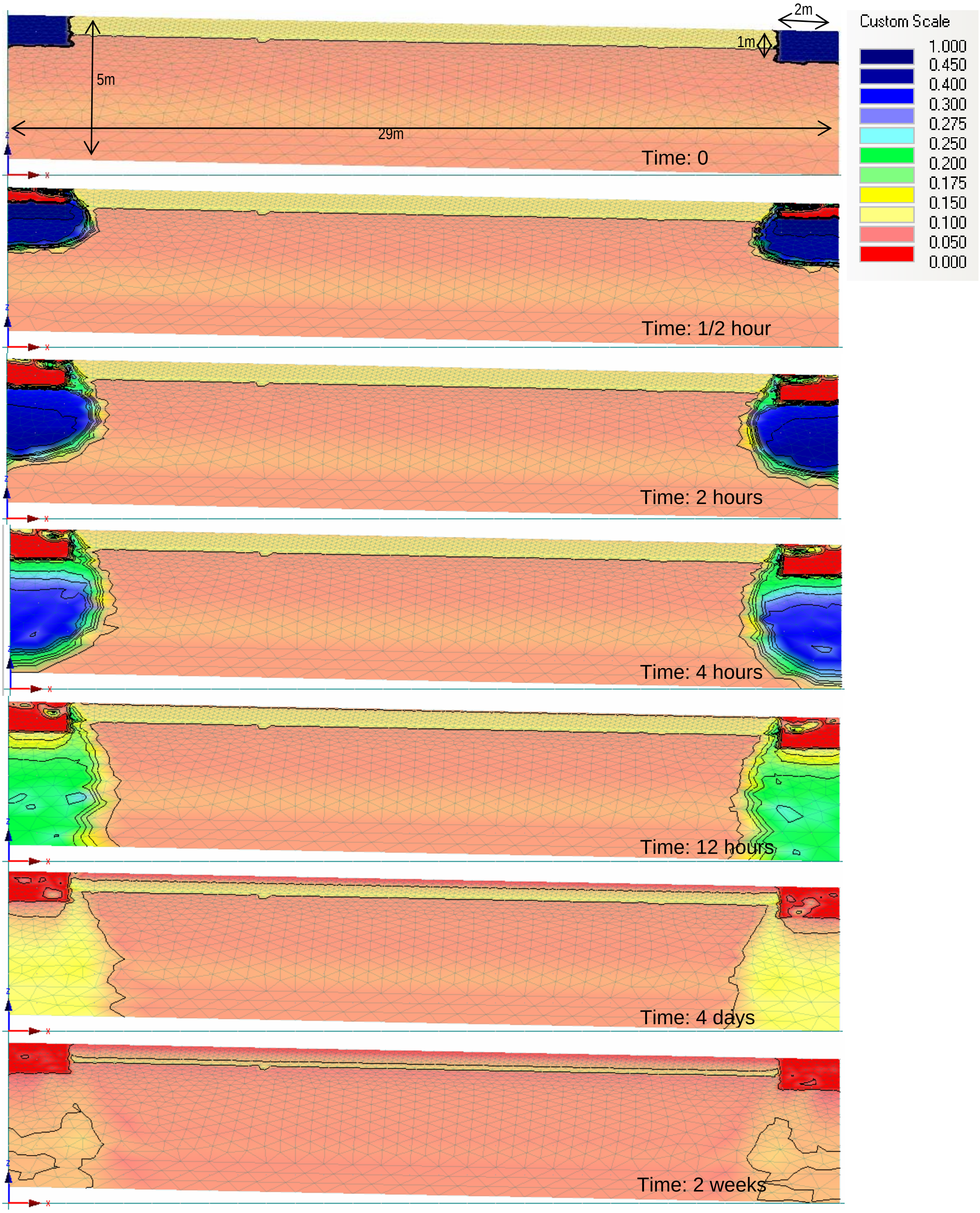


Figure 5.8 2 weeks soil moisture distribution.

5.4 Limitations

After evaluating the methodology used and the simulation processes, in this sub chapter, some limitations will be discussed.

The purpose of contour trenches is to store as much as possible water subsurface. It means trying to create a small reservoir below the trenches in the unsaturated zone. One important aspect that lacks in the simulation is the fact that vegetation starts to grow after the subsurface water content increases. Here, vegetation growth modeling is excluded where in fact it may grow and affect moisture storage. There are indeed facilities to take water uptake or transpiration into the modeling. However, this option was not assigned since the value of water uptake will be sum to surface fluxes (precipitation, evaporation, and transpiration). Thus, vegetation growth with respect to water uptake needs data such as type of vegetation, growing period, and root distribution which were not established in this study. Eventually, water merely flows down in vertical direction.

Another constraint in this study is the available data for calibration. Soil property and soil moisture data are of importance for water flow analysis. It can be seen from the scenario of different soil properties that this parameter will significantly affect both spatial and temporal water content distribution. Thus, in this study, data is limited to common soil texture, which is silty sand without any specific research on their hydraulic behavior. As a result, the soil hydraulic data found in default soil catalog provided by Hydrus 2-D and some modification are used. Consequently, the calibration step was skipped. Therefore, this study points out to validate the model with several field measurements. This will be discussed further in the recommendation part, **Chapter 6**.

The model has also constrains with respect to simulation time. One unique case here is on the trench mesh which actually has to dry out, instead of storing little moisture. In this case, the mesh should be denser at the trench part and use an appropriate retention curve. Furthermore, if assigning soil property that has a small hydraulic conductivity, it needs also a dense mesh. Thus, this condition will obviously take more time in simulation.

Chapter **6**

Conclusions and Recommendations

6.1 Conclusions

Based on the temporary available data, simulation on the most probable condition was done to see the hydrological process of contour trenches. Precipitation, runoff, filling up the trench till the infiltration processes were analyzed daily and monthly time step in a separate calculation.

Relying on runoff produce by the spacing between trenches is rather inadequate to fully fill up the trench for moderate condition (60 mm/hr). Thus, water in the trench will infiltrate in less than 1 hour. Therefore the trench seems to be exaggerated. However, if the purpose of the contour trenches is for flood control, then this dimension is sufficient to retain water and further recharge the groundwater.

Infiltration process modeling was done using Hydrus 2-D. The range of probable soil samples used is from loamy sand with high hydraulic conductivity to sandy clay to the lowest. For a fully filled condition, the time needed to dry out the trench is from a few hours for loamy sand soil to almost three weeks for sandy clay. In depth, the distribution of water content for loamy sand is almost only in vertical direction below the trench whereas sandy clay shows some horizontal flow.

Slope and spacing have minor effects with respect to the infiltration process. On the other hand, soil properties will distinguish a lot between storage capacities, both temporal and spatial. Therefore, the effect of soil layers is of importance.

It is apparent that contour trenches increase water availability for a relatively short period. The maximum additional storage due to implementation of a contour trench is 4 m^3/m. This equal to 27% soil moisture increase compared to the condition without contour trench implementation. However, here the estimation of use of this extra storage is excluded.

To design contour trenches, one has to start with the target. If the target is to maximize the groundwater recharge, then runoff should be chosen at a reasonable probability. However, if the target is on vegetation growth, then runoff accumulation is necessary to meet the water demand of the vegetation. The latter one will tend to have smaller dimension.

Further measurements need to be done to fine tune the result of modeling. This will be discussed in the recommendations.

6.1 Recommendations

The recommendations below explain more on the measurements proposed to be conducted before and after the trenches construction.

1. Soil Property
   Spatial soil properties data are essential. Estimation on the soil hydraulic parameters can be done by preceding the inverse solution. Therefore, soil moisture and pressure need to be measured. Consequently, calibration may fit to the actual condition and thus result to more accurate soil moisture analysis.

2. Infiltration Capacity
   The precipitation-runoff relation is still insufficient, since the infiltration capacity of the surface layer is unknown yet. Therefore, infiltration capacity on the soil surface needs to be conducted. Since the previous measurements on several infiltration depths showed one typical value, this measurement can be rechecked at two different places as well.

3. Vegetation Growth
   Less known aspect here is to research more on the relationship between soil water storage and vegetation with respect of its water use. Therefore, a study of local vegetation response (especially those which are going to be cultivated) to subsurface water storage is interesting.

4. Precipitation
   Although there are 5 different stations around the study area, on site precipitation should be measured as well. In real time, this local precipitation is to assure the amount of water available for filling up the trench and how much is infiltrated. Therefore, the precipitation-runoff correlation can be achieved.

5. Rainfall Simulator
   To determine the runoff during rainfall events artificially, rainfall simulator can be used. This measurement may be plotted on 2 different sizes and locations, upstream to the trench. Thus, the results will indicate to what extent trenches may fill up using runoff with respect to its spacing.

6. Waterstream and Road Runoff
   Gully discharges will be beneficial in filling up the trenches if those pass the trench areas. Therefore, roads and its water path need to be considered. The catchment of those waterstream should be investigated to ensure the amount of extra runoff available.

7. Groundwater Level
   2 groundwater level measurements are proposed to determine the boundary condition below the unsaturated zone. If the groundwater is shallow then local recharge might affect on both below and the vicinity of the trenches.

8. Evaporation
   Since evaporation rate is assumed in this study, evaporation measurement needs to be conducted. This measurement will ascertain to what extent the evaporation rate, both soil and open water surface and furthermore will fine tune the water balance.

9. Trench Design
   Practically, the trenches are designed based on the compacted layer need to be removed (depth), available heavy machine (width), and the use of this water storage (volume). Thus, to optimize the trench design one should be aware that the main goal after the storing water subsurface is to stimulate vegetation growth. This means that the further study has to combine the water use by local vegetation and sufficient retained water.

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http://fao.org
http://english.vietnamnet.vn/tech/2006/09/608544/

Appendixes **A**

Geo-hydrological Map

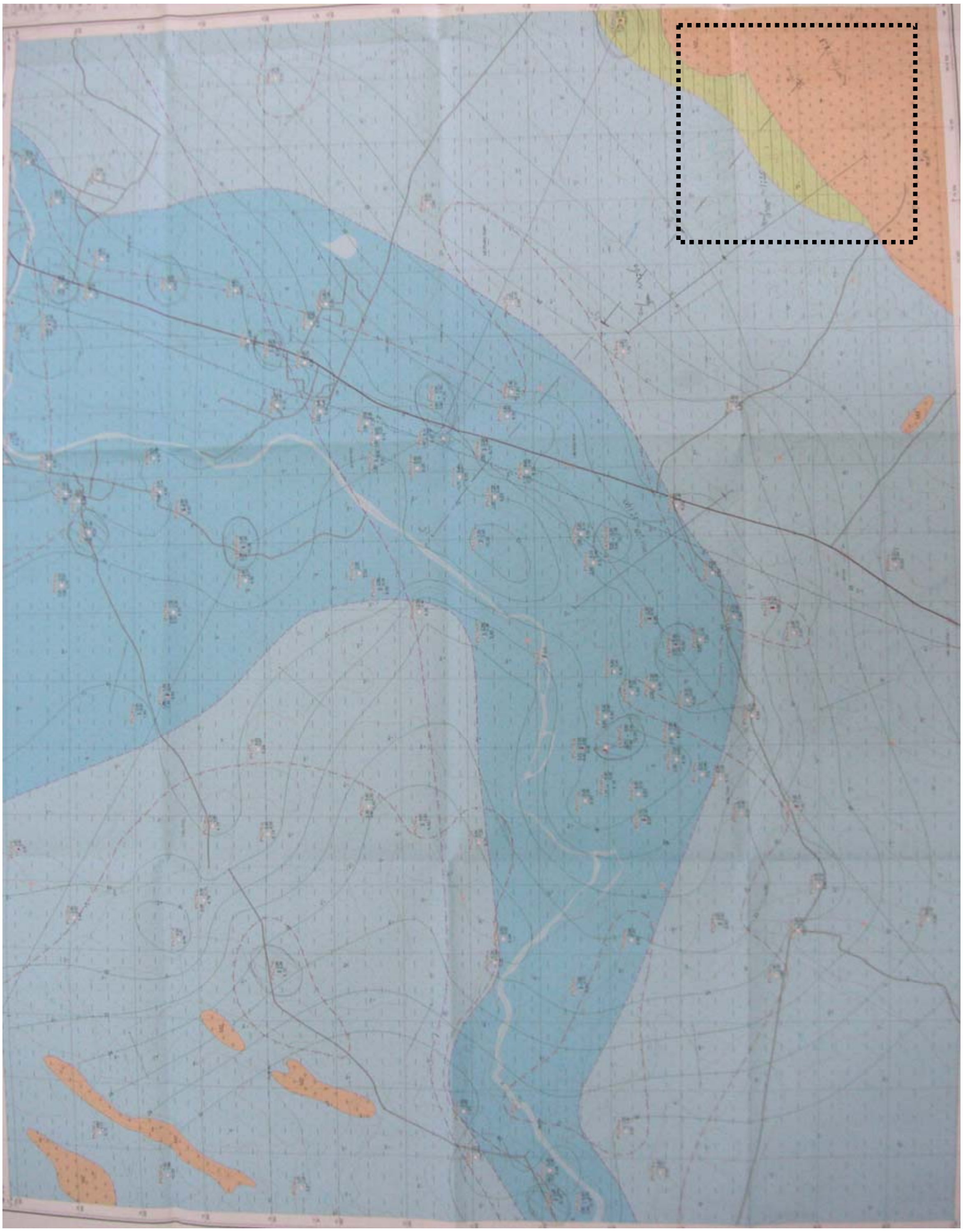

Figure A.1 Geo-hydrological map of the case study area (the black square on the right is the study area).

Appendixes **B**

Rainfall Data

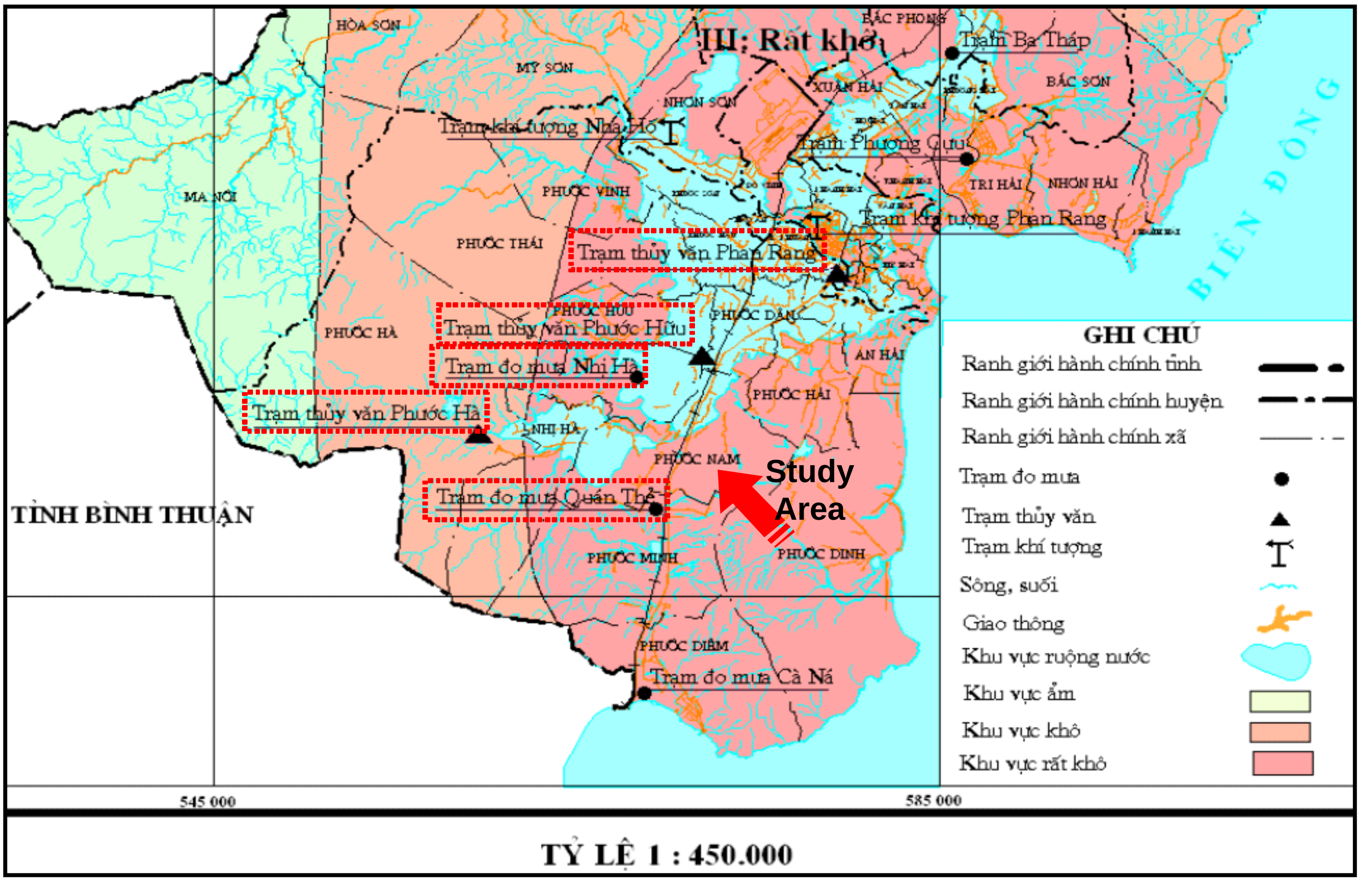

Figure B.1 5 locations of rainfall data.

Tabel B-1 Monthly Precipitation (mm)

Station : Phan Rang

Year	Month												Total
	Januar	February	March	April	May	June	July	August	September	October	November	December	
1997	0	3	0	16	140	46	104	17	134	49	44	24	576
1998	0	0	5	1	42	123	27	44	257	291	329	215	1332
1999	1	0	2	2	17	85	68	92	256	137	68	27	754
2000	6	2	0	33	45	77	86	32	47	347	291	165	1130
2001	5	0	62	63	101	74	20	85	101	95	95	156	856
2002	0	0	1	73	44	5	67	78	106	42	148	20	583
2003	0	0	3	0	98	23	19	8	121	218	253	11	753
2004	0	0	0	0	0	151	33	48	65	69	18	8	393
2005	0	0	4	0	17	25	46	39	165	202	109	214	821
Maximum	6	3	62	73	140	151	104	92	257	347	329	215	
Average	1	1	8	21	56	68	52	49	139	161	150	93	**800**
Minimum	0	0	0	0	0	5	19	8	47	42	18	8	

Notes:

- Driest year: 2004
- Wettest year: 1998

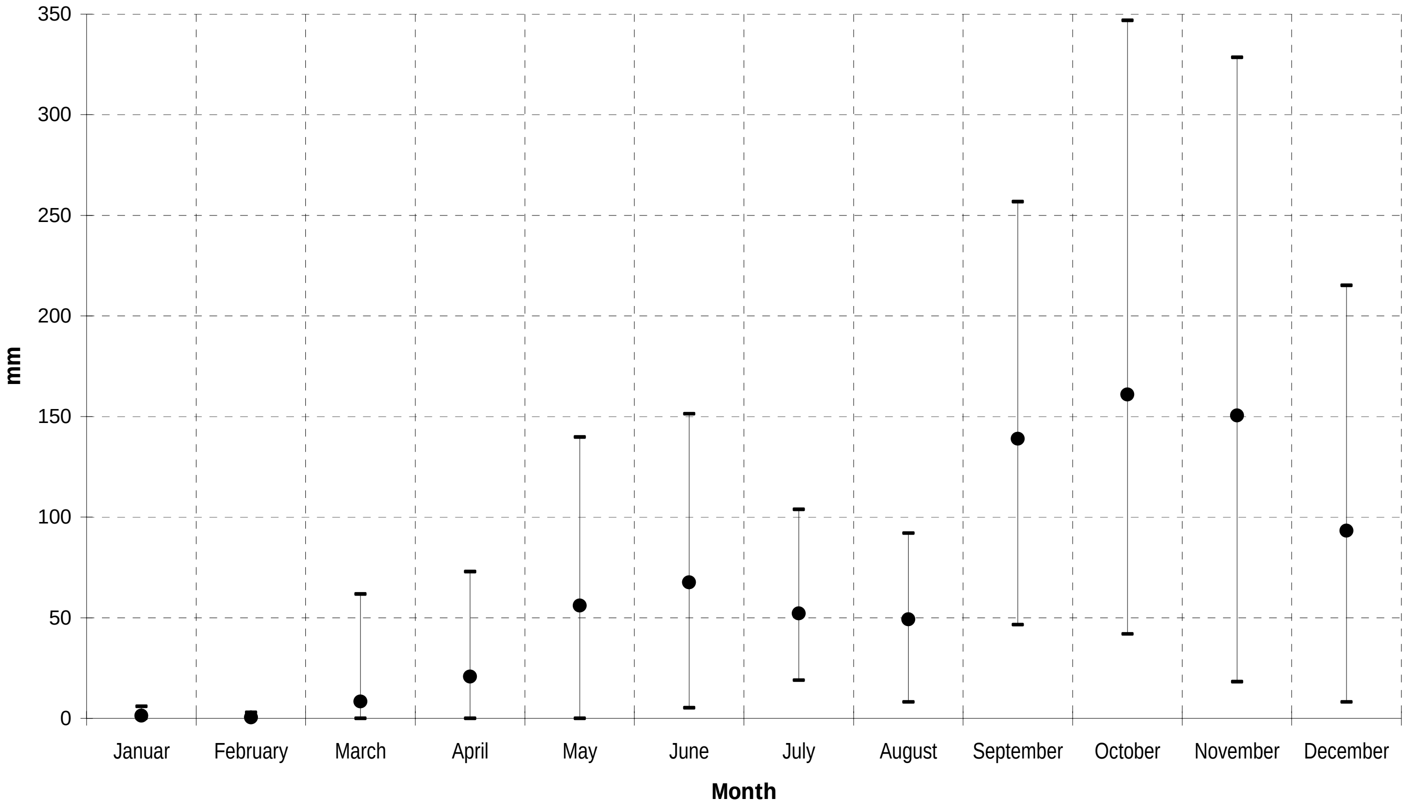

Figure B.2 Average monthly precipitation at Phan Rang station.

Tabel B-2 Monthly Precipitation (mm)

Station : Phuoc Huu

Year	**Month**												**Total**
	Januar	February	March	April	May	June	July	August	September	October	November	December	
1997	0	0	0	0	0	0	91	41	37	93	60	18	340
1998	0	0	0	0	0	0	0	0	296	281	327	142	1045
1999	0	0	0	0	0	3	14	20	100	268	206	133	744
2000	0	0	0	0	0	84	82	46	97	347	286	196	1137
2001	0	0	0	0	0	9	58	69	85	78	69	65	433
2002	0	0	0	0	0	4	7	130	139	60	173	22	534
2003	0	0	0	0	0	0	24	2	114	160	266	12	578
2004	0	0	0	0	0	137	23	53	60	74	19	6	371
2005	0	0	0	0	0	15	96	24	114	168	39	131	587
2006	0	28	40	3	47	38	99	64	152	200	10	14	695
Maximum	0	28	40	3	47	137	99	130	296	347	327	196	
Average	0	3	4	0	5	29	49	45	119	173	146	74	**646**
Minimum	0	0	0	0	0	0	0	0	37	60	10	6	

Notes:

- Driest year: 1997
- Wettest year: 2000

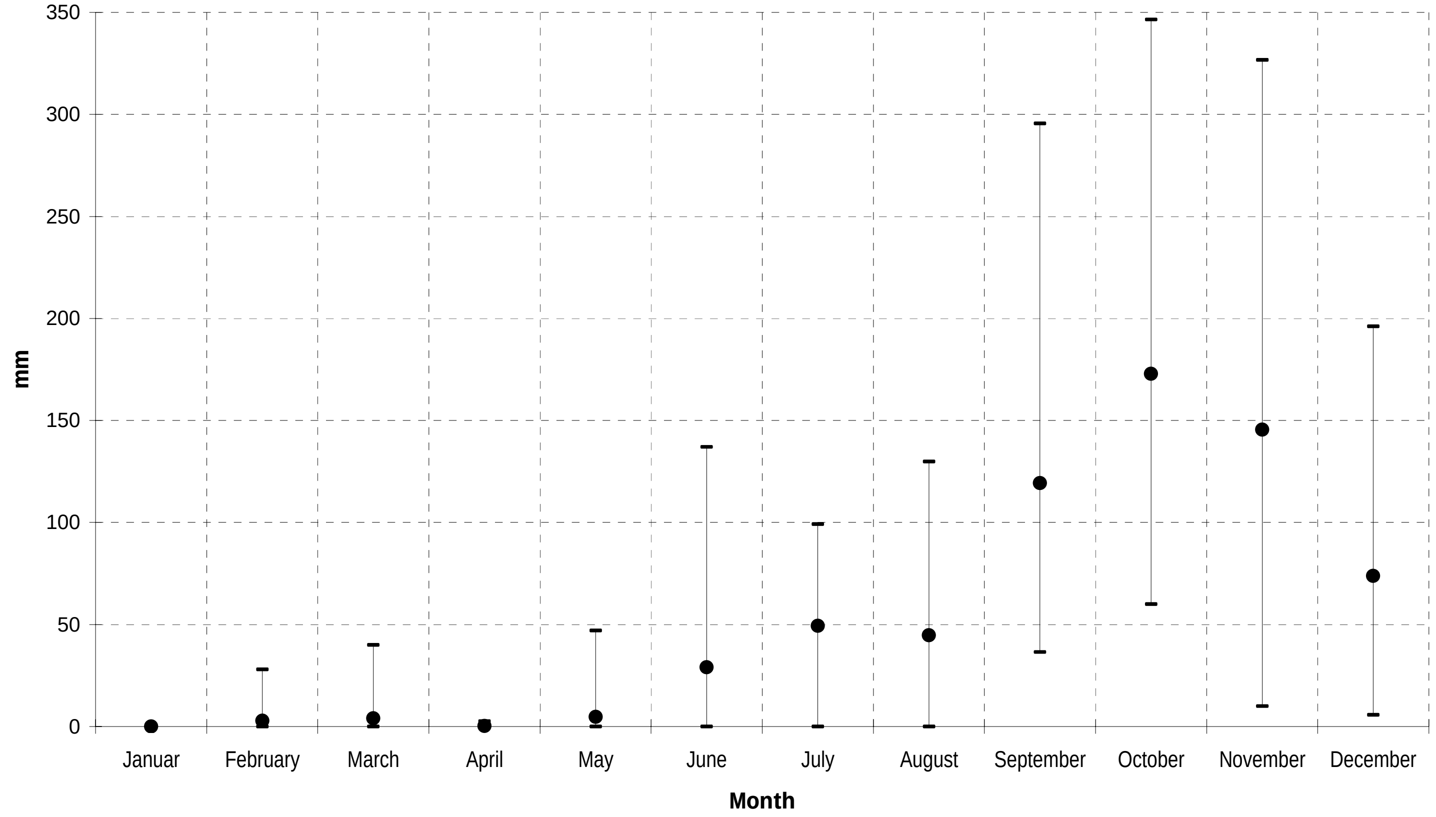

Figure B.3 Average monthly precipitation at Phuoc Huu.

Tabel B-3 Monthly Precipitation (mm)

Station : Phuoc Ha

Year	Month												Total
	Januar	February	March	April	May	June	July	August	September	October	November	December	
1996	0	0	0	0	0	70	16	125	243	222	320	176	1171
1997	0	0	0	2	93	11	159	77	205	135	51	18	751
1998	0	0	3	4	52	161	22	176	312	257	296	191	1472
1999	0	0	0	0	0	19	42	76	106	272	196	144	855
2000	0	0	0	0	0	101	244	134	122	477	268	218	1562
2001	0	0	0	0	0	75	68	99	104	114	44	59	563
2002	0	0	0	0	0	76	26	109	288	74	131	13	718
2003	0	1	1	0	158	56	142	23	170	118	302	18	989
2004	0	0	0	1	145	192	105	89	143	70	7	5	757
2005	0	0	17	1	12	73	163	29	257	189	51	199	989
2006	0	11	26	2	43	113	53	148	339	146	5	19	904
Maximum	0	11	26	4	158	192	244	176	339	477	320	218	
Average	0	1	4	1	46	86	94	98	208	188	152	96	**975**
Minimum	0	0	0	0	0	11	16	23	104	70	5	5	

Notes:

- Driest year: 2001
- Wettest year: 2000

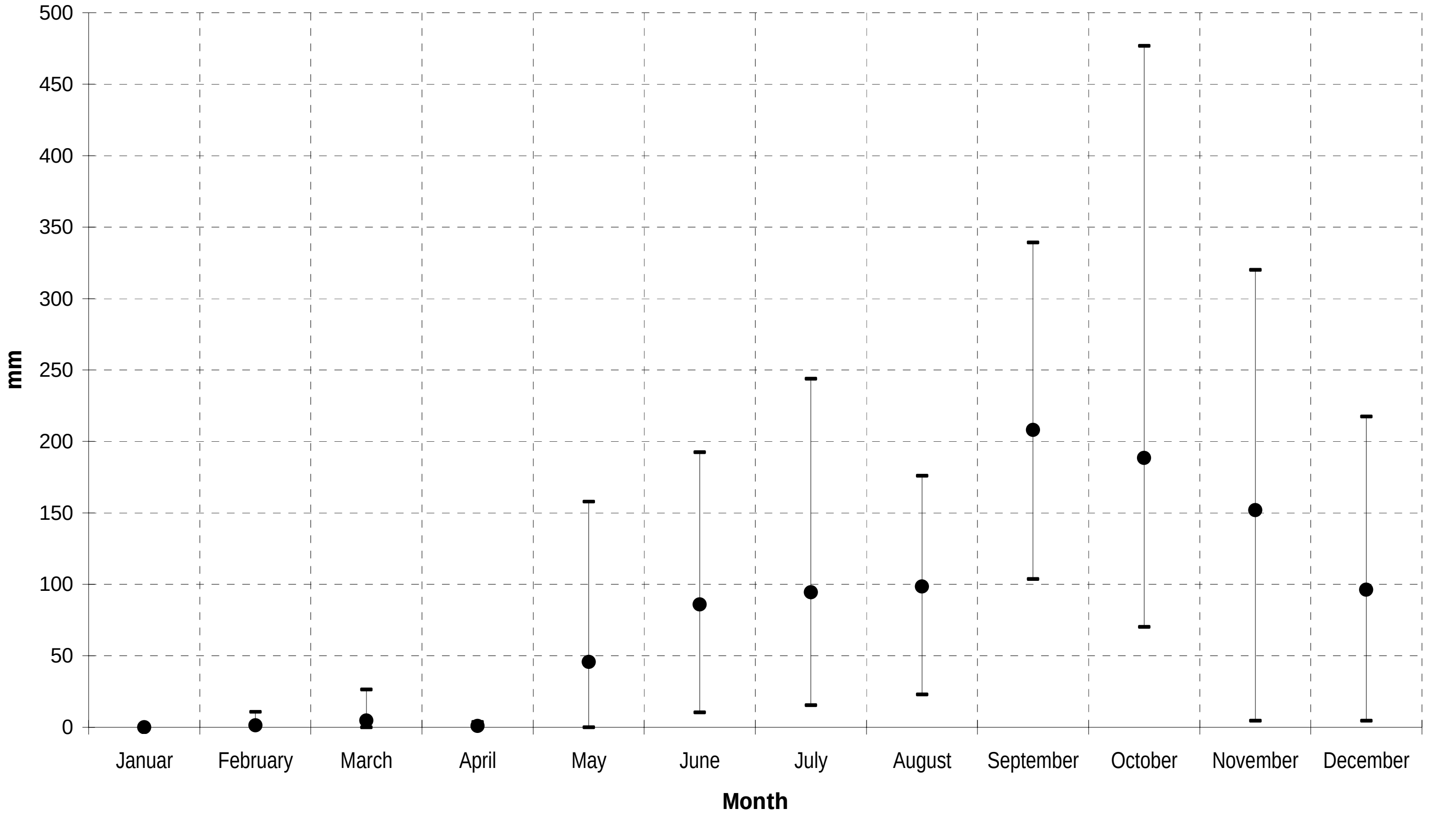

Figure B.4 Average monthly precipitation at Phuoc Ha.

Tabel B-4 Monthly Precipitation (mm)

Station : Nhi Ha

Year	Month												Total
	Januar	February	March	April	May	June	July	August	September	October	November	December	
1985	1	18	0	92	79	14	43	16	211	195	0	0	670
1986	0	1	0	0	50	81	111	185	143	101	87	171	930
1987	0	0	5	36	28	44	58	35	354	53	224	20	855
1988	0	0	0	1	41	73	79	18	237	187	80	4	721
1989	0	0	33	0	85	61	45	119	190	121	64	-	717
1990	0	0	0	3	39	87	57	98	166	125	135	-	708
1991	0	0	98	6	1	164	44	26	384	108	30	6	868
1992	0	0	0	4	32	92	155	233	145	246	26	18	951
1993	0	0	0	4	19	0	113	48	188	105	77	135	689
1994	0	0	0	1	23	162	47	124	163	107	16	47	690
1995	0	0	1	1	73	58	150	85	387	36	58	20	870
1996	3	0	0	4	248	78	32	48	149	164	209	188	1122
1997	0	0	0	2	93	11	107	68	206	145	65	13	708
1998	0	0	3	4	52	140	19	96	225	286	283	159	1267
1999	8	0	4	110	78	49	41	33	69	273	202	130	997
2000	4	1	0	24	74	107	51	53	73	403	262	230	1281
2001	1	0	79	21	252	65	79	96	139	91	72	53	946
2002	0	0	0	29	64	15	8	126	187	170	171	16	785
2003	0	0	0	0	161	25	105	13	115	166	411	13	1009
2004	0	0	0	22	103	104	8	34	53	81	16	-	420
2005	0	7	0	0	0	66	123	21	175	157	49	200	798
2006	0	0	48	0	18	39	57	26	257	192	4	14	654
Maximum	8	18	98	110	252	164	155	233	387	403	411	230	
Average	1	1	12	17	73	70	70	73	192	160	115	75	**858**
Minimum	0	0	0	0	0	0	8	13	53	36	0	0	

Notes:

- Driest year: 2004
- Wettest year: 2000

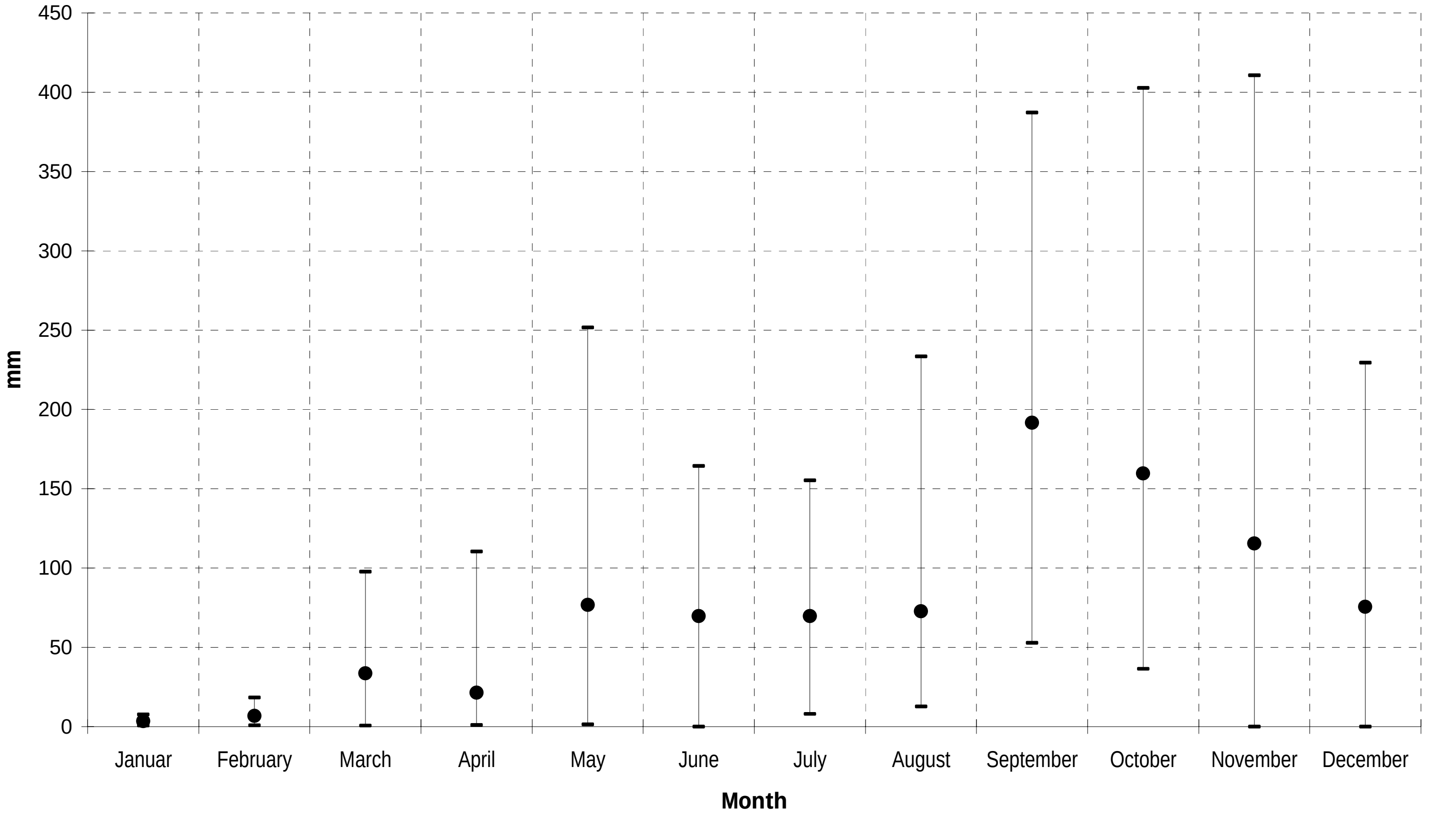

Figure B.5 Average monthly precipitation at Nhi Ha.

Tabel B-5 Monthly Precipitation (mm)

Station : Mua Quan The

Year	Month												Total
	Januar	February	March	April	May	June	July	August	September	October	November	December	
1979	0	0	0	0	0	0	0	0	0	0	508	43	551
1980	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	104	0	21	25	138	0	284	0	570
1982	0	0	135	20	40	141	0	16	89	38	15	0	493
1983	0	0	0	0	0	0	0	0	132	247	56	0	435
1984	0	0	21	0	122	3	64	120	63	69	131	38	630
1985	0	2	0	54	63	7	41	2	237	143	75	69	693
1986	0	0	0	0	62	79	42	134	111	107	118	126	779
1987	0	1	3	17	12	33	73	23	262	43	171	15	652
1988	0	1	0	0	57	69	41	9	118	185	94	8	581
1989	0	0	16	4	131	60	36	68	151	129	53	3	652
1990	0	0	0	0	38	60	53	134	39	85	132	1	542
1991	0	1	114	5	32	161	54	35	212	167	28	0	808
1992	0	0	1	0	30	102	110	136	43	246	18	9	694
1993	0	0	5	0	31	38	71	9	184	92	83	109	621
1994	4	0	0	0	3	156	40	64	177	141	32	52	670
1995	0	0	0	0	21	75	152	51	270	65	107	25	765
1996	0	0	5	9	253	108	5	79	201	261	172	235	1328
1997	0	0	0	0	144	7	115	58	143	112	72	13	663
1998	1	0	2	0	35	215	25	96	269	284	359	158	1442
1999	1	1	3	77	121	11	46	69	91	315	257	136	1127
2000	7	1	0	39	48	96	60	27	64	332	306	275	1254
2001	3	0	46	25	163	45	13	81	72	94	55	51	648
2002	0	0	0	16	71	30	23	145	165	80	126	14	670
2003	0	0	3	0	90	23	27	21	84	156	366	20	788
2004	0	0	0	0	140	195	7	45	29	99	14	5	533
2005	0	0	9	0	0	34	40	38	87	163	63	289	722
2006	13	0	44	19	54	21	60	59	215	186	10	34	714
Maximum	13	2	135	77	253	215	152	145	270	332	508	289	
Average	1	0	15	10	67	63	43	55	130	137	132	62	**715**
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	

Notes:

- Driest year: 1983
- Wettest year: 2000
- Rainfall year 1980 is excluded, 2374 mm.

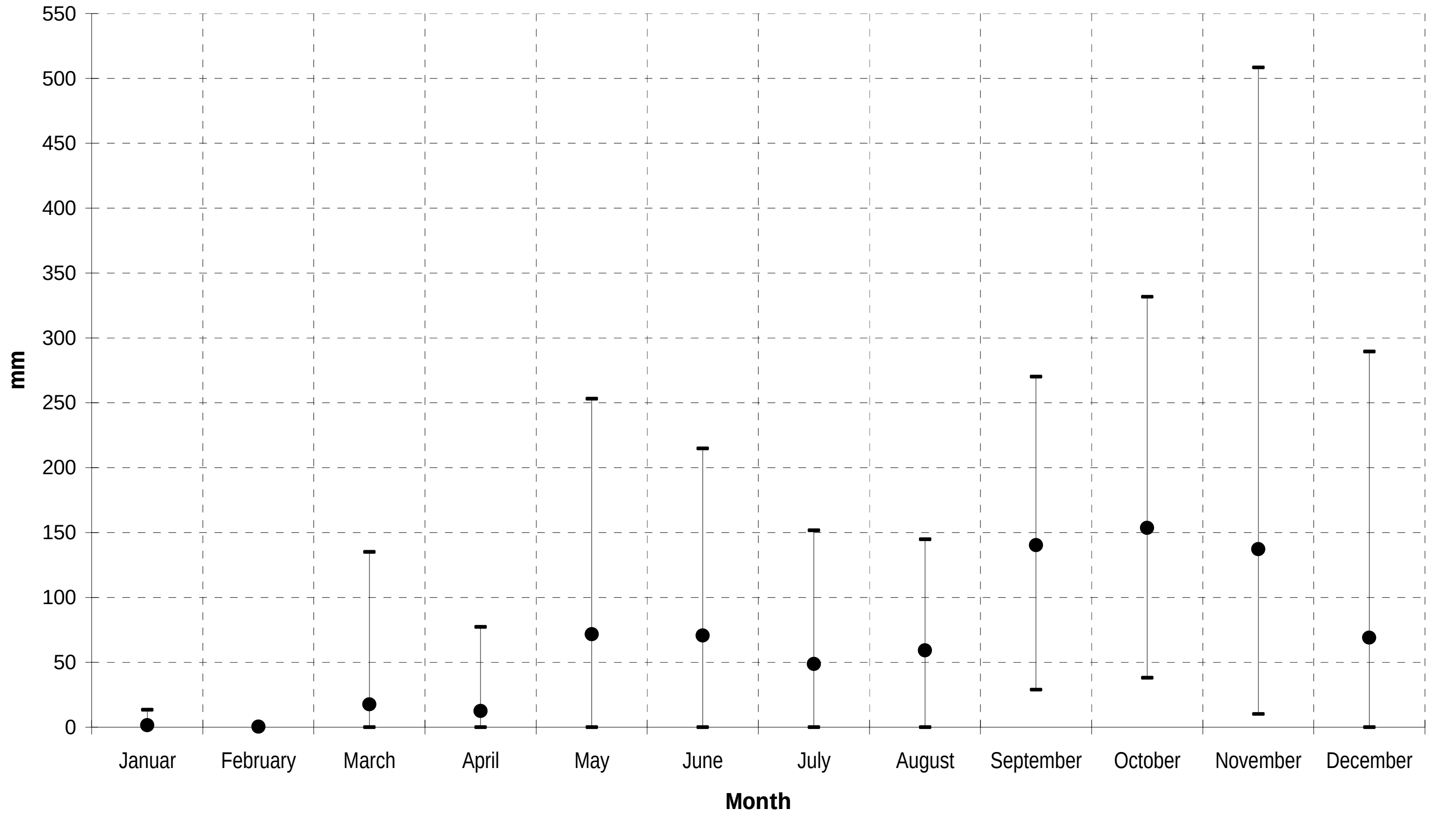

Figure B.6 Average monthly precipitation at Mua Quan The.

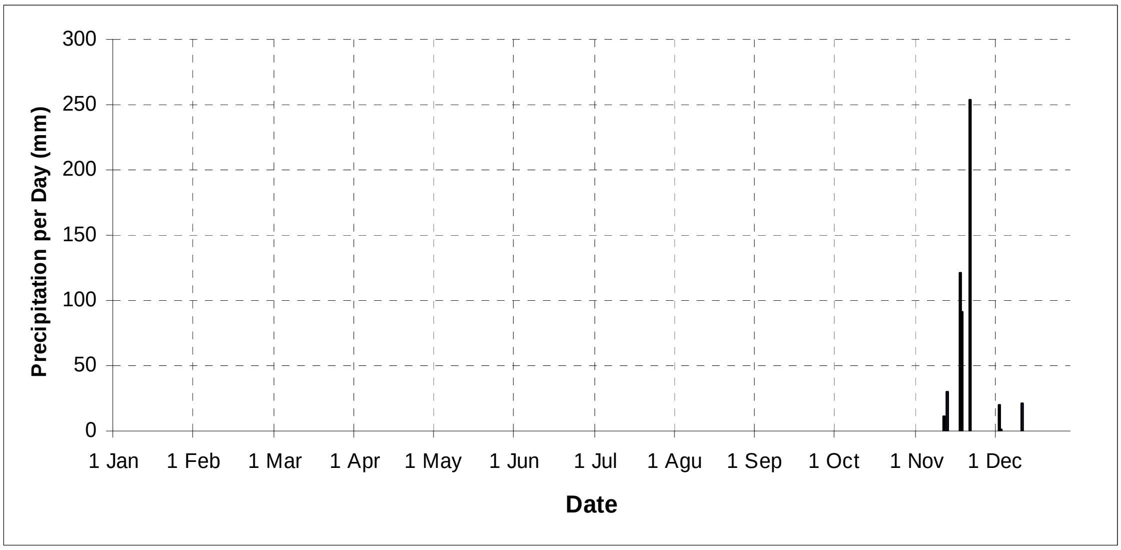

Figure B.7 Daily precipitation at Mua Quan The, year 1979.

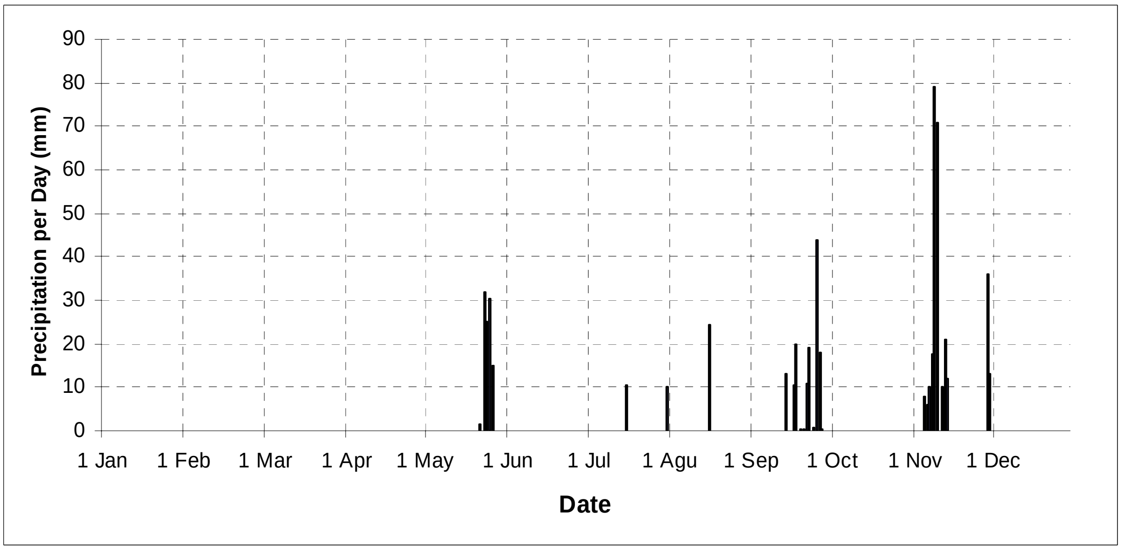

Figure B.8 Daily precipitation at Mua Quan The, year 1981.

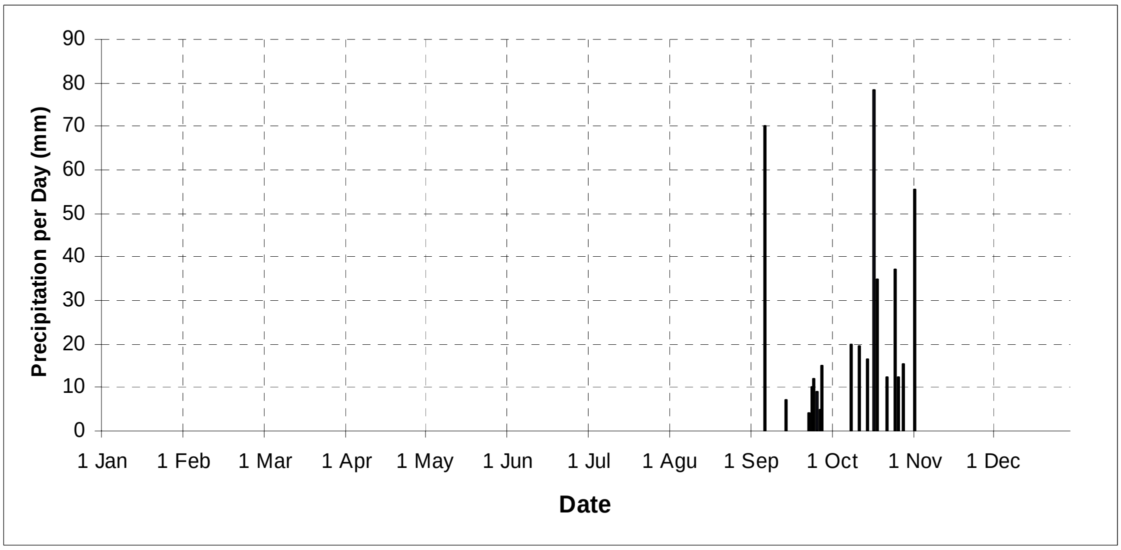

Figure B.9 Daily precipitation at Mua Quan The, year 1983.

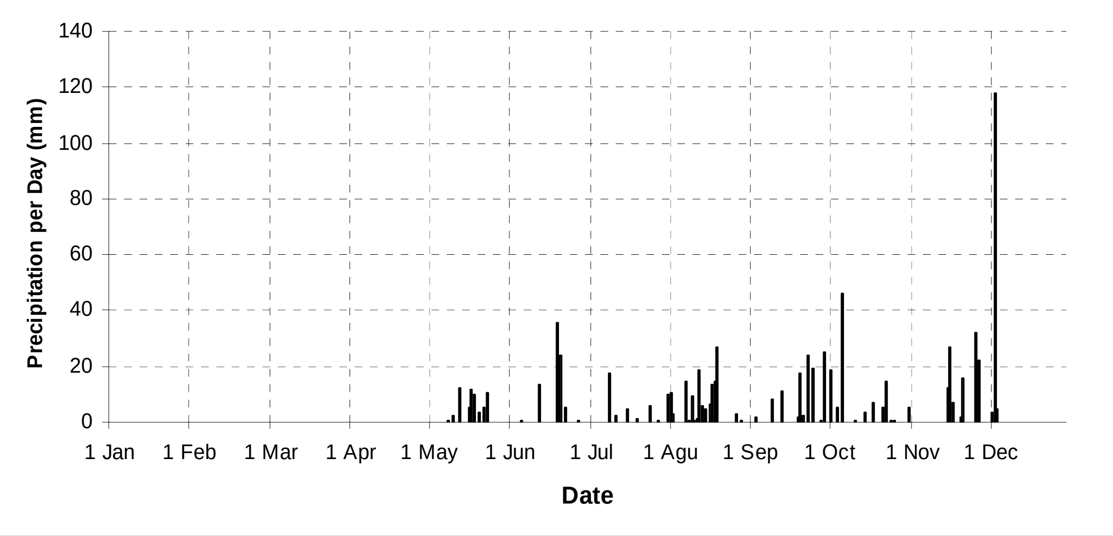

Figure B.10 Daily precipitation at Mua Quan The, year 1986.

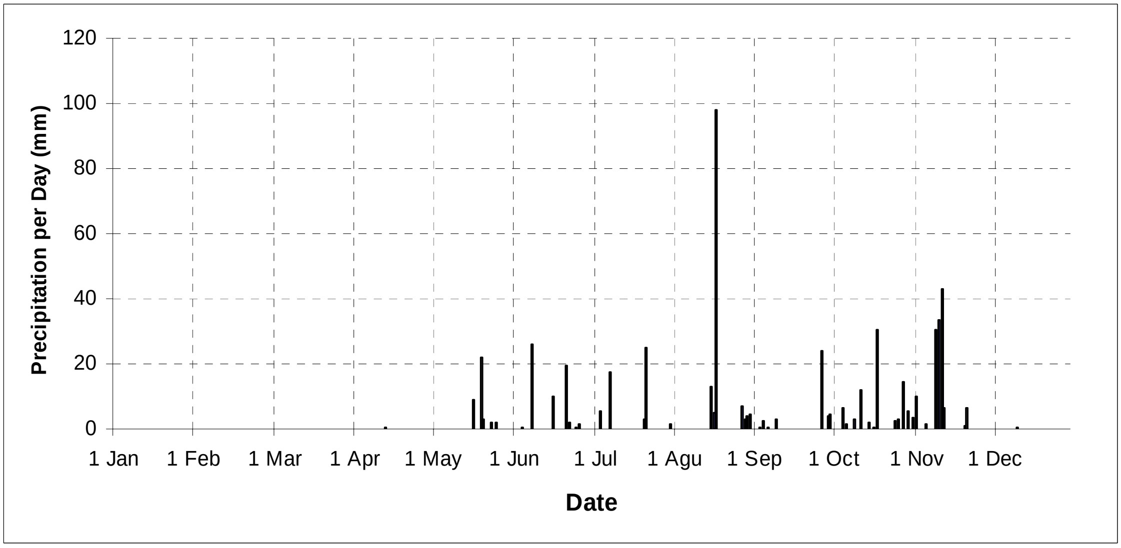

Figure B.11 Daily precipitation at Mua Quan The, year 1990.

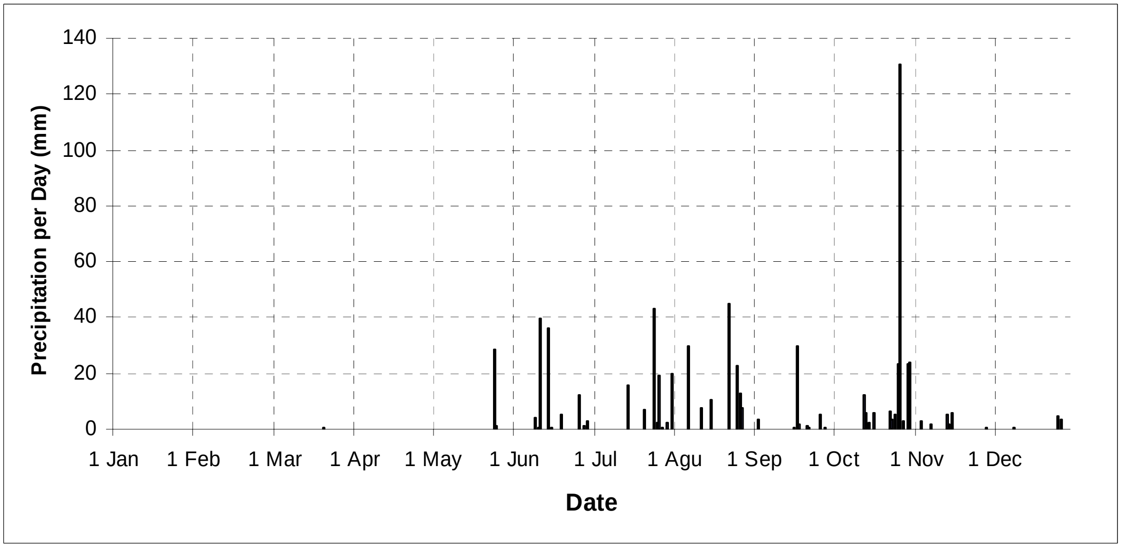

Figure B.12 Daily precipitation at Mua Quan The, year 1992.

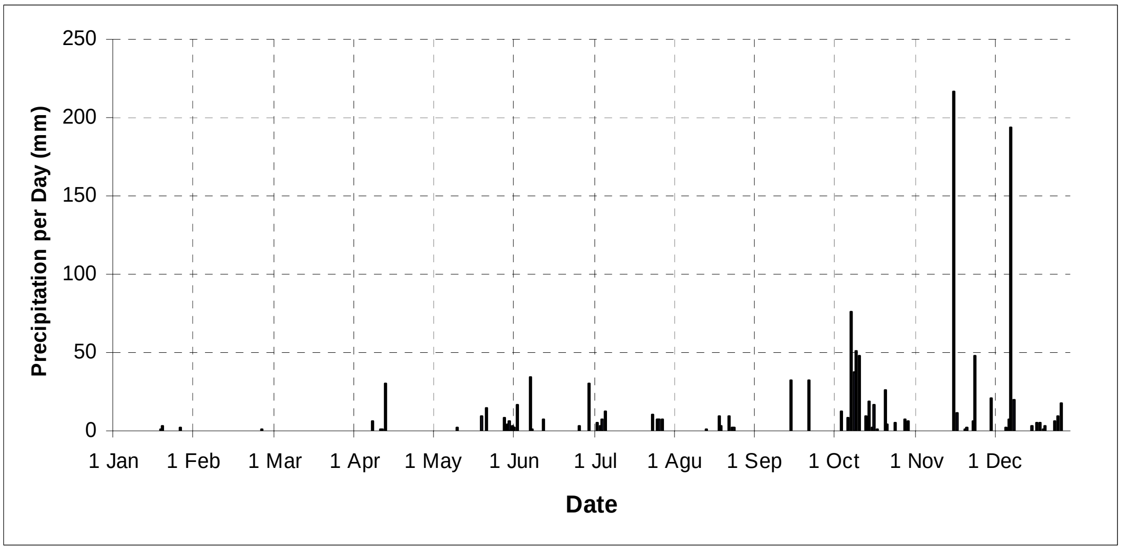

Figure B.13 Daily precipitation at Mua Quan The, year 2000.

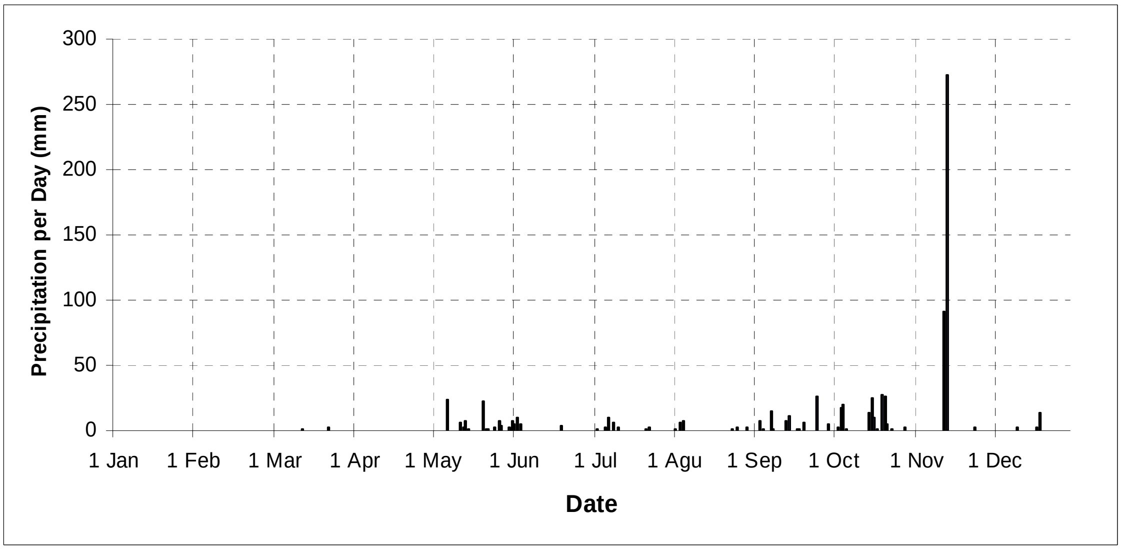

Figure B.14 Daily precipitation at Mua Quan The, year 2003.

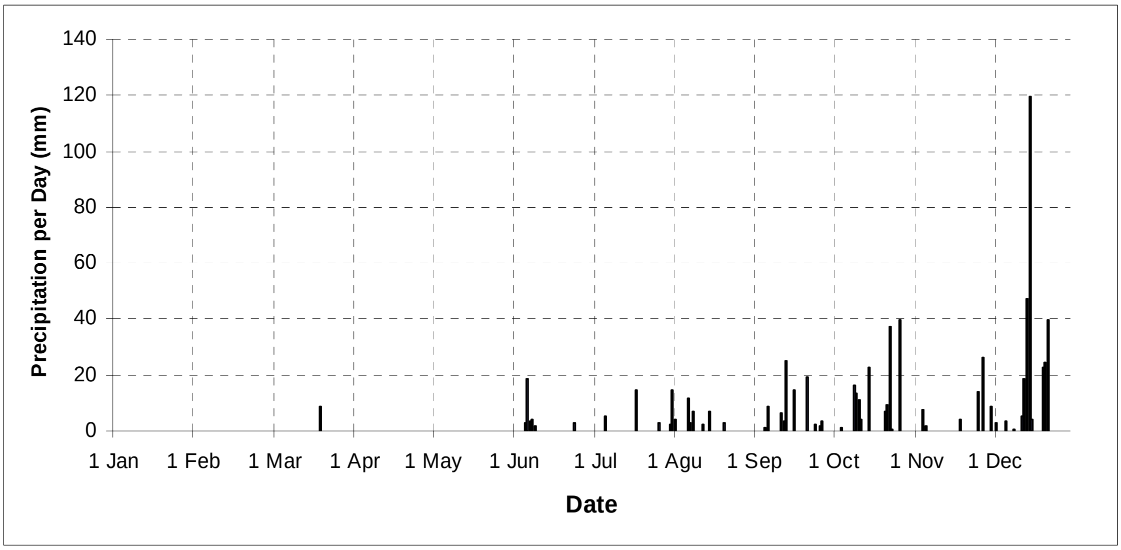

Figure B.15 Daily precipitation at Mua Quan The, year 2005.

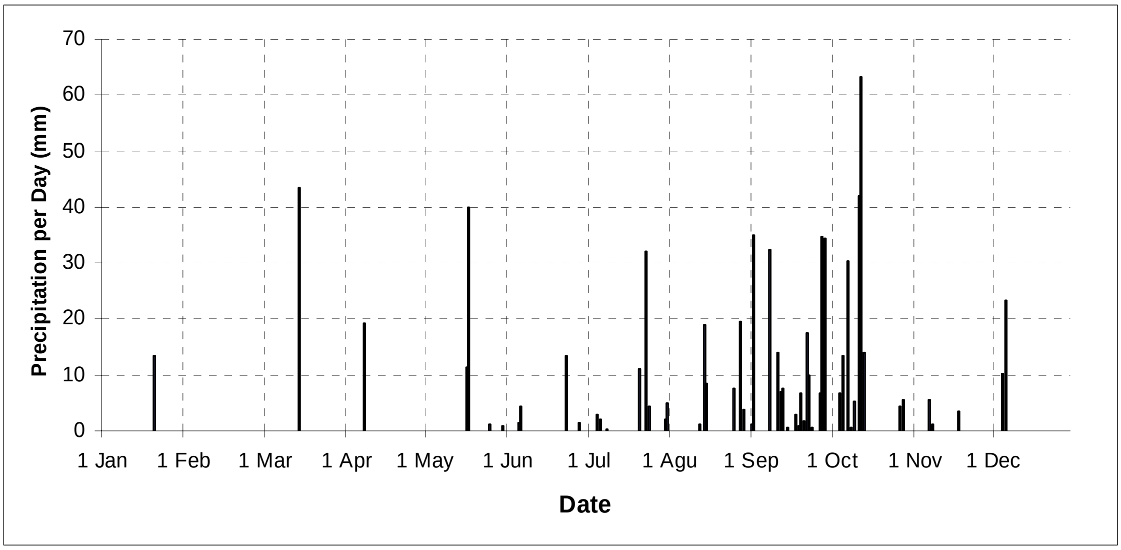

Figure B.16 Daily precipitation at Mua Quan The, year 2006.

Appendixes **C**

Groundwater Level Data

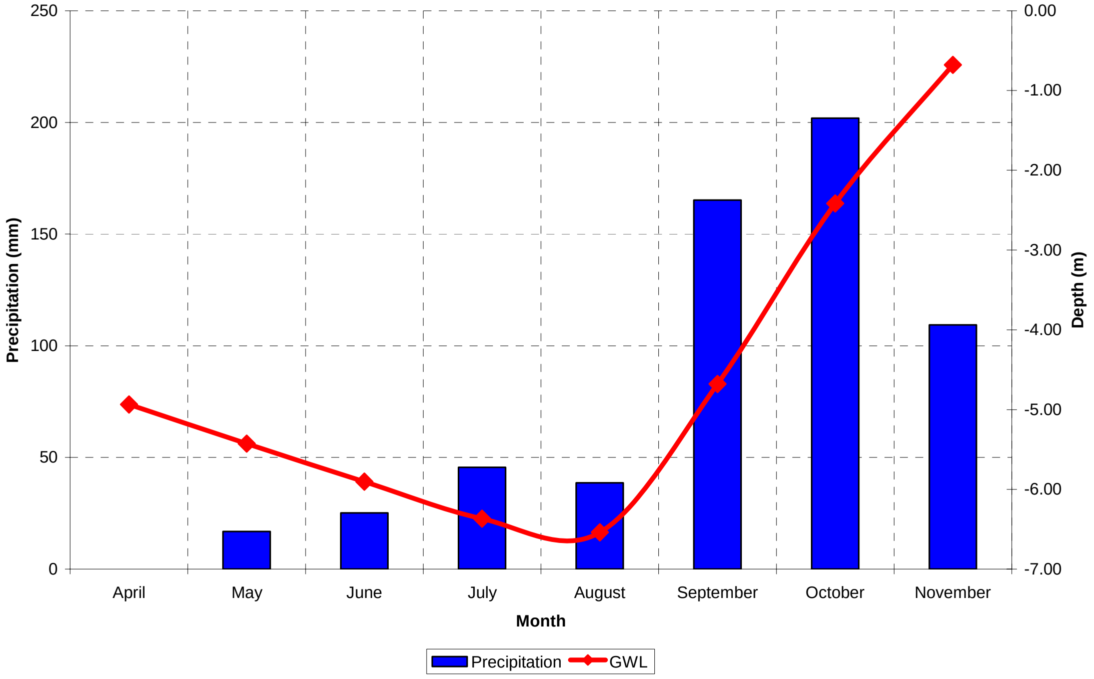

Figure C.1 Monthly Precipitation (year 2005) vs Groundwater Level at Point LKPN02.

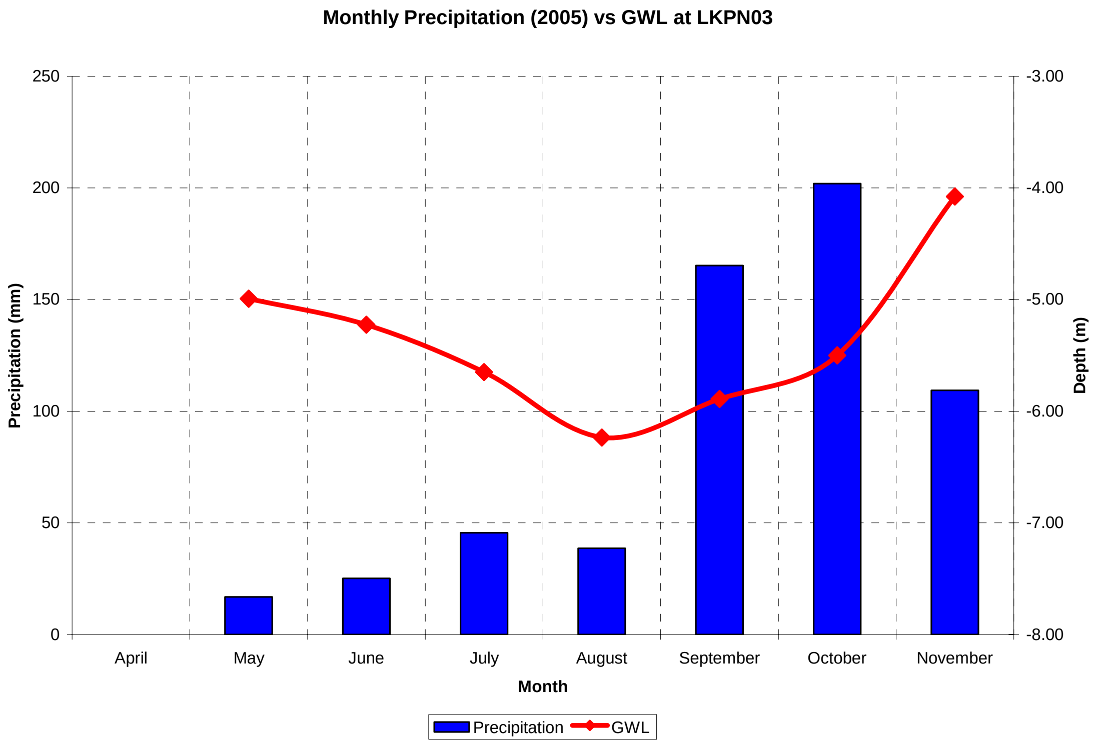

Figure C.2 Monthly Precipitation (year 2005) vs Groundwater Level at Point LKPN03.

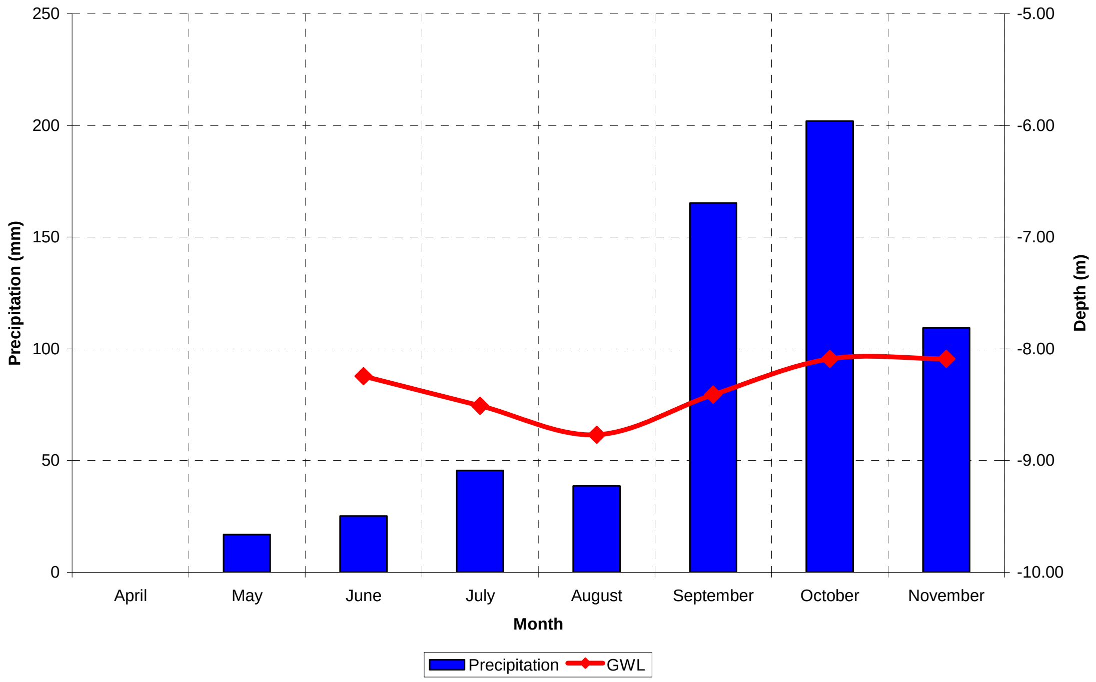

Figure C.3 Monthly Precipitation (year 2005) vs Groundwater Level at Point LKPN04.

Appendixes D

Field Visit

According to the field visit schedule, it should actually start from Monday, the 20 August 2007 till Friday, 24 August 2007. Since my flight from the Netherlands was on the 19 August in the early afternoon, I arrived on the next day at 11 a.m. in Ho Chi Minh City. There I had to wait for the next domestic flight to Na Trang which was at 3 p.m. The flight from Ho Chi Minh City to Nha Trang took 40 minutes. From Nha Trang airport to the resort where we stayed needed one and half hours by car. Therefore I reached the resort at about 5 p.m and missed the first field visit. At the reception resort I met Marieke (Royal Haskoning), Peter (Westerveld), and Thie (a Vietnamese engineer and translator).

F.1 Day 1 (Tuesday, 21 August 2007)

On the first day, we started from the resort at about 7 a.m. to the project site by a minibus. Before we went to the project site and do some infiltration test, we bought two cans and filled those with full of water. A can has a volume of 30 liters.

Figure F.1

Figure F.2

The nearest point at the site project, which can be reached by a four wheels, is the temple (see **Figure F.1**). It is located at the end of the “main road”. At this place, we met local farmers. At the first look on the environment, we may see stone hills and local plantations. According to a local farmer, in the past there were trees on the hills. However, in the 1980s, those trees were cut out for economics purposes and remained almost bare till nowadays. The stones were also explored for construction building material. Existing local plantations are beneficial for medicine and charcoal which can be sold in the market. The mentioned local plants can be seen in **Figure F.2**. The dry seed cost 15,000 Vietnamese NDong (VND) per kg. This plantation is supported by the forestry department. One of this plant needs 3 years to grow up to its ripe stage. At this period, the stem can reach a diameter of about 15 cm. Sometimes farmers let this plant grow to its mature till 10 years. When it can be harvested, 1 kg of leaves can be sold for 25,000 VND. If the plant is big enough, it can be used as charcoal with 3,000 VND per kg. Regarding their water supply, this farmer gets his water from a village where he can buy it for 40,000 VND per cubic meter. Otherwise, he may also receive water where he pays 50,000 VND per cubic meter.

To go to the planned contour trenches and sand dam location, we walked from the temple towards the creek. At some points, especially the roads, we could see soil erosion. During the walk we could also see some cattle as well (see **Figure F.3)**. Everywhere we could see sandy soil as the soil surface (see **Figure F.4**).

Figure F.3

Figure F.4

We also went to a farmer, who lived next to the creek (see **Figure F.5**). This farmer had his own farming land, which at that time was already ploughed (see **Figure F.6**). He usually plants corn and beans. The farmer who had been living there for 5 years, own 80 cattle consisted of goat, cow, and sheep. He showed us a shallow well where he got his water supply for both, irrigation and cattle. From this well and others upstream he could manage the water consumption for his cattle (see **Figure F.7**). In the rain season, this well will be flooded. He observed the maximum water level in the creek about 1 to 1.5 m above soil surface. We could also see some different plants like papaya, mango and Aloe Barbadensis Mill (see **Figure F.8**).

Figure F.5

Figure F.6

Figure F.7

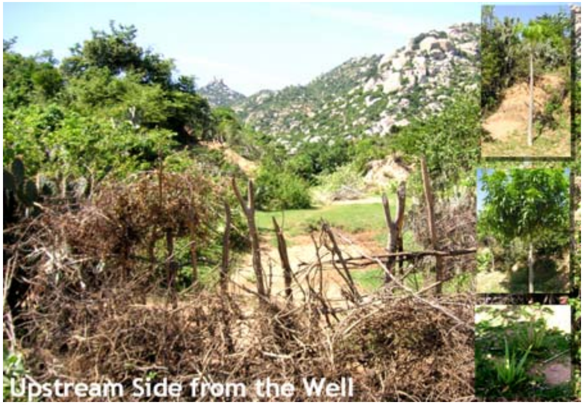

Figure F.8

We continued our walk to the downstream on the south part of the creek (see **Figure F.9**). The creek got narrower and the rockier surface could be seen clearly. We went into the creek and walked till the narrowest point where we could see some debris deposit. There we notice the location as a potential for the first sand dam (see **Figure F.10**). Further downstream, we also saw sand deposit, which was predicted to be washed out from the upstream during the wet season.

Figure F.9

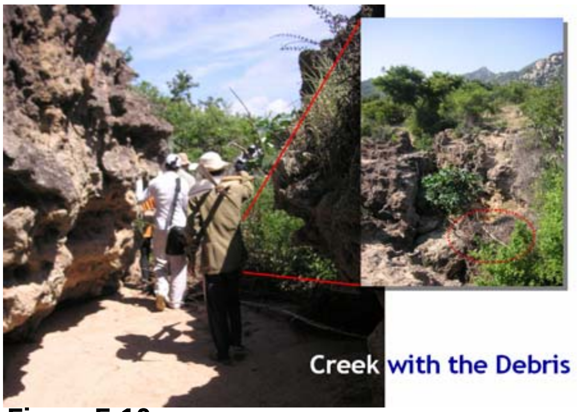

Figure F.10

On the other side of the creek, we could see a large scale of prepared farming landscape (see **Figure 10**). Annually, the soil surface used to be ploughed using heavy machine before the rain season starts. The excavated soil is pushed up to the side with all its debris. Furthermore, "furrow irrigation" was found at this site. It can be seen on **Figure F.11**, where the landscape is likely to a man made wave terrain. Bushes and cut trees were on the top of the furrow whereas grasses on the lower part. The furrow was diagonal to the contour.

Figure F.11

Figure F.12

At this "furrow irrigation" area, I did the first infiltration test. (see **Figure F.13**). The soil was dig to a depth of about 90 cm and diameter of 30 cm at the top and decreased in depth. From the soil surface to a depth of 60 cm, we may see loose sandy soil, and from 60 cm below, sandy soil combined with gravel. Since there was no water source in the vicinity, Thie, our Vietnamese translator had to call the farmer to bring the can to our location. After about 15 minutes, the farmer could bring one can with his motorcycle. However, he could not manage to bring the other one. Therefore the infiltration measurement was only once and in a short time. The hole could be fully filled with the water in the can. There I measured the water drawdown of 40 cm needed about 6 minutes or equal to 6.7 cm per minute. This high rate seemed to be fit to the initial dry condition of sandy soil. I waited the drawdown till it was dried out. Then I took three samples by using a 7 cm long pvc pipe and diameter of 4.5 cm. I weighed those samples and afterwards put them beneath the sun. However, when it came to the early afternoon, the wind blows in a very high speed. Thus, the taken soil samples could not be dried out completely in the field since it would be blown away. Furthermore, I took them to the Netherlands, dried out using a microwave and weighted again.

Figure F.13

Since the infiltration test depended strongly on water availability, in the future the test itself should be near a water source. Fortunately, there is an existing reservoir at the project site. However, the exact location for the test had not been determined.

F.2 Day 2 (Wednesday, 22 August 2007)

In the morning, I went to the location of the existing dam. From the temple, together with a local farmer by motorcycle, I went to search a suitable point for infiltration test. Straightforward, it was not easy to find one point with little vegetation and still near to the dam and also in regard to compaction. After some ride around the dam, I chose the location next to the dam which can be seen **Figure F.14**. This point seemed to me to be the most appropriate for the infiltration test. The first test was done in series, 5 holes with spacing that was equal to the depth. It means the spacing between holes with depth of 20 cm was 20 cm to the next hole which is 40 cm deep. The holes had a diameter of about 20 cm. The illustration of the longitudinal profile of the infiltration test can be found in **Appendixes G**. To dig such series of holes needed at least about 45 minutes work. In the future, to ease the work and make smaller holes, it is best to use an auger.

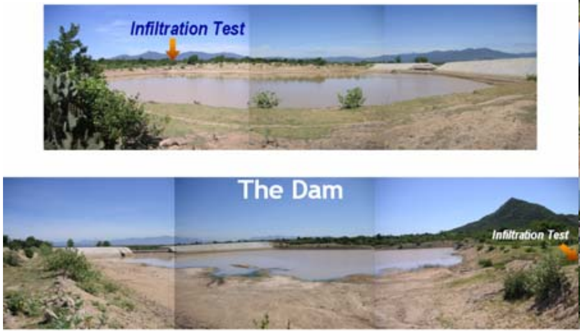

Figure F.14

Figure F.15

The infiltration itself went as expected with sufficient results. The numbers of cans used were 4. At the beginning of the test was the most demanding of water. Almost all cans were empty after the first filling up. Every time when the water in one can is less, then the local labor had to go into the reservoir to fill it with water. This was quite some hard work regarding the amount of water had to be carried from the available surface water to the test point which was about 40 m. The mechanism of this test was first noting the drawdown of one hole and directly poured with water till it reached the top level or soil surface. This measurement was done for about 50 minutes. The results of this test can be found in **Appendixes G**.

After the infiltration test, I also wanted to get a sample of vertical soil moisture. I used a 60 cm pvc pipe, with a wooden piston I made from the Netherlands. After a few centimeters hammering, the pvc pipe could enter the soil, but unfortunately reached only a depth of about 20 cm (see **Figure 15**). When we realized that hammering could not be continued, we tried to pull out the pipe. This was quite some hard work since the pipe apparently got stuck in the soil. Therefore, we had to dig around the pipe and shake a bit to ease the pull out. Eventually, when the pipe came out, it was bent. Therefore, in the future it is suggested to prepare a harder pipe material than pvc.

After lunch, a second series of holes were dig. This time, 5 holes but with “doubled” spacing. For example, between the hole of 20 cm and 40 cm deep, the spacing was 40 cm. Moreover, the spacing between the hole with 40 cm and 60 cm deep was 80 cm and so on till the depth of 100 cm. This measurement was done longer than the first measurement which was for one hour and ten minutes. The results of this test can also be found in **Appendixes G**.

F.3 Day 3 (Thursday, 23 August 2007)

In the morning, Marieke had to present the progress of the planned structures to be built (see **Figure F.16**) at the Phuoc Nam commune hall. Marieke presented shortly the proposal of the planned structures with Thie as the translator. After the presentation, there were questions and discussion session. Since the discussion was in Vietnam language, it was a bit difficult to follow the detail of the issues. However, as far as I understood, there were 2 issues raised by the locals. The first one was about the implementation of contour trenches. To a local, it seemed to be impossible since there exists hard or compacted layers at the soil surface and furthermore if the soil is excavated, and deposited at the upstream part of the trenches, thus it will block runoff into the trench. This question was answered by Peter explaining that by digging the soil surface to 1 m, it will reached to a depth where water may infiltrate rapidly. The soil deposit was misunderstood, since in realization it will be heaped at both ends of the trenches. The second issue was about the cattle excrement. The farmers usually sell their cattle excrement, whereas Peter suggested to keeping them for fertilizer. The fertilizer was proposed to be put in the trench. Before the end of the discussion, it was said that the land owner agreed to provide their land for this pilot project. The discussion ended at about 10 a.m.

Figure F.16

In the afternoon, I would like to take another infiltration test at a different location near the dam. However, there was no local labor available and therefore the measurement was cancelled. To ascertain the infiltration test in the future, there are 3 practical things to remind when asking local labor for help. First, we should provide the local labor with lunch. Second, they should be confirmed at least one day before to make sure that they do have the time and not work for others. To reach them, they do have mobile phone, but because of the different language, it was then difficult to arrange and explain this measurement. However, drawings would help much to understand our need. Third, some of them might be skilled labor (construction labor). This means that the payment will be higher. The payment for a skilled labor according to Thie ranged from 80,000 to 100,000 VND per day or about 2 to 4 Euros per day and should be agreed in advanced.

F.4 Day 4 (Friday, 24 August 2007)

On the last day, there was not much we could do. Since there is no local labor available for the infiltration test and the time was short because of our flight back to Ho Chi Minh City in the afternoon, we only spent tracking the erosion area to search for another sand dam area. We went from the downstream erosion area to the upstream. During our walk to the upstream, 2 surface water storages and 1 depression area could be seen (see **Figure F.17**). The first water storage looked like a small dam, consists of stones covered by concretes. In the middle of the dam, there is an overflow. Near to the first water storage, a second one could be found. This one looks like an excavated land with bush fence around it (see **Figure F.17**). These two existing man made water storages appeared as an effort by the locals to store rain water. For us, however, it seemed to be less to provide local with water. A depression area could be found as well (see **Figure F.18**). This area is filled with grasses and shallow surface water. On the downstream part of this depression area, there was dry plants growth. The dry plants were about 3 m high. At this point, we measured the width and height of the planned sand dam. The measured width about was 30 m and height of 3 m.

Figure 17

Figure 18

From the depression area, our walk continued to the two planned sand dam point we found on the first day. This time, we measured them to gain an overview of the planned sand dam dimension. We reached the second sand dam point first and walked afterwards to the first sand dam point. The second sand dam point (see **Figure F.19**) was measured to be 8 to 10 m wide and 3.5 m high and the first sand dam area to be 2 m wide and 3 m deep. At the first sand dam location, a wider width measurement was done. The purpose is to design a higher and wider dam to create an overflow to the planned contour trenches which are next to the channel. The width was measured to be 43 m and an extra height of 1.5 m (see **Figure F.20**).

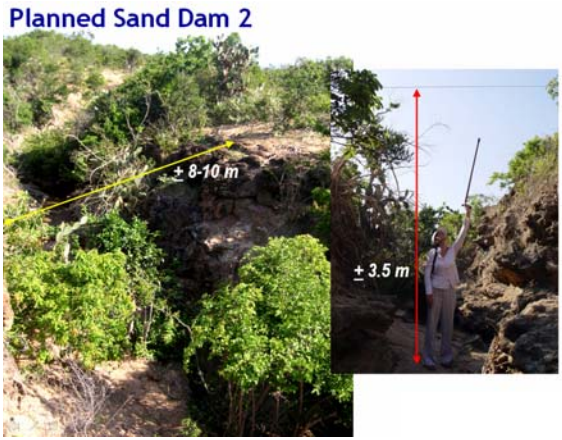

Figure 19

Figure 20

Appendixes **E**

Infiltration Test

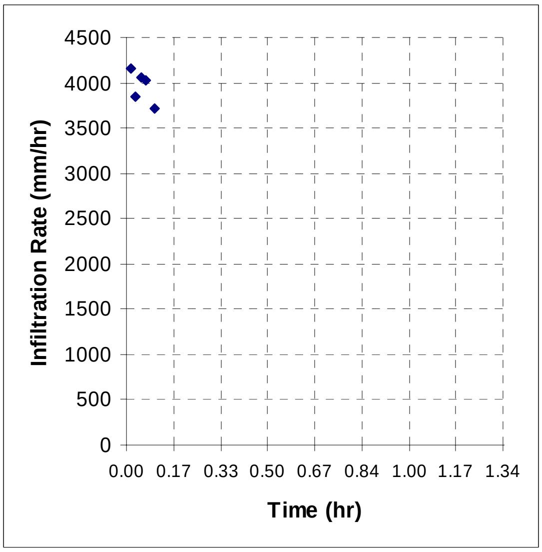

Figure E.1 The first infiltration test result for about 6 minutes.

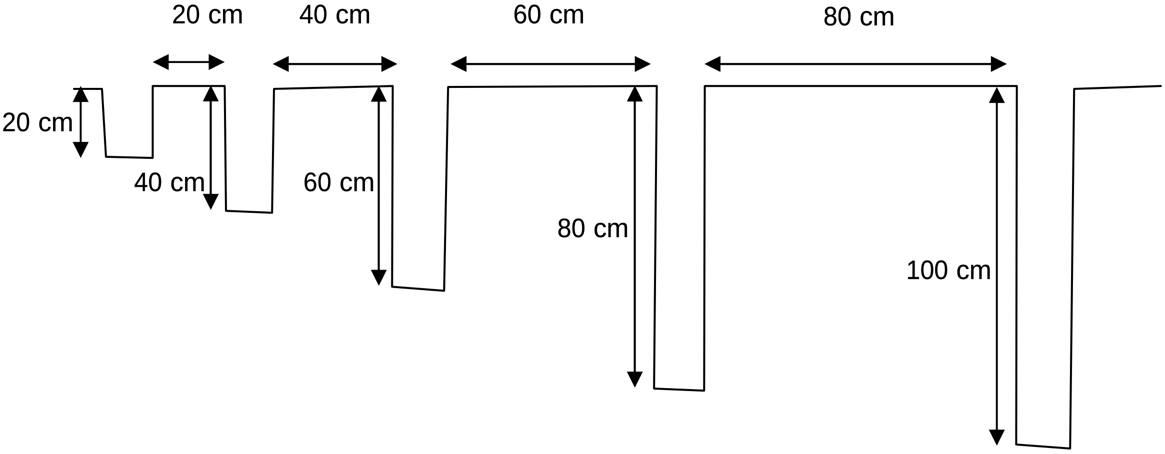

Figure E.2 Longitudinal profile of the second infiltration test.

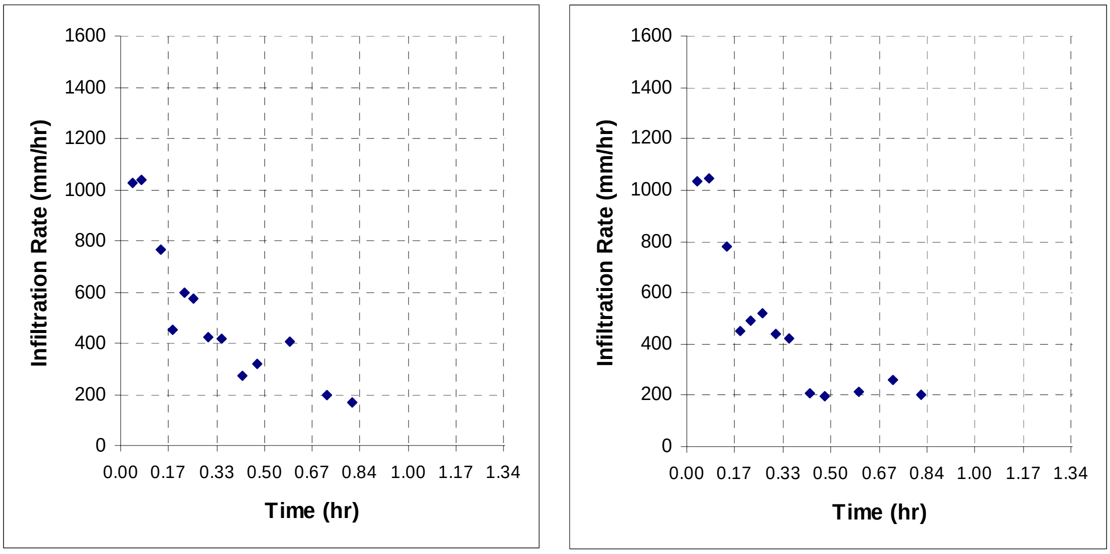

Figure E.3 The second infiltration test on 20 cm deep (left) and 40 cm deep (right).

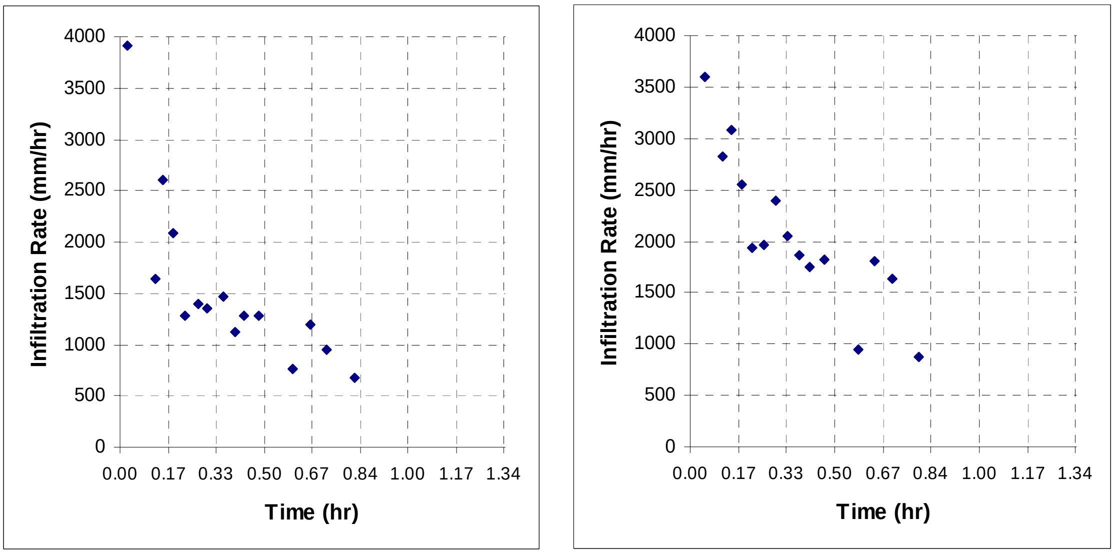

Figure E.4 The second infiltration test on 60 cm deep (left) and 80 cm deep (right).

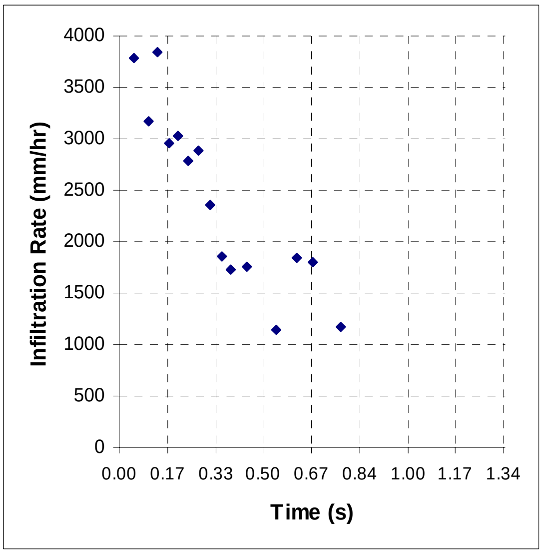

Figure E.5 The second infiltration test on 100 cm deep.

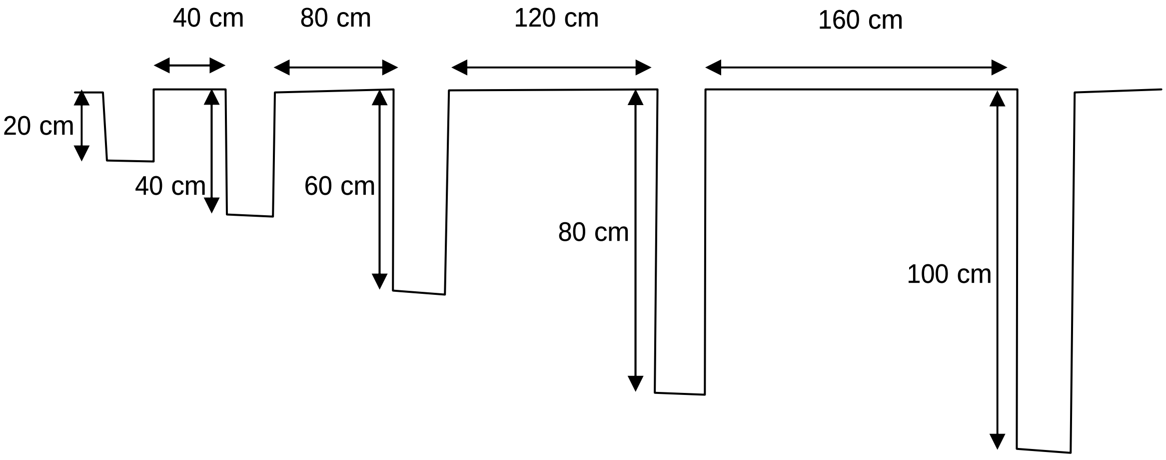

Figure E.6 Longitudinal profile of the third infiltration test.

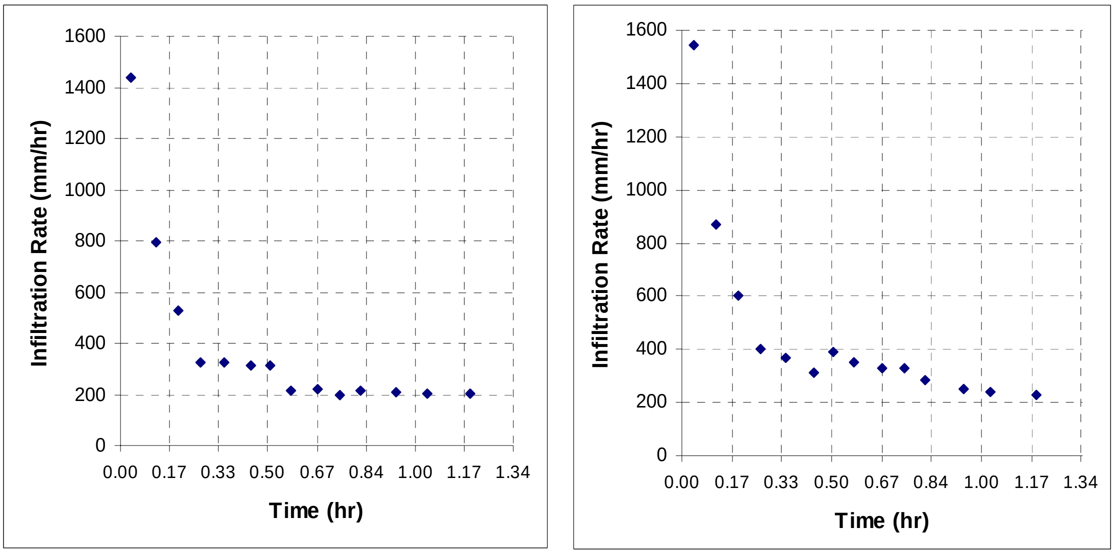

Figure G.7 The third infiltration test on 20 cm deep (left) and 40 cm deep (right).

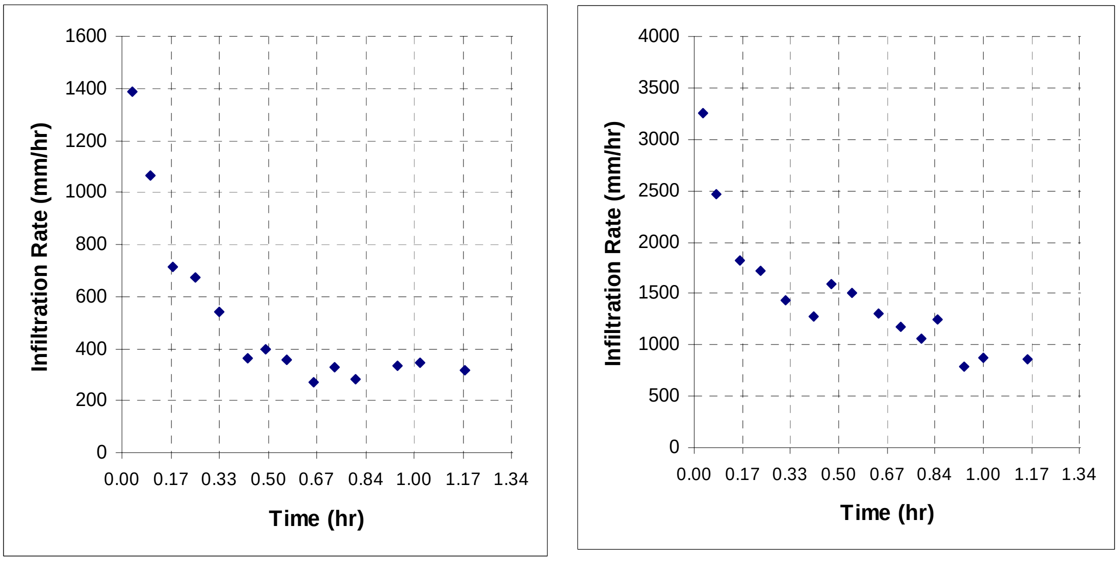

Figure E.8 The third infiltration test on 60 cm deep (left) and 80 cm deep (right).

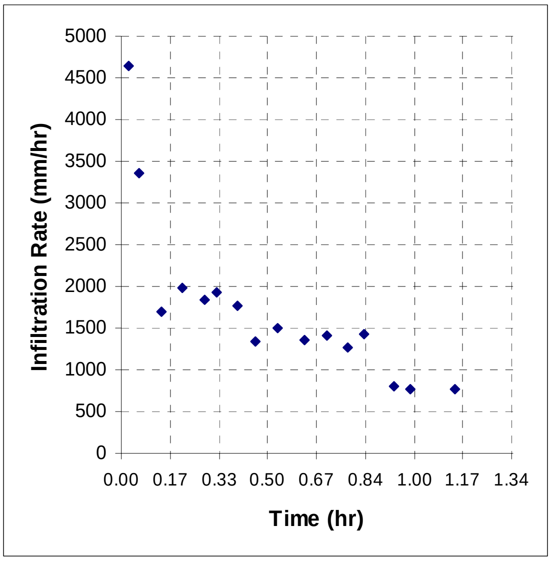

Figure E.9 The third infiltration test on 100 cm deep.