



KTH Land and Water  
Resources Engineering

# **WATER RESOURCES IN THE CULTIVATED UPLANDS OF LAO PDR - A CASE STUDY OF HUAY MAHA VILLAGE**



**A Minor Field Study**

**Anni Billving & Anna Ågren**

**Stockholm 2007**

**TRITA-LWR Master Thesis**

ISSN 1651-064X

LWR-EX-07-28



# **WATER RESOURCES IN THE CULTIVATED UPLANDS OF LAO PDR - A CASE STUDY OF HUAY MAHA VILLAGE**

**A Minor Field Study**

**Anni Billving & Anna Ågren**

Supervisor & Examiner:

**Bo Olofsson** *Professor Department of Land and Water Resources Engineering  
KTH Royal Institute of Technology, Stockholm, Sweden*

Co Supervisors:

**Hans Bergh** *Senior Lecturer Department of Land and Water Resources Engineering  
KTH Royal Institute of Technology, Stockholm, Sweden*

**Peter Jones** *Land Management Adviser Ramböll Natura  
National Agriculture and Forestry Research Institute, Vientiane, Lao PDR*

**Stockholm 2007**





## PREFACE

This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a country in Africa, Asia or Latin America. The results of the work are presented in an MFS report which is also the student's Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. The overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between universities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Office at KTH, the Royal Institute of Technology, Stockholm, administers the MFS Programme for the faculties of engineering and natural sciences in Sweden.

Sigrun Santesson  
Programme Officer  
MFS Programme



## SUMMARY

Shifting cultivation in mountainous, tropical areas has very long tradition in Southeast Asia and many other parts of the world. As long as there is enough land to cultivate with sufficient fallow periods, it is sustainable and favourable. However political reforms have resulted in population increases in many villages in northern Lao PDR, which has led to shorter fallow periods. The steep slopes and intense landuse makes the area very sensitive to soil erosion and land degradation. The Sida-financed Lao Swedish Upland Agriculture and Forestry Research Program (LSUAFRP) are running projects on agricultural development in the area. They are concerned whether the available water resources are enough for the increased population in Huay Maha, both regarding domestic and agricultural use.

The aim of this study is to survey the water resource situation in Huay Maha, a typical village in northern Lao PDR. It is a general study that focuses both on qualitative and quantitative aspects of the water resources. Since no water resource investigations had been done previously, a conceptual model of the water resources were created in order to describe and highlight possible problems and solutions. Interviews with villagers, flow measurements, water sampling and analysis, analysis of GIS data and collecting climatic data are methods that have been used in order to gather information of the water resource situation. Water harvesting methods in use have been studied and improvements and alternatives suggested.

Huay Maha village is situated in a valley surrounded by steep slopes on both sides. The bedrock is dominated by limestone and is likely affected by karst forming processes. Groundwater is not used directly, but the steady flows in the streams all year around indicate a steady discharge of groundwater. The tropical climate with one rainy season allows only one harvest per year. In Phonxay district close to half the annual precipitation falls in August. The rains are then intense and sweep away a lot of the important topsoil. After a heavy rain the streams reach maximum levels quickly and remain at maximum flows for a couple of hours, before the water is transported out of the area. Domestic water is taken from the small streams. There is discontent in all the settlements regarding the domestic water supplies because of muddy water and low flow in the pipes.

Because of the steep slopes the ultimate landuse is forest, but due to poverty the inhabitants have no choice but to cultivate the land they have been allotted. A decrease in soil fertility has been noticed since fallow period was shortened. The combination of steep slopes, short fallow periods, sensitive soils, intense rainfall and unfavourable land use has led to severe soil erosion, causing lower infiltration- and water holding capacity of the soils. The major problem from a water perspective is that the rainfall is concentrated to a short period of time, causing soil erosion and is quickly transported out of the area. Measures for delaying the water discharge out of the area, preferably soil moisture conservation, must be taken promptly. Integrated cropping with trees and crops that covers the ground well and contour trenches or reversed-sloping terraces have been identified as suitable methods to obtain this.



## SAMMANFATTNING (SUMMARY IN SWEDISH)

I stora delar av det tropiska och bergiga Sydostasien lever det urgamla skiftesbruket kvar. Så länge det finns tillräckligt med mark för att kunna rotera med långa intervall är det ett lämpligt och hållbart system. Politiska åtgärder i syfte att minska fattigdomen har orsakat en stor befolkningsökning i många bergsbyar i norra Laos. För att de nyinflyttade ska få jord att bruka i närheten av sina hem har marken omfördelats. Detta innebär att fler människor brukar samma jord och med kortare tid i träda som följd. Sida driver sedan några år tillbaka ett forskningsprogram för jordbruksutveckling i norra Laos där Huay Maha är en projektby. Frågan har väckts om de tillgängliga vattenresurserna räcker till för den ökade befolkningen, både beträffande vatten till jordbruket och för hushållsändamål.

Målet med denna studie är att kartlägga de tillgängliga vattenresurserna i området. Det är en generell studie med kvalitativa och kvantitativa inslag. Eftersom ingen undersökning eller kartläggning av områdets vattenresurser gjorts tidigare kommer en konceptuell modell att göras för att visa på eventuella problem och lösningar. Intervjuer, flödesmätningar, vattenprover, analyser av GIS-data och insamlande av klimatdata har gjorts för att skapa en så komplett bild som möjligt av vattenresurserna i området. Så kallade *Water Harvesting* metoder har undersökts och förslag på hur de kan utvecklas diskuterats.

Huay Maha ligger i en dalgång med mycket branta sluttningar på bägge sidor. Berggrunden består till största delen av kalksten och det är mycket troligt att karst processer har påverkat berget. Det tropiska klimatet med en regnperiod begränsar jordbruket till en skörd per år. Nästan hälften av årsnederbörden i Phonxay faller i augusti. Regnen är då intensiva och spolar bort mycket jord. Grundvatten används inte alls, dricksvatten tas från bäckar på bergssluttningarna. En majoritet av dessa bäckar har vattenflöde året om, vilket tyder på ett kontinuerligt utflöde av grundvatten i området. Efter ett kraftigt regn stiger vattennivåerna i bäckarna snabbt. De höga flödena varar några timmar innan vattnet återgår till normala nivåer. Det råder missnöje bland befolkningen angående att dricksvattnet är lerigt och det är lågt flöde i dricksvattenledningarna.

Ursprunglig regnskog är den optimala markanvändningen på de branta sluttningarna i området, men befolkningen har inget annat val än att odla på den mark de har blivit tilldelade. Bönderna uppger att skörden har blivit lägre än tidigare när de nu har färre fält att odla på. Största delen av området har brantare sluttningar än vad litteraturen rekommenderar för water harvesting metoders tillämplighet.

Den pågående degraderingen av mark och vattenresurser är inte hållbar. Låg infiltration och försämrade lagringskapacitet i jordarna är ett resultat av den extrema erosion som pågår i området. För att bryta denna negativa trend måste åtgärder för att öka infiltrationen och fördröja vattenutflödet vidtagas omedelbart. Integrerat jordbruk med träd och grödor som täcker marken samt olika typer av små terrasseringar och diken är exempel på lämpliga metoder för att åstadkomma detta.



## ACKNOWLEDGMENT

During our work with this Master Degree Thesis we have received help and support greater than we could ever have imagined. Thanks to Sida for financing this Minor Field Study, The Lao Swedish Upland Agriculture and Forestry Research Program (LSUAFRP) for receiving us in Laos and to KTH Land and Water Resources Engineering for examining and supervising along the way.

There are some people who deserve special mentioning. Thanks to Professor Bo Olofsson, our supervisor and examiner at KTH, who has been amazingly helpful. We are grateful for his deep engagement in preparations and fieldwork as well as analysis of data and the process of writing and for all the encouragement. Thanks to Mr Peter Jones, our supervisor in field, who helped with everything from contacts with key people, introduction to the study area and insightful information regarding Laos and Laotians as well as being a great company. Thanks to Mr Carl Mossberg for providing support and encouragement from the very first contact until the end of our stay in Laos.

This study was enabled by the National Agriculture and Forestry Research Institute, (NAFRI), the Northern Agriculture and Forestry Research Institute (NAFReC) and LSUAFRP. Thanks to Mr Sysongkham Mahathirat and Mr Houmchitsavath Sodarak for approving our field study. Our great appreciation to the staff at NAFRI in Vientiane who helped with everything from translations, providing maps and information. Also thanks to Ms Emelie Nilsson who provided us with data and information about Laos before our departure.

While living out in field we received invaluable help and friendship from our translator Mrs Sisopha Phongcharoen, without whom we would have been truly lost! Our warm gratitude and appreciation goes to all the staff at Nam Bo field station, amongst which Ms Chittavanh Keolasy and Mr Khamsonpheng Inthavong have been extraordinary helpful during the fieldwork. A special gratitude is directed towards the villagers of Huay Maha and Pong Pao for their kindness and generosity. You made our visit an unforgettable memory.

We are very grateful for the expert help and advises given by many of the staff working at the Department of Land and Water Resources Engineering at KTH. Thanks to our assistant supervisor Mr Hans Bergh who has been of great help along the way and to Göran Baurne, our opponent. Special thanks to Mr Jerzy Buczak for his kind technical assistance whenever we had problems with the computer and to Joanne Fernlund for help with editing this report.

Finally, we would like to send our warmest gratitude to our families and friends, without whose support we would never have managed! Any mistakes or incorrectness stated in this report is solely due to misunderstandings by the authors.



## LIST OF ABBREVIATIONS

DAFEO	District Agriculture and Forestry Extension Office
DEM	Digital Elevation Model
EC	Electrical Conductivity
FAO	Food and Agriculture Organisation
GIS	Geographic Information Systems
LAO PDR	Lao People Democratic Republic
LSUFARP	The Lao Swedish Upland Forestry and Agriculture Research Program
M a s l	Meter above sea level
NAFReC	Northern Agriculture and Forestry Research Centre
NAFRI	National Agriculture and Forestry Research Institute
RC	Root Constant value
Sida	Swedish International Development Cooperation Agency
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSLCC	Soil Survey and Land Classification Centre
TDS	Total Dissolved Solids
UTM	Universal Transversal Mercator



## TABLE OF CONTENTS

Summary .....	vii
Sammanfattning (Summary in Swedish) .....	ix
Acknowledgment.....	xi
List of abbreviations .....	xiii
Table of contents .....	xv
Abstract .....	1
Background.....	1
Purpose and Objectives .....	3
Limitations of the study .....	3
The study area .....	4
Previous studies .....	4
Water and soil linkage.....	4
Water harvesting.....	6
Rainwater harvesting.....	6
Runoff harvesting.....	6
River diversion and dams.....	7
Soil moisture conservation.....	7
Method .....	7
Field study.....	7
Interviews.....	7
Water flow measurements.....	9
Water sampling and field analyses .....	9
Infiltration tests .....	10
Maps and GIS analysis.....	10
Water balance .....	10
Results .....	11
Climate.....	11
Rainfall .....	11
Temperature .....	11
Evapotranspiration .....	11
Humidity .....	13
Geology.....	14
Bedrock .....	14
Soils .....	14
Infiltration Capacity .....	19
Infiltration Capacity .....	20
Slope .....	20
Vegetation .....	21
Landuse .....	23
Water in cultivation.....	23

Domestic water and consumption .....	26
Surface Water .....	26
Water flows.....	26
Water Chemistry .....	29
General Observations .....	31
Water balance .....	33
Baseflow .....	33
Water balance equation parameters .....	34
Water Balance Calculation.....	35
<b>Discussion.....</b>	<b>36</b>
Accuracy.....	36
Water resources .....	38
Water quality.....	38
Water balance .....	38
Sustainability.....	40
Water Harvesting.....	40
<b>Conclusions and recommendations .....</b>	<b>41</b>
Domestic water.....	41
Cultivation .....	41
<b>References .....</b>	<b>43</b>
<b>Appendix I Interviews .....</b>	<b>45</b>
<b>Appendix II Rainfall DAFEO.....</b>	<b>51</b>
<b>Appendix III Rainfall Measured Outside Phonxay District.....</b>	<b>53</b>
<b>Appendix IV Temperature and Evapotranspiration .....</b>	<b>55</b>
<b>Appendix V Calculated Evapotranspiration .....</b>	<b>57</b>
<b>Appendix VI Water Flow Calculations In Matlab .....</b>	<b>59</b>
<b>Appendix VII Infiltration Capacity .....</b>	<b>63</b>
<b>Appendix VIII Geology Map Phonxay District.....</b>	<b>65</b>

## ABSTRACT

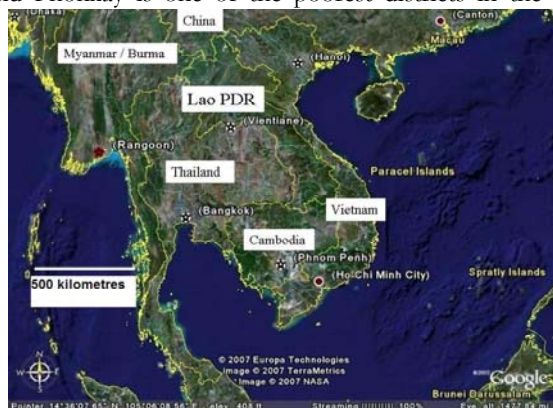
Cultivation on steep slopes and erosion is a reality in many places in the world, and pose a difficult challenge in many developing countries that rely on cultivation for their survival.

In northern Lao PDR the long dry period limits cultivation to one harvest per year, while the intense rains cause erosion and damage to crops in the uplands dependent on cultivation. Due to political decisions villagers have moved from the isolated areas to villages with access to roads. Huay Maha is one such village where increased population cause land deficit. The cultivation system is shifting cultivation, which is no longer sustainable since the fallow periods are too short. The combination of steep slopes, short fallows and intense rains lead to degradation of soil and water resources. Therefore a development of water management, especially regarding agriculture but also for domestic use, is considered necessary. This general study contains aspects regarding both quantity and quality of water resources, the usage of these resources as well as specific recommendations on how to increase infiltration and minimize runoff and erosion. For domestic use the quantities in the area are sufficient but the water supplies can be improved most importantly regarding sedimentation to remove mud from the water. From an agricultural point of view the main problem is that rainfall do not infiltrate but quickly runoff, causing erosion of the important topsoil. The most important conclusions are that in order to increase infiltration and storage, the ground should be well covered with vegetation, crops preferably combined with trees along the contours and physical barriers constructed to harvest runoff and sediments.

**Key words:** Lao PDR, water resources, water balance, soil erosion, cultivation on steep slopes, water harvesting, soil moisture conservation

## BACKGROUND

Lao People's Democratic Republic (Lao PDR, Laos) is a landlocked country in Southeast Asia neighbouring Thailand, Myanmar, China, Vietnam and Cambodia (Fig. 1). The study village Huay Maha is situated in Phonxay district, Luang Prabang Province in northern Laos (Fig. 2). Laos is one of the least developed countries in the world (Sida 2007) and Phonxay is one of the poorest districts in the



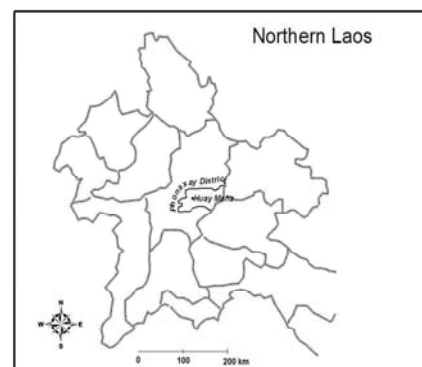
*Fig. 1. Satellite image over Southeast Asia (Google Earth 2007)*

country (NAFRI 2005). About 80 % of the Lao population lives in rural areas and about 40 % is said to live in poverty. Many of those are ethnic minorities living in the upland regions.

The government of Laos has applied a village relocation program in order to reduce poverty. Access to roads and communications as well as hospitals and schools has been identified as key factors for reducing poverty. The objective with the program is to move people to where these facilities are located or are planned to be built. The district's

relocation strategy includes reducing 72 villages (2002) to 41 (2005) by moving people (LSUARFP 2006). Huay Maha is one of those villages into which people have been relocated because of its location close to the road and school. In consequence, the population of the settlements were doubled in 2001-2002.

The topography in Phonxay is mountainous with very steep slopes and narrow valleys. The climate is tropical with one rainy season per year, usually



*Fig. 2. Overview of northern Laos with Phonxay district and Huay Maha Village marked within Luang Prabang Province (modified from LSUARFP 2006)*

between June and September. Original landcover is tropical forest but today most of the land has been converted to agricultural land. The main issue in Phonxay district is the lack of productive and arable agricultural land, due to the rough mountainous terrain (LSUARFP 2006) (Fig. 3).

Shifting cultivation has traditionally been the major cultivation system in Laos. Today it is most common in the uplands. The farmers in Huay Maha all use shifting cultivation or slash- and burn technique. Rice is the main crop cultivated and base source of



**Fig. 3. View over Huay Maha's mountainous surroundings (Billving 2006)**

nutrition. The cycle for upland rice in Huay Maha are usually slashing in January-February, main burning in March-April, sowing in June and harvesting in October. The land is then left in fallow for a couple of years, and they move on to the next field and the procedure is repeated. How long the land is left in fallow depends on how many fields the farmer has. No irrigation is used in Huay Maha and the farmers are highly dependent on rainfall.

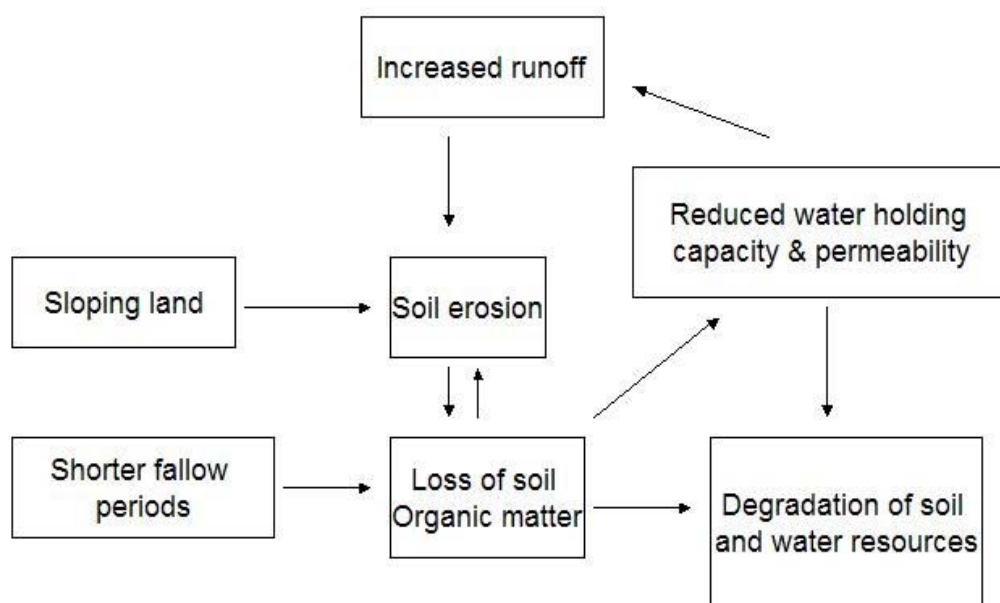
In order to help the new settlers to make a living, a land allocation program was designed in 2006 (Jones 2007). Cultivation land was allocated and redistributed by the district to the villagers. This has resulted in fewer fields for each family and an increased stress on land due to shorter fallow periods

(Mossberg 2006).

Sloping land and shortened fallow periods can cause degradation of soil and water resources. Shortened fallow periods and soil erosion both causes a reduction of soil organic matter (SOM), which is important for the soil's ability to hold and transport water. When the water holding capacity and permeability is reduced, runoff and soil erosion is increased. This negative chain of events is continued (Fig. 4) (Young 1989). However, a clear understanding of the linkages between hydrologic pathways and erosion mechanisms is missing for mountainous areas of tropical Southeast Asia (Sidle et al 2005).

The Lao Swedish Upland Agriculture and Forestry Research Program (LSUAFRP) work with research for improving livelihoods in the upland of Laos. The program is financed by Sida and run by Ramboll Natura and has the overall goal of; "Improvement of upland farmers' livelihoods for poverty alleviation and sustainable use of natural resources" (LSUAFRP 2006). The program's counterpart is the governmental organization National Agricultural and Forestry Research Institute (NAFRI).

Huay Maha is one of LSUAFRP's target villages for research on improved agricultural techniques. Identified limitations for cultivation in the area are lack of water and decreasing soil fertility due to soil erosion (LSUARFP 2006). Concerns have been raised from LSUARFP if the available water resources can provide the increased population (Mossberg 2006).



**Fig. 4. A simplified model of how land use changes, soil and water properties and soil erosion interacts. Based on Young's (1989) description.**

No previous investigations have been made regarding the water resources in Huay Maha. A small-scale soil conservation project involves a few families in Huay Maha village, which is also interesting from a soil moisture conservation perspective.

### Purpose and Objectives

The ongoing soil and water resource degradation in Huay Maha is representative for many parts of the tropical world where cultivation takes place on steep slopes. This comprehensive study will contribute to an in-depth understanding of the local problems concerning water resources that may be applicable in other regions as well.

The aim with this study is to contribute to a sustainable usage of water resources and end the degradation of soil and water resources. This is a general study that contains both qualitative and quantitative aspects of water resources for domestic and agricultural use. In order to enable increased drinking water quality and sustainability in cultivation, a descriptive survey of the present water situation will be performed. Possible problems and opportunities will be highlighted and further studies suggested.

Since no previous investigations regarding the water

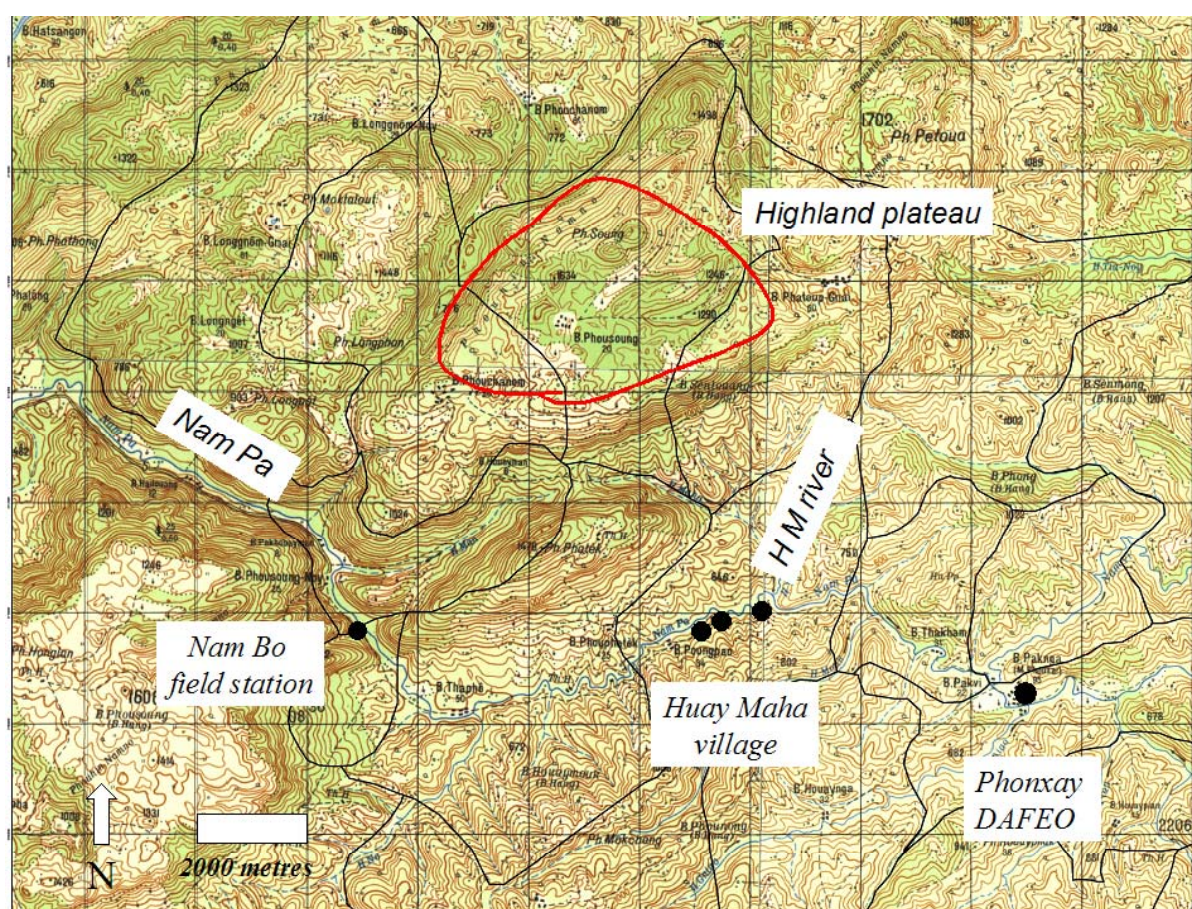
resources has been made in Huay Maha, a conceptual model will be created in order to quantify the available water resources. To represent the fluctuations over time, a water balance will be set up on a monthly basis. This will include estimations of the runoff and infiltration terms of the water balance. Water harvesting methods in use will be investigated and potential methods for development will be presented.

The objectives of the study are:

- To increase the awareness of local people's present water resource situation by surveying, modelling and quantifying these resources.
- To investigate local water harvesting methods in use and suggest improvements from a literature study.
- To suggest measures for a sustainable usage of land and water resources.

### Limitations of the study

This is a water resource study focusing on available water for both cultivation and domestic use.



*Fig. 5. Overview of Nam Pa river valley in northwestern part of Phonxay district. The three settlements of Huay Maha village are marked as well as Nam Bo field station and Phonxay District Agriculture and Forestry Extension Office (DAFEO). (Topographic map provided by NAFRI 2006)*

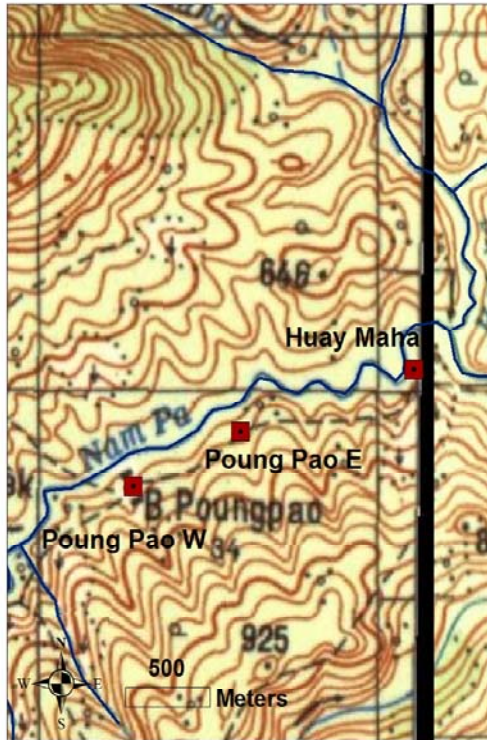


Fig. 6. The three settlements of Huay Maha village (modified data from NAFRI 2006).

Fieldwork was limited to usage of water and direct water measurements. Regarding soil, landuse, vegetation and climatic data, it has been collected from other sources. Groundwater is discussed but not directly studied.

### The study area

Huay Maha village consists of three different settlements: Pong Pao West, Pong Pao East and Huay Maha (Huay Maha Latitude 19 57 38 N; Longitude 102 29 53 E, 400 m a s l) (Fig. 5; Fig.6).

Originally the Khamu ethnic group used to live in the valleys and the Hmong tribe up in the mountains. In Pong Pao East, the 8 families have been living there for 25 years. The main settlement Pong Pao W (Fig. 7) is situated barely one kilometre from Pong



Fig. 7. Picture of Pong Pao West. (Ågren 2006)

Pao E. It was formed in 2001 and has about 900 inhabitants. Huay Maha settlement, population 400, consists of both original and immigrated inhabitants (Table 1).

A local road stretches along the Nam Pa river valley and connects the centre of the district to road 13. Today 14 of the original 72 villages in Phonxay district have access to the road.

## PREVIOUS STUDIES

When precipitation hit the ground it either runs off or infiltrates. If the water infiltrates into the soil it can become available for plants, stored as soil moisture or transported in the soil to groundwater aquifers or outflow points. Water that runs off at the surface is likely to remove and transport soil particles, so called soil erosion.

This chapter describes the link between water and soil as well as methods to affect the flow paths of water, i.e. water harvesting.

### Water and soil linkage

In undisturbed tropical forests, the infiltration capacity of surface soils is generally high. Most rainwater infiltrate and is transported to streams as subsurface flow. Since subsurface flow predominates, surface erosion is usually low in undisturbed tropical forests (Sidle et al 2005).

Clearing forest to achieve agricultural land can have considerable effects on water pathways and soil erosion (Sidle et al 2005). Erosion of topsoil decreases the available water in residual soils. This decrease is a limiting factor for vegetation growth, especially in areas with dry periods (Sidle et al 2005). Also Young (1997) stresses that forest has better soil structure and higher infiltration capacity than cultivated land. The connections between soil erosion and water resources are multiple and complex. Moldenhauer and Hudson (1988) make the following statements:

- Erosion increases exponentially with slope on bare soils.
- When soil is lost, the potential water storage capacity is reduced.
- When topsoil is eroded, soil organic matter is lost and the soils porosity and water holding capacity is decreased.
- Loss of soil results in decreased infiltration and increased runoff.
- Runoff causes erosion. Runoff does often but not always increase with slope gradient. Runoff shows a strong correlation with land cover.
- Soil erosion also generates negative effects further downstream, so called off-site effects.

A study in Burundi regarding effects of vegetation cover and slope on runoff and soil loss showed that when slope is increased from 15 to 30 %, soil loss is

**Table 1. Population (Pop.) distribution in three settlements of Huay Maha Village 2006. Est. Yr is the year when the settlement was established. "Origin of inhabitants" refers to if the inhabitants are relocated, or "immigrated", from the highland plateau or if they originated from the valley (Appendix I).**

Settlement	Pop.	Est. yr	Origin of inhabitants
Huay Maha	405	1986	Original and immigrated inhabitants
Poung Pao West	924	2001	Immigrated inhabitants
Poung Pao East	34	1980	Original inhabitants
Total	1363		

**Table 2. Conversion table for slope units; percent and degrees**

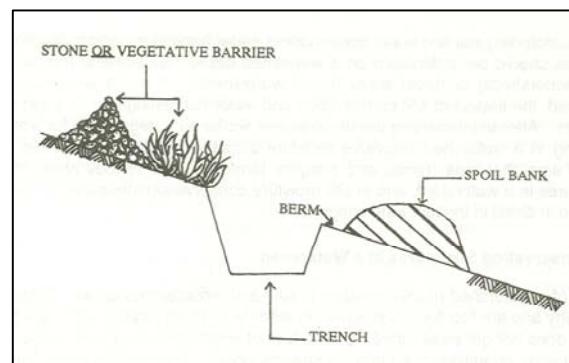
Percent	1	5	10	25	50	100	173
Degrees	0.57	2.86	5.7	14	22.5	45	60

doubled and runoff increases 1.6 times (El-Hassanin et al 1993). Vegetation cover was also shown to have a great influence on soil loss and runoff. Forest cover was most effective in minimising runoff and erosion, second best was the grasses then cultivated crops and worst the bare fallow (El-Hassanin et al 1993). Evans (1996) states that a natural forest has an infiltration capacity about twice the infiltration capacity on cultivated land. Since trees use a lot of water the water yield is lower in a forested area than one that is not, but the water has less sediments

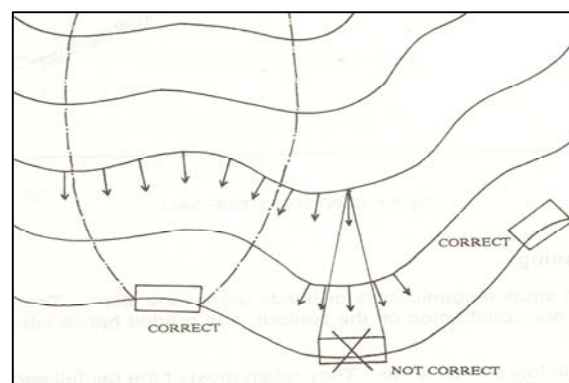
Infiltration has been studied at numerous places in the world, however it is very site specific, making comparisons difficult. The available data to help assume good values for infiltration is landuse, soil and slope. Relevant literature disagrees as to how some of these factors affect infiltration. Regarding slope, runoff is usually increased by increased gradient (El-Hassanin et al 1993; Fox et al 1997; Assouline & Ben-Hur 2006). However, crusting processes must be considered when looking at infiltration on steep slopes, since soils with a surface seal may have infiltration rates that increase with increasing slope (Assouline & Ben-Hur 2006; Janeau et al. 2003).

Soil organic carbon (SOC) is considered to be one of the most important indicators of the productivity of low input farming systems, such as shifting cultivation. Several studies show a positive relationship between fallow length and SOC content (Bruun et al 2005). Rerkasem (2004) says that shifting cultivation can be sustainable and productive when there is enough land to allow rotations of 10-20 years.

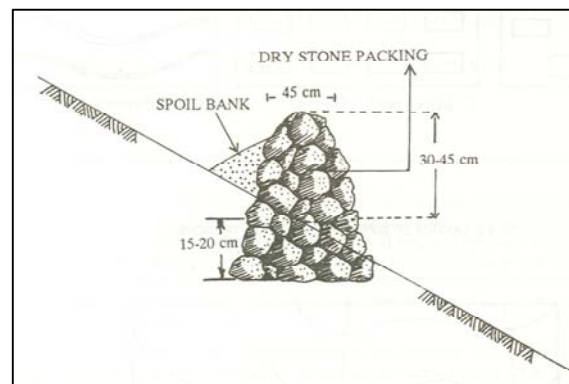
For soil conservation the most important is to have the soil covered by organic matter (Young 1989). Trees with canopies higher than a few meters only reduce the erosion by the effect of its litter. This is because the size of raindrops is increased by accumulation on large leaves and the raindrops reach



**Fig. 8. Model of how a contour trench can be constructed (Sivanappan 1992)**



**Fig. 9. Illustration of correct and not correct location of trenches, in order to collect as much water as possible. (Sivanappan 1992)**



**Fig. 10. Model of how bunds can be dimensioned (Sivanappan 1992)**

more than 95 % of its velocity during a free fall from 8 m (Young 1989). The tree roots also play an important role. Young (1989) stresses some of the most important functions; Tree roots can take up water and nutrients from a greater depth than crops, increasing the efficient usage of water. The available water capacity of the root zone may be 400 mm for mature forest on a clay loam, while it may be 200 mm for a moderate deep crop on the same soil (Dunne & Leopold 1978). The roots provide the soil with organic matter and capture water from the soil and thereby reducing leaching losses. Roots also assist in the binding of soil particles into structural aggregates, increasing soil stability.

Clearing steep forested slopes always induces a high erosion risk. There are two different ways of reducing this risk; the first is to reduce the steepness by terraces or benches, the other to cover the slope with dense crops (Moldenhauer & Hudson 1988).

Teak usually suppresses ground vegetation, it is therefore important to ensure that the litter is left to protect the soil to prevent erosion (Evans 1996). Soil loss under teak plantations has been found to be several times greater than under natural forests (Evans 1996).

### Water harvesting

In this study water harvesting is defined as methods to utilize runoff, rainfall or water from rivers or small watercourses. It includes rainwater harvesting but neither large-scale excavation of groundwater nor large reservoirs but rather inexpensive, low technology simple methods.

Most methods have multiple effects, for example reduced runoff is positive for soil moisture and both these factors decrease erosion. Water harvesting is more economically beneficial at gentle slopes since more earthwork is required to achieve the same storage volume at steep slopes (Reij et al 1988).

Worth paying attention to is that in the following document slope is described both in degrees and percent where 100 % corresponds to 45° (Table 2).

### Rainwater harvesting

The most common method of traditional rainwater harvesting is probably to collect rainwater from roofs or other hard surfaces. This water can be used continuously or stored for periods with less water. Unless the storage tank and area of collection are very large, the water will not be enough for any substantial irrigation. It can, however, be a very good method for collecting water for domestic needs.

### Runoff harvesting

Physical structures can be used to shorten the slope length and thereby harvest surface runoff (Moldenhauer & Hudson 1988). These barriers can be impermeable or semi permeable such as hedgerows. They can be made as trenches, bunds or as a combination. Besides from the increased soil moisture they also have the effect of minimizing erosion and crop damage by, if well constructed, draining excess runoff out of the field.

*Contour trenching* slow down the runoff by breaking the slope at certain intervals. The trench should be constructed with a barrier of stones or vegetation upstream the trench to capture sediments (Fig. 8). Cross sections typically range between 1000-2500 cm<sup>2</sup> and can be as short as 3.5 m to several hundred meters long (Sivanappan 1992). The vertical and horizontal distances between the structures depend on precipitation, slope and soil depth. The location should be chosen to maximise runoff capture (Fig. 9) (Sivanappan 1992).

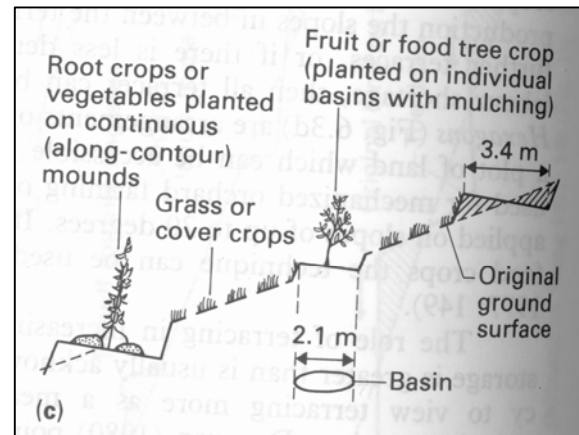


Fig. 11. Illustration of mini-convertible terraces (Barrows 1987).



Fig. 12. Illustration of micro basins (Moldenhauer & Hudson 1988).

Another method to cut the slope in intervals is by constructing *contour bunds*. The bund can be constructed with stones and is partly cut into the slope to gain stability (Fig. 10). This method is recommended only for fields with slope less than 5 % (Sivanappan 1992).

*Contour ploughing* means that the field is ploughed along the contour lines. It only decreases erosion with about 10 % (Moldenhauer & Hudson 1988). The benefits of tillage are debated, and it may have adverse effects such as erosion and oxidation of soil organic matter (Barrow 1987).

*Terraces* exist in many different designs. They can be horizontal, inward sloping or outward sloping. One method of runoff harvesting recommended by Barrow (1987) on slopes with 7-30° gradient is the reverse-sloping bench terraces. This is appropriate in humid tropics where surplus runoff may be a problem at times. According to Singh & Singh (2000) reverse sloping terraces is appropriate in high rainfall areas with low permeability on gradients 6-33 %. A variety of this is the so-called mini-convertible terraces (Fig. 11).

For tree planting *micro basins* can be beneficial (Fig. 12). It is a constructed semi-circle on the downslope side of the tree capturing runoff (Moldenhauer & Hudson 1988). This requires less earthwork than the mini-convertible terraces, but is not as effective in capturing large amounts of surface

runoff. Therefore they are probably more sensitive to extreme rains.

A low cost alternative to the structures along the contours is the vegetative measures, called *strip cropping*. A grass, for example the vetiver grass, planted along the contours can be an economic way of reducing runoff flow velocity. Thereby soil moisture can be increased and erosion decreased (Sivanappan 1992). Barrows (1987) mentions hedges as a way of increasing dew and precipitation, reduce evapotranspiration and possibly fixing nitrogen in the soil. Barrows (1987) claims strip cropping is appropriate only on slopes with a gradient less than 8.5°.

*Integrated cropping* is a method of sharing the resources in a field between different crops. The arrangement should be along the contours. Intercropping rice with other crops under upland rainfed condition has showed that intercropping gives a more efficient rainwater usage than planting only rice, especially during drought periods (Gouranga et al. 2003). A recommended rice-based cropping system is to mix rice with pigeon pea since rice has shallow roots and pigeon pea has deep roots (Singh & Singh 2000). This can be extended to increase fertility of the soil by incorporation of the nitrogen rich pigeon pea into the soil.

#### River diversion and dams

By *diverting water* from rivers or streams irrigation can be enabled. A simple measure is to construct a weir or bund across a stream where the surrounding land is relatively flat or gently sloping. The water is then spread out before returning to the course downstream. Many different terms are used in literature regarding this method, for example water spreading, wadi farming, check-dam farming and bund irrigation.

Nilsson (1987) mentions *percolation ponds* as a method for groundwater recharge and possibly irrigation. That type of dam should be built on a permeable surface, at a site where minimum earthwork gives maximum storage volume. Gradient should not exceed 16 %, otherwise it will be very hard to find a site with acceptable storage volume compared to the dam height (Nilsson 1987). According to Nilsson, groundwater dams have the advantage of lower evaporation than open water surfaces, the pollution risk is lower and the land can be used for something more than water storage.

Singh & Singh (2000) suggest *indigenous bamboo drippers* as a method of irrigating fields with water from mountainous springs or watercourses. The method is gravity run and based on bamboo pipes collecting and spreading water over fields providing a constant irrigation (Singh & Singh 2000).

#### Soil moisture conservation

Vegetation slow down runoff and give the water more time to infiltrate. It also improve the structure of the soil and thereby the water holding capacity

(Singh & Singh 2000). Increased infiltration and water storage capacity decrease soils erodibility. Measures to achieve this are for example mulching, fertilization and low tillage methods (Moldenhauer & Hudson 1988). Sheet and rill erosion can be reduced by up to 90 % if crop residues are left on the surface, so called mulching (Verplancke et al 1988). The use of mulch as a water conserving method gave 55 % higher crop yield than non-mulched plots in a study under upland conditions in Malaysia (Verplancke et al 1988). The same study also showed an increased water use efficiency of 90 % on mulched crop compared to non-mulched crops, a decreased runoff but an increased total drainage. Barrow (1987) refers to other authors questioning the effect of mulching as a soil moisture conservation method, but agrees of the increased infiltration caused by the slowed flow.

## METHOD

### Field study

The field study took place in Huay Maha village, Phonxay District, Luang Prabang Province during three weeks in October and November 2006.

The area has been limited by defining an approximate catchment boundary. One important exception from this is Nam Pa river that is allowed to flow into the “catchment” (Fig. 13). The mountain slopes surrounding Nam Pa and Huay Maha stream (downstream the intersection with Huay Keo) constitute the primary study area. These are the most important areas for cultivation. The secondary area is the outer limits of the catchment with steep slopes and the highland plateau (Fig. 5). These areas are included in the water balance but direct measurements and classifications of these areas are not within the scope of this study. However samplings were made of the ponds on the highland plateau used as drinking water by cattle.

### Interviews

Four group interviews were held. The group interviews contained questions regarding domestic water use and water for cultivation purposes (Appendix I). Attempts were made to have representatives both from the Khamu and Hmong ethnicities, and both men and women from each ethnicity. The interviewees were selected with help from the Head of Village in all settlements. All interviews took place in the settlements, usually in someone's home. The interviews were held early morning or late evening so as not to disrupt the rice harvest.

The questions for the group interviews were carefully prepared. Discussions were held with experienced staff from NAFRI on exactly how to formulate the questions to avoid misunderstandings. The questions were discussed with and explained to the translator before the interviews to ensure a correct understanding of questions and concepts.

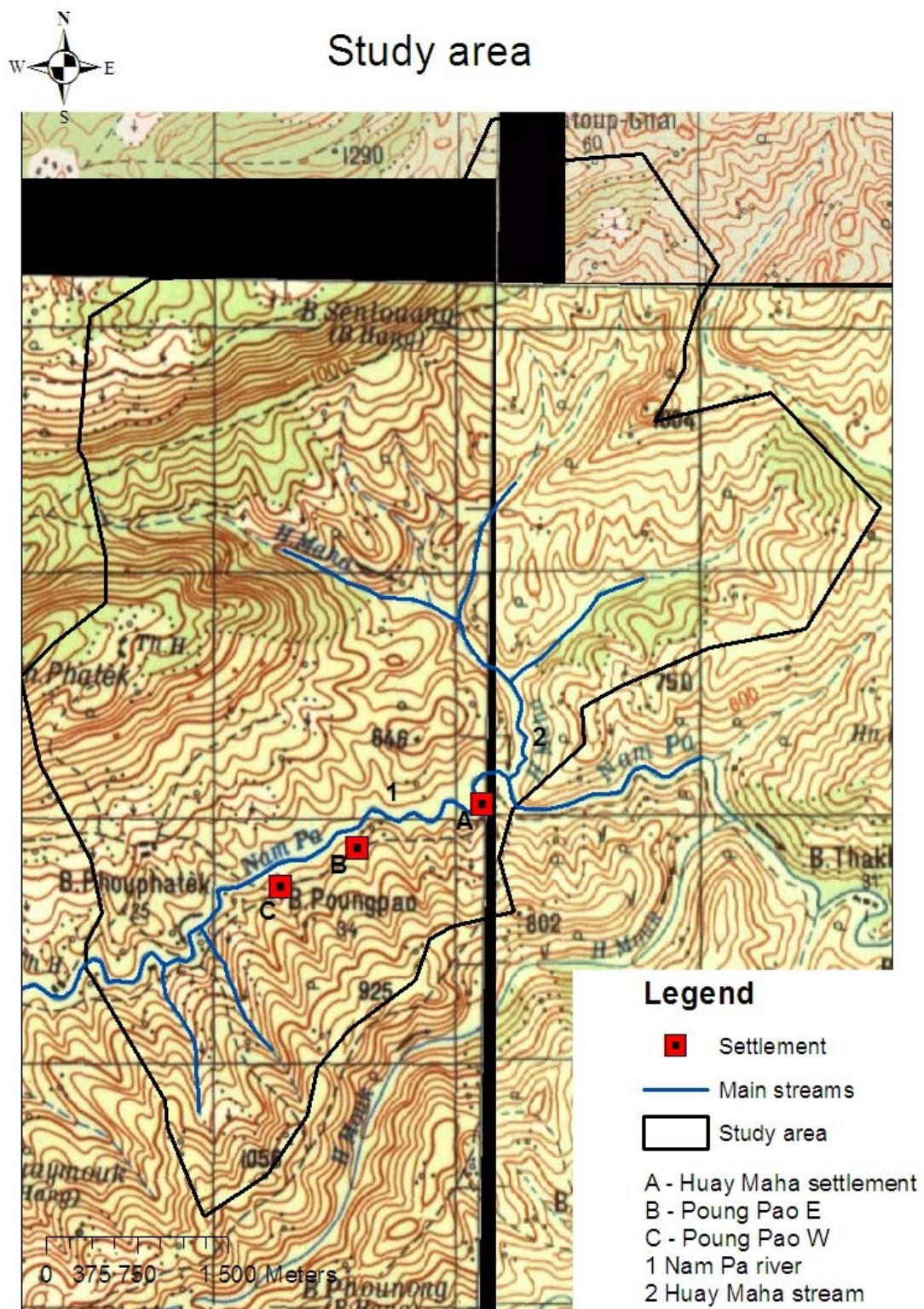


Fig. 13. Topographic map over the study area with the boundaries of the “catchment”, the settlements and main streams highlighted (Data modified from NAFRI 2006).

A hired interpreter translated from English to Lao. The answers were then translated back so follow up questions could be asked. At least one staff member from NAFReC joined the interviews. Afterwards the answers were discussed with the staff from NAFReC and the translator to make sure nothing was missed or misunderstood.

A few informal individual interviews were also held in field with the villagers and staff from NAFReC. This is complementary information to the general observations in field.

### Water flow measurements

The streams and small rivers are the only easily available and continuous water resources in the study area. Therefore the cross sections and flow velocities were measured to calculate the flow and get a picture of the seasonal variations for the most important aquifers.

Cross section and flow velocities were measured for Nam Pa river, Huay Maha stream and a few smaller streams. The smaller streams were divided into two categories, small or medium, and one stream for each category was chosen and considered representative for all. Nam Pa was measured at inflow and outflow of the study area. A rope and a folding rule were used for measuring width and depth. A watch, a rope and a bamboo pipe were used in order to measure flow velocity. Precise flow measurements were difficult with these simple methods. A local farmer and staff from NAFReC were interviewed regarding water fluctuation over time in the streams.

Flow quantities were calculated in Matlab, using the trapetz function to obtain the cross section (Appendix VI).

### Water sampling and field analyses

Water samples were taken for analysing pH, electrical conductivity (EC), total dissolved solids (TDS),

chloride ( $\text{Cl}^-$ ), nitrate ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ). The parameters were analysed in order to characterize the water and provide information regarding its flow paths. Further more ammonium may indicate bacterial pollution. Chloride concentration can be used to calculate the turnover time of groundwater. Nitrate may be a sign of nutrient leakage from the soil.

All samples were collected in 50 ml plastic bottles that were rinsed with the water before filling the bottle completely. Attempts were made to sample water without mixing it with the air. However, some of the streams sampled were so shallow that water had to be collected using one bottle to fill another and thereby mixing it with air and also risk getting sediments in the sample while holding the bottle firmly to the bottom. In the larger tributaries the water was sampled at 10 cm below the surface in the middle of the stream. The samples were contained in outdoor temperature but shielded from sunlight until analysis could be made (between one and four days after sampling except for nitrogen and ammonium analysis which took longer). Water samples were taken from Nam Pa, Huay Maha, small streams, water supply taps and tanks, ponds and springs. It did not rain during the field trip and no precipitation sample could therefore be taken.

EC, pH and TDS were measured using a combined instrument (Hanna Instruments pH/EC/TDS Meter, HI 9811). The equipment was calibrated before the first set of measurement. Due to lack of calibration equipment, calibration was not possible before the second or third set of measurements.

Chloride was analysed with a chloride field kit (Hanna Instruments, HI 3815).

The water samples were sent to the Chianaimo Water Treatment Plant Laboratory in Vientiane for analyzing nitrate and ammonium. The ammonium samples were analysed by the Tillman method and nitrate by the Sodium Salicylate method.

*Table 3. Rainfall distribution in Phonxay 1994-2006 (District Agriculture and Forestry Extension Office 2006).*

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>Tot rain [mm]</b>	1138	1059	1562	1018	1296	1196	1584	1431	1562	1284	1173	993	975
<b>Days with rain</b>	65	68	97	92	88	98	97	81	97	80	93	68	78
<b>Months w rain</b>	10	10	10	9	11	10	12	9	11	10	10	11	9

*Table 4. Monthly rainfall (mm) distribution in Phonxay 2005-2006 (District Agriculture and Forestry Extension Office 2006).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<b>2005 [mm]</b>	0.0	46.0	41.2	36.2	44.0	91.0	133.5	443.5	120.5	4.5	30.5	0.0	990.9
<b>2006 [mm]</b>	0.0	18.0	4.0	75.0	60.5	122.0	85.6	377.7	147.3	64.5	0.0	0.0	890.1
<b>Average</b>	0.0	32.0	22.6	55.6	52.3	106.5	109.6	410.6	133.9	34.5	15.3	0.0	940.5
<b>Percent</b>	0.0	3.4	2.4	5.9	5.6	11.3	11.6	43.7	14.2	3.7	1.6	0.0	100.0

Colour and turbidity was estimated visually by shaking a bottle, holding it to the light and determine the colour and turbidity relative one another. These values were added and gave a number between 0 (clear) and 8 (yellow and very turbid).

### Infiltration tests

Infiltration test were performed in order to see the soils potential capacity to allow infiltration. The soils in the study area are eutric cambisols, acrisols and some leptosols. The infiltration capacity was measured for the cambisols. Due to the great need of water the test of soil infiltration capacity had to be made at locations close to a sufficient water source. The chosen locations were close to the bottom of the valley at flat land. One infiltration measurement was made in each location. Infiltration holes were dug with the size 50 x 50 x 50 cm. The soil profile was described and the soil was saturated before the infiltration time was measured. A known volume of water was added to the pit. The infiltration was measured using a watch and a folding rule and recording every time the water level sank 1 cm.

### Maps and GIS analysis

Maps regarding soil, topography and geology over the study area were provided by NAFRI. Digital data regarding prevailing crops and vegetation was provided by Sanchez (2007). These data have been used in order to analyse and describe the natural conditions of the area.

The study area boundary, Nam Pa and the small

streams were digitised in Arc Map from the topographic map and the digital elevation model (DEM) provided by NAFRI. The spatial reference UTM 48 N, Krasovsky 1940 was used. Arc Map and Arc Catalog were used for analysis and illustrations such as calculation of areas of different soil types, vegetation and slope.

### Water balance

The water balance is an assessment of the different in- and outputs of water to an area over time. It is a way of modelling water quantities and flow paths. In this study the following water balance equation has been used:

$$P = E + R + I + dS$$

Where P is the precipitation, E is the actual evapotranspiration, R is the total runoff, I is the infiltration and dS is the difference in storage of water (Sivanappan 1992). Over a long enough time dS can assumed to be zero (Grip & Rodhe 1994). In this study, one year is considered sufficient to make this simplification.

Precipitation has been collected from metrological stations. The actual evapotranspiration was calculated by the Grindley model as described by Shaw (1994). The runoff was calculated from discharge data. The infiltration was calculated as the rest term.

A hydrograph is a graph or a table showing the flow rate over time at a specific point in a stream (Chow et al 1988). Mekong River Commission has performed discharge measurements in Nam Pa river,

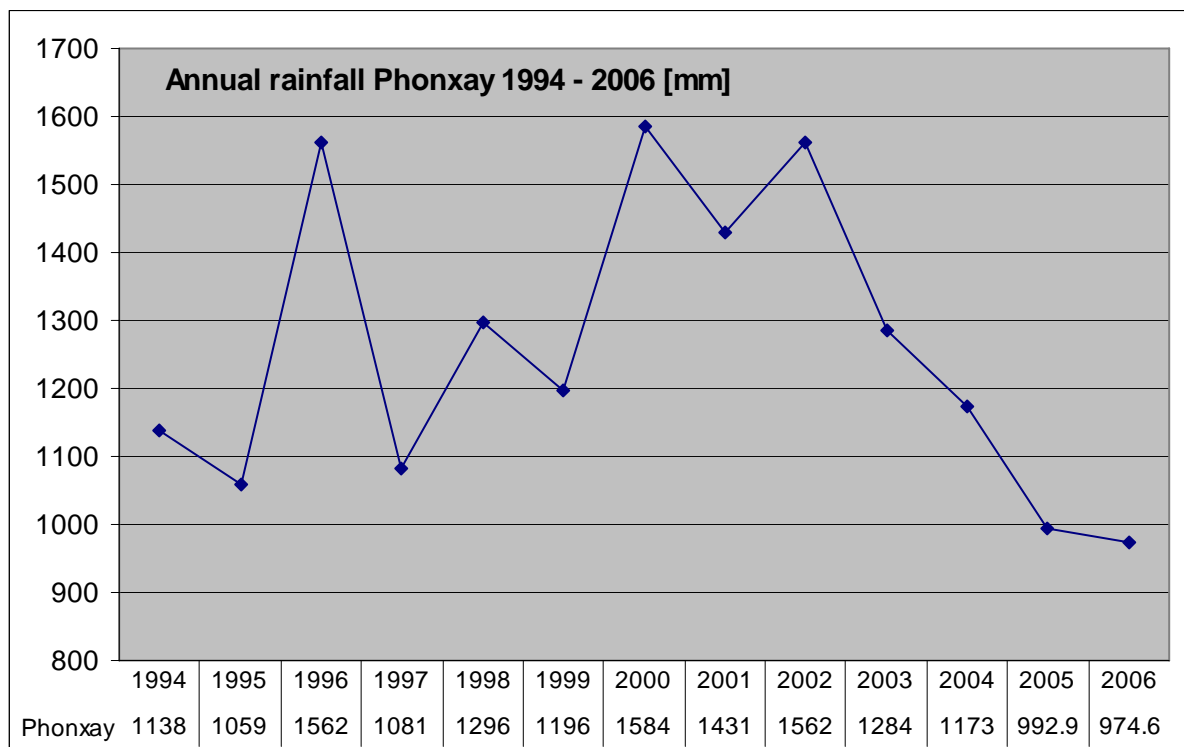


Fig. 14. Annual rainfall distribution in Phonxay district (District Agriculture and Forestry Extension Office 2006).

downstream the study area. These data has been modified to represent the study area. From the discharge data, a so-called recession curve was calculated. The recession curve provides information regarding the recession of a flow after a rain or a period of rains. It was calculated using a formula of exponential decay as presented by Chow et al (1988).

The discharge data and the recession curve constitute a hydrograph. From this hydrograph a baseflow separation was made in order to estimate the groundwater outflow and the runoff part of the discharge. This enabled annual approximations of runoff and infiltration. Monthly the precipitation and evapotranspiration was used to illustrate deficit and surplus over the year.

The methods used in the water balance are described in greater depth under the results to ease the understanding of the calculations.

## RESULTS

### Climate

The climate in Laos is typically tropical. The wet season stretches from mid-April to mid-October and is dominated by a humid southwest monsoon. The dry, cool period is from November to February and the dry and hot season from March to mid-April.

### Rainfall

The average rainfall in Laos is 1600 mm/year but varies significantly over the country. About 75 % of the precipitation occurs during the wet season (FAO 1999). Most frequently occurring natural

disasters in the country are floods and droughts.

The District Agriculture and Forestry Extension Office (DAFEO) at Phonxay district centre (Fig. 5) have measured precipitation since 1994. Daily precipitation data are available since 2005. Number of days and months with rain were also given for previous years, but not which specific days or months.

The rainfall in Phonxay district has varied between 971-1584 mm/year during 1994-2005 (Table 3). Out of these, the highest rainfall fell year 2000 and the least in 2006. Days with rain varied between 65-98 during the same period (Table 3). A significant amount of the annual rainfall falls in the rainy season, June-September, with a high peak in August (Fig. 14; Table 3). The altitude for precipitation sampling is estimated to 400 m a s l (Fig. 5).

Data were also collected from three different climate stations in and around Luang Prabang: Luang Prabang, Xiengngun and Pak Ou (Fig. 15). The climate station in Luang Prabang is situated at about 300 m a s l, the one in Pak Ou at 360 m a s l and the one in Xiengngun at 380 m a s l. The amount of rainfall in Luang Prabang and Pak Ou are quite similar, and their precipitation curves synchronize fairly well (Fig. 16). The rainfall curve for Xiengngun is similar to the other two, but with a constant lower precipitation between April-October (Fig. 16). The rainfall in August is noticeable higher in Phonxay than in the other places, especially compared to Xiengngun (Fig. 16).

The climate station in Phonxay, about five kilometres from Huay Maha village, is by far the closest one to the study area (Fig. 5). Therefore extra attention is put to those data. In Phonxay district, 40-45% of the annual precipitation fell in August 2005 and 2006 (Table 4). The highest daily rainfall was recorded on August 21<sup>st</sup> 2006 when 120 mm of rain fell between 07 am - 07 pm. This was high above all other records, the second largest rain of 60 mm was noticed four days later. In 2005 the highest recorded rain was 43 mm during 12 hours and 70 mm during 24 hours (Appendix II). The average rainfall in August 2006 was 12.2 mm/day and the median was 8 mm/day. In August 2005 the average daily rainfall was 14.3 mm/day and the median 10 mm/day. With reservation that data sources originates from different years, the rainy season is shorter and more intensive in Phonxay than from the other stations (Fig. 16).

### Temperature

The monthly mean temperature in Phonxay varies between 22.4-30.0°C (Fig. 17) (Nilsson & Svensson 2005). Normally temperature changes about 0.65°C per 100-meter altitude and precipitation also changes by elevation (Shaw 1994). Since the altitude difference within the study area is about 1100 m, the climate range is significant within the study area.

### Evapotranspiration

The evapotranspiration is the evaporation plus the transpiration by plants in the area. The potential



Fig. 15. Map of Luang Prabang Province marked with location of climatic stations from which data has been used (Luang Prabang, Pak Ou, Phonxay & Xieng-Ngun) (Map modified from NAFRI 2006).

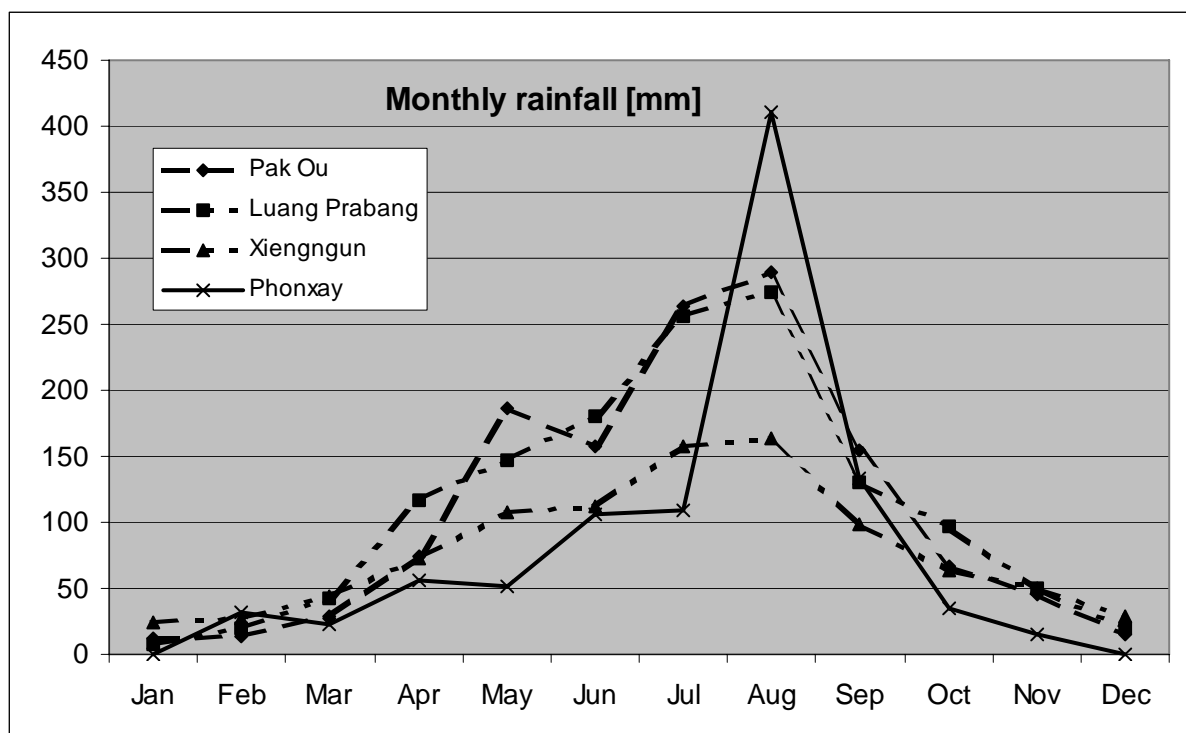


Fig. 16. Comparison of monthly precipitation for different climate stations in the region. The values from Xiengngun are based on average monthly data 1998-2005 (Appendix III). The values from Pak Ou were collected 1992-2004, and the data from Luang Prabang originate from 1985-1998 (Appendix III). The data from Phonxay are based on daily measurements 2005-2006 (Appendix II). (Agro-metrology station Luang Prabang 2006: District Agriculture and Forestry Extension Office 2006 ).

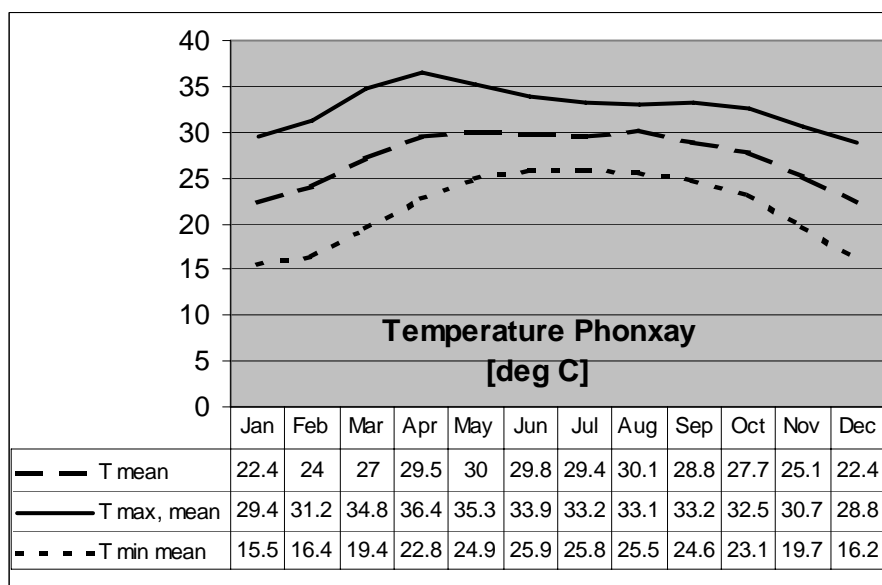


Fig.17. Temperature distribution in Phonxay district. Data interpolated by Nilsson & Svensson (2005) from 34 different climate stations in Southeast Asia. All values represent the temperature at sea level.

evapotranspiration is the evapotranspiration that will take place when the available water is not a limiting factor. This means that as long as the moisture content in the soil is at the field capacity of the soil or higher, the actual evapotranspiration will be equal to the potential evapotranspiration (Shaw 1994). This is realistic for the rainy season, June-September, when rainfall exceeds the potential evapotranspiration and soil moisture is being refilled. The rest of the year the

actual evapotranspiration will be lower than the potential one.

Nilsson & Svensson (2005) calculated the potential evapotranspiration in Phonxay district. The potential evapotranspiration is at its maximum in March-April when it is at average 5 mm/day (Table 5).

The relationship between the monthly rainfall in Phonxay 2005-2006 and the potential evapotranspiration (PET) for the same area show a

water deficit for these years (Table 5). Rainfall data from 2005-2006 shows lower precipitation than the annual average for Phonxay. By comparing the annual rainfall with the potential evapotranspiration one may get an overview of the average water balance. The average difference between rainfall and potential evapotranspiration is  $-1.1$  mm and the median difference is  $-61.8$  mm (Table 6). This indicates a rather balanced water balance. Since the potential evapotranspiration is higher than the actual evapotranspiration, the difference between rainfall and the actual evapotranspiration is positive.

The difference between the actual evapotranspiration and potential evapotranspiration is called soil moisture deficit and is important from an agricultural point of view. The actual evapotranspiration was calculated using the Grindley model (Shaw 1994) (Appendix V). A root constant value (RC) is used to estimate the soil moisture deficit. The root constant value for woodland (200 mm) was used. As a comparison it was also calculated with the RC value for grassland (75 mm) (Fig. 18).

The study area consists of mainly cultivated land. Since the RC value for cultivated land is between the RC value for grass- and woodland, the actual evapotranspiration should therefore be within that interval as well (Shaw 1994). By using the RC value

for woodland in the calculations, the actual evapotranspiration will be somewhat overestimated for the mainly cultivated area. While using the RC value for grassland will result in a probable underestimation. In the later calculations, the actual evapotranspiration obtained for the RC value for woodland will be used, since the vegetation in the area is more similar to wood than grass. As a consequence the water balance term  $P-E$  is underestimated, and the amount of water that can infiltrate and runoff is likely to be somewhat greater than estimated.

### Humidity

In Huay Khot the minimum and maximum humidity have been measured every day between 1998-2005. The maximum humidity shows average and median values of almost 100 % for 2004 and 2005. The minimum humidity shows average and median values of around 60 % for 2004 and around 65 % 2005 (Table 7). The high humidity values indicate that there is a lot of water in the air that soil and vegetation can utilize. Part of it is likely to condensate as dew during the night.

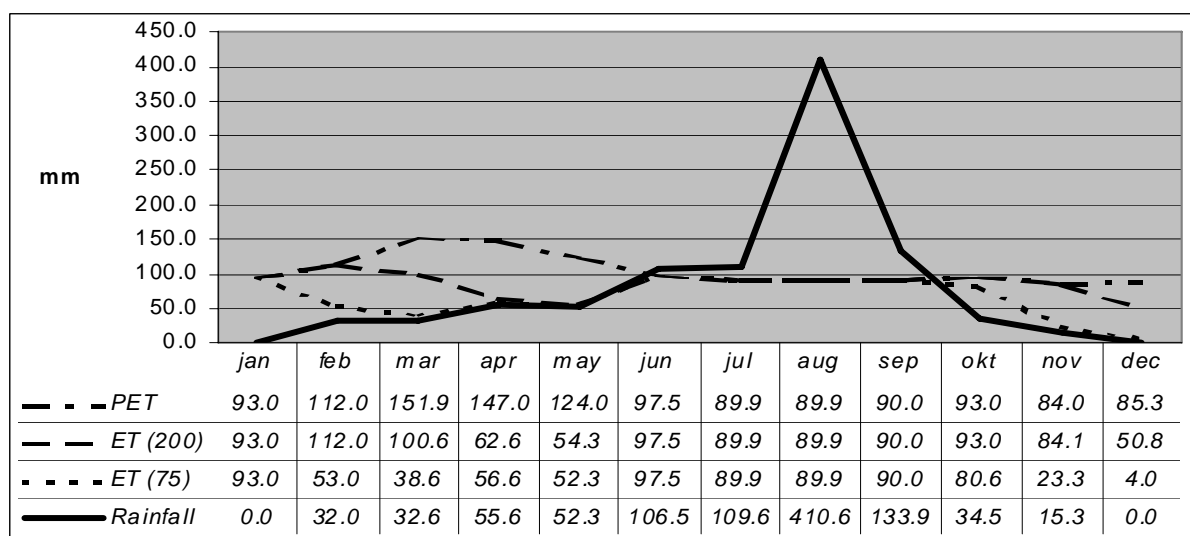


Fig. 18. Rainfall data over Phonxay in relation to the potential evapotranspiration (PET) and the calculated values of actual evapotranspiration (ET) with the two different root constant values of 200 and 75 mm, referring to woodland and grassland (Raw data regarding rainfall from District Agriculture and Forestry Extension Office 2006, PET from Nilsson & Svensson (2005) Appendix IV, ET calculations in Appendix V and RC values from Shaw (1994)).

Table 5. Average rainfall in Phonxay 2005-2006, Potential evapotranspiration (PET) in Phonxay and monthly difference between rainfall and PET in Phonxay district, all in mm (Rainfall from District Agriculture and Forestry Extension Office 2006, PET from Nilsson & Svensson 2005.).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Diff
Avg. rainfall	0.0	32.0	32.6	55.6	52.3	106.5	109.6	410.6	133.9	34.5	15.3	0.0	982.8
PET	93.0	112.0	151.9	147.0	124.0	97.5	89.9	89.9	90.0	93.0	84.0	85.3	1257.5
Rainfall - PET	-93.0	-80.0	-119.3	-91.4	-71.8	9.0	19.7	320.7	43.9	-58.5	-68.8	-85.3	-274.7

**Table 6.** The annual rainfall (District Agriculture and Forestry Extension Office 2006) is compared to the average potential evapotranspiration (PET) Nilsson & Svensson 2005).

	Rainfall Phonxay [mm]	Mean PET Phonxay [mm]	Diff [mm]
1994	1137.7	1257.5	-119.8
1995	1059.3	1257.5	-198.2
1996	1561.6	1257.5	304.2
1997	1081.0	1257.5	-176.5
1998	1296.0	1257.5	38.6
1999	1195.7	1257.5	-61.8
2000	1584.0	1257.5	326.6
2001	1430.5	1257.5	173.1
2002	1561.8	1257.5	304.4
2003	1284.4	1257.5	27.0
2004	1172.5	1257.5	-85.0
2005	992.9	1257.5	-264.6
2006	974.6	1257.5	-282.9
Average	1256.3	1257.5	-1.1
Median	1195.7	1257.5	-61.8

**Table 7.** Relative humidity (%) measured at Xieng-Ngun. Hd min is the minimum humidity per day and Hd max is the maximum humidity per day (Agro-Meteorology Station Luang Prabang 2006)

	2004		2005	
	Hd min	Hd max	Hd min	Hd max
Average	58.8	96.3	64.4	97.7
Median	61	96	66	99

## Geology

### Bedrock

There is an existing geology map over the study area with unknown origin (Appendix VIII). According to this, there is a mixture between "Calcaeous series with mainly massive limestone with conspicuous relief, subordinate shale and sandstone" and "Argillite series: shale, mudstone, siltstone and fine-grained sandstone". From observation in field, notations have been made of porous bedrock. West of the study area limestone cliffs with cave openings are visible. Close to Huay Maha River, structured layers of supposed shale were observed.

No specific scientific data is gathered about the bedrock situation in Huay Maha, but it seems likely that the landscape is under karstforming processes. Karst can be defined as "Terrain with distinctive landforms and drainage arising from greater rock solubility in natural water than is found elsewhere" (Ritter et al 1995). Karst is most likely to be found in limestone in temperate and tropical climate. The development of karst or karstification is dependent on many different factors. Among the most

important are the porosity and the secondary porosity, i.e. how much water the rock may hold and transport, within the rock and in joints and fault zones (Ritter et al 1995). A comparison between typical hydraulic conductivities of the main soils and bedrock within the study area shows the possible importance of karst for water transport (Table 8).

Hydrologic pathways in karst terrain are extremely difficult to predict, since water flows in underground network system, most often irregular. Large amounts of water may infiltrate through swallow holes or river channel floor depending on how developed the underground drainage networks are.

### Soils

The Soil Survey and Land Use Classification Centre (SSLCC) at NAFRI have produced a soil map over Phonxay district. A physiographic map was compiled from surveys and aerial photos as a basis for the field survey. There are three different kinds of soil types within the study area; acrisols, cambisols and leptosols (Fig. 19; Table 9).

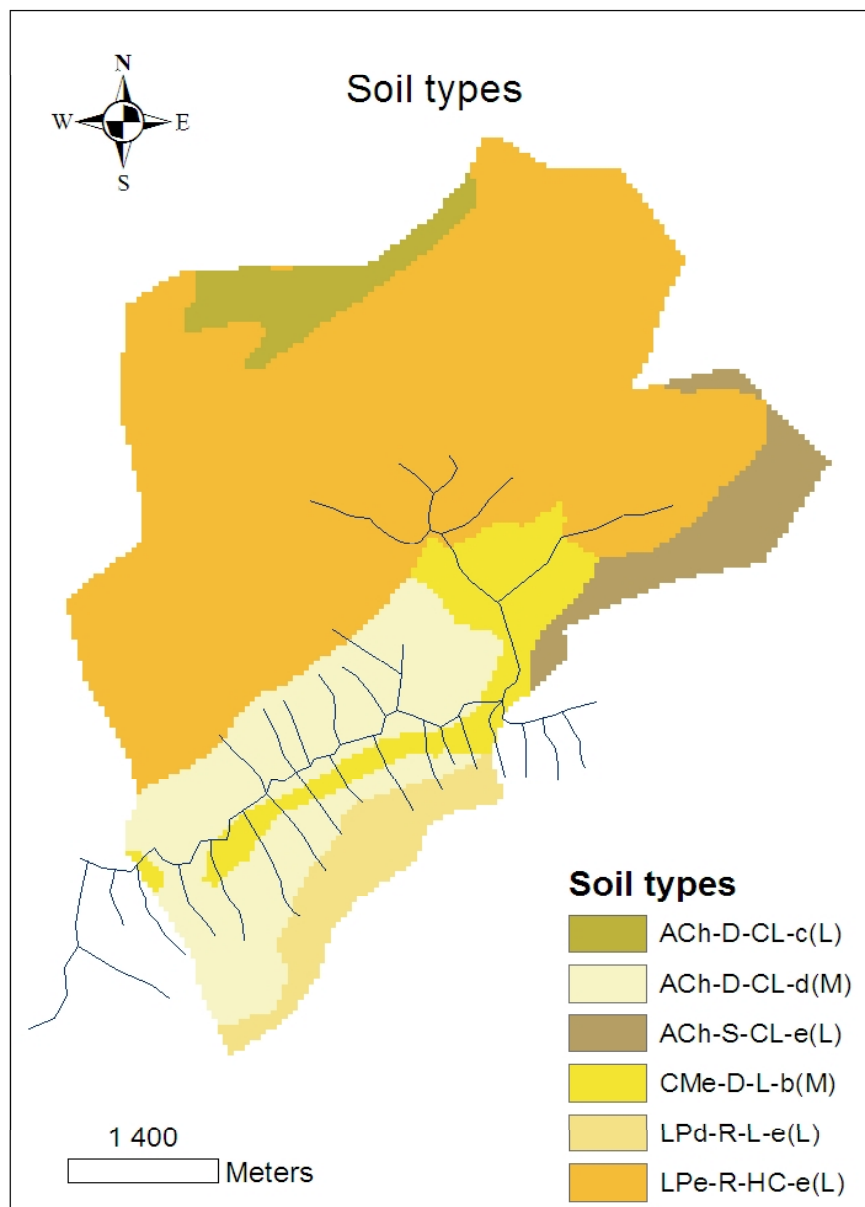
Acrisols are represented at almost 30 % of the study area, mainly on the slopes north and south of Nam Pa river where much of the cultivation land is located. It is there a medium fertility clay loam with a depth of more than one metre on slopes that varies between 16-30 %. The second area with acrisols is at the highland plateau where it is also a deep clay loam but with low fertility and slope varying between 8-16 %. The third area is northeast of Nam Pa where it is a shallow clay loam with low fertility on slopes between 30-55 % (Table 8).

Acrisols are a strongly weathered acid soil with an argic horizon, a subsoil accumulation of clay. Light forest is the natural vegetation type, and the surface soil is porous when under a protective forest cover. If the forest is cut down, the valuable A-horizon is degraded, and a hard surface crust is formed (FAO 1998). The crust limits the infiltration capacity, increase runoff and enhance soil erosion. It is not a very productive soil and should be used with restriction in agriculture. Suitable crops are acid-tolerant ones such as pineapple, cashew, oil palm and rubber (FAO 1998).

Cambisols are found on the relatively flat land along Nam Pa and in Huay Maha river valley (Fig. 19). It represents a little bit less than 10 % of the study area (Table 10). It is there a deep loam with medium fertility and slope varying between 2-8 % (Table 9). Cambisols has an A-, B- and C-horizon. The soil type is medium-textured. Most cambisols has a high porosity and a good water holding capacity. The internal drainage is usually good. Cambisols on steep slopes, especially in highlands, are best kept under forest. Eutric cambisols has a base saturation of 50 % or more (FAO 1998)

**Table 8. Porosity and hydraulic conductivity for soils and rocks found within the study area. (Modified from Knutsson & Morfeldt 2002).**

Geology	Porosity		Hydraulic conductivity					
	Primary [%]	Secondary	Range [m/s]					
			10 <sup>0</sup>	10 <sup>-2</sup>	10 <sup>-4</sup>	10 <sup>-6</sup>	10 <sup>-8</sup>	10 <sup>-10</sup>
<b>Soil</b>								
Clay	40-55	Between aggregates						
Silt	40-50	Temporary						
<b>Bedrock</b>								
Limestone	1-50	Fractures, karstic						
Shale	-	Fractures						



**Fig. 19. Soil types in the study area.** (Source: Soil Survey and Land Use Classification Center, SSLCC) The acronyms in the soil types legend should be read as follows; ACh: Acrisols - D: deep (>100 cm depth) - CL: clay loam - c : (rolling (slope 16-30%) - (L): Low fertility rate . All the acronyms are shown in table 9.

Acronym	Soil type	Acronym	Description
ACh	Acrisols	D	Deep soil >100 m
CMe	Eutric Cambisols	R	Rock outcrop 0-30 cm
LPd	Dystic Leptosols	S	Shallow soil 30-50 cm
LPe	Eutric Leptosols		

Acronym	Soil texture	Acronym	Slope	Acronym	Fertility
CL	Clay loam	b	2-8%	(L)	Low
HC	Heavy clay	c	8-16%	(M)	Medium
L	Loam	d	16-30%		
		e	30-55%		

*Table 9. Acronyms with explanations for soil types in Fig. 19. (Nilsson & Svensson 2005; FAO 1998)*

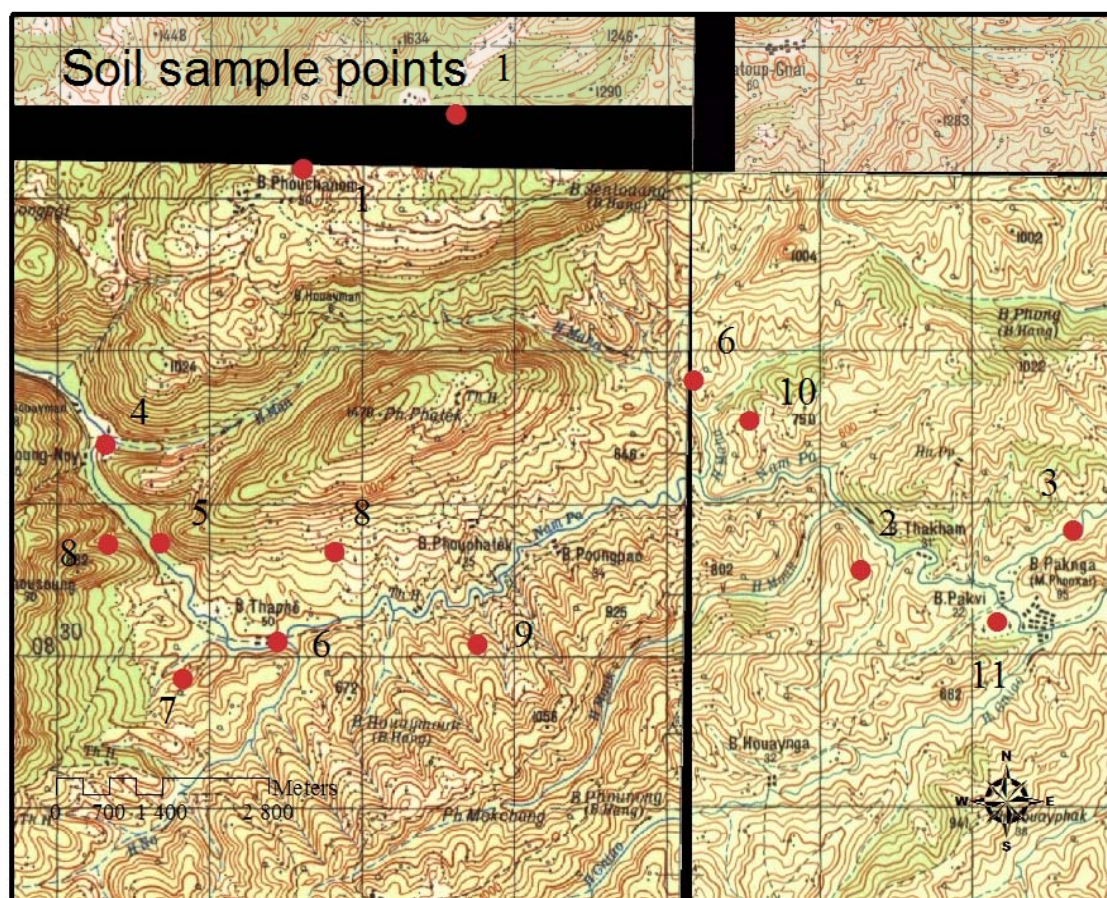
Leptosols are the predominating soil type in the study area, covering about 65 % (Table 10). It is located in the northern part of the catchment on the steep slopes between the valley and the highland plateau (Fig 19). It is there heavy clay with rock outcrop, low fertility and 30-55 % slope. Another leptosol can be found in the most southern part of the study area. It is there a low fertility loam with rock outcrop on slopes ranging 30-55 % (Table 9).

Leptosols found on hill slopes are generally more productive than the ones found on flat land (FAO 1998). However the soil type is very sensitive to erosion and therefore forest is the favorable

landcover. Leptosols have a low water holding capacity and the internal drainage is excessive which can result in drought even in areas with humid climate (FAO 1998).

SSLCC have taken 14 soil samples within or close by the study area (Fig. 20). These were reduced to 11 soil mapping units. Textural distribution and chemical properties were analysed for two or more layers in each sample. The soil particle size distribution was divided in three categories; fine sand with a particle diameter of 0.2-0.02 mm, silt with diameter 0.02-0.002 mm and clay with diameter less than 0.002 mm.

Clay loam and clay are the most common soils in this



*Fig. 20. The location of eleven different soil mapping units identified from fourteen different soil samples by Soil Survey and Land Classification Centre (SSLCC) at NAFRI, within or close by the study area.*

area (Fig. 21). Worth noticing is that the soil classification in Fig. 21 is based on the United States Department of Agriculture (USDA) classification, which applies a slightly different particle size distribution than the measured one. Usually clay and clay loam should have good water holding capacity with low hydraulic conductivity (Table 8). Due to the different soil classification systems, constant values for clay loam have been replaced by silt, but should have approximately the same particle size. The hydraulic properties for clay and silt are similar even

though silt may have slightly higher hydraulic conductivity (Table 8).

Something unknown regarding local conditions, but important from a hydrologic point of view, is the soil structure, or the way the individual soil particles are clustered together in aggregates. In clay-rich soils, where the openings between the aggregates are the only way for water to percolate and flow, the soil structure is extremely important (Ritter et al 1995). Olsson (2004) state the importance for soil physical properties to be investigated regarding water holding capacity and infiltration.

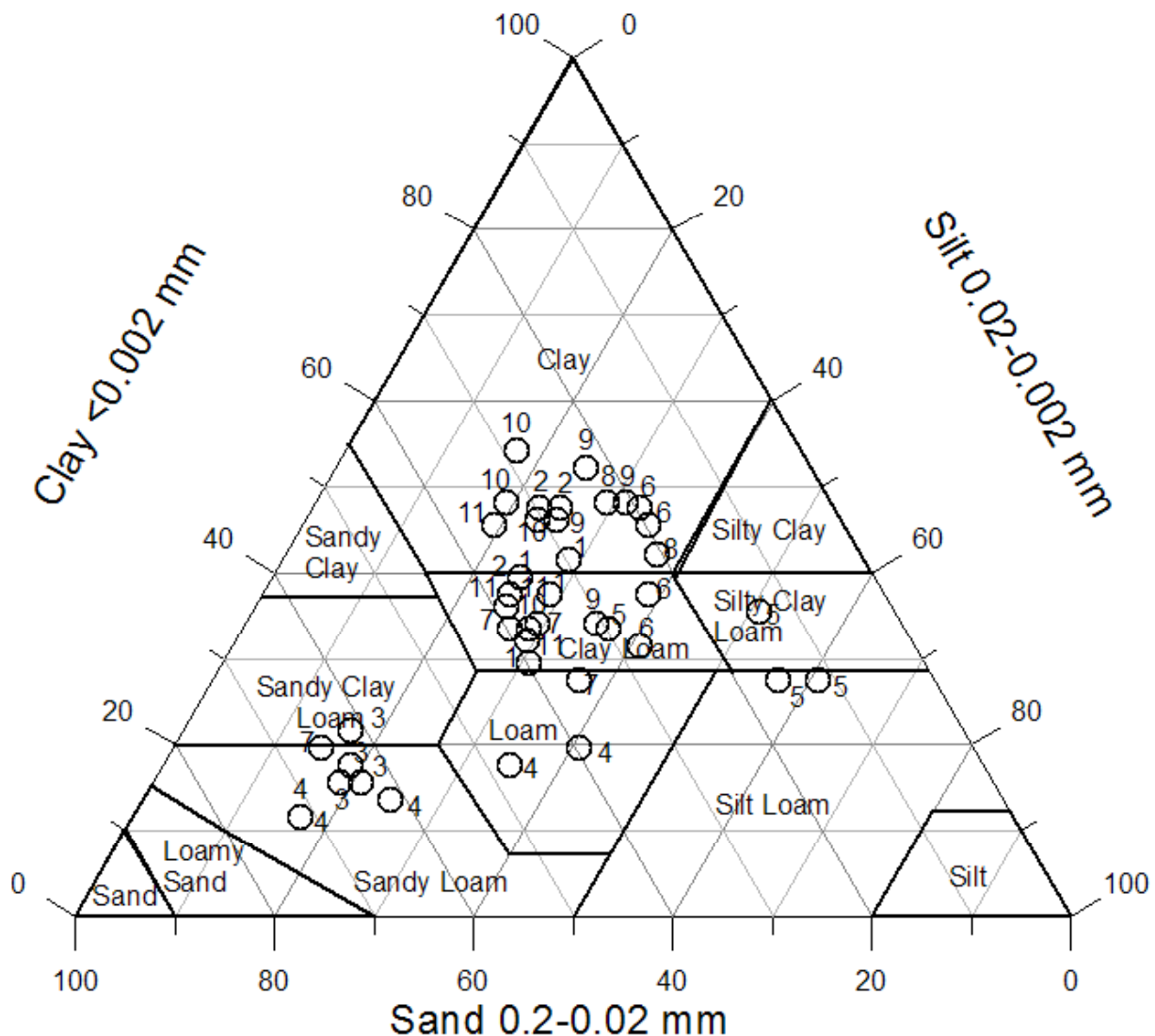


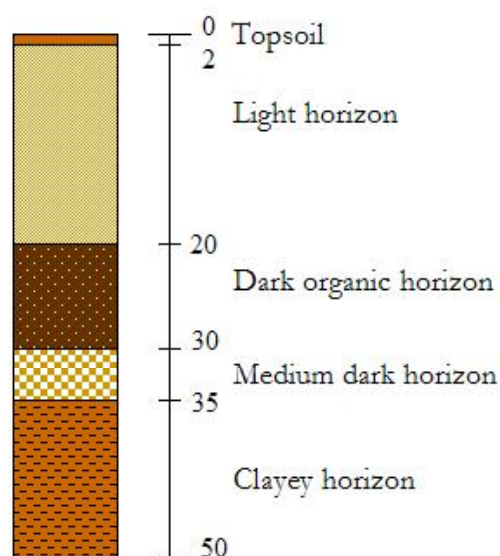
Fig. 21. Textural distribution of the soil samples taken by SSLCC, put in a ternary diagram by the authors. The soil definition is done by the United States Department of Agriculture, USDA, classification (Shaw 1994)

**Table 10. Soil type distribution within the study area (Soil Survey and Land Classification Centre, SSLCC 2006)**

Soil type	Area [ha]	Percent
ACh-D-CL-c(L)	130.8	4.0
ACh-D-CL-d(M)	570.3	17.6
ACh-S-CL-e(L)	181.0	5.6
CMe-D-L-b(M)	244.8	7.5
LPd-R-L-e(L)	165.3	5.1
LPc-R-HC-e(L)	1954	60.2
<b>Total</b>	<b>3246</b>	<b>100</b>

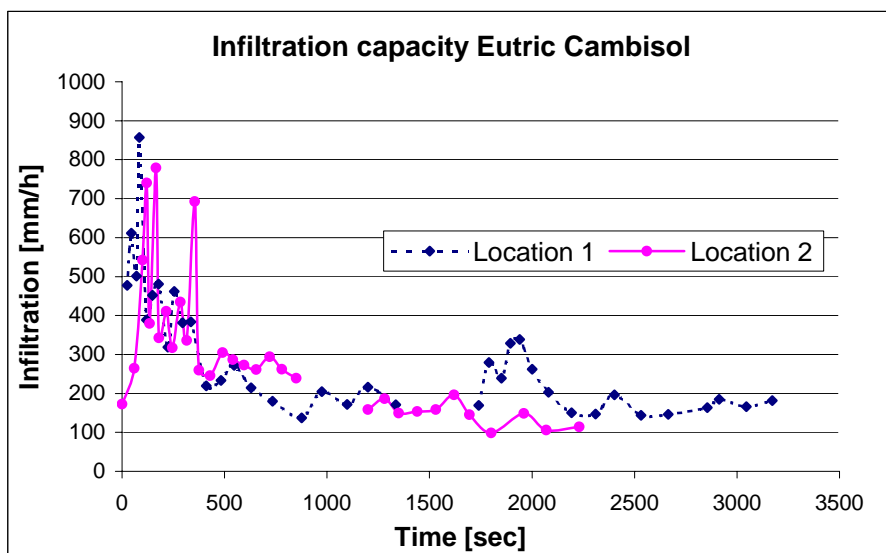
The farmers in Laos have different ways of classifying soil. Similar for the Hmong and the Khamu ethnicities in Huay Maha is that they classify soil from properties and colour. Such can be “soft and red soil” or “rocky soil, black rock” (NAFRI 2003). Colour in soils can be used as an indicator for different properties (Ritter et al 1995). Ticehurst et al (2006) shows the relationship between soil colour, iron content and saturation period. In a soil that is well drained and rarely saturated, the iron can exist as hematite,  $\text{Fe}_2\text{O}_3$ , which gives the soil a red colour, while in a soil with less drainage that is saturated in periods, iron tends to exist as goethite,  $\text{FeOOH}$ , which gives the soil a yellow colour. The colour range from red – brown – yellow – grey, and correspond to an increased degree of saturation (Ticehurst et al 2006). Black and dark brown colours indicate high organic contents and light-grey and white soils indicate presence of  $\text{SiO}_2$  or  $\text{CaCO}_3$  (Ritter et al 1995). However, small amounts of a pigment can cause a

**Cm below soil surface**

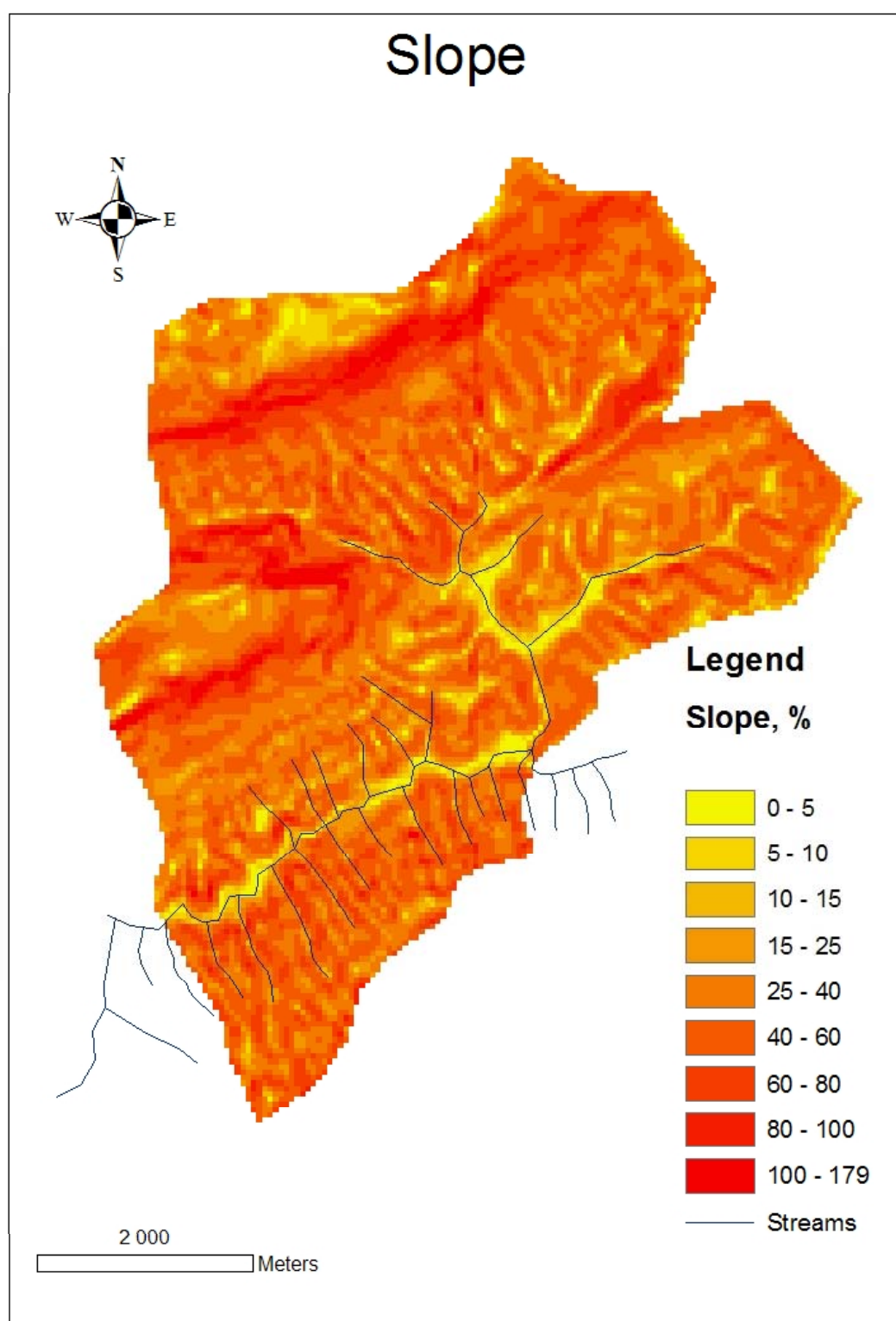


**Fig. 22 Soil profile at the shore of Nam Pa 100 m upstream of intersection with Huay Maha. (Location 1 19 57 48 N, 102 30 04 E).**

discolouration, so drawing too many conclusions of a soil property from colour alone is not recommended (Ritter et al 1995). A study performed by Saito et al (2006) shows that local farmer's knowledge and description of soils very much correlate with scientific analyses.



**Fig. 23. Infiltration capacities measured by the authors. Location 1 is on the shore of Nam Pa, 100 m upstream of intersection with Huay Maha. Location 2 is in Pong Pao W settlement. .**



*Fig. 24. Slope classification over the study area. 100% slope corresponds to 45 degrees. (Modified data from NAFRI 2006)*

### ***Infiltration Capacity***

Infiltration capacity was measured in field by the authors at two locations for the eutric cambisols. The test required available water close by, and therefore only soils close to streams could be measured.

Location 1 was about 20 m from Nam Pa's shore, about 100 m upstream of the inflow of Huay Maha. The land was in fallow at this site, with light vegetation. It was flat and likely receives overland flow from the slopes to the south. The site was approximately three metres higher than the water level in the river, so the river does not cover this land after a "normal" heavy rain. The soil had several horizons. The topsoil was 2 cm thick with some fine roots. 2-20 cm below the surface was a slightly lighter horizon. 20-30 cm down there was a distinct dark horizon, partly black with organic matter wooden residues. At the depth of 30-35 cm the soil was lighter and below this, 35-50 cm below the surface the soil was more clayey and moist (Fig. 22).

The infiltration capacity had a decreasing trend with time (Fig 23). It has roughly the shape described by Horton's equation:  $f(t) = f_c + (f_0 - f_c) * e^{-kt}$

Where  $f$  is the infiltration rate,  $t$  is the time,  $f_0$  is the initial value of the infiltration rate,  $f_c$  is the constant infiltration rate it will stabilize at and  $k$  is a decay constant (Chow et al 1988). The parameter of interest is  $f_c$ . At location 1 the infiltration capacity approached 0.040 mm/s or 144 mm/h (Appendix VII).

The infiltration capacity was also measured in Pong Pao W settlement (location 2) about 10 m west of Huay Mehteng and 1.5 m higher than the stream. The land was relatively flat with weeds and low vegetation. The mountain slope is likely to produce overland flow at heavy rains. The soil was reddish-brown, unsorted and contained much stones and gravel. The stones were soft and could be broken with the shovel. Roots penetrated about 10 cm below the surface. There were no clear horizons but the clay content increased with depth. The infiltration capacity had a decreasing trend at this site as well (Fig. 20). The infiltration capacity at location 2 approached 0.035 mm/s or 126 mm/h (Appendix VII).

The average infiltration capacity for the two locations is 135 mm/h. The eutric cambisols in both measured locations are deep loams (Fig. 19). The measured infiltration capacity is significantly higher than the infiltration capacity of 3.4 mm/h for loam mentioned by Shaw (1994).

### ***Slope***

The slopes have been extracted from a digital elevation model of Phonxay district (Fig. 24). The slopes range from zero to 179 %, the most prevalent slopes being in the interval 30-70 % (Fig 25). Only 1.9 % of the land within the study area has less slope than 5 % (Table 11), and that land is mainly located around the streams (Fig. 24). From the prevailing crop & vegetation map (Fig. 26) it is evident that cultivation takes place on slopes up to at least 60 % and in a few places up to 80 %. The slopes on the northern side of Nam Pa are less steep than the slopes on the southern side. Observe that 100 % slope corresponds to 45°.

Almost one third (28 %) of the study area has a slope less than 30 %, this is the land primarily suitable for water harvesting methods. The rest of the land (72 %) is land with more than 30 % slope, where conservation measures are badly needed but sustainable cultivation is difficult to achieve.

An external project has provided NAFRI with a watershed classification map (Fig. 27). Based on slope, the map points out which areas that are most sensitive to soil erosion, recommends suitable landuse and where conservation measures are most needed.

*Class 1* - Areas that due to very steep slopes are sensitive and need water and soil conservation. As a rule, this land should be kept under permanent forest cover. This class cover large areas south of Nam Pa, around Phou Phatek and south of the highland plateau

*Class 2* - is considered to be less prone to water and soil degradation than class 1, but the slopes are still steep and the recommended landuse is forest, both for conservation and production. Agroforestry and grazing can be appropriate if accompanied with strict conservation measures. Class 2 covers the slopes north of Nam Pa and around Huay Maha

*Class 3* - The slopes are medium to steep and landforms are less sensitive to erosion. The recommended landuse are of greater range. Still conservation measures are recommended and agricultural crops should be accompanied with trees. Class 3 covers small areas close to Huay Maha

*Class 4 and 5* - moderate and gently sloping areas that are in less or no need of soil and water conservation measures. Only a tiny plot on the highland plateau falls into class 4. Class 5 does not exist within the study area.

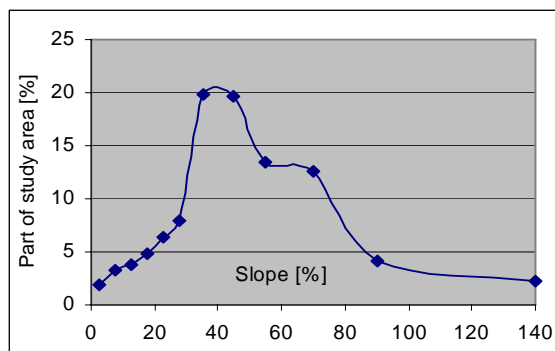


Fig. 25. Graph showing part of the study area with certain slope (data modified from NAFRI 2006).

Table 11. Part of area with certain slope (calculated from fig 24)

Slope [%]	Area [ha]	Area [%]
0-5	61.8	1.9
5-15	233.8	7.2
15-30	619.3	19.0
30-50	1281.0	39.4
50-80	848.8	26.1
>80	207.5	6.4

### Vegetation

The most important vegetation types in the study area are forest, fallow and cultivated land. The cultivated land has been further classified according to which type of crop that is grown (Fig. 26). Since fields that were cultivated in 2006 may be in fallow 2007 and vice versa and the type of crops also varies over time, emphasis in this section is on amounts of land with certain vegetation, rather than precise locations of different crops or vegetation types.

A mere 45 % of the area was in fallow 2006. Rice is the main crop cultivated. Upland rice covers 25.5 % percent of the total land cover and paddy rice 1.6 % (Table 12). Not shown in the landuse map is that in some of the rice fields corn is integrated. The difference between “forest” and “mixed forest” is not defined. However “mixed forest” is a relatively small proportion compared to “forest” and together they add up to 21 % of the total landuse. Bamboo, banana, cassava, fruit trees, job’s tears, rubber, sesame and teak occupy small areas, in total about 6.6 % of the area. Not the entire study area was mapped by Sanchez (2007) but the percentage distribution is assumed to be comparable for the whole study area.

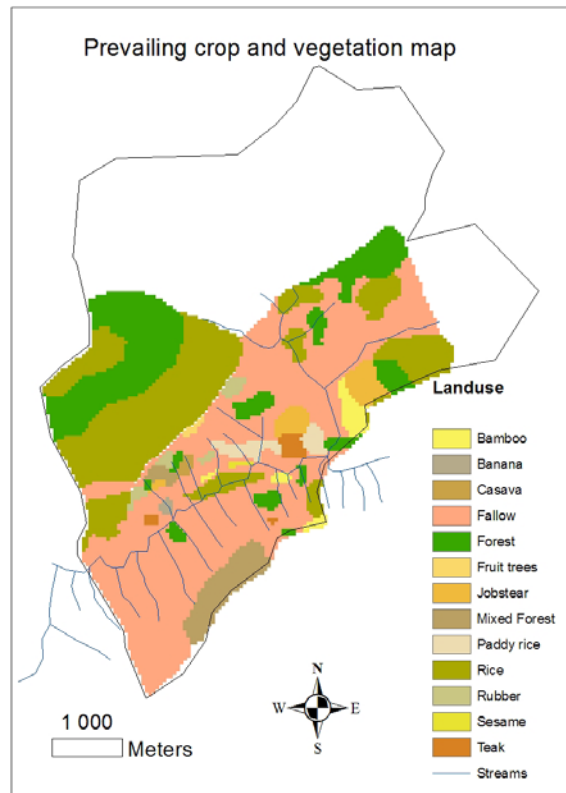
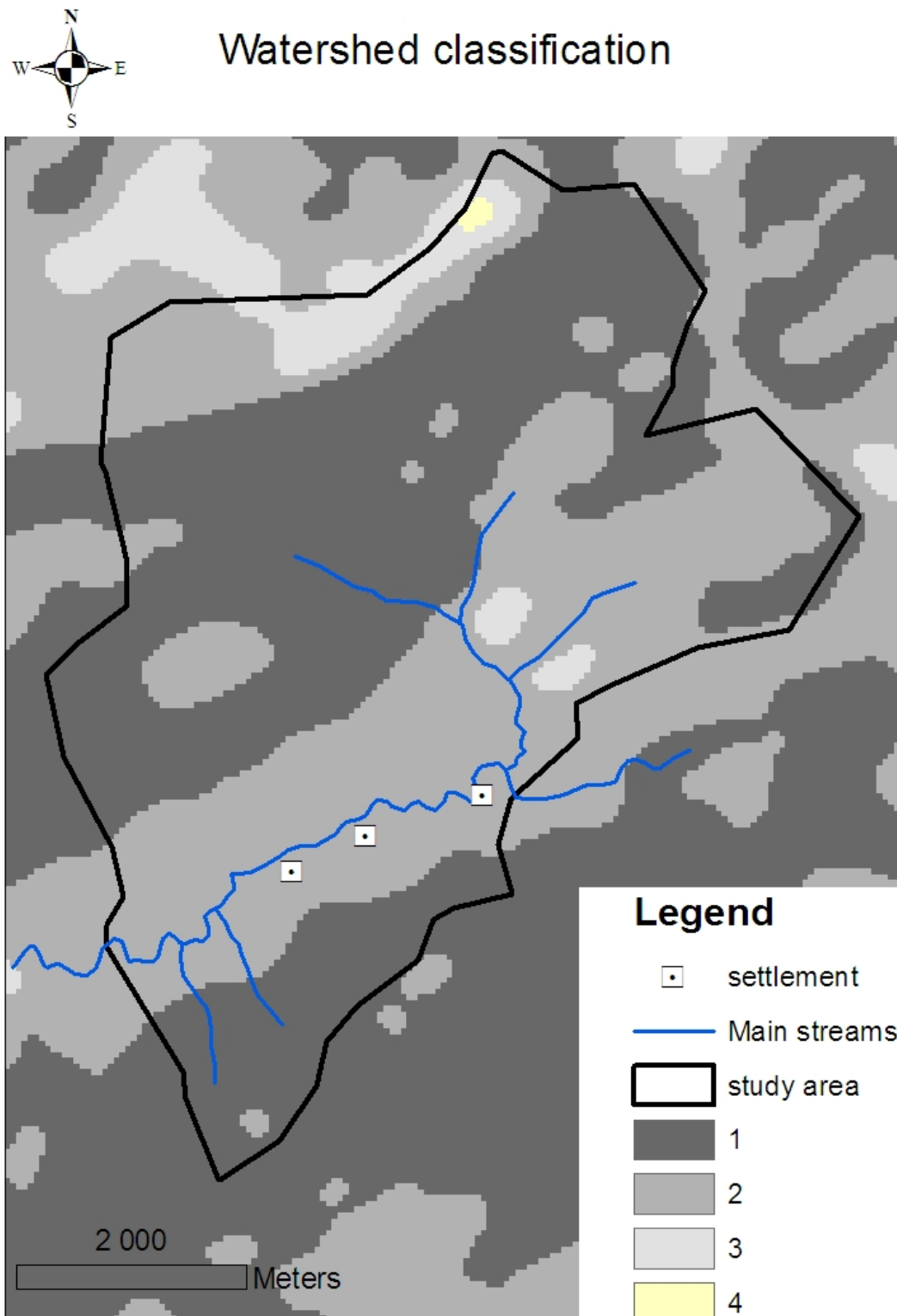


Fig. 26. Prevailing crop and vegetation within study area. For white area, no data were available. (Modified from Sanchez 2007).

Table 12. Part of study area that has been classified with certain vegetation. (Sanchez 2007).

Landuse	Area [ha]	Percent
Bamboo	31.3	1.6
Banana	3.8	0.2
Casava	5.8	0.3
Fallow	861.5	45.4
Forest	325.3	17.1
Fruit trees	3.5	0.2
Jobstear	44.3	2.3
Mixed Forest	74.0	3.9
Paddy rice	30.0	1.6
Rice	482.8	25.5
Rubber	19.0	1.0
Sesame	2.3	0.1
Teak	15.5	0.8
<b>Total</b>	<b>1899</b>	<b>100</b>



*Fig. 27 Watershed classifications. Class 1 - Very steep slopes, sensitive and need water and soil conservation. Should be kept under permanent forest cover. Class 2 - Less prone to water and soil degradation than class 1, but the slopes are still steep and the recommended landuse is forest. Class 3 - Medium to steep slopes. Conservation measures are recommended and agricultural crops should be accompanied with trees. Class 4 and 5 - moderate and gently sloping areas that are in less or no need of soil and water conservation measures (Modified data provided by NAFRI 2006).*

## Interviews

### Landuse

The farmers in Pong Pao E have lived there for about 25 years. Before the land allocation program, 2001-2002, they had 5-8 fields per family. Today they have 2-3 plots per family and they cultivate on a new plot each year. Before when they had eight years of fallow period, the soil recovered well. Today they get less yield, the weed grow well but not the crop.

The settlement Huay Maha has existed since 1986. Before 2001 they had many plots, but after the land allocation program they are only allowed 2-3 plots per family. They plant one year and then the land is in fallow 2-3 years. They use the slash- and burn technique. Job's tears and sesame is the main source of income. The first year they cultivate on a plot they get about 2000 kg rice per hectare. If they cultivate a second year on the same plot they get less.

All the inhabitants in Pong Pao W are new settlers from the highland. They have lived in the valley for about five years. Each family has three or four plots. They grow rice the first year, job's tears the second and sesame the third year. Then the land is in fallow for a couple of years. Some families use a new plot every year and some families still cultivate their fields in the highland where they used to live before. They have not changed the fallow time since they moved to the valley.

According to Mr Peter Jones senior adviser at NAFRI, the plot sizes range between 0.8-1.2 ha (Jones 2007). For commercial crops like corn, the area may be larger. The number of plots per family varies between 1-8. Many families have four plots. Usually the new settlers are the ones with fewer plots (Jones 2007).

According to Mr Inthavong (2006), responsible for LSUAFRP field station in Nam Bo, there has been a landuse change because of the population increase in the village. Forest is cut down in order to obtain more land for cultivation. He believes that the newly deforested land is not good for cultivation since it is too steep and soil fertility is low. In Pong Pao E there is a small area of conservation forest, which is protected from deforestation. DAFEO have prohibited people to cultivate close to the streams in order to have a buffer zone that preserves the water. They also recommend cultivation of vegetables along Nam Pa for manual irrigation. Today only a few of the fields along Nam Pa are used for vegetables.

### Water in cultivation

There was not enough rain for cultivation during 2006, according to the farmers in Huay Maha. Some of the rice, corn, job's tears and sesame died. Rice is planted in June and there was not enough rain for the rice to germinate this year. Previous year there was also a rain deficit but fewer crops died then.

In Pong Pao W the men stated that it rains enough every third year. In May-June there is a water deficit. In July-September there are sufficient water amounts every year. They grow the same crops every year; rice,

**Table 13. Land use distribution in Huay Maha from interviews (Appendix I)**

Crop	Area [Ha]	Percent
Rice	70	21
Job's tears	55	17
Sesam	40	12
Teak	7	2
Fallow land:		
Young (2 yr)	80	24
Old (4-5 yr)	80	24
<b>Total</b>	<b>332</b>	<b>100</b>

job's tears, corn and sesame. The women in Pong Pao W stated it begins to rain in early July, so they plant the rice in late June, otherwise they will not get much yield.

In Pong Pao E the inhabitants stated that they have rainwater deficit every year. They grow rice, Job's tears and sesame.

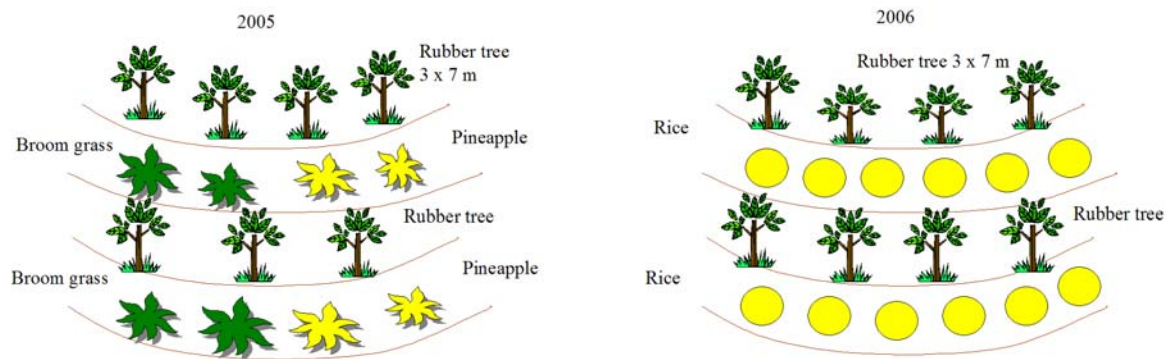
Mr Inthavong (2006) believes that there is not enough rain for cultivation in this area. He also thinks that it is impossible to divert water around Huay Maha because the surrounding slopes are too steep.

### Soil erosion

Most of the fields are located in medium-steep slopes. All but the women in Pong Pao W confirmed that they have problems with soil erosion after heavy rainfall. They loose much soil due to heavy rainfall and sometimes even crops. The men in Pong Pao W told that one heavy rain may sweep away 1 cm of soil in flat land and the average loss in steep slopes is 2 cm. The first year with a new crop there is no problem, but the second and third year there is a problem according to the men in Pong Pao W. The women in Pong Pao W stated that they do not have problems with soil erosion since their plots are situated in flat areas. Later they admitted that others might have problem with soil erosion. The women in Pong Pao W were the only ones who stressed that the climate in the upland is more favourable for cultivation than down in the valley where it is too hot. They still grow rice and corn in the upland where it is more humid and the yields are larger than in the valley.

In Huay Maha, the minimum soil loss is 1.5 cm and maximum 3 cm after one heavy rainfall. Sometimes crops are swept away. In Pong Pao E, 2-3 cm of topsoil is lost after one heavy rain. They emphasize that the consequence is that the crops do not grow well when soil is swept away.

Assuming that 2 cm of soil with a density of 1.4 t/m<sup>3</sup> is lost after one heavy rain, the resulting soil loss is 280 t/ha and heavy rain. Assuming it occurs three or 1000 t/ha\*yr. This estimation shows an extremely high erosion rate, compared to literature and previous studies. Sidle et al (2005) compares different soil erosion rates in Southeast Asia. In Chiang Rai,



**Fig. 28.** Example of how integrated cropping and contour lining look like in Sida's project in Huay Maha. The left picture shows crops that are grown the first year. The right picture shows which crops that are grown on the same plot the second year.

Thailand, upland rice shows erosion values of 61-90 t/ha\*yr on slopes 17-27° in one study, and 460 t/ha\*yr on slopes 11-29° in another. In Chiang Mai, Thailand, upland rice shows the medium value of 89 t/ha\*yr. Undisturbed natural and secondary rainforest shows erosion rates of 0.01-1.2 t/ha\*yr throughout Southeast Asia. Moldenhauer and Hudson (1988) shows extreme erosion values of 564-747 t/ha\*yr from a study in Ivory Coast where rainforest on steep slopes had been transformed to agricultural land. The estimated erosion in Huay Maha is without doubt a significant problem.

#### Soil and soil moisture conservation

The knowledge of measures for preventing soil



**Fig. 29.** Picture of integrated cropping & contour lining from Sida-project in field (Billving & Ågren 2006).

erosion is limited among the farmers. However the men in Pong Pao W and the farmers in Huay Maha have heard about contour lining and integrated cropping from DAFEO. According to staff from NAFRI, 4-5 families are involved in Sida's contour lining project. The families within the project planted rubber, pineapple and broom grass in 2005. The second year, in 2006, they planted rice as the integrated crop between the somewhat grown up rubber trees (Fig. 28; Fig. 29). While the rubber trees are growing they also grow vegetables, soybeans and corn. The vegetables are for consumption while working in field and the surplus is sold. When the rubber trees have grown up there will be a forested area (Keolasy 2006). The families involved in the project are satisfied with the method. NAFReC has also introduced them how to reduce soil erosion by leaving weeds on the ground. Earlier they used to cut down weed in March, burn in April and seed in June. Then the trees grew well the first year but not the second. Instead they should let the weed grow during the dry season and not cut it down until the rainy season begins and it is time to plant new crops.

Families who are not involved in the project do not use any conservation measures. They cannot afford rubber or any other plant to alternate with. The men in Pong Pao W want Sida to help all the families financially. The women in Pong Pao W and inhabitants in Pong Pao E state that they do not use and have never used any soil- or soil moisture conservation measures. The women mention that when staff from the district comes to inform about new cultivation techniques they only talk to the men. The women do mainly household labour but also work in the fields.

#### Rainwater Harvesting

No one in the three settlements use any kind of traditional rainwater harvesting today. But when they lived at the highland plateau (Pong Pao W & Huay Maha), they collected rainwater from the roofs and led it in bamboo pipes to a dug well. The quantities were not enough for their needs. They still drink from that water when they are up there looking after their livestock. Their livestock drinks from natural ponds, which is said to be enough.

Table 14. Summary of the most important interview results. (Appendix I).

Settlement	Crops	Nr fields	Water resource situation		Erosion after heavy rain	Soil moisture conservation	Pollutants
			Cultivation	Domestic			
<b>Poung Pao East</b> Pop. 30-35	Rice, Job's tears, Sesame	Before 2001: 5-8 plots/fam. 2006: 2-3 plots/fam	Water deficit every year	1 supply with 3 taps, 1 functioning Consumption [l/p*d] : ~20  Deficit May-June, then washing in Nam Pa  No quality problems Boil the water before drinking  1 hour prep for collecting & boiling /day	2-3 cm	No knowledge	No fertilizers or pesticides  Keep animals away from streams  Place garbage a bit away from village
<b>Poung Pao West</b> Pop. 900	Rice Job's tears Sesame Corn	Moved here 2001. 3 or 4 plots/fam.	Water deficit 2 of 3 years in May-June. July-Sept. always ok.	1 supply, 12 taps 2 functioning Consumption [l/p*d]: <10 (m) ~50 (w)  Complaints about muddy water & too small pipes. 1 hour queue for collecting water in morning & evening  Always a deficit, they use another stream as well	Flat land: 1 cm, Steep slopes: 2 cm	Men know about contour lining & integrated cropping, not women	No fertilizers or pesticides  The men claims that they burn their garbage - women that they do not  Keep animals away from streams
<b>Huay Maha</b> Pop. 400	Job's tears Rice Corn, Taro Bean Chili Eggplant	Before 2001: many 2006: 2-3 plots/fam.	Usually water deficit. In 2006 crops died due to water deficit	1 supply, 4 taps Consumption [l/p*d] : ~10 Water deficit in dry season  Kidney problems, suspect it is connected to water supply  Half an hour collecting water each day, boiling not included	1.5-3 cm	Integrated cropping & contour lining	No fertilizers or pesticides  Keep animals away from streams  Put garbage somewhere, when enough- someone burns it

### *Domestic water and consumption*

All three settlements have a drinking water supply, financed by a EU-project. They use the supplies for drinking and cooking. The water is tapped from the small streams on the southern hill slopes of the valley. Nearly all families boil their water before drinking it. Some women also filter their water through fabrics. The district office has had a campaign where the villagers were told to boil the drinking water. When out in field they drink directly from the streams. They wash their clothes and take a bath in Nam Pa.

In Huay Maha there are about 400 people and four taps. Water consumption is estimated to six buckets per day and family. Three buckets in the morning and three in the evening. They spend about half an hour every day collecting water, boiling not included. Each family consists of 8-10 people. They have problem with mud in the streams close to the fields. Some of the villagers have problems with their kidneys, which they think is a result of the water from the water supply. During the wet season they use only the water supply, but in the dry season there is a water deficit and they use Nam Pa as well. Before 1989 they used Nam Pa for drinking water. All the villagers used to have problems with their stomachs and vomited. The district funded a water supply and the villagers did the labour. After changing water supply they felt dizzy less often.

Poung Pao W with more than 900 inhabitants has one domestic water supply with 12 taps, out of which two work well. The people who live close to the water supply uses that water, but most of the villagers prefer to take water from Huay Mehteng (Fig. 27). There is always a water deficit in the supply, the pipes are too small, the water is muddy and they get lime residues on the pots when boiling the water. The water in Huay Mehteng is said to have no quality problems. There is a deficit during the dry season but it does not dry out completely. In the rainy season they wash their clothes in Huay Mehteng and during the dry season they use Nam Pa for the same purpose. When the village was new some families used Nam Pa as drinking water, but no one do that anymore.

The women in Poung Pao said that each family uses about 20 buckets per day for a family of nine people since they have a lot of water and it is free. The men in the same settlement estimate the water consumption to 100 litres per day for a family of 14. When everybody wants to collect water at the same time in the morning and in the evening, they may have to queue up to one hour.

In Poung Pao E they have three taps out of which two is out of order. A little bit more than 30 people take all their domestic water from their water supply all year round, with exception for May-June when there isn't enough water for bathing in the supply. They then bath in Nam Pa. Their estimated consumption is eight buckets per day for a small family of five. It takes them about one hour to collect and boil the water.

According to Inthavong (2006), the DAFEO wants to improve the domestic water supplies by changing the pipes, but there is no budget for that.

### *Potential pollutants*

None of the interviewees use any fertilizers or pesticides. In all three settlements they have agreements of keeping their animals away from the streams. In one of the settlements there are goats around Huay Mehteng, but since they belong to the deputy, the other villagers do not dare to say anything. In Huay Maha they have pens for hens and chicken.

In Poung Pao W the men states that they burn their garbage while the women states that they throw their garbage along the road sloping towards Nam Pa. They clearly state that they do not burn their garbage. In Poung Pao E they have no special place for their garbage but they usually place it a bit away from the village. In Huay Maha garbage is burnt.

No one in the area have a toilet, they all go to the forest. The men in Poung Pao W said that they usually go a far bit into the forest. The women said that they would like to have a toilet if they had enough water. Tomawong (2006), headman of Huay Maha settlement said that DAFEO has promised them a toilet. Today they go to Nam Pa River.

The complete answers from the interviews are found in Appendix I and a summary of the interview results are shown in table 14.

## **Surface Water**

### *Water flows*

The surface water in the area consists of Nam Pa river and its' tributaries (Fig. 30; Table 15). The largest of these tributaries is Huay Maha, collecting water from the streams in northeast and joining Nam Pa shortly after its inflow to the study area (Fig. 30). On the mountain slopes north and south of Nam Pa river there are a 17 small streams, some of which are seasonal. Out of these small streams two are treated separately since they have a larger flow than the others.

The last rain event prior to the fieldwork was on October 9<sup>th</sup> 2006. It was a heavy rain causing maximum flows in all the streams in the area (Tomawong 2006; Keolasy 2006). The flow measurements were made between October 18<sup>th</sup> and 26<sup>th</sup>. Some of the larger streams probably had a higher flow than normal this time of year because of this, but the smaller streams are according to the villagers only raised for a couple of hours and then recede to normal levels. The measured flows were at most locations described as normal for the dry season, even at the minimum level for some streams.

Nam Pa river was measured at it's in- and outflow of the study area (Fig. 31). At the inflow Nam Pa had a cross section of 5.86 m<sup>2</sup> (Fig. 29), an average flow velocity of 1.54 m/s and this gave a flow Q of 9.02 m<sup>3</sup>/s (Table 16). The flow velocity was

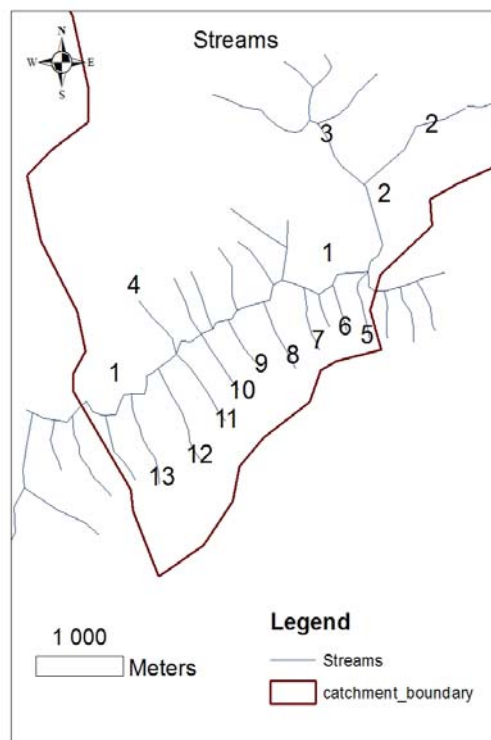


Fig. 30. Map showing the streams in the study area (Modified from NAFRI 2006). See Table 15.

Table 15. Name of streams related to Fig. 30.

Stream no	Name
1	Nam Pa
2	Huay Maha
3	Huay Keo
4	Huay Panoi
5	Huay Wang Pou
6	Huay Ong
7	Koa Luang
8	North Kokten
9	Huay Poung
10	Huay Namlin (Kokten)
11	Huay Mehteng
12	Huay Njort
13	Huay Gamlao

significantly higher at the northern shore than in the middle and south side of the river. A varying flow over the cross section is typical for meandering rivers (Ritter, et al 1995). The cross section at this point was also measured on October 19<sup>th</sup> and then the maximum water level was estimated (Fig. 30).

At the outflow of the area Nam Pa had a cross section of 6.20 m<sup>2</sup>, an average flow velocity of 1.09 m/s and this gave a flow Q of 6.76 m<sup>3</sup>/s (Fig. 32 and Appendix VI).

Huay Maha collects water from an area of 21.28 km<sup>2</sup>, which is 66 % of the total study area. The western branch (Huay Keo) had a baseflow of 0.82 m<sup>3</sup>/s

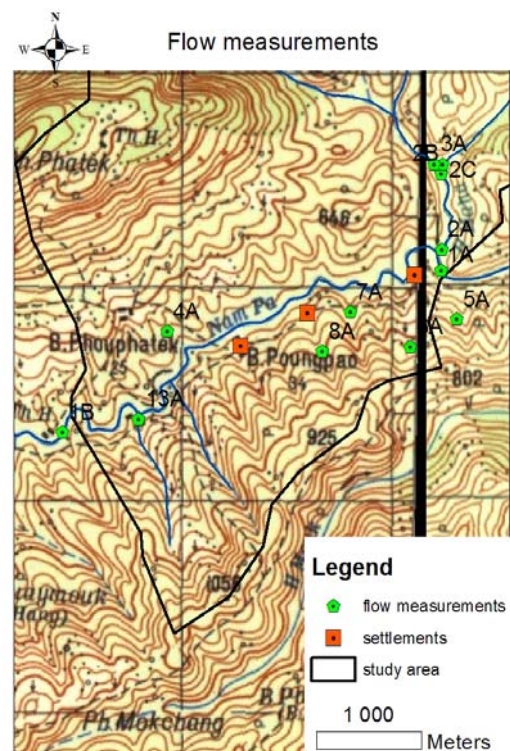


Fig. 31. Map showing location where flow measurements were performed. (Topographic map from NAFRI 2006).

(Table 16) but in the dry season this is reduced by half and it dries out completely in May. After a heavy rain the water level rise to 1 m depth, but 1 hour later the stream is 0.45 m deep instead of 1 m and a few days later the flow will be back to normal (Appendix I). Downstream the intersection of Huay Keo Huay Maha had a cross section of 0.22 m<sup>2</sup> normally and maximum cross section 12.5 m<sup>2</sup>. Mr Bounta Tomawong (2006) described it: “Then no man can cross it”, which indicates that the flow must also be much higher than normal. This shows a very high rain response.

The cross section and flow velocity was measured just before Huay Maha intersects with Nam Pa. The cross section was found to be 0.18 m<sup>2</sup>, the flow velocity 1.48 m/s and this gave the flow Q of 0.27 m<sup>3</sup>/s. This flow was measured on October 26<sup>th</sup>, 15 days after the heavy rain. The flow was also measured on October 19<sup>th</sup> and then had a significantly larger flow, 0.97 m<sup>3</sup>/s. The flow 15 days after the rain is considered more representative of the base flow.

Huay Gamlao and Huay Mehteng run down the slope in the south western part of the area. Huay Gamlao's cross section and flow velocity was measured just before its intersection with Nam Pa and assumed to be representative for Huay Mehteng also. It has a cross section of 0.057 m<sup>2</sup>, a flow velocity of 0.23 m/s and this gave a flow Q of 0.013 m<sup>3</sup>/s, or 13 l/s.

There are 15 small streams running down the sides of the mountain slopes to Nam Pa. Out of these 11

**Table 16.** Measured surface water flows in Huay Maha. The cross section and the resulting flow  $Q$  were calculated using Matlab (Appendix VI). The minimum flow  $Q_{min}$  could only be determine for the streams that dry out and Nam Pa. Nam Pa was calculated by using Manning's equation. Maximum cross sections are based on local farmer's estimation of maximum water levels. No in column 2 are correlated to the numbers in Fig. 31

Stream	No	Date	Cross section [m <sup>2</sup> ]	Flow [m/s]	$Q_{measured}$ [m <sup>3</sup> /s]	$Q_{min}$ [m <sup>3</sup> /s]	Max cross section width x depth [m]
Nam Pa	1A	061026	5.86	2.0; 1.14; 1.48*	9.02	3.7***	25 x 2.5
Nam Pa	1B	061026	6.20	1.11; 1.07**	6.76	-	-
Huay Keo	3A	061019	0.095	0.58	0.055	0	2.7 x 1
Huay Maha	2B	061019	0.22	0.81	0.18	-	14 x 0.9
Huay Maha	2C	061019	0.087	0.54	0.047	-	-
Huay Maha	2A	061019	0.40	2.40	0.97	-	8 x 1.4
Huay Maha	2A	061026	0.18	1.48	0.27	-	8 x 1.4
Huay Gamlao	13A	061026	0.057	0.23	0.013	-	0.5 x 1
Huay Ong	6A	061018	0.03	-	-	-	-
Huay Panoi	4A	061026	0.002	0.30	0.059	0	-
Huay Wang Pou	5A	061026	-	-	$1.39 \cdot 10^{-5}$ ****	-	4 x 0.35
Koa Luang	7A	061019	0.018	-	-	-	3 x 1.4
North Kokten	8A	061018	0.002	-	-	-	2.5 x 0.25

\*North side 2 m/s, Middle 1.14 m/s and South side 1.48 m/s

\*\*North side 1.11, middle 1.07 m/s

\*\*\*Calculated using Manning's equation

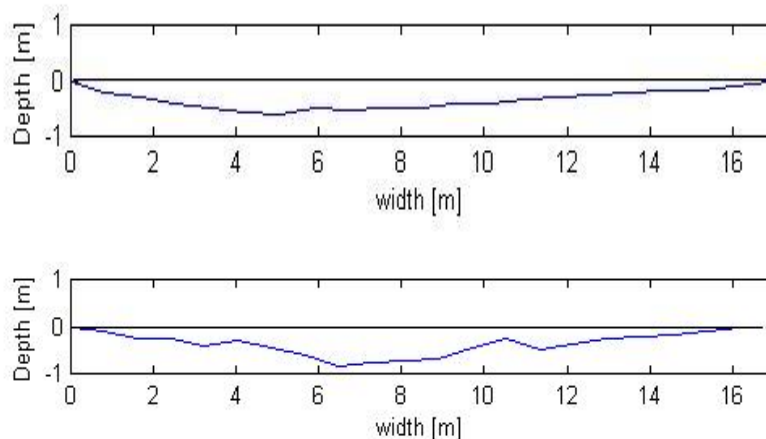
\*\*\*\*Measured by timing the filling of a bottle with known volume

were on the southern slope (facing north) and 4 on the northern slope (facing south). All of them have cutted down in the slopes, they are highly rain responsive but have a steady base flow all year around, with a few exceptions. Huay Panoi was chosen as a representative stream. The cross section was measured to 0.020 m<sup>2</sup> and the flow velocity 0.29 m/s which gave the flow  $Q$  0.0059 m<sup>3</sup>/s or 5.9 l/s.

The total flow reaching Nam Pa from the streams in the study area is:

$$\sum H \text{ Maha} + 2 \cdot H \text{ Gamlao} + 15 \cdot \text{small streams} = 0.27 + 2 \cdot 0.013 + 15 \cdot 0.0059 = 0.38 \text{ m}^3/\text{s}$$

By comparing the in- and outflow of Nam Pa to the area, it seems like Nam Pa has lost 2.26 m<sup>3</sup>/s during its course through the area. This is not realistic, since several streams intersect with the river adding 0.38 m<sup>3</sup>/s to its flow. Since Nam Pa is located at the bottom of a valley and should receive groundwater outflow, the losses are not likely to be much larger than the evaporation. However, the flow patterns in karst areas such as this one may not behave this way. Still it is most likely that Nam Pa receives at least 0.38 m<sup>3</sup>/s during its course through the area at the time of the measurements. Because of this anomaly the flow measurements are viewed critically. As has been discussed previously it is likely that the outflow from the area was underestimated.



**Fig. 32** Cross sections of Nam Pa river at inflow (upper) and outflow (lower) of the study area 26/10 2006. (Created in Matlab, Appendix VI)

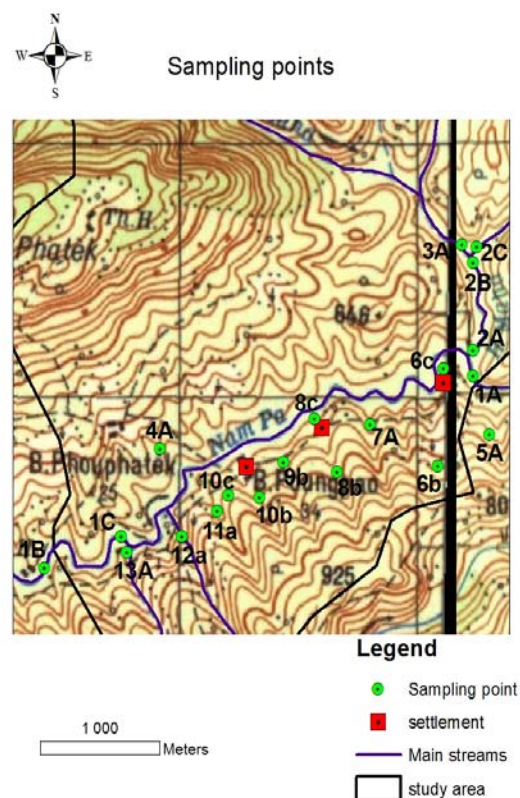
### Water Chemistry

Water has been sampled and analysed for 23 different sources or locations, some of them twice (Fig. 33). The chemistry of the water is important since it may limit the usage if, for example, it contains pollutants. However, the water chemistry also provides information regarding the processes the water has undergone on its path to the sampled source. It was primarily to characterize the water from a hydrogeological point of view that the chemistry was examined in this study.

According to the results (Table 17) pH varied between 6.9 and 8.5 with an average of 8.0. This is within the acceptable range for drinking water, which is between 6.5 and 8.5 (DeZuane 1997). However the obtained results for pH and nitrate are not accurate and will therefore not be interpreted further.

The conductivity depends on the ionic content of the water and is normally determined by the presence of dissolved minerals (DeZuane 1997). Electric conductivity varied between 0.17 mS/cm and 0.57 mS/cm with the springs having the highest values and the ponds on the highland the lowest. Among the streams Nam Pa had lower values than the smaller streams. There was no correlation between EC and chloride, but since the chloride content was very low it is expected that some other ions play a more important role for the electrical conductivity. The electrical conductivity was slightly lower at the first sampling than at the later.

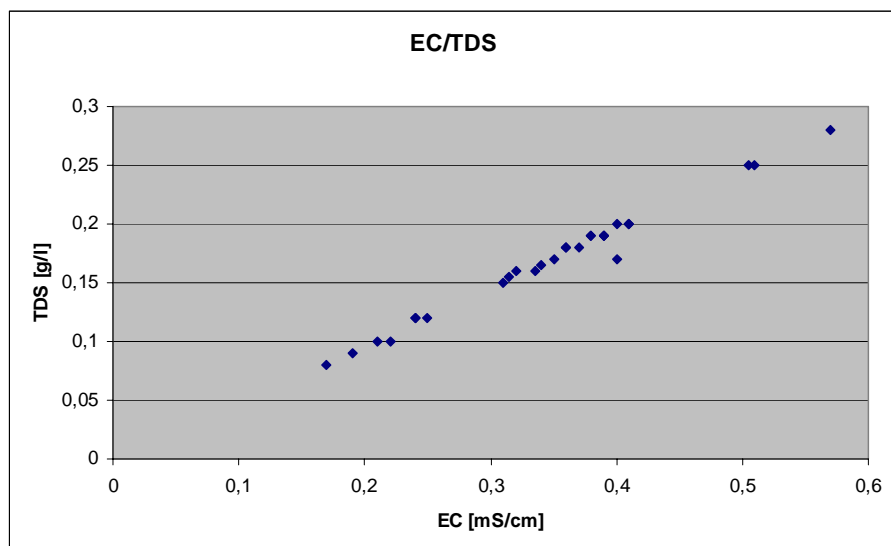
TDS reflects mainly the content of inorganic salts such as for example carbonates, chloride, sulphate and nitrate but to some extent also content of organic matter (DeZuane 1997). TDS varied between 0.08 g/l and 0.28 g/l. The lowest values were for the ponds on the highland and the highest in the springs. Nam Pa and Koa Luang had the lowest values for TDS among the streams. Since TDS is greatly influenced by ionic content, TDS and EC are related. The relation between EC and TDS in these results is linear with EC in mS/cm being on average twice the value for TDS in g/l (Fig. 34).



**Fig. 33.** Water sampling locations for chemical analyses of surface water, except for springs & ponds. The indexes are correlated to table 17 & Fig. 30. Capital letters mean samples were taken directly from streams and small letters means that sample were taken from a tank or a tap. (Topographic map from NAFRI 2006).

For drinking water an acceptable limit of total solids should be 0.5 g/l according to DeZuane (1997), which all the analysed samples were below, but then dissolved solids is not the sole part in the limitation.

Colour is caused by the presence of iron, manganese, humus, peat, plankton and weeds, while turbidity is caused by clay, silt and organic matter (DeZuane



**Fig. 34.** The relation between Electric Conductivity (EC) and Total Dissolved Solids (TDS) in the samples collected in the study area in October-November 2006. (Table 17)

**Table 17. Chemical analysis of surface water in Huay Maha. The index number refers to the stream no in Fig. 29. Capital letters refers to samples collected directly from the stream while small letters refer to samples from tanks and taps. For pH, Electric Conductivity (EC) and Total Dissolved Solids (TDS), the average value from two measurements are given with a standard deviation less than 3 % for all samples. Ammonium (NH<sub>4</sub>) and nitrate (NO<sub>3</sub>) was calculated from the analysis results of from Chianaimo Water Treatment Plant Laboratory. Colour and turbidity are grouped together and determined by visual classification where 0 indicates no colour or turbidity and 8 indicates yellow colour and high turbidity.**

No	Source	Stream	Date	pH	EC [mS/cm]	TDS [g/l]	Cl [mg/l]	NH <sub>4</sub> [mg/l]	NO <sub>3</sub> [mg/l]	Col. & Turb.
6b	Tank	Huay Ong	061018	8.4	0.40	0.17	4	0.51	14.26	6
6c	Tap	Huay Ong	061018	8.5	0.32	0.16	3	0.15	5.93	6
6c	Tap	Huay Ong	061031	8.0	0.35	0.17	6	0.13	<0.02	5
10b	Tank	Huay Namlin (Kokten)	061018	8.3	0.34	0.17	3	0.22	11.51	6
10c	Tap	Huay Namlin (Kokten)	061018	8.4	0.34	0.16	5	0.22	7.35	5
10c	Tap	Huay Namlin (Kokten)	061101	8.0	0.51	0.25	8	0.21	<0.02	1
8c	Tap	North Kokten (Namlin)	061019	8.2	0.40	0.20	2	0.22	2.48	6
8b	Tank	North Kokten (Namlin)	061018	8.2	0.39	0.19	2	0.15	3.19	5
3A	Stream	Huay Keo	061019	8.2	0.36	0.18	4	<0.06	3.19	1
2C	Stream	Huay Maha	061019	8.2	0.39	0.19	3	1.31	0.40	1
2B	Stream	Huay Maha	061019	8.2	0.38	0.19	2	0.04	3.19	1
2A	Stream	Huay Maha	061019	8.1	0.38	0.19	2	<0.06	8.72	1
2A	Stream	Huay Maha	061026	8.0	0.39	0.19	4	0.06	<0.02	1
1C	Stream	Nam Pa	061026	8.3	0.24	0.12	5	0.90	<0.02	1
1C	Stream	Nam Pa	061019	8.2	0.21	0.10	2	0.15	8.72	6
1A	Stream	Nam Pa	061019	8.2	0.22	0.10	1	0.37	7.35	6
1A	Stream	Nam Pa	061026	8.3	0.25	0.12	2	<0.06	<0.02	1
7A	Stream	Koa Luang	061019	7.8	0.24	0.12	2	0.24	8.72	6
	Spring		061024	7.2	0.57	0.28	3	0.28	<0.02	0
	Spring		061024	7.2	0.51	0.25	3	0.04	<0.02	0
11a	Tap	Huay Mehteng	061101	8.1	0.41	0.20	5	<0.06	<0.02	1
13A	Stream	Huay Gamlao	061025	8.3	0.36	0.18	5	<0.06	<0.02	1
13A	Stream	Huay Gamlao	061026	8.0	0.31	0.15	2	0.05	<0.02	2
12A	Stream	Huay Njort	061025	8.1	0.32	0.16	6	<0.06	<0.02	1
5A	Stream	Huay Wang Pou	061026	8.1	0.37	0.18	4	0.13	<0.02	2
4A	Stream	Huay Panoi	061026	8.1	0.41	0.20	2	0.04	<0.02	1
	Pond		061031	7.3	0.19	0.09	9	2.44	<0.02	6
	Pond		061031	6.9	0.17	0.08	9	2.19	<0.02	8

1997). Colour and turbidity were classified visually, relative one another. Therefore these results are without unit and only valid for comparing the waters in this study. The colour and turbidity are grouped together since it is difficult to visually determine them independently one another. Turbidity can protect pathogens from treatment and can thereby be regarded as a microbiological parameter, says DeZuane (1997). The colour and turbidity showed no relation with TDS. However, it showed a correlation with the sampling date. The samples from October 18-19<sup>th</sup> had higher values for colour & turbidity than

the samples taken on October 24<sup>th</sup> -November 2<sup>nd</sup>. It should be considered that it was a heavy rain on October 9<sup>th</sup> that resulted in maximum flow in all the streams in the area. Huay Maha river and its tributary Huay Keo had low values at all times of measurements.

Chloride content was low at all sites. The highest values were on the highland ponds (9 mg/l) and in Pong Pao W (8 mg/l on Nov 1<sup>st</sup>). Chloride is not unhealthy in small quantities, and most people cannot detect the taste while the content is lower than 250 mg/l (World Health Organization 2003b). The

concentrations discovered in this area are normal for unpolluted water, which usually have chloride concentrations <10 mg/l (World Health Organization 2003b). The low concentration of chloride is sign of a rapid, shallow turnover of water.

Ammonium varied between <0.06 mg/l for several streams and water supplies up to 2.19-2.44 mg/l for the highland ponds. These samples and Huay Maha stream (1.31 mg/l) upstream the intersection of Huay Keo were the only ones exceeding 1 mg/l, which is the limit for drinking water in Laos. Normal values for groundwater is <0.2 mg/l unless the strata has a high content of either iron, humic substances or there is a forest above the aquifer when the ammonium levels may be as high as 3 mg/l. Surface water may have ammonium content as high as 12 mg/l (World Health Organization 2003a). If the ammonia levels are higher than the natural ones this indicates faecal pollution (World Health Organization 2003a). The fact that the ponds on the highland had relatively high concentrations of both ammonium and chloride indicates possible pollution.

#### **General Observations**

The personal observations made in field follow no specific methodology, but are complementing information noted in field.

#### Domestic Water Supplies

There were five streams in the area used for drinking

water in the settlements, all of which were surrounded by forest. The water supplies were all driven by gravity (Table 18).

Except for the water supply from Huay Pong and Huay Mehteng, which had no storage tanks, all others were fed with water by a bamboo pipe through an open gap in the lid.

Huay Mehteng in Pong Pao W had the simplest construction; a bamboo pipe collected water from the stream, there was no plug and no storage, just a diverted flow. Pong Pao W also had two other water supplies from different streams. The stream flow was prevented by a weir in Huay Pong and had so been in Huay Kokten previously. From Huay Pong a pipe led the water to an outlet point. There was a continuous, unplugged flow from the pipe. From Huay Kokten water was collected in tanks for storage and sedimentation. The water was piped to a larger storage tank of at least 3 m<sup>3</sup>. The pipe from this tank led to 12 different outlet taps, but most of these were dry or had a very low flow. The outlets were plugged with wooden plugs but there were a constant leakage.

Pong Pao E uses North Kokten for water supply. They had a coarse net and some stones in the stream before the intake, but the flow was not slowed down. There were small tanks at the inlet and one larger tank by the village. From this the water was piped to three taps but there was only flow in one of them. A wooden plug stopped the flow.

**Table 18. Schematic summary of domestic water supplies in the settlements. (Data gained from general observations during the field study by Billving & Ågren 2006).**

Settlement (Stream)	Inlet	Storage	Sedimentation	Pipes	Taps	Other observations
Huay Maha (Huay Ong)	Bamboo with airholes + lower iron pipe	1 tank ~0,5 m <sup>3</sup> filled 10-20 %	No filter or special sedimentation tank	outer diameter 7 cm, shallow	4 taps, 1 only dripping. All have wooden plugs with steady leakage	2 tanks to reduce pressure
Pong Pao W (Huay Kokten)	Bamboo	2 tanks ~0,5 m <sup>3</sup> + 1 large tank >3 m <sup>3</sup>	1 tank with stones ~150 mm in diameter	outer diameter 3-4 cm, shallow	12 taps, 4 works and 6 are plugged. All plugs are wooden. Taps with water are leaking	Some people collect water in old petrol cans! Weir constructed but not in use anymore.
Pong Pao E (North Kokten)	Bamboo	small tanks + large tank >2 m <sup>3</sup>	coarse stone filter before intake + sedimentation tank	shallow/ above surface	3 taps but only flow in 1	Previous construction still there; bamboo pipes with intake further downstream. Fish pond downstream intake. Iron reducing bacteria.
Pong Pao W (Huay Pong) 10 families	Not seen (under ground) but outlet iron pipe	No tank but weir stops flow	No filter or special sedimentation tank	inner diameter 4 cm	1 pipe constant flow, no tap, no plug	Weir constructed. Fish pond downstream intake. Iron reducing bacteria.

Huay Maha settlement took their water from the stream Huay Ong. The intake was about 200 m above the village on the mountain slope. There was a small tank with two incoming water pipes, one iron with a low flow and one bamboo pipe feeding the tank from the top. The lid was open. The storage capacity was limited to less than 1 m<sup>3</sup>. There were two tanks between the intake and the village to reduce the pressure (Tomawong 2006). There were four taps in the village, among which three were functioning. All taps had wooden plugs but there was still ongoing leakage.

Streams not used for domestic supplies

Investigated streams besides the ones used for domestic supplies are Nam Pa, Huay Maha, Huay Keo, Huay Houm, Huay Panoi, Huay Gamlao and Huay Wang Pou. There were much fine sediment and clay in the stream bottoms. Fields surround these streams for the most part. A rust-coloured moist

covering with an oily shimmering was observed at some locations, which indicate presence of iron and bacteria that reduces this iron (Table 19). It is generally most prevalent in saturated locations. The iron reducing bacteria was observed at locations where weirs or such prevented stream flow and the soil was therefore saturated.

Huay Maha and Huay Keo are clearly meandering. The streams on the mountainsides towards Nam Pa have carved the terrain. There were a few small fishponds constructed across streams on the southern side of Nam Pa. Across Nam Pa a semi permeable weir was constructed to concentrate the flow to a micro hydropower wheel.

The springs studied are located in Nam Bo village about five kilometres from the study area (Fig. 4). One of the springs had a significant flow velocity, about 0.5 m/s. The cross section was 120 x 10 cm, giving an approximate flow of 0.06 m<sup>3</sup>/s. The water

**Table 19. Schematic summary of the small streams within the study area not used for domestic water supplies. (Data gained from general observations during the field study by Billving & Ågren 2006).**

Stream	Surrounding	Flow*	Bottom	Usage	Other facts
Huay Wang Pou	Fields to the west, forest and teak plantation to the east	Small	Clayey	Drink when in field	Iron reducing bacteria + visible erosion under teak. A dry stream intersects from the west.
Huay Maha	Fields, most in fallow. Much Bamboo	Medium	Sand, stone and fine sediment underneath. Some bedrock	Irrigation by hand. Drink when in field, has a small pond at the stream bank [for sedimentation]	Clear meandering. Clayey river banks. In some places soft bedrock of sedimentary origin along the stream.
Huay Keo	Fields, most in fallow. Much Bamboo	Medium	Sand and stone, fine sed. Underneath. Some bedrock	Drink when in field	Clear meandering. Clayey river banks
Huay Houm	Fields	Small	Clayey		
Nam Pa	Fields, most in fallow + cemetery and settlements	Large	Clay and sand	Fishing, Bathing, washing	Weir by Pong Pao W for micro hydropower. Debris, divided in 2 channels over a section [last heavy rain altered course]
Huay Gamlao	Bamboo	Medium	Clay but more stones and gravel before intersection with Nam Pa	Drink when in field	Stream valley 2 m deep before intersection with Nam Pa
Huay Panoi	Fields (paper mulberry, rubber, pineapple, sesame, corn)	Small	Sand and fine sediment	Drink when in field	

\*Flow categories [m<sup>3</sup>/s]; small= <0.01, medium =0.01-0.1, medium-large =0.1-1, large =>1

was ponded before entering Nam Pa river. The water comes from fractures in the limestone bedrock and has its outflow under the road about 20 m from the cliff. A cave can be seen at the mountainside as well as fractures that are 5-10 m long and 30-80 cm wide and several meters deep. The rock is clearly weathered; it has white, red and black discolorations from precipitates. Water was dripping and running over the rock. There are another, smaller spring close by. It turned into a large pond and then flew on as a stream with a cross section of about 3 x 0.8 m further down but it had a slower flow, about 0.25 m/s.

#### Highland plateau

The highland plateau (Fig. 5) was hilly with low vegetation, about chest height. The soil was reddish and sorted with much fine sediment. The much visible rock had cavities. At the deserted settlement Ban Phousong there were low deciduous trees growing. A fenced area had deep fractures of dried out clay (about 5-10 cm deep). The area was hilly but no clear flow direction could be determined. It is likely that rainwater either infiltrates or flows to the local depressions and ponds. The ponds on the highland were greenish and clearly eutrofied. Farmers were fishing in the largest pond.

#### **Water balance**

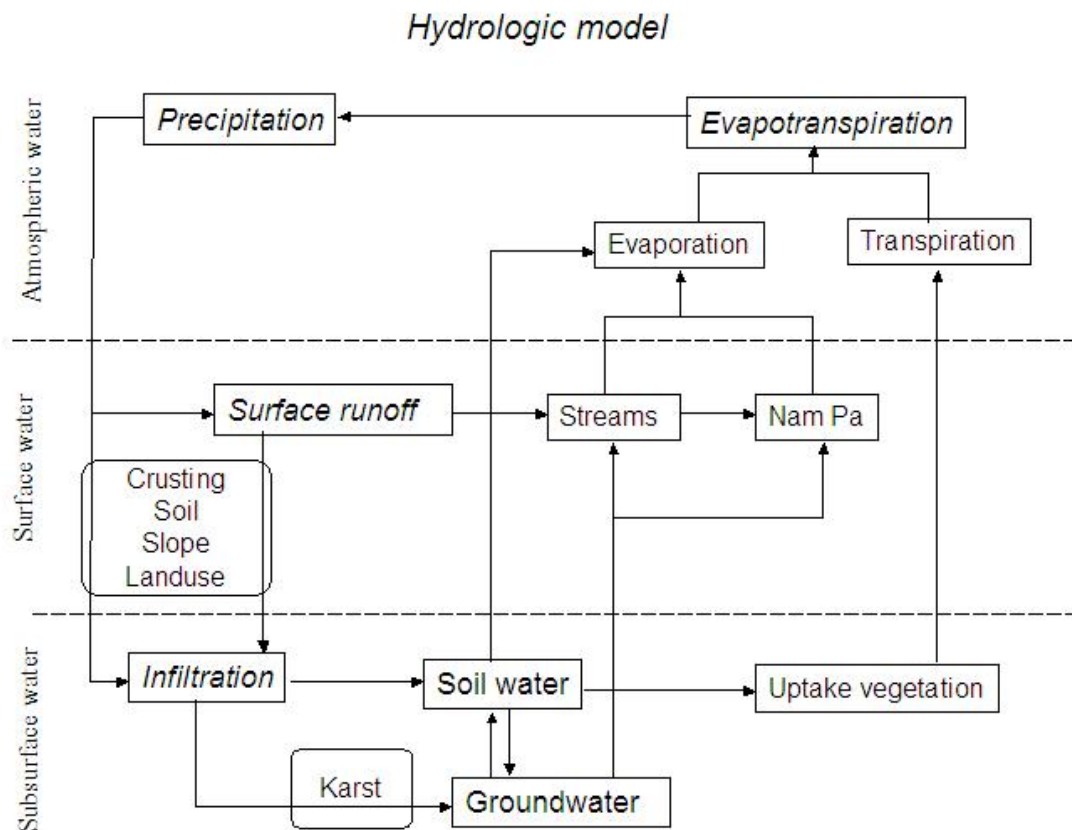
Water flow paths are multiple and complex. In order

to illustrate and quantify water flows within the area, a hydrologic model has been created (Fig. 35). This model describes the hydrological cycle, internal flow paths, storage and uncertainties. Each parameter is discussed in the following chapters.

#### **Baseflow**

Discharge data has been taken from Mekong River Commission (MRC) (1993). Discharge has been measured in Nam Pa at Ban Kok Van, about 20 km northeast of Luang Prabang (Latitude 19 57 20 N and Longitude 102 17 90 E). The drainage area is estimated to 700 km<sup>2</sup>. Measurements have been made since 1988, but daily values are given only for August to November 1993.

Huay Maha village and the defined catchment in this study is located about 30 km upstream the measured discharge point. The study area of 32.46 km<sup>2</sup> represents about 4.6 % of the “discharge data catchment size”. In order to estimate the discharge and baseflow in Huay Maha, numerical values have been set in proportion to the area, assuming that the discharge is equally distributed over the entire area (Fig. 36). The specific discharge for the entire catchment for Nam Pa in 1993 was 14.9 l/(s\*km<sup>2</sup>) in August, 19.2 l/(s\*km<sup>2</sup>) in September, 12.2 l/(s\*km<sup>2</sup>) in October and 6.73 l/(s\*km<sup>2</sup>) in November (MRC 1993).



**Fig. 35. Hydrologic model illustrating how water circulates within the study area, reservoirs and important factors that determine flow paths (developed from Chow et al. 1988)**

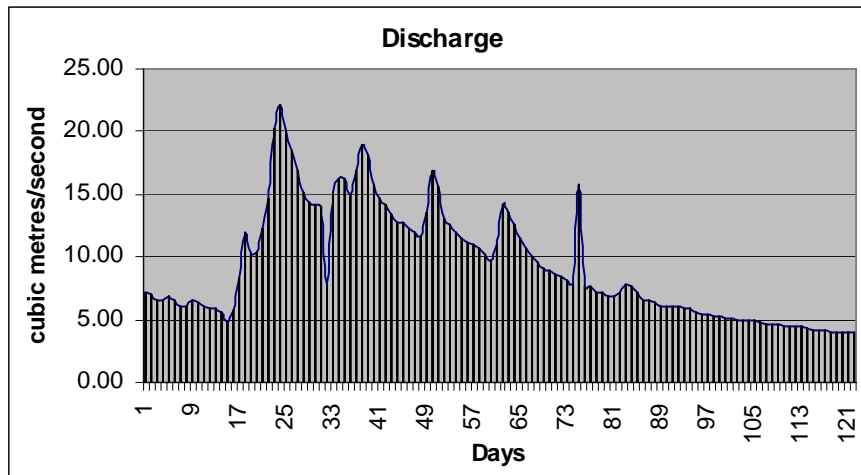


Fig. 36. Discharge data from Nam Pa at Ban Kok Van (Mekong River Commission 1993). Day 1 represents August 1<sup>st</sup>

There is no precipitation data accounted for in the same area and year in available sources, so the discharge cannot be weigh against the amount of rainfall it represents.

Daily measurements from the whole catchment were multiplied with 0.046, representing the contributed daily discharge for the study area between August and November. As discharge data showed stabilized decreasing values in October and November, the *Baseflow recession curve* could be calculated with the formula suggested by Chow et al (1988).

$$Q = Q_0 e^{-(t-t_0)*\lambda}$$

Where Q is the flow at time t,  $Q_0$  is the flow at time  $t_0$ , time  $t_0$  is the time when recession begins, e is the natural logarithm and  $\lambda$  is a constant.

After experimenting with different initial values, the  $\lambda$ -value of  $0.0126 \text{ m}^3/(\text{s}*\text{day})$  was used to describe the baseflow recession (Fig. 37).

Several estimations concerning discharge and baseflow had to be done due to lack of data. The missing discharge values were estimated by assuming the discharge to be a normal distribution curve with August as the peak. The curve was assumed to follow precipitation with some delay, with a minimum in February-March. Rainfall data taken into consideration were measured in Phonxay 2005-2006. The minimum discharge value before the curves rises up again was set to  $0.06 \text{ m}^3/\text{s}$  lasting a time period of 60 days.

The baseflow separation from the discharge was done by drawing a straight line between the lowest point before the rising limb and the baseflow recession point from which  $\lambda$  was calculated (Chow et al 1988). The baseflow is then assumed to be the volume under the baseflow curve (Fig. 38).

The baseflow for one year in Huay Maha was approximated to  $40.8 \text{ m}^3/\text{s}$ , given the total volume of discharge  $3.5*10^6 \text{ m}^3/\text{year}$  and the average discharge  $0.112 \text{ m}^3/\text{s}$ .

The runoff can be seen as the difference between discharge and baseflow (Chow et al 1988). Since discharge data is missing for parts of the rainy season,

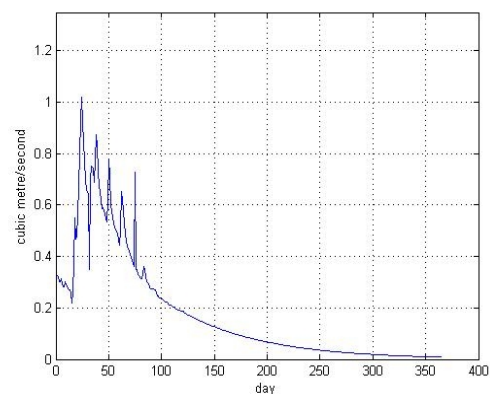


Fig. 37. Baseflow recession curve for Nam Pa at outflow of study area. Day 1 represents August 1<sup>st</sup>. Discharge data from MRC has been modified to correlate to a smaller catchment area. Baseflow recession curve have been calculated in Matlab from formula by Chow et Al (1998) and generates a  $\lambda$  value of  $0.0126 \text{ m}^3/\text{s}*\text{day}$ .

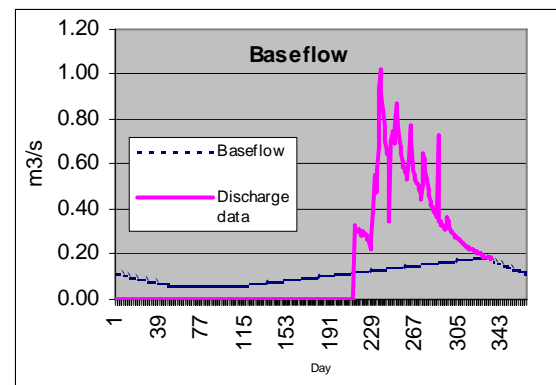


Fig. 38. Baseflow separation from discharge data (modified from Mekong River Commission 1993). Day 1 represents January 1<sup>st</sup> and discharge data available from August 1<sup>st</sup>.

the runoff with a calculated value of  $3.2*10^6 \text{ m}^3/\text{yr}$  is probably underestimated.

#### Water balance equation parameters

The results from the baseflow separation were used to set up the water balance

*Water balance equation:  $P = E + R + I + dS$*

#### Precipitation

The precipitation value used in the water balance is the annual average from Phonxay district office 1994-2006. When data is needed on a monthly basis the years 2005-2006 is used.

#### Evapotranspiration

In the calculations the evapotranspiration obtained for the RC value 200 mm will be used. This is likely to be an overestimation for the cultivated land, meaning that the water balance will be somewhat underestimated.

#### Runoff

The precipitation that does not infiltrate will form surface runoff. Here, interception by vegetation is neglected. The combination of steep slopes, the possibility of soil crusting processes, the removal of forest and the witnesses from farmers of problems with soil erosion makes it likely to believe that a significant part of the precipitation becomes surface runoff in this area.

Runoff has been estimated together with the baseflow by using flow data from Nam Pa downstream the study area. This term includes both the surface runoff and the subsurface runoff. (Mekong River Commission 1993). This can be used to calculate the specific discharge. It will be assumed that the study area contributes proportionally to the flow. This enables approximate calculations of runoff and baseflow.

#### Infiltration

The infiltration is difficult to estimate since no measurements have been made regarding this in the area. The infiltration capacity provides information about the potential rate of infiltration, when the soil is saturated and the surface is ponded. However, these conditions are rarely fulfilled. The measured infiltration capacity in the study indicates that all water would infiltrate. However, this cannot be the case since erosion is known to be a significant problem. Since data is available regarding discharge and this can be used to estimate the runoff, infiltration was calculated as rest term assessed over the year.

#### Storage

Water can be stored as groundwater, soil moisture, surface water and in vegetation (Grip & Rodhe 1994). The positive term of  $dS$  is the recharge of the storage and the negative term is the water losses except evapotranspiration. This can be estimated since the main part of the outflow consists of the water fed to the streams. The groundwater that comes to the streams eventually ends up in Nam Pa. The part of the flow in the streams that comes from the groundwater is the baseflow. When it does not rain all water in the streams comes from groundwater. Most of the streams in the study area do not dry out during the dry season, which means that there is a constant discharge of groundwater to the streams.

Over a longer period of time, usually several years, the storage term can be assumed to be zero (Grip & Rodhe 1994). That period is assumed to be one hydrologic year in this study. It is appropriate to set the beginning of the hydrologic year to a time when the storage is approximately equal from year to year. In this study the start of the hydrologic year is set to January.

Storage is refilled when precipitation exceeds evapotranspiration, usually in June-September (Fig. 18). During the rest of the year, water is discharged from storage.

When the heavy rains occur it is possible that surface water in parts of the streams infiltrates and recharges the groundwater. How much groundwater that is recharged or discharged and flow patterns of this is extremely hard to predict since the region consists of developed karst, and the groundwater may be transported long distances.

#### ***Water Balance Calculation***

Since  $dS$  is assumed to be zero, the water balance equation is reduced to  $I = P - E - R$

Precipitation = 1256 mm/yr

Evapotranspiration = 1018 mm/yr

Runoff + baseflow = 6.77 Mm<sup>3</sup>/yr = 0.21 m<sup>3</sup>/s

When the runoff is separated from the baseflow in the discharge curve it gives a total runoff of 3.24\*10<sup>6</sup> m<sup>3</sup>/yr or 0.10 m<sup>3</sup>/s on average.

By relating this to the area the following is obtained:

Runoff = 3.24\*10<sup>6</sup> / (32.46\*10<sup>6</sup>) = **100 mm/yr**

If R=100 mm/yr is used, the following infiltration is obtained:

Infiltration = 1256 – 1018 – 100 = **138 mm/yr**

This gives the relation:

$I / P = (138/1256)*100 = 11 \%$

meaning that according to these results about 11 % of the precipitation infiltrates.

The infiltration and the runoff are directly linked since the water that does not infiltrate will form runoff. Therefore the sum  $I + R = 238$  mm/yr is of interest. Since the baseflow separation is somewhat uncertain, the possibility of the runoff being greater on the infiltration's expense should be considered.

#### ***Sensitivity Analysis of the water balance***

Since the evapotranspiration is assumed to be overestimated, a sensitivity analysis of this parameter will be done. If E is in fact only 90 % of the estimated E one gets:

1256 – 0.9\*1018 = 340 mm/yr.

This means that if E is decreased with 10 %, the runoff + infiltration term is increased by 42 %. It is hereby clear that the actual evapotranspiration has a significant impact on the final values. The precipitation has an equally large impact, but these values are measured and are therefore much more accurate than the evapotranspiration.

If the calculated evapotranspiration for the grassland is used the following is received:

$$P - E = 1256 - 769 = 487 \text{ mm}$$

This is 105 % higher than the results obtained using the woodland root constant value. This clearly states the importance of caution in interpreting these results.

The average measured discharge in Nam Pa was  $5.53 \text{ m}^3/\text{s}$  in 1988-1991, further downstream (MRC 1993). This can be used as a comparison to the outflow estimated from the study area that was:

$$\text{Baseflow} + \text{runoff} = 0.11 + 0.10 = 0.21 \text{ m}^3/\text{s}$$

The measured discharge at Ban Kok Van was adjusted by multiplying the size of the study area in relation to the total catchment area of Nam Pa  $\text{Discharge} * (\text{Study area} / \text{Total area})$

$$5.53 * (32.5 / 700) = 0.26 \text{ m}^3/\text{s}$$

The discharge estimated from the hydrograph is of the same magnitude as the modified measured discharge from Ban Kok Van. Therefore the discharge from the study area can be assumed to be fairly accurate, but the difference indicates that the runoff and/or the baseflow may be underestimated.

#### Huay Maha

Huay Maha stream has a catchment of  $21.3 \text{ km}^2$ , constituting 66 % of the total study area. Assuming that this area has the same specific discharge as the catchment for Nam Pa's full length gives:

$$Q_{\text{HM}} = Q_{\text{NP}} * (\text{catchment}_{\text{HM}} / \text{catchment}_{\text{NP}})$$

Where  $Q$  is the discharge in  $\text{m}^3/\text{s}$  for the indexed watercourse and catchment is the catchment area for the indexed watercourse in  $\text{km}^2$ .

$$Q_{\text{HM}} = 5.53 * (21.3/700) = 0.17 \text{ m}^3/\text{s}$$

If the discharge in Huay Maha is  $0.17 \text{ m}^3/\text{s}$  on average over the year it gives a total discharge of:

$$0.17 * 365 * 24 * 3600 = 5.3 * 10^6 \text{ m}^3/\text{year}$$

The presented results are all general estimations. In the discussion some important considerations for more site specific modelling is presented.

## DISCUSSION

### Accuracy

In this study a wide range of data has been collected to provide an image as complete as possible over the water resources in Huay Maha village. Below the accuracy of each specific part is stated, but the additive effect of these uncertainties is difficult to determine. Generalisations and simplifications are necessary and motivated in such a broad study as this one, but the reader should be aware of the limitations and accuracy. Still the data from different sources confirm each other to a large extent, which implies reliability of the overall situation described.

Interviews including a translator always convey uncertainties in the answers. For many of the

questions the respondents discussed with each other and answered quite long in Lao, which was summarized by the interpreter in one or a few sentences. In order to prevent misunderstandings the questions were discussed with the translator in advance and the results discussed afterwards. Although one cannot eliminate that some misunderstandings may have occurred. Cultural differences also affects how questions are put and answered. One lesson learnt was that the ideal way for getting exhaustive answers was to ask "leading questions", something that should be avoided due to western interview standard. The number of people who participated actively in the group interviews varied between the interviews. During some of the interviews only half of the participants said anything at all. When the head and/ or deputy of the village was present they had a more active part in answering than the others.

An initial idea was to have a gender approached on the interviews and speak to men and women separately, but this was not always practically possible. From the separate interviews, some interesting contradictions in answers arose but most of the answers were comparable and confirmed each other. The people have lived there for different time periods and therefore their perspectives may vary.

One aim with this study was to calculate the water balance on a monthly basis in order to get a good description of the water resource situation. The monthly determination of the water balance was however not possible due to lack of data. Generalizations, estimations and simplifications have been made when calculating all the input parameters to the annual water balance. The water balance is discussed based on the other results in the study. With this knowledge, the results are believed to represent a fairly accurate image of the water resources even though caution needs to be applied before reading too much into specific figures.

Regarding climate it should be kept in mind that it varies also over such a small area as the study area. Temperature, precipitation and evapotranspiration may vary according to location and altitude. The altitude within the study area varies between 400-1400 m a s l. This has not been taken into account and adds uncertainty but the variations are assumed to be acceptable. Still, when applying the results from the water balance calculations at a specific location within the area it is important to be aware of the local variations in climate. For example did the women in Pong Pao W mention that the climate in the highland is more favourable for cultivation than in the valley.

Evapotranspiration is known to vary locally since, for example landuse, certainly has an impact. The potential evapotranspiration was measured at stations relatively far from the study area and the values were interpolated by Nilsson & Svensson (2005) over a fairly large area. It means that at a specific location such as within the study area, the values may be

somewhat different. The actual evapotranspiration was calculated for woodland and grassland according to Shaw (1994) with in-data of potential evapotranspiration from Nilsson and Svensson's (2005) interpolated values. The calculated actual evapotranspiration differs approximately 100 % between woodland and grassland respectively. Although the calculated actual evapotranspiration cannot be said to be reality, they show the likely variability for this parameter.

Several people did independently of each other tell about the most recent heavy rain that occurred on October 9<sup>th</sup> 2006. The rainfall data from Phonxay district office recorded 2 mm of rain at the morning of October 10<sup>th</sup>, which is completely unlikely for a rain that caused maximum flows in all the streams in the area. Most days no value for precipitation has been recorded at all by DAFEO in Phonxay. This makes it unclear if the rainfall actually was zero those days, if it was a very local rain or if somebody simply forgot to keep record. It is likely to believe that the measured precipitation is more or less correct but somewhat underestimated since a few rains might have been missed. Daily measurements have been recorded at the DAFEO since 1994, but the books with daily records before 2005 are lost. Only annual values are available for 1994-2004. This makes the precipitation data less accurate than could have been achieved. Specific years the precipitation differ from the average values, so caution in applying these values should be taken.

The heavy rain that fell on October 9<sup>th</sup>, which is in the beginning of the dry season, could be explained by a typhoon that swept in over southern Vietnam in the beginning of October causing rain later than normal in Laos. This heavy rain may have had an impact on the measurements made 10 days later giving higher values than normal for stream flows at that time of the year.

The used method of measuring flow velocity is somewhat simplified and lack in accuracy. For example flow velocity varies with depth. For the inflow of Nam Pa to the study area, the average flow velocity was 1.54 m/s and the average standard deviation for southern, middle and north side was 0.17 m/s. This gives the interval of accuracy about 10 % for measured flow velocities for the time and location of the measurements. Since the results in this study are only glimpses of conditions at specific parts of the stream for a certain moment, it should not be used as anything but indications.

The local streams on the hill slopes were classified into three classes according to discharge. The magnitude of the discharge is likely to be representative for the time of year, but the heavy rain on October 9<sup>th</sup> may still have had some impact especially on the larger streams and Nam Pa. Before doing specific calculations or dimensioning for a specific stream more detailed measurements is required.

Working with digital data always includes lack in accuracy. The pixel values are interpolated and generalized over a specific area, in this case 50x50m. The digital maps provided by NAFRI lacked in metadata and it is therefore difficult to determine its accuracy. However, the overall picture of the area that was obtained from the digital data is considered to be fairly trustworthy.

The completion of the hydrograph and the following baseflow separation is believed to be relatively accurate although smoothed for that year, but the application of this to any year is more unreliable. The comparison with the annual average discharge from four earlier years (1988-1991) shows the likely size of the variations between these periods is about 16 %.

Regarding the water balance calculation several simplifications have been made. The generalization that the specific discharge is evenly distributed over the whole catchment is a necessary assumption. The assumption that the total storage term is zero over a long period of time may not be accurate for one year only. Further uncertainties are present since the area probably consists of karst terrain and very limited data regarding bedrock makes flow paths particularly uncertain.

The results from the chemical analysis that was performed by the Chianaimo Water Treatment Plant Laboratory shows great difference in magnitude for water samples taken at the same spot within two weeks difference. The authors therefore regard the results with suspicion. No conclusions of value can be drawn for nitrate and ammonium.

The pH is sensitive to mixture with air, which is difficult to avoid completely with sampling, transport and later analysis. To avoid the pH from being raised significantly this parameter should be analysed directly in field. This was not done and therefore the pH had time to reach equilibrium with the carbon dioxide in the air and it is possibly about two units higher than natural (Ribolzi 2006). When analysing Chloride, during titration most samples changed colour on the first drop of indicator, which means that the chloride content was possibly too low to detect with this method. Therefore the chloride results rather indicate a maximum content than a specific value. Colour and turbidity were classified visually, relative one another. Therefore these results are only valid for comparing the waters in this study.

Olsson (2004) recommends some cautiousness when interpreting SSLCC's soil results. Relatively few soil- and auger samples were taken and some unrealistic values have been identified in the chemical analysis. Some soil samples have been classified as low topsoil fertility even though pH and carbon contents are high and the concentration of phosphorous and potassium is extremely high (Olsson 2004).

## Water resources

### *Water quality*

All the inhabitants in the study area expressed dissatisfaction with their domestic water supplies. Muddy water, lime residues in pots and under dimensioned pipes were the most common complaints. From observations in field one could see that in all three supplies the lids had been removed in order to increase the water intake via a bamboo pipe from the top. The open lids make it possible for different pollutants including small animals to enter the tanks.

In Huay Maha the sand filter in the sedimentation tank was removed and replaced with rocks. The explanation was that it took too long for the water to filtrate and the filter got dirty quickly and was difficult to clean. The purpose with the fine sand is to clean the water by a slow sedimentation process. The fact that it got dirty quickly could be seen as an indication that the water is dirty but also that the filter was effective. There was also complaints regarding low or no flow in many taps. The villagers believe that this is because the pipes are under dimensioned. That could be part of the problem, but another reason for the limited flow in the taps could be that sediments have plugged the pipes. Thus the removed filters might be part of both the quantity problem and the problem with muddy water. Many of the taps have broken down but there is no money for reparation.

Some of the villagers in Huay Maha have problems with their kidneys, which they believe is caused by the water from the supply. The fact that the tap in Huay Maha village had high values for colour and turbidity also at the second sampling date supports the villagers' complaints regarding the quality of their water, but is more difficult to explain from a scientific point of view. The possible correlation between turbidity and pathogens mentioned by Zuane (1997) supports the need for proper sedimentation tanks in all water supplies.

Ammonium was analysed since it is an indication of faecal contamination, but the concentrations discovered are sufficiently low for drinking water except maybe for the ponds in the highland. Still more parameters need to be checked, more samples taken and a more reliable analysis would be required to make any conclusions regarding the quality of the drinking water. The cattle likely cause the pollution of the ponds on the highland.

The water in Nam Pa is not recommended for drinking since all pollutants in the area as well as upstream may end up there. Likely is faecal contamination from humans and animals and nutrients leaking from the fields providing a favourable environment for bacterial growth. This was confirmed by Tomawong (2006) who informed about previously bad health of the villagers when drinking from Nam Pa.

No specific potential pollutants have been identified. No one uses pesticides or fertilizers. They have rules

of keeping animals away from water supplies, even though it is not always followed. The garbage consists mainly of organic matter, which may or may not be burnt. The only visible pollutant was the residue of soap and plastics that were left by the water supplies.

Water samples taken sooner after the heavy rain had more colour and turbidity than the ones taken about one week later. This correlation support the suspected erosion caused by the heavy rain, since the higher colour and turbidity are likely caused by eroded matter transported to the streams. This correlation between sampling date and colour and turbidity is true except for Huay Maha stream and Huay Keo, which had little colour and turbidity at all sampling dates. This could in part be due to the fact that they have a larger flow, which minimise the risk of getting sediments in the bottle at time of sampling. A contributing factor could also be the surrounding land since these streams are located in a separate part of the study area. The fact that the eroded matter likely settles before reaching the streams probably makes the flood banks more favourable for cultivation than most land in the area.

The ponds on the highland plateau are used as drinking water by the cattle. It is still standing water that is likely not refilled except for times of precipitation. The ponds are eutrofied and it is therefore not surprising that the values for colour and turbidity were high. The clarity of the water from the springs was natural since the groundwater has been filtered through the soil and sedimentation have taken place.

### *Water balance*

In many parts of the world there is a lack of water, both for domestic and agricultural use. However in many cases, the annual amount of precipitation is not the problem but the lack of storage capacity and the uneven distribution over the year (Olofsson 2006). Without sufficient storage capacities the precipitation quickly disappears out of the area, and the inhabitants cannot make use of the rainfall. In Huay Maha the precipitation is very concentrated to the rainy season. In 2005 & 2006, 40-45 % of the annual precipitation fell in August. In the dry season it is usually dry for months. When a lot of rain falls during a short time, the water does not constitute a positive resource but an erosive force.

The water balance provides an estimated volume of water in circulation. One aim with this study was to do a water balance on a monthly basis. However it was not possible due to lack of data, and it was done on an annual basis instead. The annual water balance may be misleading since different parameters and variations over time have cancelled each other out.

### *Infiltration*

The measured infiltration capacity showed an average value of 135 mm/h for eutric cambisols. Theoretically all rains with intensity less than that would infiltrate, and no water would runoff. However, for several reasons that is not the case.

One explanation is that the measurements for practical reasons had to be done close to Nam Pa or a water supply where the terrain was flat, while most of the land has steep slopes. Fifty centimetres of the topsoil was removed before the measurement began, resulting in that the permeability of the topsoil layer was not taken into consideration. If a crust is formed on the topsoil, the infiltration capacity of the soil half a meter below is of less importance.

The calculated annual infiltration from the water balance model says that the actual infiltration is 138 mm/yr. This number is misleading and unlikely. The evapotranspiration is withdrawn directly from the precipitation, when in fact the water that evapotranspires have usually first infiltrated into the ground or run off at the surface. The effect of this is that the part of the infiltration and runoff that will evapotranspire at a later stage is not included in the estimated figures.

The farmers in Pong Pao W said in the interviews that there is enough rain for cultivation every third year while in Pong Pao E they said that there is always a water deficit. A study in Bangladesh of one kind of upland rice says that it needs 180-300 mm water/month (Islam et al. 1991). Even though the estimated infiltration of >100 mm/year is underestimated, the crop growth in Huay Maha is certainly limited by water availability.

Soil and soil type greatly affects the infiltration and the ability of the soil to hold water. The organic content of a soil is important for the water holding capacity and the chemical composition of the soil is important partly because of its effect on crust formation. Regarding grain size, larger particles allow more rapid flow than smaller ones since the voids are larger. Clay normally has low permeability and high water holding capacity (Knutsson & Morfeldt 2002). Much of last years rice fields were situated on low fertility eutric leptosols on slopes varying between 30 - 55 %. According to FAO (1998), leptosols have low water holding capacity, are very sensitive to soil erosion and terracing or agroforestry should be used. From the particle size distribution it seems like the water holding capacity is reasonably good, since the clay content is high. However several facts indicate the opposite, such as the erosion sensitivity of acrisols and its likelihood to form a surface crust that retains infiltration.

Slope impacts infiltration, but as has been explained the correlation is not clear, and it is therefore difficult to use as a modelling parameter. Also landuse is an important parameter that impact infiltration. Vegetation increases infiltration by the roots that penetrate the soil. Dense ground vegetation also slows down the runoff. Generally it can be said that increased coverage of the soil with vegetation cause increased infiltration. Natural forest has infiltration rates about twice the rate on cultivated land (Evans 1996). According to the watershed map distributed by NAFRI (2006), cultivation is not recommended at all in large parts of the area, the only

sustainable landcover is forest. In areas where cultivation could be accepted, conservation measures and favourable crops should be used. However, the farmers in Huay Maha live out of farming and have no choice but to cultivate the land they have been allotted.

Clearing forest in favour of agricultural land may have considerable effects on water pathways and soil erosion (Sidle et al. 2005). In Huay Maha, one small stream “disappeared” after clearing forest in favour of cultivation (Keolasy 2006). Also when a field was turned into conservation forest, the flow in the nearby stream increased. These observations support Evans (1996) statement of the benefit of forest from a water perspective.

#### Runoff and flows

The surface runoff was calculated to be 100 mm/yr in the water balance. This number is probably underestimated, since the evapotranspiration is overestimated due to the chosen RC value, and the rain curve is smoothed, eliminating the characteristic peaks. The relationship between the runoff and the infiltration in the calculated water balance is 100/138 mm/yr. This may look like the infiltration is high and the runoff low, but one should keep in mind that in undisturbed tropical forests almost all water infiltrates and moves to the streams as subsurface flows (Sidle et al. 2005). Worth emphasizing is also that the calculated runoff is the amount of water that reaches Nam Pa as surface water. Parts of the precipitation begin as overland flow and infiltrate further down in the catchment. The runoff may be higher on the steep mountain slopes, but infiltrate when reaching gentler slopes. In the water balance this will be under the term infiltration, but it is important to consider that during the transport as runoff, erosion will have taken place. The results from the calculated water balance conclude that the runoff is significant.

Years with high precipitation, runoff is likely to increase more than infiltration, since infiltration is limited by the infiltration capacity of the soil and the storage volume. Likewise in years with lower precipitation the runoff is expected to decrease more than the infiltration. Consideration to rain intensities and distribution over time is needed for a more certain prediction.

All the streams in the area are highly rain responsive, with stream depths increasing about ten times immediately after heavy rains. This indicates fast transport of the water to the streams. It is likely that a significant part of the water is transported as runoff since it is so quick and the erosion is as high as 2 - 3 cm after heavy rains according to the farmers. For the small streams these heavy flows are washed out quickly and usually recede to normal levels within a few hours. The quick outflows of heavy rains illustrate the inability of the area to maintain large water quantities coming at a short time. For Huay Gamlao, Huay Keo and Huay Maha the maximum flows caused by the heavy rains declines steadily

during more than a week before approaching normal values. This indicates increased amounts of groundwater to cause the longer high water levels in these streams. Most streams have a steady flow all year around indicating a stable groundwater outflow constituting the baseflow.

The shallow and rapid turnover of water in the soil implicated by the low chloride content means a fast transport in the upper layer of the soil (Olofsson 2007). It is then likely that the soil is leached and highly weathered. Colour and turbidity are caused by particles most prevalent in the soil, and therefore also indicate shallow water transport. This corresponds well with the previous conclusions drawn regarding flows and erosion.

A factor that might explain part of the rapid flow to the streams is the argic horizon of the acrisols. When heavy rains occur, water may infiltrate through the upper horizon and then accumulate above the argic horizon, causing lateral subsurface flow and erosion. If the upper soil is degraded and the argic horizon becomes topsoil, a crust is formed and water will hardly infiltrate at all.

Huay Maha and Huay Keo are not as steep as many of the other smaller streams investigated and they collect water from a different area. The fact that Huay Maha and Huay Keo had little visible matter or colour indicate that it receives a larger portion groundwater compared to surface runoff than the other streams. Huay Maha and Huay Keo's significantly low values for colour and turbidity could partly be because of the greater flows making it easy to avoid getting bottom sediments in the samples. Natural variations probably account for some of the difference. The correlation may not be accurate enough to interpret any far going conclusions. Still, if this is true, it is an indication of a potentially good area for cultivation on the stream banks since they may receive more sediments than they loose.

### Sustainability

More people are sharing the same cultivation area today than seven years ago, which result in shorter fallow periods and land degradation. All the potential cultivation land in the area is already in use and the most recently deforested areas are not good enough for cultivation (Inthavong 2006). The fallow time seem to be not more than five years, which is far lower than the 10-20 years that is recommended by Rerkasem (2004) for a sustainable shifting cultivation. The soil types acrisols and leptosols are known to be very sensitive to soil erosion. Shifting cultivation on acrisols is sustainable only if fallow time is several decades (FAO 1998). Forest has evidently been cut down at acrisols within the study area. The original good infiltration- and water holding capacity has been lost, and runoff is increased which results in increased soil erosion.

More than 70 % of the area has a slope of 30 % or more, which can be considered as steep slopes (Young 1997; Moldenhauer & Hudson 1988). The

change of landuse in combination with very steep slopes and heavy seasonal rains makes the area very prone to soil erosion. Several farmers did independently of each other estimate the average soil loss to 1-3 cm after one heavy rain. The rough estimation of erosion of  $10^6 \text{ kg}/(\text{ha} \cdot \text{yr})$  proves the magnitude of the problem. All literature and previous studies draw the identical conclusion; forest clearance on steep slopes in tropical climate is devastating.

The farmers who have lived down in the valley for several years confirm that the crops do not grow as good as previously when the fallow time was longer. Some of the farmers have to cultivate on the same field two or three years in a row before rotating, with a lower yield as a result. Unfortunately the soil fertility will continue to be decreased unless measures are taken to conserve and restore the soils. Considering that runoff is the driving force in erosion and the fact that there is a water deficit for cultivation during most of the year, measures that combine soil and moisture conservation are necessary.

Generally, agroforestry measurements are recommended in order to slow down soil erosion (FAO 1998). Worth noticing is that shifting cultivation is a sort of agroforestry, but recommended methods are probably other alternatives like hedge rowing and integrated cropping. Suitable crops mentioned by FAO (1998), which actually were observed in one of the project fields on acrisols, are rubber and pineapple.

Land degradation lead to degradation of water resources. The infiltration and storage capacity is reduced which influences the available water for the crops negatively. When water runoff instead of infiltrating, more soil is lost and the problem is enlarged.

### Water Harvesting

There are difficulties with diverting water from the streams to the fields by simple methods, due to the terrain. Several meters differ in height between the streams and the fields. However, Huay Maha and Huay Keo as well as Nam Pa are identified as possible streams for irrigation of the surrounding fields. This might be appropriate since there is some gently sloping on these stream banks and there is significant flow in the streams. For the rest of the area, primary focus should instead be water harvesting methods that increase infiltration and minimize erosion.

For soil moisture conservation, runoff is the amount of water possible to decrease in favour of infiltration. If no water runs off, the greatest amount of infiltration is likely in the interval 240-490 mm/yr, assuming the storage term to be zero, the precipitation to be normal and the evapotranspiration to be in between the values for woodland and grassland. Still, this infiltration does not include the water that later evapotranspirate.

The families involved in the Sida project with integrated cropping and contour lining seemed

satisfied with the result. The other farmers said that they were not familiar with any measures or lacked money to invest in crops for integrating. However, simple methods like leaving weed on the ground to gain a protective soil cover do not cost any money. Still no one of the farmers interviewed were familiar with that method. The women told that when staff from the district arrives to inform about new cultivation techniques they only speak with the men. The women expressed interest in learning more about agricultural techniques.

Trenches, reverse sloping terraces or other methods to cut the slope into shorter intervals are appropriate in this area. These methods not only prevent some runoff and increase infiltration and soil moisture, it also collects sediments in the runoff water and reduces the erosion problem since the soil and nutrients can be maintained within the area even though a downward movement is inevitable. Structures to collect runoff need to be designed so that the heavy floods do not destroy them. For this data regarding rainfall and runoff should be collected during at least two years prior to construction (Pacey & Cullis 1986).

Land with gradient less than 30 % has the best potential for water harvesting methods to increase yield with reasonable amounts of labour to maintain the systems. This is not an exact limit, but an arbitrary value based on the available literature, which rarely mentions methods appropriate on steeper slopes than 30 % due to the amount of earthwork required to achieve sufficient storage volumes. But cultivated land with slopes steeper than 30 % are in even greater need of conservation measures to decrease erosion. Preferably this land should be kept under natural forest cover, but when that is impossible effort should be put into maintaining a dense soil cover and collecting runoff and sediment in those fields as well. Though one should be aware of that in spite of the efforts it is not likely to be sustainable in the long run, but the degradation is slowed down. This is in accordance with the Watershed classification map.

## CONCLUSIONS AND RECOMMENDATIONS

### *Domestic water*

The total quantities of water from the small streams are believed to be enough to supply the present populations domestic needs all year around. The supply in Pong Pao W needs to be improved to meet the needs in the village. Suggested methods to achieve this are storage of water from Huay Mehteng and/or larger pipe from Huay Namlin in addition to a more efficient water usage. By repairing the plugs and avoid leakage and waste, a lot of water can be saved. If these measures are not sufficient, usage of more streams for drinking water may be required.

To minimise the potential risk of bacterial contamination, the importance of proper sedimentation tanks and filters is stressed. A measure

that could be used is to cover the openings in the tanks with some kind of filter. The water quality in the supply in Huay Maha could be worth investigating further. The most important recommendations regarding domestic water are:

- To install sand filters in sedimentation tanks for all domestic water.
- To save more water by stopping leakage and waste.

These measures are important prerequisites before developing the water supplies any further, and can make a significant impact on both quality and quantity of water.

### *Cultivation*

The acute problem with soil erosion needs to be dealt with promptly. Soil erosion is extreme in the area. Restoring a degraded soil includes not only saving the soil physically but also improving soil organic matter, porosity, available water capacity and infiltration rate. Soil should not be left bare, particularly not for the rain period. In the teak plantations it is of outmost importance that the litter is left on the ground. To have the soil covered with organic matter is an easy and inexpensive method of protecting the soil and restore soil organic matter that could be used to a much larger extent within the study area.

Structures such as bunds or trenches may help in capturing sediments in the runoff on the downslope of the plantations as well as sloping fields. Design of such structures must be determined site specific with respect to slope, soil depth etc.

Land with gentle slopes close to streams such as surrounding Huay Maha stream and Nam Pa river are in low abundance, but some small plots exists. That land has potential for vegetable production or other valuable crops, as DAFEO suggests. River diversion or construction of check dams are not explicitly recommended, but in case of such a development Huay Maha and Nam Pa are the most suitable streams. A further study on how irrigation can be developed in this area is recommended.

Integrated cropping is beneficial from several points of view. Crops should be chosen with different root depths in order to maximize the uptake of soil water and nutrients. Integrating trees is Young's (1989) best advice. Crops should also be chosen so that the ground is well covered. The land suitability of crops should include an assessment of their water requirements compared to the available water at the site.

There is a lack of water over the year for the current cultivation. The solution to the agricultural constraints must include adjusted cropping methods including moisture and soil conservation. It should be possible to obtain larger yields as well as restore or at least slow down the degradation of the soils in the area.

The most important recommendations regarding cultivation are:

- To maintain a dense vegetative cover or have organic matter to protect the soil.
- To use crops with different root depths in the same field to obtain a more effective usage of water and nutrients and have deep roots that bind the soil well.
- To cut the slopes into shorter intervals using terraces, bunds or trenches in order to increase infiltration and capture eroded sediments.

- To study the possibility of diverting water from Huay Maha, Huay Keo or Nam Pa to the surrounding moderately sloping land.

If some or all of these measures are taken infiltration will increase and runoff and erosion decrease. This will also improve the soil fertility compared to if nothing is done. Effort should be put into spreading knowledge of these water harvesting methods since they are applicable without any large investments except for labour. If cultivation is carried on without conservation it is unlikely that the land can support the present population in the long run.

## REFERENCES

- Assouline S. & Ben-Hur M. (2006) *Effects of rainfall intensity and slope gradient on the dynamics of interrill erosion during soil surface sealing*. Catena 66 (2006) p 211-220.
- Barrow C. (1987) *Water Resources and Agricultural Development in the Tropics*. Longman Scientific & Technical 356p.
- Bruun T.B. Mertz O. & Elberling B. (2005) *Linking yields of upland rice in shifting cultivation to fallow length and soil properties*. Agriculture, Ecosystems and Environment 113 (2006) p 139-149.
- Chow V.T. Maidment D.R. & Mays L.W. (1988) *Applied Hydrology*. McGraw-Hill International Editions. 572 p.
- Dunne T. & Leopold L.B. (1978) *Water in Environmental Planning*. W.H Freeman and Company, San Francisco. 818p.
- El-Hassanin A.S. Labib T.M. & Gaber E.I. (1993) *Effect of vegetation cover and land slope on runoff and soil losses from the watersheds of Burundi*. Agriculture, Ecosystems and Environment, 43 (1993) p 301-308.
- Evans J. (1996) *Plantation Forestry in the Tropics*, 2<sup>nd</sup> edition. Oxford University Press. 403p.
- Fox D.M. Bryan R.B & Price A.G. (1997) *The influence of slope angle on final infiltration rate for interrill conditions*. Geoderma 80 (1997), p 181-194.
- Gouranga K. Ravender S. & Verma (2003) *Alternative cropping strategies for assured and efficient crop production in upland rainfed rice areas of eastern India based on rainfall analysis*. Agricultural Water Management 67 (2003), p 47-62.
- Grip H. & Rodhe A. (1994) *Vattnets väg från regn till bäck*, 3rd edition. Hallgren & Fallgrens Studieförlag AB. 155p.
- Islam J. Bhuiyan L.R & Ghani A. (1991). *Supplemental irrigation- a safeguard technique for successful cultivation of Monsoon rice (transplanted Aman) in Bangladesh*. Kluwer Academic Publishers, Irrigation and Drainage Systems 5: p351-362.
- Janeau J.L. Briquet J.P. Planchon O. & Valentin C. (2003) *Soil crusting and infiltration in steep slopes in northern Thailand*. European Journal of Soil Science (2003) 54, p 543-553.
- Knutsson G. & Morfeldt C.O. (2002) *Grundvatten – teori & tillämpning*, 3rd edition. AB Svensk Byggtjänst. 227 p.
- Mekong River Commission (1993) *Lower Mekong Hydrologic Yearbook 1993*. 477p.
- Moldenhauer W.C. & Hudson N.W. (1988) *Conservation Farming on Steep Lands*. Soil and water conservation society. 296p.
- Nilsson E. & Svensson A.K. (2005) *Agro-Ecological Assessment of Phonxay District, Louang Phrabang Province. Lao PDR. A Minor Field Study*. Physical Geography and Ecosystems Analysis, Lund University
- Nilsson Å. (1987) *Groundwater dams for rural water supply*. Intermediate Technology Publications, London .
- Pacey A. & Cullis A. (1986) *Rainwater harvesting – The collection of rainfall and runoff in rural areas*. Intermediate Technology Publications. 216 p.
- Reij C. Mulder P. & Begemann L. (1988) *Water Harvesting for Plant Production*. World Bank technical paper number 91 p123.
- Rerkasem B. (2004) *Land and Water Resources*. ACIAR Proceedings No 116e. p.105-118.
- Ritter D.F. Kochel R.C. & Miller J.R. (1995) *Process Geomorphology*, 3rd edition. Wm. C. Brown Publishers. 544p.
- Singh V.P. & Singh R.K. editors (2000) *Rainfed Rice A Sourcebook of Best Practices and Strategies in Southern India*. International Rice Research Institute. 292p.
- Saito K. et al. (2006). *Farmers' knowledge of soils in relation to cropping practises: A case study of farmers in upland rice based slash-and-burn systems of northern Laos*. Geoderma xx(2006) xxx-xxx.
- Selvaraju R. & Ramaswami C. (1997) *Evaluation of fallow management practices in a rainfed vertisol of peninsular India*. Soil and Tillage Research 43 (1997). p 319-333.
- Sidle R.C. et al. (2005) *Erosion processes in steep terrain – Truths, myths, and uncertainties related to forest management in Southeast Asia*. Forest Ecology and Management 224 (2006) p 199-225.
- Sivanappan R.K. (1992) *Soil and water conservation and water harvesting*, 2<sup>nd</sup> edition. Tamilnadu Social Forestry Project, Indo-Swedish Forestry Coordination Programme 116p.
- Shaw E.M. (1994) *Hydrology in Practise*. Chapman & Hall. 569 p.
- Ticehurst J.L. et al. (2007) *Interpreting soil and topographic properties to conceptualise hillslope hydrology*. Geoderma vol 137 Issues 3-4 (2007) p 279-292.
- Verplancke H. Maesschalck G. & De Boodt M. (1988) *Effect of water conservation on the yield of upland crops in the humid tropics*. Agricultural Water Management, 14 (1988) p 277-286.
- World Health Organization (2003a) Ammonia in Drinking-water. Published in Guidelines for Drinking-water Quality 2<sup>nd</sup> ed vol 2. WHO Geneva 1996.
- World Health Organization, (2003b) Chloride in Drinking-water. Published in Guidelines for Drinking-water Quality 2<sup>nd</sup> ed vol 2. WHO Geneva, 1996.

- Young A. (1989) *Agroforestry for Soil Conservation*. CAB International. 244p.
- Young A. (1997) *Agroforestry for Soil Management* 2<sup>nd</sup> edition. CAB International 320 p.
- Zuane J. de. (1997) *Handbook of Drinking Water Quality*, 2<sup>nd</sup> edition. John Wiley & Sons Inc. 575 p.

### Other References

- District Agriculture and Forestry Extension Office, Phonxay (2006) *Climatic data*
- FAOa (1998) *World Reference base for soil resources, world soil resources reports – 84*. Downloaded from <http://www.fao.org/docrep/W8594E/w8594e00.HTM> (2007-04-10)
- FAO (1999) *Lao People's Democratic Republic* <http://www.fao.org/ag/agl/aglw/aquastat/countries/laos/index.stm> (2007-04-10)
- Inthavong K (Oct-Nov 2006) Field station coordinator at NAFReC's field station in Nam Bo village, Phonxay district *Personal communication*
- Jones P. Land Management Adviser (2007) LSUARFP. *Personal communication*
- Keolasy C. (2006) Forestry researcher at NAFReC's field station in Nam Bo village, Phonxay district. *Personal communication*
- LSUARFP (2006) Profile of Phonxay district, Luang Prabang Province, 4p
- Mossberg C. (2006) Team Leader LSUARFP *Personal communication*
- NAFReC Agrometeorology station Huay Khot (2006) *Metrological data*
- NAFRI (2003) *Field Report on Indigenous Soil Taxonomy, Household Diagnostic Survey and Market research in Phonsay District*. Socio-economic unit, 10 p.
- NAFRI (2005) *Improving Livelihoods in the Uplands of the Lao PDR - A Sourcebook Volume 1: Initiatives and Approaches*. 251 p. Available at: [http://www.nafri.org.la/03\\_information/sourcebook/Volume1.htm](http://www.nafri.org.la/03_information/sourcebook/Volume1.htm)
- Olofsson B. (2007) Professor KTH Land and Water Department. *Personal Communication*.
- Olsson M. (2004) *Report on Soil Surveys and its Implementation in the Lao Swedish Agriculture and Forestry Research Programme*. Department of Forest Soils, SLU, Uppsala, Sweden.
- Ribolzi O (Nov 2006) Hydrogeochemist, International Water Management Institute *Personal communication*
- Sanchez J.F. (2007) *Applicability of knowledge-based and fuzzy theory-oriented approaches to land suitability for upland rice and rubber, as compared to the farmers' perception. A case study of Lao PDR* (MsC Thesis). Downloaded from [http://www.itc.nl/library/papers\\_2007/msc/gem/sanchez.pdf](http://www.itc.nl/library/papers_2007/msc/gem/sanchez.pdf) 2007-04-05
- Sida: <http://www.sida.se/sida/jsp/sida.jsp?d=543> (Last view 2007-04-02)
- Soil Survey and Land Classification Centre at NAFRI (2006) *Digital data regarding: topography, land use, watershed classification and soil*.
- Tomawong B. (Oct 2006) Head of Huay Maha settlement *Personal communication*

## APPENDIX I INTERVIEWS

### Questions for Group Interviews

#### Cultivation and Farming

1. In the upland, is the amount of rainfall enough for the crop you grow?
2. Do you have problems with that the soil is swept away with rainwater (erosion)?
  - a. If so, how much is lost?
  - b. Have the loss of surface soil affected the cultivation?
3. Do you take any measures to conserve soil and soil moisture (for example logs or stones along contours, strip cropping)?
4. Have you used any water and soil conserving methods previously and how did it work?
5. Have you heard from administration regarding water and soil conservation measures?
6. Do you use any fertilizers or pesticides? If so, which ones and in which fields?
7. Since the population was increased here, how much more often do you cultivate the same land?
8. Have you noticed any change in the soils since they are cultivated more often?

#### Domestic Water

9. Where do you collect water for drinking, washing and cooking needs?
10. How much water do you use in your household (buckets/day)?
11. Is there enough water in the water supply?
  - a. If not, how much is lacking?
  - b. When is there a deficit?
12. What are your preparation methods for drinking water?
13. How much time do you spend each day on collecting and preparing water?
14. What quality issues are there in the water supply? Colour, taste, odour, getting unwell from drinking etc
15. Do you take any precautions to prevent contamination of water?
16. What do you do with your garbage? Where do you put it?
17. Where do you pee and poop?
18. Have you heard from administration regarding water quality and health?

### Interview Huay Maha, 25/10 2006. Men and women

Very few Hmong women in Huay Maha speak Lao. A separate interview with women was supposed to be held in the morning after, but on request of Mr Bounta Tomavong, there was only one interview.

#### *Interviewees;*

Mrs Some Khamu

Mrs Sy Khamu

Mrs Phoua (leader of women's union, Hmong)

Mr Sinxay Fachisong Head of village, Hmong

Mr Bounta Khamu, deputy head of village

Mr Phai Khamu

Mr Cheu Hmong

The interview took place in Mr Bounta's house. Mr Bounta and Mr Sinxay were the most active persons in the interview. Mrs Phoua, Mrs Some and Mrs Sy spoke a little bit as well. Since the interview took place quite late and people tried to sleep in the same room, the interview was about 1 hour. All the questions were asked, but not as many follow-up questions as previously.

1. This year it hasn't been enough rain. Some of the rice, corn, job's tears and sesame has died. Previous year also deficit, but less crops died then. Rice is planted in june, and there was too little rain then. The rice cannot germinate (grow well).
2. Yes, minimum 1.5 cm and maximum 3 cm is swept away after one heavy rainfall. Sometimes crops are swept away.

3. Intergrated cropping. Rice, job's tears, corn, taro, gasua, beans, chilli, eggplant and some vegetables in the same plot. (Some of the crops are not for sale, only consumption when they are out in field). *Ms Chittavanh Keolasy told us later that they cut down weed and put it on the ground to increase soil moisture.*
4. No
5. No
6. No
7. The village started in 1986. Increased population last years. Job's tears and sesame is the main income. Each family is allowed maximum 2-3 plots. They plant one year, and then the land is in fallow 2-3 years. Before they could have many plots. They use the slash and burn technique, which is allowed in their fields/plots, but nowhere else. The district has allocated the area, so now only 2-3 plots/family.
8. Yes, they have. First year they get 2 tonnes of rice from one hectare, the second year they get less.
9. They use the water supply for drinking and cooking. Nam Pa for bathing and washing. In the rainy season they uses only the water supply, but there is not enough water in the dry season. They wash their dishes in the water supply.
10. About six buckets per day and family. Three in the morning and three in the evening. One family consists of 8-10 persons. On daytime, when they are in their fields they use the water there.
11. See (9)
12. They boil their drinking water in the morning and in the evening, but not when they are out in their fields. The main streams that they uses in their fields are:
  - a. Huay Maha
  - b. Huay Keo
  - c. Huay Pa heo
  - d. Huay peek
  - e. Huay Makkhaen
  - f. Huay Wang pau
13. Ten minuets for collecting 2 buckets of water. Boiling not included.
14. They have problems with mud in the streams close to their fields. Kidney problems with water from the water supply, even though they boil it. They are not sure that is it because of the water but they think so.
15. They have village regulations that don't allow animals close to the streams that they drink from. The animals are kept in houses far from here
16. They put away their garbage somewhere and when someone sees much garbage they burn it.

Question 17 and 18 were not asked since Mr Bounta Tomawong had answered them extensively on the interview on Oct 18

About 40 families have livestock up in the highland plateau, which drink from the water in the ponds. The ponds are enough for the cattle. The people who watch the cattle drink from small streams up there, but in April-May the streams have dried out. They collect rainwater in dug wells (which they constructed when they lived up there) that they uses when the streams are dry.

### Interview Poug Pao E, 30/10 2006

Interviewees; 3 men, 1 woman (all Khamu ethnicity)

Mr Thongsy

Mr Phim Ounthavong

Mrs La

Mr Mouy

The interview was held in the evening in Mrs La's house. Mr Thongsy and Mr Phim talked the most. Chittavanh Keolasy (NAFRE staff) helped the discussion.

1. There is not enough rainwater. Every year there is a deficit. They grow rice, Job's tears and sesame.
2. 2-3 cm of topsoil is lost after one heavy rain. The crops is affected by that, they don't grow well when the soil is swept away.
3. No
4. No
5. No. *(Mrs La's family is in the Sida project, but it is possible that only her husband knows about the methods according to Chittavanh Keolasy)*

6. No
7. They have lived here for 25 years. Before they had about 5-8 different plots to alternate between. After the land allocation and population increase they have 2-3 plots per family. They change plot every year. *[The land allocation change took place 2001-2002 according to staff at the field station]*
8. They get less crop now, they don't grow well. Before when they had 8 years of fallow the soil recovered well. But it doesn't do that now. Only weed grow well, not crop.
9. They use the water supply for all purposes all year around. Except in April-May when they take a bath in Nam Pa.
10. 8 buckets/day for a small family of 5 people. 33-34 people live in this settlement, 8 families.
11. *not asked*
  - 12 They boil their water before they drink it. All families do this, except when they are in their fields.
  - 13 1 hour per day to collect and prepare the water.
  - 14 There are no quality problems with the water supply
  - 15 No precautions, but they do not have animals close to the stream.
  - 16 There is no special place for garbage, but they put it quite far away from the village.
  - 17 They do not have toilets, they go to the forest.

Cemetery is shared with the big Pong Pao settlement.

- 18 Yes, the nurse told them to boil the water and to make a toilet and to sleep under the mosquito net.

They would like the district to help with the water supply since the pipes break often. *(Chittavanh Keolasy: District where here and she asked about the water supply in Pong Pao. They said they would send someone of their staff to look after and maintain the water supply. That would be part of the EU project. This was last week but she is not sure they will do it)*

This village do not have animals at the highland plateau.

#### Interview Pong Pao W, 24/10 2006. Men

Interviewees; 7 men; 5 Hmong and 2 Khamu

Mr Vaxeng Song

Mr Nor Heu

Mr Wa Souava

Mr Yia Ki – Deputy of village

Mr Khamphay

Mr Bounphaeng

Mr Saly – Head of village

The men said that they pay 4000 kip per family and year to the district for maintaining the water supply. They say that there is not enough water in the water supply. They told the district 2 years ago, but they haven't done anything about it yet.

1. If it is enough water one year, the two years after there is not enough. May-June there is water deficit. July-September enough rain (every year). They grow the same crops every year; rice, job's tears, corn and sesame. For rice there is enough rain in June-July.  
*(They plant the rice in June or July and the rest of the crops in June) Sesame they harvested last month. Only one cropping period per year, no cultivation during dry season. Job's tears in November and corn early October (info from Chittavanh Keolasy, participating Nafrec staff)*
2. If slope, heavy rain sweep away soil. First year for new crop there is no problem, but second and third year could be a problem. They lose much soil and even crops. In flat land they may lose one centimeter after heavy rain and in steep slopes, the average loss is 2 cm after heavy rainfall.
3. They plant rubber, line contouring by measuring with A-frame. Staff from the district has come to the village to inform them about line contouring. The district informed that line contouring is both for soil and soil moisture conservation.
4. They have tried contour lining before with good results. But only 4-5 families who are in the Sida project. The other families who are not in the project cannot afford rubber or another plant to alternate with. *(Here the people got a little bit upset, they thought that the Sida project should help all the families, not only a few)*
5. see (3)

6. No fertilizers, no pesticides
7. *[The district has allocated the land for the resettled farmers. Each family has 3 or 4 plots].* First year they can grow rice, second year job's tears and third year sesame if they don't have many plots. Then the land is in fallow for a few years. Those who has 3 or 4 fields uses one new plot every year. They cultivate one plot one year, the next year they move on to the next plot, and the third year to the third plot. The land that is not cultivated is in fallow. Those families with few fields, goes up in the mountains one year to cultivate there, where they lived before. All inhabitants in Poug Pao are new settlers, they moved here about five years ago. They have had the same fallow period all the time.
8. *irrelevant question since all have moved here recently*
9. They take water for drinking and cooking from the stream Huay Meteng. They wash clothes and bath in Nam Pa. There is not enough water in the water supply, (which comes from Huay Namlin).
10. They use about 100 litres per day in a big family, which consists of about 14 persons.
11. April-May, they use water from the stream. Then there is no water in the water supply. They say that the pipes are too small. [The people who live close to the water supply uses that water and those who lives close to the stream uses that water]
12. they boil the water from the stream and from the supply. Some families also filter their water through fabrics.
13. 20-30 people may go to the stream at the same time for collecting water. Then they have to queue for about 1 hour.
14. Water from the water supply is not good, it is muddy, coloured and you get lime residues on the pots when they boil the water. The water from the stream is said to be good.
15. They don't take any precautions to prevent the water from contamination. Before they sometimes had animals close to the water, but not anymore. They have pens (houses) for hens and chicken.
16. The men said that they burn their garbage.
17. The men said that two families have a toilet. The others go to the forest, they usually go far into the forest.
18. The district told them to boil the water before drinking it in 2002. They boiled it before that as well. There is a nurse from the district who goes out in the village for injection about once a year. Also informs about health.

They have used Nam Pa for drinking and cooking previously. When the village was new, 7-8 families used Nam Pa. But no one uses it anymore.

Before when they lived in the mountains, they used rainwater harvesting. They collected the water from the roof, lead it by bamboo sticks to a dug well, where they stored it. But it wasn't enough for their needs.

#### **Interview Poug Pao W 25/10 2006. Women.**

The interview took place at 07 am in the village

Interviewees; 4 women; 1 Hmong and 3 Khamu

Mrs Ya head (of women's elder union, Hmong (part of Sida project))

Mrs Pong

Mrs Home

Mrs Bouachanh

Only Mrs Ya and one more woman spoke during the interview. Ya has lived here since year 2000.

1. The rain is not enough, it starts to rain early in July so they plant late otherwise they cannot get much yield.
2. No problem with erosion since they choose their field plots in flat areas. Only some have problem. Grow rice and corn in the upland. Down here it is too hot for the crop. Better in highland since it is humid get much yield.
3. No. Most don't take any measures and they don't have any contour lining. Only 1 crop/area unless part of the Sida project.

Chittavanh Keolasy say this is not true, they plant bananas, cucumbers, watermelons but they do not count them. Often for example banana trees around a field. Sida project mixed crops, they want only ackawood but sida say they must plant others too otherwise they do not get ackawood seedlings.

4. No.
5. They do not know about this, when the district come here to introduce this they talk only to the men. Ya know about the rubber plants and fodder. Husband introduce to the women in the field, but women does mostly household work. Women also work with weeding.

Chittavanh Keolasy: They grow rubber, pineapple and broomgrass (Non timber forest product) since 2005. Since 2006 they also grow rice integrated with rubber. Both intercropping and contour lining.

6. No
7. *irrelevant question to new settlers*
8. *see (7)*
9. In rainy season they wash their clothes in Huay Mehteng. They also get most of their water from there. In the dry season they sometimes wash their clothes in Nam Pa, the water supply is not enough. Water in Huay Mehteng is better than water supply.
10. They use a lot of water since there is much water and it is free. About 20 buckets/day and family. One family usually 9 people.
11. There is always a deficit in the water supply, even though that stream has more water than Huay Mehteng. Water from water supply contains limestone and colour. In the stream there is less water in the dry season but it doesn't dry out.
12. Filter water with fabric before they collect it and then boil it before they drink it. *Chittavanh Keolasy: maybe about 10 families do not boil the water before they drink it*
13. Many people want to get water at the same time so they have to wait about 20 min. It takes about 1 hour to collect and boil 3-4 buckets of water.
14. Huay Mehteng not muddy and no limestone. They do not have any health problem because they boil it before drinking and they tell their children not to drink directly from the stream.
15. There are goats around Huay Mehteng in daytime, but they cannot say anything because the goats belong to the deputy of the village.
16. Garbage is put along the road sloping towards Nam Pa. They do not burn their garbage. *[Mrs Ya showed us where they put the garbage, but it was very little there. Do not believe that is all the garbage from the village if they do not burn it, but Chittavanh Keolasy say taking care of garbage is women's work so they should know.]*
17. They have no toilet in the village, they go to the forest. They would like to have toilets in their houses if there was enough water.
18. A nurse from the district comes 1-2 /year and interview them and tell them about water and health; that you should boil the water before you drink it.

There are about 924 people in this village. They want to know if we can tell them some better way to prepare their water.



## APPENDIX II RAINFALL DAFEO

Rainfall (mm) Measured in Pakvi at Phonxay District office

Source: DAFEO

Year 2006

Year 2000																									
Date	Jan 07 19	Feb 07 19	Mar 07 19	Apr 07 19	May 07 19	June 07 19	July 07 19	Aug 07 19	Sep 07 19	Oct 07 19	Nov 07 19	Dec 07 19	Total												
1						6																			
2																									
3																									
4								11		3															
5		8					10.5		9	2															
6		6						22		4															
7				6						5															
8								8		8															
9										6															
10				8				12	30	3															
11					8			22	1.5	2															
12					10			8		6															
13		4								2															
14								1		5															
15							10.7			10.5															
16						10.5			24	6.5															
17										1.5															
18								8	4.8																
19								10.5	35																
20			3	9		1				8															
21						25		14																	
22					6	15		10.8	20																
23					20.5	25			11																
24					2			8																	
25					3		25	6																	
26				3			24.2	10.2																	
27								60	4																
28						15.5	12.2																		
29				12				1.5	10.2																
30																									
31				12				10.2																	
32			20	25		10		6																	
33				1				10																	
34																									
35							28																		
Total	0	0	0	18	20	4	63	12	29	31.5	46	76	57.6	28	160	217	85.3	62	22	42.5	0	0	0	0	974.25

Year 2005

Year 2005																									
Date	Jan 07	19	Feb 07	19	Mar 07	19	Apr 07	19	May 07	19	June 07	19	July 07	19	Aug 07	19	Sep 07	19	Oct 07	19	Nov 07	19	Dec 07	19	Total
1									3.5						37										
2									3						10				4.5						
3				21				7	0.5				3.5	3				9							
4				25				3						3		35		7							
5														9	3			6							
6												15				14		9				10.5			
7												27				20	18	20							
8															18										
9														5											
10																									
11													5												
12							4.5									10						20			
13						13										18									
14																20									
15						10.2							4			17									
16					2							18				7	18								
17																17	43								
18																3	5		12						
19																									
20						9		2.5					15												
21						9						13													
22													20			31	3								
23										2						10	5								
24												18	25												
25							9			6				27		30	40								
26																	1.5								
27								10.2					1					38							
28																									
29																15.5									
30											20					8									
31									9				13			6									
Total	0	0	0	46	2	41.2	13.5	22.7	9	35	0	91	86.5	47	156	288	19.5	101	0	4.5	0	30.5	0	0	992.9

Rainfall measured at Pakvi at Phonxay District Centre Office by DAFEO.

Year	Rainfall mm	Days with rain	Months with rain
1994	1137.7	65	10
1995	1059.3	68	10
1996	1561.6	97	10
1997	1081.0	92	9
1998	1296.0	88	11
1999	1195.7	98	10
2000	1584.0	97	12
2001	1430.5	81	9
2002	1561.8	97	11
2003	1284.4	80	10
2004	1172.5	93	10
2005	992.9	68	11
2006	974.3	77	9

**APPENDIX III RAINFALL MEASURED OUTSIDE PHONXAY DISTRICT**

Rainfall data in mm/month measured at three different climate stations in northern Laos. Data received from climate unit of NAFReC.

**Station Name: Luangpr**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	4.9	31.7	17.7	132.3	128.8	116.1	141.8	292.6	103.7	22.4	101.5	0	1093.5
1986	0	0	10.4	267.3	214.9	373.4	352	210.4	62	267.2	54.6	27.5	1839.7
1987	2.2	29	47.6	145.5	57.4	122.5	180.2	193.5	130.9	28.1	98.9	0	1035.8
1988	0.8	31.7	1.5	155.8	173.8	141.1	240.4	181.4	39.2	174.7	15.3	0	1155.7
1989	13.7	0	69.1	132.4	156.3	154.2	287.4	288.9	160.8	130.5	21.9	0	1415.2
1990	9.7	50.6	77.8	127.9	114	193.2	329.3	208.3	262.4	61.1	199.4	0	1633.7
1991	9.9	0	47.5	32.6	169.8	103	179.7	267.2	206.4	21.8	19.4	6.3	1063.6
1992	19.3	91.1	0	49.7	65.7	124.6	297.1	283.7	92.9	58.4	9.5	137.2	1229.2
1993	0	0	76.8	80.7	146.1	212.5	263.5	189.5	100.6	118.6	0	1	1189.3
1994	0	5.4	110.7	19.2	170.2	243.6	202.5	366.1	151.6	31.6	18.5	81.6	1401
1995	7.5	4.8	8.7	49	201.5	239.4	331.4	541.5	118.8	167	71.3	7	1747.9
1996	0	22	38.9	147.2	151.6	219.9	291.8	302.4	176.6	185	61.2	0	1596.6
1997	1.5	0.4	56.9	105.7	144.3	147.7	311.6	258.5	128.4	40.1	2.4	0	1197.5
1998	27	2.2	33	178.1	160.9	138.2	179.4	265.4	99.4	47.1	25.5	7.5	1163.7
1999	9	0	44.1	60.3	203.5	281.1	73.9	285	197.5	97.9	54.9	24.5	1331.7
<b>Average</b>	<b>12.12</b>	<b>18.10</b>	<b>34.33</b>	<b>95.26</b>	<b>146.81</b>	<b>179.45</b>	<b>225.16</b>	<b>266.31</b>	<b>163.05</b>	<b>95.65</b>	<b>29.76</b>	<b>12.21</b>	<b>1278.21</b>

**Station name: Pak Ou**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	0	0	0	44.4	75.1	130.8	286.7	199.8	71.2	63.7	25.8	76.3	973.8
1993	0	0	0	100.5	131.2	93	260.4	204.3	245.7	104.5	0	0	1139.6
1994	0	31.5	42.1	61.6	114.6	238.3	177.8	358.7	69.7	37.1	13.4	107.6	1252.4
1995	33	0	6.7	30.7	311.3	167.6	225.7	272.8	116	20.1	61.7	0	1245.6
1996	0	19.6	64.1	85.6	174	180.6	83.8	289	117.2	167.5	60	0	1241.4
1997	4.7	0.4	37.3	102.6	63.1	126.3	495.2	195.9	220.4	92.6	0	0	1338.5
1998	19.8	0.5	27.3	114.6	107.5	103.8	167.8	300.6	71.4	32	0	0	945.3
1999	1.1	0	22.5	142.7	210.6	233.4	169.8	541.4	385.3	60.7	62.1	0	1829.6
2000	0	92.9	7.3	20.4	222.7	49.8	466.3	171	132.2	0	174.1	0	1336.7
2001	0	0	115.8	17.9	268.7	132.3	220.9	268.8	57	22.5	45.6	0	1149.5
2002	44.1	3	30.1	63	248.7	168.8	474.3	240.1	121.4	113.5	71.7	14.2	1592.9
2003	59.5	36.2	14.2	50.9	56.4	215.1	160.1	261.1	190.7	46.6	0	0	1090.8
2004	0	0	4.7	137.1	443.3	216.1	232.9	456.6	218.8	100	67.2	0	1876.7
2005													
<b>Average</b>	<b>12.5</b>	<b>14.2</b>	<b>28.6</b>	<b>74.8</b>	<b>186.7</b>	<b>158.1</b>	<b>263.2</b>	<b>289.2</b>	<b>155.2</b>	<b>66.2</b>	<b>44.7</b>	<b>15.2</b>	<b>1308.7</b>

**Site: Hkstation (NAFReC), Huay Khot, Xiang-Ngeum**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1998	33.4	6.4	29.1	168.3	162.0	104.4	117.8	289.2	61.8	34.3	42.8	13.0	1062.5
1999	2.5	0.0	32.7	114.3	275.8	260.2	112.8	146.0	183.5	86.8	33.2	34.3	1282.1
2000	0	59.4	12.2	66.9	213.3	253.8	178.1	207.8	187.3	79	0	0	1257.8
2001	1.4	0	133.1	70.8	109.4	141.3	340.1	236.3	165.6	173.8	0	8.4	1380.2
2002	32	15.8	9	54.9	333	138.4	354.1	301.9	131.6	86.9	83	62	1602.6
2003	10.8	27.6	18.4	141.2	107.2	165.6	161.6	303.1	326	0	3.3	0	1264.8
2004	22	0	0	156.4	241.2	181.6	221.4	190	175.4	31.4	70.6	0	1290.0
2005	0	51	52.4	68	174.4	128.8	275.6	261.2	327.4	12.4	10.2	0	1361.4
<b>Average</b>	<b>12.76</b>	<b>20.03</b>	<b>35.86</b>	<b>105.10</b>	<b>202.04</b>	<b>171.76</b>	<b>220.19</b>	<b>241.94</b>	<b>194.83</b>	<b>63.08</b>	<b>30.39</b>	<b>14.71</b>	<b>1312.68</b>

Source: NAFReC, climate unit



## APPENDIX IV TEMPERATURE AND EVAPOTRANSPIRATION

Interpolated data over Phonxay district. T mean is the mean temperature/month. T max mean is the monthly average of the daily maximum temperature. T min mean is the monthly average of the lowest daily temperature. PET is the monthly average of the potential evapotranspiration.

	T mean [deg C]	T max mean	T min mean	PET [mm/d]
January	22.4	29.4	15.5	3.0
February	24.0	31.2	16.4	4.0
March	27.0	34.8	19.4	4.9
April	29.5	36.4	22.8	4.9
May	30.0	35.3	24.9	4.0
June	29.8	33.9	25.9	3.3
July	29.4	33.2	25.8	2.9
August	30.1	33.1	25.5	2.9
September	28.8	33.2	24.6	3.0
October	27.7	32.5	23.1	3.0
November	25.1	30.7	19.7	2.8
December	22.4	28.8	16.2	2.7

Source: Nilsson & Svensson (2005)

Rainfall measured by the DAFEO (2006) compared to interpolated potential evapotranspiration by Nilsson & Svensson 2005.

	Rainfall Phonxay [mm]	Mean PET Phonxay [mm]	Diff [mm]
1994	1137.7	1257.5	-119.8
1995	1059.3	1257.5	-198.2
1996	1561.6	1257.5	304.2
1997	1081.0	1257.5	-176.5
1998	1296.0	1257.5	38.6
1999	1195.7	1257.5	-61.8
2000	1584.0	1257.5	326.6
2001	1430.5	1257.5	173.1
2002	1561.8	1257.5	304.4
2003	1284.4	1257.5	27.0
2004	1172.5	1257.5	-85.0
2005	992.9	1257.5	-264.6
2006	974.6	1257.5	-282.9
Average	1256.3	1257.5	-1.1
Median	1195.7	1257.5	-61.8



**APPENDIX V CALCULATED EVAPOTRANSPIRATION**

Actual evapotranspiration in Phonxay calculated according to the Grindley model as described by Shaw (1994)

	Rainfall Phonxay	PET Phonxay	Rainfall - Evapot.	Potential SMD	RC 200 mm		RC 75 mm		Rain-Eta (rc200)
					SMD	Et a	SMD	Et a	
<b>Jan</b>	0	93	-93	93	93	93	93	93	-93
<b>Feb</b>	32	112	-80	173	173	112	114	53	-80
<b>Mar</b>	32.6	151.9	-119	292	241	101	120	39	-68
<b>Apr</b>	55.6	147	-91	383	248	63	121	57	-7
<b>May</b>	52.25	124	-72	455	250	54	121	52	-2
<b>June</b>	106.5	97.5	9	446	250	98	121	98	9
<b>July</b>	109.6	89.9	20	427	250	90	121	90	20
<b>Aug</b>	410.6	89.9	321	106	106	90	101	90	321
<b>Sept</b>	133.9	90	44	62	62	90	62	90	44
<b>Oct</b>	34.5	93	-59	120	120	93	108	81	-59
<b>Nov</b>	15.25	84	-69	189	189	84	116	23	-69
<b>Dec</b>	0	85.25	-85	275	240	51	120	4	-51
<b>Total</b>	<b>982.8</b>	<b>1257.45</b>				<b>1018</b>		<b>769</b>	<b>-35</b>

Rainfall Phonxay is the average precipitation in mm year 2005-2006 measured by DAFEO.

PET Phonxay is the monthly potential evapotranspiration calculated from Nilsson & Svensson 2005.

Rainfall- Evapot. is the difference between precipitation and potential evapotranspiration.

Potential SMD is the potential soil moisture deficit and it is calculated using  $SMD_i = SMD_{i-1} - (Rainfall - Evapot.)$  where i is the month

SMD is the actual soil moisture deficit for a certain root constant (RC) value.

Et a is the actual evapotranspiration for a certain root constant value.

Eta month i = SMD month i - SMD month (i-1) + Rain month I

**RC root constant                      mm**

grass                                      75

root crops (potatoes)                100

cereals                                    140

woodland                                200

Eta = Etp untill SMD =RC + 25

Rain-Eta (rc200) is the difference between the precipitation and the actual evapotranspiration for the root constant value 200.



## APPENDIX VI WATER FLOW CALCULATIONS IN MATLAB

The following code was run in Matlab version 7.3 (R2006b) to calculate and plot cross sections (A) of streams and the resulting flow (Q). The sign “%” denotes comments; Matlab ignores text on a line after “%”.

### % Nam Pa river Outflow of catchment 26/10

```
clc, clear all, close all
% Depth in cm, 0 value added at beginning
DnampaOutcm=[0 8 24 27 42 29 44 59 85 78 72 68 44 26 48 36 27 20 19 10 0];
% Depth in meter and as a negative value from the surface
DnampaOut=-0.01*DnampaOutcm;
% Width 16.2 m, creates vector with the step 16.2/20
WnampaOut=[0:(16.2/20):16.2];
figure (1)
plot(WnampaOut, DnampaOut), axis equal, axis([0 17 -1 1])
legend('WnampaOut');
xlabel('width [m]'), ylabel('Depth [m]');
AnampaOut = trapz(WnampaOut, DnampaOut)
% the area above the curve is integrated using the trapetz method
% Average flow velocity 26/10 was 1,09 m/s
QnampaOut=(-1)*AnampaOut*1.09
% Flow Q of Nam Pa at outflow = 6,76 m3/s
```

### % Nampa river Inflow to catchment 26/10

```
clc, clear all, close all
% Depth in cm, 0 value added at beginning and end
DnampaIncm=[0 23 28 40 48 57 60 50 53 50 47 40 40 35 30 27 22 16 19 8 0];
% Depth in meter and as a neg value from the surface
DnampaIn=-0.01*DnampaIncm ;
% Width 16,9 m, create vector with the step 16,9/20
WnampaIn=[0:(16.9/20):16.9];
figure (2)
plot(WnampaIn, DnampaIn); axis equal, axis([0 17 -1 1])
legend('WnampaIn');
xlabel('width [m]'), ylabel('Depth [m]');
AnampaIn = trapz(WnampaIn, DnampaIn)
% the area above the curve is integrated using the trapetz method
% Average velocity at inflow was 1,54 m/s
QnampaIn=(-1)*AnampaIn*1.54
% The flow Q of Nam Pa at the inflow to the catchment was 9,02 m3/s
```

### % Nampa river Inflow to catchment 19/10

```
clc, clear all, close all
% Depth in cm, 0 value added at beginning and end
DnampaIncm=[0 7 42 46 51 56 55 54 46 56 51 46 48 53 41 38 30 6 0];
% Depth in meter and as a negative value from the surface
DnampaIn=-0.01*DnampaIncm ;
% Width 16,9 m, create vector with the step 21,8
WnampaIn=[0:(21.8/18):21.8];
figure (2)
```

```

plot(WnampaIn, DnampaIn); axis equal, axis([0 25 -3 1])
legend('WnampaIn');
xlabel('width [m]'), ylabel('Depth [m]');
AnampaIn = trapz(WnampaIn, DnampaIn)
% the area above the curve is integrated using the trapetz method
% Area Nam Pa inflow 19/10 was 8,79 m2

% Maximum Nampa river Inflow 19/10
clc, clear all, close all
% Max Depth in cm, 0 value added at beginning and end
DnampaInMax1=[0 1 2.07 2.42 2.46 2.51 2.56 2.55 2.54 2.46 2.56 2.51 2.46 2.48 2.53 2.41 2.38 2.30 2.06 1 0];
% Depth in meter and as a negative value from the surface
DnampaInMax=-DnampaInMax1;
% Max Width 25 m, create vector with equal steps
WnampaInMax=[0:(25/20):25];
figure (2)
plot(WnampaInMax, DnampaInMax); axis equal, axis([0 25 -3 1])
legend('WnampaInMax');
xlabel('width [m]'), ylabel('Depth [m]');
AnampaInMax = trapz(WnampaInMax, DnampaInMax)
% the area above the curve is integrated using the trapetz method
% Area Nam Pa in max =54,08 m2

% Huay Maha river, before intersection with Nam Pa 26/10
clc, clear all, close all
% depth in cm, 0 added at beginning and end
Dhuaymahacm=[ 0 9 10 7 6.5 8.5 11 9 7 1 0];
% Depth in m as a negative value from the surface
Dhuaymaha=(-0.01)*Dhuaymahacm;
% Width 2,62 m, create vector with equally long steps except for the added values
Whuaymaha=[0.01 0.298889 0.587778 0.876667 1.165556 1.454445 1.743334 2.032223 2.321112 2.61000 2.62];
Ahuaymaha = trapz(Whuaymaha, Dhuaymaha)
% the area above the curve is integrated using the trapetz method
%Average flow velocity is 1.48 m/s
Qhuaymaha=(-1)*Ahuaymaha*1.48
% huaymaha 26/10 cross section =0.198 m2 & Q=0.29 m3/s

%Huay Maha river, before intersection with Nam Pa 19/10
clc, clear all, close all
% depth in cm, 0 added at beginning and end
Dhuaymahacm=[0 37 34 23 8 0];
%Depth in m as a neg value from the surface
Dhuaymaha=(-0.01)*Dhuaymahacm;
% Width 1,70 m, create vector
Whuaymaha=[0 0.01 0.61 1.01 1.41 1.70];
AhuaymahaOct19 = trapz(Whuaymaha, Dhuaymaha)
% the area above the curve is integrated using the trapetz method
% Average flow velocity is 2.4 m/s
QhuaymahaOct19=(-1)*AhuaymahaOct19*2.4

```

% huaymahaOct19 cross section =0.40 m<sup>2</sup> Q = 0.97 m<sup>3</sup>/s

**%Huay Maha river, before intersection with Huay Keo 19/10**

```
clc, clear all, close all
% depth in cm, 0 added at beginning and end
Dhuaymahacm=[ 0 5 5 6 8 8 6 6 5 0];
%Depth in m as a neg value from the surface
Dhuaymaha=(-0.01)*Dhuaymahacm;
% Width 1,60 m, create vector with equally long steps except for the added values
Whuaymaha=[0.01 0.2075 0.405 0.6025 0.8 0.9975 1.195 1.3925 1.59 1.6];
Ahuaymaha = trapz(Whuaymaha, Dhuaymaha)
% the area above the curve is integrated using the trapetz method
% Average flow velocity is 0,54 m/s
Qhuaymaha=(-1)*Ahuaymaha*0.54
% Qhuaymaha = 0,0497 m3/s Ahuaymaha =0,0921 m2
```

**% Huay Keo 19/10**

```
clc, clear all, close all
% depth in cm, 0 added at beginning and end
Dhuaykeocm=[ 0 6 6 9 8 7 3 0];
% Depth in m as a neg value from the surface
Dhuaykeo=(-0.01)*Dhuaykeocm;
% Width 1,70 m, create vector with equally long steps except for the added value
Whuaykeo=[0 0.01 0.29 0.57 0.85 1.13 1.41 1.7];
Ahuaykeo = trapz(Whuaykeo, Dhuaykeo)
% the area above the curve is integrated using the trapetz method
% Average flow velocity is 0,58 m/s
Qhuaykeo=(-1)*Ahuaykeo*0.58
% Qhuaykeo 0,0587, cross section 0,10 m2
```

**% Small tributaries (Huay Panoi represents) 26/10**

```
clc, clear all, close all
% Depth in cm, 0 added at the end
Dsmalltribcm= [0 4 5 5 4 1 0];
Dsmalltrib=(-0.01)*Dsmalltribcm;
%Width is 0.55 m, create vector with equally long steps except for the last, added value
Wsmalltrib=[0 0.108 0.216 0.324 0.432 0.54 0.55];
Asmalltrib = trapz(Wsmalltrib, Dsmalltrib)
% the area above the curve is integrated using the trapetz method
%Average flow velocity is 0.294 m/s
Qsmalltrib=(-1)*Asmalltrib*0.294
% Asmalltrib =0.020m2 Qsmalltrib = 0.0059m3/s
```

**% Medium tributaries (Huay Gamlao represent) 26/10**

```
clc, clear all, close all
% Depth in cm, 0 added at the beginning and end
Dmedtribcm= [0 10 5 9 8 4 0];
% depth in m as a negative value below the surface
Dmedtrib=(-0.01)*Dmedtribcm;
```

```
%Width is 0,80 m, create vector with equally long steps except for the added values
Wmedtrib=[0 0.01 0.205 0.4 0.595 0.79 0.80];
Amedtrib = trapz(Wmedtrib, Dmedtrib)
% the area above the curve is integrated using the trapetz method
%Average flow velocity is 0,231 m/s
Qmedtrib=(-1)*Amedtrib*0.231
% Amedtrib =0.0573 m2 Qmedtrib =0.0132 m3/s
```

**APPENDIX VII INFILTRATION CAPACITY**

Infiltration capacity measured November 1<sup>st</sup> 2006 by Billing & Ågren.

AreaInf is the infiltration area. Inf is the infiltration capacity.

<b>Location 1 (19 57 48 N, 102 30 04 E)</b>				<b>Location 2 (19 57 19 N, 102 29 02 E)</b>			
<b>Time from start [sec]</b>	<b>Depth [cm]</b>	<b>AreaInf [m2]</b>	<b>Inf [mm/h]</b>	<b>Time from start [s]</b>	<b>Depth [cm]</b>	<b>AreaInf [m2]</b>	<b>Inf [mm/h]</b>
0	30	0.847		0	32		
25	29	0.827	477	60	31	0.870	172
45	28	0.807	611	100	30	0.850	265
70	27	0.787	501	120	29	0.830	542
85	26	0.767	857	135	28	0.810	741
119	25	0.747	388	165	27	0.790	380
149	24	0.727	452	180	26	0.770	779
178	23	0.707	481	215	25	0.750	343
223	22	0.687	319	245	24	0.730	411
255	21	0.667	462	285	23	0.710	317
295	20	0.647	381	315	22	0.690	435
336	19	0.627	384	355	21	0.670	336
410	18	0.607	220	375	20	0.650	692
482	17	0.587	233	430	19	0.630	260
546	16	0.567	272	490	18	0.610	246
630	15	0.547	215	540	17	0.590	305
734	14	0.527	180	595	16	0.570	287
876	13	0.507	137	655	15	0.550	273
975	12	0.487	205	720	14	0.530	261
1098	11	0.467	172	780	13	0.510	294
1200	10	0.447	216	850	12	0.490	262
1335	9	0.427	171	930	11	0.470	239
Refilled 60,2 liter				Refilled 38,4 liter			
1700	24.5	0.737		1200	24	0.730	
1740	24	0.727	170	1280	23	0.710	158
1790	23	0.707	279	1350	22	0.690	186
1850	22	0.687	239	1440	21	0.670	149
1895	21	0.667	329	1530	20	0.650	154
1940	20	0.647	339	1620	19	0.630	159
2000	19	0.627	262	1695	18	0.610	197
2080	18	0.607	203	1800	17	0.590	145
2192	17	0.587	150	1960	16	0.570	99
2310	16	0.567	147	2070	15	0.550	149
2402	15	0.547	196	2230	14	0.530	106
2532	14	0.527	144	2385	13	0.510	114
2665	13	0.507	146				
2855	11.5	0.477	163				
2912	11	0.467	185				
3045	10	0.447	166				
3172	9	0.427	182				



## APPENDIX VIII GEOLOGY MAP PHONXAY DISTRICT

Received from NAFRI 2006

