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# Evaluation of Land Use Systems for Water and Soil Conservation in Groesbeek, the Netherlands, Using LISEM

Department of Theoretical Production Ecology
Wageningen Agricultural University, The Netherlands

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**By Li Tao**

December, 1998

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**Thesis presented to Wageningen Agricultural University**
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# 荷兰呼斯贝特地区水土保持土地利用系统的评价

作者：李　涛

(硕士论文)

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# Acknowledgements

This thesis presents the main results from a MSc study initiated in June 1998. It is finished at end of December 1998. The MSc thesis study includes some field and laboratory works, but the main work is performed on computer. I enjoyed this work, my knowledge and experience is expanded through this study, although it was sometimes painstaking especially when I encountered unexpected difficulties during this study. I would like to take this opportunity to express my sincere gratitude to following persons and organizations that made my study possible and pleasant.

First of all, I am grateful to Japan Government and the Wold Bank for their kindly provided financial support. At same time, they create a great chance for me so that I have opportunity to improve my knowledge, experience and skills.

My sincere gratitude goes to my supervisors Dr. Peter Leffelaar, Dr Martin van Ittersum, Mr. Jannes Stolte and Dr. Coen Ritsema for their best academic advice, their continuous concern and friend helps. Particularly, Mr. Jannes Stolte, thank you very much for that you spent much time to support my study. This thesis could not be in the current shape without my supervisors' valuable knowledge, ideas, efficiency, responsibilities and efforts.

I am grateful to people working at Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), for their kind support, expertise and the many ways of help. I am grateful to Mr. Gerard Veerman and Mr. H.G.M. v.d. Elsen, for their support on field and laboratory works, and supply of accurate data.

I also thank the Department of Ecological Agriculture, it developed so many advanced courses to improve my knowledge and skills. I could not perform the MSc thesis study smoothly without these useful and helpful knowledge and skills. Here, I thank Prof. E.A. Goewie, Mr. G.J.M. Oomen, Ms. ir. R. Boersma, Course director -- Dr. K. G. Eveleens and other very knid teachers. They give me knowledge and power to face the challenge of future.

I am particularly grateful to people working at Dean's Office. Their enthusiastic helps ensure my study went smoothly.

I am grateful to my classmates for their special hospitality and kind sharing with me time and company.

Here, I especially thank my wife Guo Yongqin for her love, understanding, patience and support all the way throughout my study.

Thank you all people concerned in my study.

Li Tao

Wageningen, the Netherlands, December 1998

# Abstract

This paper is from a MSc thesis study. It presents succinctly the basic theory and algorithm of LISEM that is a water erosion model developed by Department of Physical Geography of Utrecht University and The Winand Staring Centre, Wageningen. The version 5.0 of LISEM was used in the study. This paper also simply summarizes the effects on water and soil conservation of several land use systems and water and soil conservation measures. The improved methods of data collection and process are introduce in this paper.

In this study, LISEM was used to evaluate the effects on water and soil conservation of various land use systems and measures. LISEM was first calibrated by comparing the measured and simulated results in order to find out the suitable time step and initial soil hydraulic pressure head. In the particular case, the time step of 60 seconds and initial soil hydraulic pressure head of -70 cm for winter period and of -500 cm for spring period can unsure that the probability of significant differences between simulated and measured result was below 1%.

In the catchment studied, sandy soil covers 80.5% of the total area. The relative altitude is less than 53 m. 70% of the total surface area has slope with a gradient less than 5%, and only 6.1% of the area is somewhat stepper (slope >10%). Basis of current land use system, green manure crop, grass strip, conservation natural area, grass land were introduced into the catchment to form five newly different land use systems.

The land use system, introduced grass strip in field with 5 meters wide and space less than 400 meters, natural area and green manure crop (Yellow Mustard) on bare parcels in winter into current land use system, significantly reduced total runoff by 7 ~ 62%, total soil loss by 6.7 ~ 71%, total soil erosion by 6.8 ~ 38.6%, and soil deposition within catchment by 7 ~ 27%, and increased catching capacity for moving soil by 7.7%. The land use system introduced grass strips of 1.5 meters wide alongside both sides of the roads into current land use system also had efficient effects on water and soil conservation. The other land use system, in which arable land were changed into grassland, was the best land use system in the particular catchment. It could avoid soil loss and reduced the soil erosion to the lowest level. The three land use systems could be used in future.

Compared with bare land, green manure crop could significantly reduce total runoff by 27.6 ~ 53.1%, total soil loss by 28.8 ~ 62%, total soil erosion by 22.3 ~ 31.2%, and soil deposition by 16.7 ~ 20%, and increase catching capacity 7.1 ~ 16.1%.

Natural area could reduce total runoff by 0.7 ~ 6%, total soil loss by 0.7 ~ 7%, and total soil erosion 1.7 ~ 8.3%.

Grass strips remarkably reduced total runoff by 2.5 ~ 46.8%, total soil loss by 4.3 ~ 67%, and total soil erosion by 8 ~ 35%, and increased catching capacity by 2.9 ~ 17%. In addition, the effects on water and soil conservation of grass strip alongside both sides of the roads was much better than those of grass strips in filed in this particular catchment.

Compared with arable land, grassland very significantly reduced total runoff by 79.3 ~ 91.2%, total soil loss by 88 ~ 96%, total soil erosion by 90.9 ~ 94.6%, and soil deposition by 89.9 ~ 94.5%, and increase catching capacity by 43 ~ 85%.

## 摘　要

这是一篇硕士论文，研究工作及报告编写完成于荷兰瓦赫林根农业大学。其简述了一个新的水土流失动态数学模型 (LISEM) 的基本原理及基本计算公式。同时，概述了数类土地利用系统与水土保持措施的效果，为开发新的水土保持土地利用系统提供参考。这篇论文祥细地介绍了在研究过程中经过改进的 LISEM 数据前处理技术，提高了数据输入的自动化程度，并自动纠正数据与地图转换过程中出现的错误。

在这项研究中，LISEM 被用于评价数个新的水土保持土地利用系统和水土保持措施的水土保持效果。在实际应用之前，通过对比实测与摸拟数据确定了最佳摸拟时间步骤与初始土壤水分含量，以保证摸拟结果与实际值的差异达到显著的机率小于 1%。

研究集中于一个面积为67.055公顷的小流域，80%为平均表土粒经 222微米的沙土，相对高差小于 53米，70%的土地坡度小于 5%，仅有 6.1%的土地坡度大于10%。在小流域现有土地利用系统的基础上，联合或单独引入 5米宽、间距小于400米的田间生草带；沿所有道路两侧种植 1.5米宽的生草带；建立自然保护带；在冬季休闲地种植绿肥构成四种新的土地利用系统。同时，将所有农耕地改为牧草地构成另一种新的土地利用系统。

在现有土地利用系统的基础上，联合引入田间生草带、自然保护带、冬季休闲地种植绿肥，明显地减少总径流量 7.0 ~ 62.0%，总土壤流失 6.7 ~ 71.0%，总土壤侵蚀 6.8 ~ 38.6%，小流域内土壤沉积 7.0 ~ 27.0%，并平均增加拦截土壤流失能力7.7%。沿所有道路两侧种植 1.5米宽的生草带的土地利用系统也有明显的水土保持效果。而所有农耕地改为牧草地的土地利用系统基本可以避免土壤侵蚀。这三种土地利用系统都可以根据实际情况选择应用。

对照裸露休闲地，绿肥地显著减少总径流量 27.6 ~ 53.1%，总土壤流失 28.8 ~ 62.0%，总土壤侵蚀 22.3 ~ 31.2%，小流域内土壤沉积 16.7 ~ 20.0%，并增加拦截土壤流失能力 7.1 ~ 16.1%。

自然保护带减少总径流量 0.7 ~ 6.0%，总土壤流失 0.7 ~ 7.0%，总土壤侵蚀1.7 ~ 8.3%。

生草带明显地减少总径流量 2.5 ~ 46.8%，总土壤流失 4.3 ~ 67%，总土壤侵蚀 8.0 ~ 35.0%，并增加拦截土壤流失能力 2.9 ~17.0%。在这个特殊的小流域内，道路两侧生草带的水土保持效果明显好于田间生草带。当遇特大降雨，水土流失超过生草带的蓄存能力，生草带的水土保持效果下降。

相农耕地，牧草地极显著减少总径流量 79.3 ~ 91.2%，总土壤流失 88.0 ~ 96.0%，总土壤侵蚀 90.9 ~ 94.6%，小流域内土壤沉积 89.9 ~ 94.5%，并增加拦截土壤流失能力43.0 ~ 85.0%。

# Chapter 1
# Introduction

Nowadays, soil erosion as one of the important causes of land degradation is a widespread phenomenon in the world (Table 1.1). It implies reduction of resource potential by a process or a combination of processes acting on the land. Water erosion is one of the main processes on land (UNEP/GRID Sioux Falls, 1996). Water erosion causes serious losses of water, soil and nutrients, or even natural disasters. The soil productivity is continuously decreased in erosion places, and eventually the ecosystem may be destroyed. Most water erosion is actually induced by inappropriate agricultural activities or by unreasonable utilization of natural resources. Hilly agricultural areas are particularly susceptible to water erosion (Rochter, 1978; De Lpoey, 1983, 1986; Boardman, 1990; Evans, 1990; Luk S.H., Cai Q.G., 1990; Kwaad, 1991; Mathier and Roy, 1993).

Table 1.1: Soil erosion situation in the world (Zachar, 1982)

| Continents | Total surface area ($10^6 km^2$) | Average annual erosion losses ($ton/km^2$) | Depth of soil removed per year (mm) | Absolute values for erosion losses ($10^9 ton$) |
|---|---|---|---|---|
| Asia | 44.89 | 610 | 0.435 | 27.4 |
| Africa | 29.81 | 715 | 0.510 | 21.3 |
| North America | 20.44 | 491 | 0.350 | 10.0 |
| South America | 17.98 | 701 | 0.500 | 12.6 |
| Europe | 9.76 | 84 | 0.06 | 0.8 |
| Australia | 7.96 | 273 | 0.195 | 2.2 |
| World | 130.84 | | | 74.3 |

In China, water erosion as a wide spread phenomenon exists widely. The Loess Plateau is well-known for its very deep loess deposition and serious soil erosion. It mainly consists of hills with steep slopes and erosion gullies. In South China, especially in the hilly areas, soil erosion has obstructed the development of the agricultural and social economy. Inappropriate agricultural activities induce and accelerate water erosion. So far, agricultural production still conflicts with the conservation of the environment (or resources). Moreover, it is important to improve the living standards of the inhabitants and the socio-economic situation in the area. Simultaneous achievement of agricultural, socio-economic and ecological purposes, especially the two purposes of appropriate agricultural production and conservation of the environment (sustainable agricultural production) is a major task for scientists.

The Groesbeek area of the Netherlands also regularly experiences problems with water runoff and soil erosion. Problems comprise sedimentation of clay particles in the lower areas and the loss of fertile soil and crops from the erosion area. In addition, elements of the landscape are damaged by the erosion.

Comparing the Dutch case, the Chinese problem and the worldwide problem, the magnitude of the problems, the socio-economic shortages, weather condition and agricultural activities differ considerably. However, the biophysical and agricultural principles that play a role are very similar. Water erosion is almost exclusively caused by inappropriate human activities. Therefore, the methods developed to solve the problem in the Dutch situation may be suitable for other places with similar problems.

Water erosion is a very old topic of research and many aspects have been discussed in thousands of research reports. Since the 1980's, scientists have successfully used mathematical methods to predict and to discover the optimal measures to control erosion (Kirkby M.J. et all, 1980; Tanaka T. 1982; Rosewell C.J. 1986).

Agronomic or biological measures, soil management and mechanical measures can all be used for the purpose of water erosion control. Appropriate land use options combining agronomic measures with suitable soil management not only achieve erosion control, but also improve the ecosystem and enhance soil productivity. The planning or alternation of land use has to consider the soil conditions such as the type and erodibility of soil; the occurrence of rocky outcrops and the steepness of the slopes; the present degree of erosion; suitability of the land for crop production, grazing and forestry; the climate conditions and the economic tolerance, i.e., the degree to which the losses caused by erosion induce decreases in production, income and living standards of inhabitants. The combined use of different measures, such as grass strip, crop rotation, etc., is the best way to optimize effects on water and soil conservation. However, in order to find out appropriate land use options, advanced evaluation methods are necessary.

The LImburg Soil Erosion Model (LISEM) is one of the first examples of a physically based model which can be used for planning and conservation purposes and which is completely incorporated in a raster Geographical Information System (PC-RASTER) (Roo-APJ-de, et al, 1996). This incorporation facilitates easy application in larger catchments, improves the user-friendliness by avoiding conversion routines, and allows remotely sensed data to be used. Processes incorporated in the model include rainfall, interception, surface storage in micro-depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall and throughfall, detachment by overland flow, and transport capacity of the flow. Special attention has been given to the influence of tractor wheel tracks, small roads and surface sealing. Vertical movement of water in the soil is simulated using the Richards' equation. LISEM can realistically simulate the erosion situation since it has been calibrated and validated in a study in Limburg (De Roo, A.P.J. & R.J.E. Offermans, 1995). Therefore, it can reliably model the erosion situation of a land use system.

Data used in LISEM can be easily entered into a GIS environment, and its output is expressed in maps, which makes it possible to evaluate the soil erosion situation for a small catchment but also for large regions. Therefore, LISEM is not only a powerful tool to assess effects of erosion control in land use scenarios, but it can also be used to simulate water erosion and to develop appropriate land use systems in large areas.

The present study concentrated on the use of LISEM in the Groesbeek area. The algorithm in the LISEM model was applied to calculate sediment and water transport in several small catchments in Groesbeek for four rainfall events, and assess the consequences of alternative scenarios in terms of water discharge reductions and sediment yield. The possible land use scenarios have been suggested on the basis of LISEM to address water and soil conservation.

This report presents the theory of LISEM (Chapter 2), as well as data types and collection for use in LISEM (Chapter 3). The effects of simulating time step and initial soil hydraulic pressure head on water discharge and sediment yield in LISEM are discussed Chapter 4. Soil conservation effects of six land use scenarios are compared, and the optimal land use scenarios for Groesbeek are suggested in Chapter 5. The utilization of LISEM in China is discussed in chapter 6.

# Chapter 2
# The Water Erosion Modeling and Land Use Options for Erosion Control

## 2.1 Water erosion modeling

### 2.1.1 Introduction of water erosion models

Soil erosion by water is the gross amount of soil moved by drop detachment or runoff. It has been a problem since man began cultivating the land, but its intensity and worldwide occurrence have increased with the intensification of agricultural activities. It is caused by inappropriate human activities such as over-grazing and deforestation. The severity of water erosion is determined by soil erodibility, land use system and some climatic factors.

Soil conservation specialists have for many years attempted to estimate soil loss from individual fields or slopes to find land use practices which would ensure long-term productivity of the soil. Many equations for soil loss, runoff, water transport, sediment yield, rill erosion, etc., have been developed to describe water erosion. Many models of soil erosion have been developed to explain, predict or estimate the soil erosion process, runoff and yield of sediment.

Before selecting an approach to the modelling of water erosion, it must be specified whether the objectives of a study involve prediction or explanation. Unfortunately, the early soil erosion models could not accurately describe the mass movement due to some undetermined factors, or they could not be used in large areas due to the problem of dealing with large amounts of spatial data inputs even if the accuracy met the practical requirements.

The well-known empirical model - Universal Soil Loss Equation (USLE) (Equation 2.1) (Smith and Wischmeier, 1958, 1978), and its modifications, such as the Modified Universal Soil Loss Equation (MUSLE) (Williams & Berndt, 1977), the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1987) and the Differentiated Universal Soil Loss Equation (DUSLE) (Flacke et al., 1990), were developed to estimate long-term average annual soil loss, so their application to a particular event may not be appropriate. Moreover, although the R, K, L and S factors can be calculated from data on rainfall, soil physical properties and observations (Wischmeier & Smith, 1958, Romknes et al., 1986, Hudson, 1971), evaluation of the cropping management factor (C) and the erosion control practice factor (P) included in the estimation models is often very difficult, because the effects of erosion control vary greatly with different cropping and management systems and control practices. In addition,

$$A = RKLSCP \quad \text{............} \quad (2.1)$$

A: the soil loss ($kg/m^2.s$);
R: the rainfall erosivity factor;
K: the soil erodibility factor;
L: the slope length factor;
S: the slope gradient factor;
C: the cropping management factor;
P: the erosion control practice factor

the USLE and its derivatives are not dynamic in time and space. Therefore, their application to situations for which factor values have not yet been determined is especially dangerous. Although expedient and often necessary for conservation planning purpose, extrapolation is always hazardous. Moreover, these models cannot be used to describe the change in erosion with time and space.

Physically based models such as ANSWERS (Beasley et al., 1980), CREAMS (Foster et al., 1981), WEPP (Nearing et al., 1989), and EUROSEM (Morgan, R.P.C., et al., 1992) calculate the total loss or movement of soil, or the sediment yield, by describing all processes involved in water erosion. Their application has been limited to small areas or very short periods of time because of the difficulty of data input. Moreover, they cannot distinguish or express the mass movement with spatial variables.

Recently, some GIS-physical models have been developed to address the spatial distribution of water erosion. Researchers have been developing soil erosion models which use spatially distributed data and geographic information by means of the Geographical Information System (GIS) (De Roo, et al., 1996; De Roo, 1993; Petersen, 1997; Evans, 1997; McKimmey; 1996). This approach was introduced in Van Deursen (1995) and Van Deursen and Kwadijk (1990). The principles of integrating simulation models and GIS has been demonstrated in LISEM (De Roo, A.P.J., et al., 1994), a modified version of ANSWERS and RHINEFLOW (Van Deursen & Kwadijk, 1993). The PCRaster (Van Deursen & Wesseling, 1992) has often been used to prototype the water erosion simulation model in order to achieve complete integration between GIS and the dynamic model. Moreover, some scientists have incorporated the soil loss estimation model into a GIS prototyping environment to predict soil loss in large scale situation or to service regional land use planning (Chakroun et al., 1993). The advantage of this incorporation is its easy application to large catchments, even over the large regions, because of the improved user-friendliness, and because it allows remotely sensed data to be used. In addition, large amounts of data can be easily input and results, such as sediment yield, can be shown directly on maps. However, although these models use crop parameters, such as leaf area index, crop height, coverage, etc. and soil moisture as their original input data, they do not include sub-models to simulate the changes in these parameters over long periods of time. Such changes may be negligible over a short period, but they cannot be neglected over long periods. Therefore, most of these models can so far only be used to simulate water erosion over short periods.

### 2.1.2 The LISEM

LISEM (the LImburg Soil Erosion Model) was developed in 1994 by the Department of Physical Geography of Utrecht University and The Winand Staring Center. Version 5.0 of LISEM made in 1997 was used in the study. It simulates the hydrology and sediment transport during and immediately after a single rainfall event in a drainage basin. It simulates both the effects of the current land use and the effects of soil conservation measures. Its development and structure were based on experience with the ANSWERS and SWATRE models, although the process description was partially changed.

#### *2.1.2.1 Basic theory*

In the physically based approach, processes incorporated in LISEM include rainfall, interception, surface storage in micro-depressions, vertical movement of water in soil, overland flow, channel flow, detachment by rainfall and throughfall, detachment of overland flow, transport capacity of the flow and sediment yield.

In LISEM, all detailed processes are completely incorporated into the raster Geographical Information System and expressed in terms of the GIS command structure. The study area is divided into many grid squares with equal areas. The grid square is the basic simulation area, and simulation is done grid square by grid square. All input data are entered on maps, and spatial changes can be accurately quantified and presented. Figure 2.1 shows the simulation processes in LISEM.

The results are expressed as maps indicating the spatial distribution, or showing the erosion situation for different field points and crop types.

#### *2.1.2.1.1 Rainfall*

Rainfall data for use in LISEM have to refer to rain intensity. Such data can be obtained by means of the rain-gauges installed in fields or from the nearest meteorological station. LISEM can generate a map showing spatial distribution of rainfall intensity and temporal variability of rainfall. LISEM calculates the temporal value of rain intensity by averaging input rain intensity data located within its calculating time range.

#### *2.1.2.1.2 Interception by vegetation*

Crops or natural vegetation can intercept and store some water in their leaves and stems. The maximum storage capacity for any crop or natural vegetation has been estimated by Von Hoyningen-Huene (1981) (Equation 2.2). Equation (2.3), developed by Mewwiam (1960) and modified by Aston (1979), is used to simulate the cumulative interception.

$$MS = 0.935 + 0.498 \times LAI - 0.00575 \times LAI^2 \quad \text{......... ..(2.2)}$$

$$CI = MS \times \left(1 - e^{0.046 \times LAI \times \frac{CR}{MS}}\right) \quad \text{............(2.3)}$$

MS: Maximum storage by vegetation (mm);
LAI: Leaf area index (- or $m^2/m^2$);
CI: Cumulative interception (mm);
CR: Cumulative rainfall (mm).

#### *2.1.2.1.3 Soil water situation and infiltration*

LISEM permits a choice of six methods to approximate the infiltration and soil water situation. Second method was used in our study.

- no infiltration;
- Richard's equation for soils and wheel tracks in SWATRE sub-model 1;
- Richard's equation for soils, wheel tracks and soil crusts in SWATRE sub-model 2;
- Holtan/Overton infiltration equation in the Holtan/Overton sub-model ;
- One layer Green/Ampt equation in Green/Ampt sub-model 1;
- Two layer Green/Ampt equation in Green/Ampt sub-model 2.

**Richard's equation** (Equation 2.4) is combined with the Darcy equation. For unsaturated situations, equation 2.5, converted from equation 2.4 (Mualem, 1976; Van

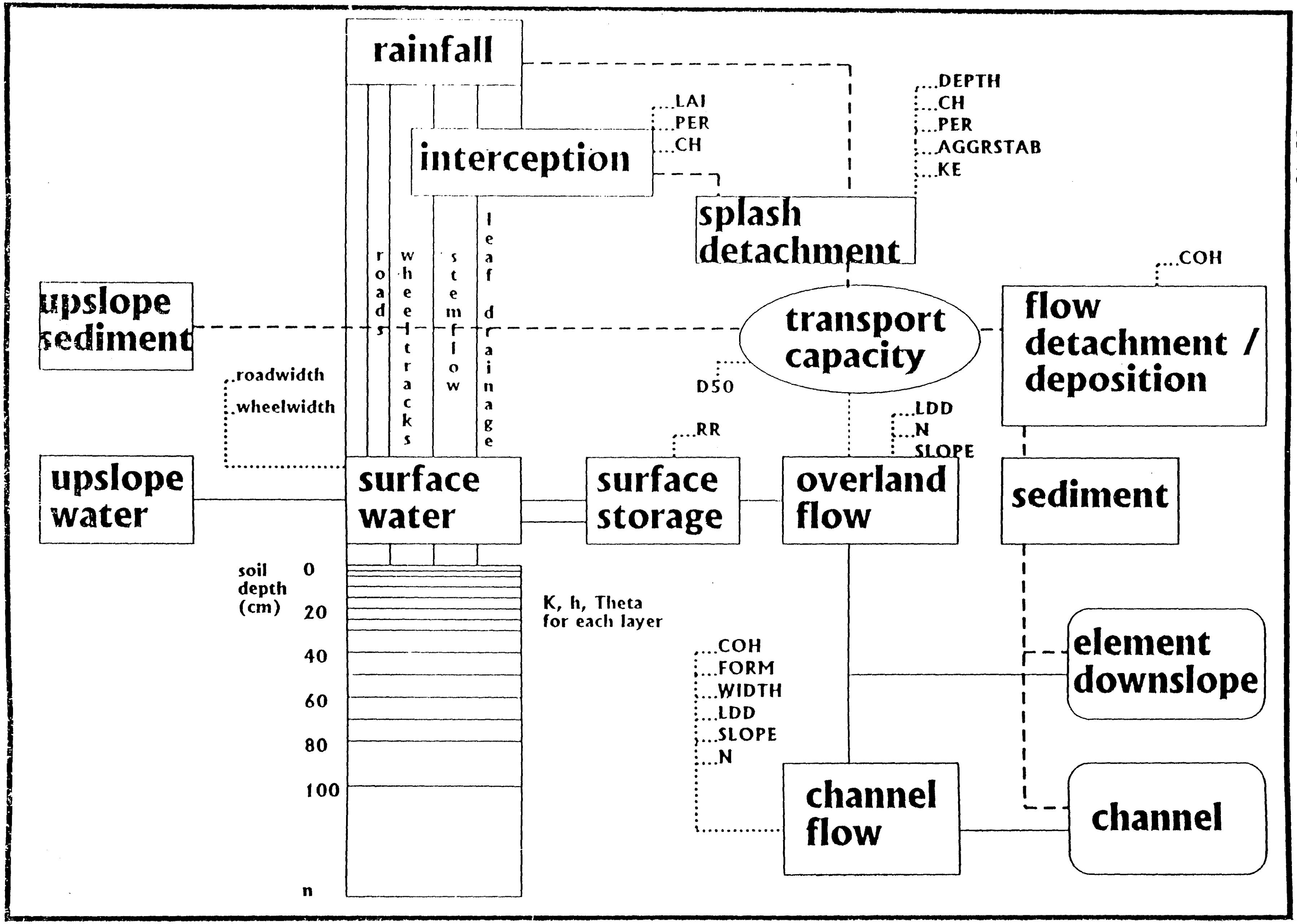


Figure 1. Flowchart of the LISEM model.

Genuchten, 1980) is used in the SWATRE sub-model. The best approximation of the soil water situation and infiltration can be achieved if soil physical data are complete.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} K(h)\left(\frac{\partial h}{\partial z} + 1\right) \quad \text{.........} \quad ..(2.4)$$

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z} K(h)\left(\frac{\partial h}{\partial z} + 1\right) \quad \text{............}(2.5)$$

Θ: Soil water content ($m^3/m^3$);
K: Hydraulic conductivity (m/s);
h: Pressure potential (m);
Z: Soil layer thickness or gravitational potential (m);
C: Soil water capacity ($m^3/m^3$);
t: Time (s).

**Green & Ampt Equation** and **Holtan & Overton equation** (de Roo, 1993): These are used to simulate the cumulative infiltration particularly if detailed soil physical data are lacking. It can be used to calculate soil infiltration capacity during periods of light or no rainfall. The infiltration rate is expressed in terms of cumulative infiltration, initial soil water content, potential storage capacity, etc.

### *2.1.2.1.4 Storage by soil surface*

If rainfall exceeds interception and infiltration, the excess rainfall will fill all depressions. The random roughness is used as a variable to express the depression situation. Storage by the soil surface is simulated by the Onstad equations (1984) (Equations 2.6 and 2.7).

$$RETMAX = 0.12 \times RR + 0.031 \times RR^2 - 0.012 \times RR \times S \quad \text{..........}(2.6)$$

$$DETSTART = RETMAX \times (0.0527 \times RR - 0.0049 \times S) \quad \text{...........}(2.7)$$

RETMAX: Maximum depressional storage (mm)
RR: Random roughness (mm);
S: Slope gradient (m/m).
DETSTART: Rainfall excess needed to start runoff (mm).

### *2.1.2.1.5 Fraction of the surface covered with water and isolated surface*

Overland flow occurs if the rainfall exceeds the total interception, infiltration and the potential soil surface storage. In fact, overland flow already occurs if part of the soil surface is covered by water (equations 2.8 and 2.9). Liden et al. (1988) have proved that some depressions are temporarily isolated and do not contribute to overland flow. Generally, the isolated depressions cover at least 20% if depressional storage is less than 75% of RETMAX. The isolated soil surface can also be computed with the equation 2.10.

$$FWAMAX = 0.152 \times RR - 0.008 \times RR^2 - 0.008 \times RR \times S \quad \text{...........}(2.8)$$

$$FWA = FWAMAX \times \left(\frac{RET}{RETMAX}\right)^{0.6} \quad \text{..........}(2.9)$$

FWAMAX: The maximum fraction of the soil surface covered with water;
FWA: The actual fraction of the soil surface covered with water;
RET: Depressional storage (mm).

$$FWAISO = 0.20 \times FWA \times \left[1 - \frac{\frac{RET}{RETMAX} - 0.75}{0.25}\right] \text{............}(2.10)$$

FWAISO: The fraction of the isolated depressions (-).

#### *2.1.2.1.6 Overland flow and channel flow detachment*

If rainfall is sufficiently heavy (i.e., exceeds the total of infiltration, micro-depression and interception by crop) and prolonged run-off take place, soil can be entrained in the flow. Horton overland flow (Horton, 1993), saturation overland flow (Dunne, 1978) and channel flow occur separately or concurrently as processes of water erosion. The redistribution of soil can be predicted quantitatively by describing the processes by which overland flow arises and soil is entrained by such flow (Wright, 1986, 1987; Wright & Webster, 1991; Chow et al., 1988; Moore & Foster, 1990, ). In LISEM, overland flow detachment rate can be approximated by equation 2.11 and 2.12, which were ever used in EUROSEM model (Morgan, 1994 and Morgan et al. 1992, Rauws & Govers, 1988).

$$OFDR = y \times w \times V_s \times (TC - C) \quad \text{.........} \quad (2.11)$$

$$y = \frac{1}{0.89 + 0.56 \times COH} \quad \text{...............} \quad (2.12)$$

OFDR: Overland flow detachment rate ($kg/m^3$);
C: Sediment concentration ($kg/m^3$);
TC: Transport capacity ($kg/m^3$);
$V_s$: Settling velocity of the soil particles (m/s);
w: Flow width (m);
y: Effect of cohesion on settling velocity (-);
COH: Cohesion of the soil at saturation (kPa).

#### *2.1.2.1.7 Splash detachment*

Splash is the process of soil aggregates being broken down by raindrops and the particles being carried off by water. The process of detachment by raindrop impact should ideally be related to the momentum of the raindrops (rainfall intensity), the thickness of the water layer over the surface and the stability of the soil aggregates or coarse grain content (Kirkby,1980, Foster &Meyer, 1975, Elwell & Stocking 1973). Splash detachment is simulated as a function of soil aggregate stability , rainfall kinetic energy and the depth of the surface water layer (De Roo, et al., 1996) (Equations 2.13 and 2.14). Equation 2.14 is used if soil aggregate stability data is lacking. Different

$$SDR = \left[\frac{2.82}{SAS} \times KE \times \exp^{-1.48 \times DEPTH} + 2.96\right] \times (P - I) \times \frac{(dx)^2}{dt} \quad \text{..........} \quad (2.13)$$

$$SDR = \left[\frac{0.1033}{COH} \times KE \times \exp^{-1.48 \times DEPTH} + 3.58\right] \times (P - I) \times \frac{(dx)^2}{dt} \quad \text{..........} \quad (2.14)$$

$$KE = 15.8\sqrt{CH} - 5.87 \quad \text{..........} \quad (2.15)$$

$$KE = 8.95 + 8.44\log_{10}(RI) \quad \text{...........} \quad (2.16)$$

SDR: Splash detachment rate (kg/s);
SAS: Soil aggregate stability (median number of water drops);
COH: Soil cohesion ($KP_a$);
KE: Rainfall kinetic energy ($J/m^2/mm$);
DEPTH: Depth of the surface water layer (mm);
P: Rainfall (mm);
I: Interception by crop (mm);
CH: Crop height (m);
RI: Rainfal intensity (mm/h).
dx: Grid size of maps (m);
dt: Time increment (s).

kinetic values are used in the simulation process; equation 2.15 is used to simulate the kinetic value of leaf drainage, while equation 2.16 is used to simulate the kinetic energy of direct rainfall.

#### *2.1.2.1.8 Transport capacity*

Transport capacity is related to the overland flow and affects splash detachment, rill and inter-rill erosion (Guy et, al., 1987, Everaert, 1991). Several equations have been suggested for the transport capacity of overland flow (Govers, 1990, Foster & Meyer, 1972, Aziz &Scott, 1989; De Roo et al., 1996; Morgan, 1994). Equation (2.17), introduced by Govers, is used to address transport capacity.

$$TC = Cl \times [S \times V - 0.4]^{Dl} \quad \text{.......... .. (2.17)}$$

TC: Volumetric transport capacity ($m^3/m^3$);
S: Slope gradient (m/m);
V: Mean flow velocity (m/s);
Cl, Dl: Empirically derived coefficients (Govers, 1990).

#### *2.1.2.1.9 Rill and inter-rill erosion*

Rill erosion is due to detachment by flow water. Inter-rill erosion always results from both soil detachment and subsequent transport (Guy, 1987); it depends on rainfall properties, soil properties and surface properties (Park et al., 1982, Mutchler & Young, 1975, Meyer, 1981, Waston & Laflen, 1986). Several equations have been used to describe the rill and inter-rill erosion (Yalin, 1963, Dillaha & Beasley, 1983, Beasley et al., 1980). Recently, flow detachment and deposition have been simulated using equations from the EUROSEM model (Morgan et al., 1992; Morgan, 1994; De Roo et al., 1996). Equation 2.18 is used to calculate the deposition rate where the transporting capacity of the flow exceeds the sediment concentration in the flow.

$$DEP = w \times v_s \times [TC - C] \quad \text{.......... (2.18)}$$

DEP: Deposition rate ($kg/m^3$).

### *2.1.2.2 Utilization of LISEM*

LISEM is a new model and there have only been a few examples of its application. It has been used to study hydrology and sediment transport during a single rainfall event. It was used and calibrated in the Limburg area of the Netherlands. It is currently being used to study soil conservation the very steep loess area of the Chinese Loess Plateau (a cooperative project entitled a participatory approach to soil and water conservation planning, integrating soil erosion modeling and land evaluation, to improve the sustainability of land use on the Loess Plateau in Northern China). It has also been used to select or evaluate land use systems for erosion control in the southern Dutch province of Limburg (Kwaad, 1994).

As indicated, the current LISEM model can only simulate these aspects during single rainfall events. It is not ideal for the evaluation of land use options, because it cannot continuously model these aspects over a whole year or crop growing season or predict the changes over long periods of time. Moreover, it is necessary to calibrate the model before it can be used in a particular case in order to get reliable results. The simulation time step and the initial soil hydraulic pressure head can significantly affect the simulation results.

### 2.1.2 Summary

LISEM is incorporated in the raster Geographical Information System and expressed in terms of the GIS command structure. The model simulates rainfall, surface storage in micro-depressions, throughfall, detachment by overland flow, and the transport capacity. It is possible to calculate the effects of land use changes and to explore soil conservation scenarios. Large amounts of data can be easily converted into maps by a few commands in PC-Raster environment, and LISEM uses these maps as input data. The simulation results can be expressed as maps. Therefore, LISEM is a powerful model for the simulation of soil erosion during a single rainfall event, and a user-friendly tool for the evaluation of land use scenarios or systems to control the water erosion.

Compared to other soil erosion models, LISEM has some disadvantages, such as the fact that it only simulates aspects of soil erosion during single rain events and over very short periods. However, because of the many practical advantages mentioned above, we chose LISEM as a tool to look for optimal land use systems to control soil erosion in the Groesbeek area in the Netherlands.

## 2.2 Land use options and soil conservation

In arable land, the final purpose of water erosion research is to optimize the land use system in order to prevent or control soil erosion (Stocking et al., 1989), and to achieve the goal of sustainable production or to maintain soil loss below a threshold level (de Graaff, 1993). Reconnaissance analysis of erosion systems, taking into account the occurrence and different types of erosion in different land use units, may represent the best strategy for choosing a system of integrated soil protection that is suitable for erosion control at specific sites (Chisci, 1994).

Land use options for soil conservation include crop rotation, pasture use, afforestation and forest management, and strip cropping. Land use can be classified by the relative efficiencies of crop cover that protect the soil from erosion, but a classification of this kind must be specific for each region and soil type (Younis et al., 1993), as well as address the topographical feature, slope gradient, slope length and position within a watershed. In general, changes in the land use system aim to increase coverage, surface roughness, infiltration, and so on, and their conserving effects may vary (Table 2.1). Furthermore, the measures to be taken also depend on the socio-economic condition and the local agricultural tradition.

Table 2.1: The effects of various soil conservation practices on the detachment and transport

| Strategies | Rain splash | | Runoff | |
|---|---|---|---|---|
| | Detachment | Transport | Detachment | Transport |
| Covering soil surface | * | * | * | * |
| Increasing surface roughness | - | - | * | * |
| Increasing control strips (network) | -+ | + | + | + |
| Increasing surface depression storage | + | + | * | * |
| Increasing infiltration | - | - | + | * |

Note: - no control; + moderate control; * strong control; -+ not effective control, after RPC Morgan (1986). This table only presents the qualitative effects, it can be referred when designing new land use system.

### 2.2.1 Crop rotation

For the purpose of soil and water conservation, the simplest way to combine different crops is to grow them consecutively in a rotation system. Crop rotation supplies high coverage at any time of the growing season, which reduces the soil erosion (Kinnell, 1996; Thai Phien, 1988). It is very important to provide the highest crop coverage possible during the rainy season, because erosion rates rise rapidly if low surface coverage periods such as seed bed and seedling stages coincide with intensive rain periods. Many examples show that different effects on soil erosion control can be obtained with different crop rotation systems such as shifting cultivation, row-crop cultivation, and grazing and cropping. In the Limburg loess area of the Netherlands, the following crop systems were compared: maize with winter rye (A), maize with summer barley (B), maize with stubble field in winter (C), and permanently bare ground (D). The total soil losses in of systems D, C, B and A were equivalent to 16.0, 10.8, 3.4 and 1.7 $t.ha^{-1}.yr^{-1}$ respectively (Kwaad, 1994). McConkey (1997) proved that soil loss in the fallow season in a cropping-fallow system was about 86% of the total loss.

### 2.2.2 Inter-cropping and mixed cropping system

The aim of inter-cropping or mixed cropping is to increase productivity from the land as well as to protect the soil from erosion by providing the highest coverage possible at any time of the growing season. These cropping systems are quite appropriate for steep areas without machine cultivating practices. Plants can form layers of coverage very quickly, especially in the rainy season ( Thai Phien, 1988). In steep areas with loamy soil, the total runoff and the total soil loss in a mixed cropping system are about 20% and 10% of that of bare land respectively (Rafael A. Veloz and Logan, 1988).

### 2.2.3 Strip cropping or grass strip

Strip cropping or grass strip means that some high coverage crops or grasses are inserted into the main crops to obtain a strip structure over the whole area. With strip cropping or grass strip, row crops and protection-effective crops are grown in alternating strips aligned to the contours or perpendicular to the direction of water flow. Erosion is largely limited to the row-crop (grass) strips and soil removed from these is trapped in the next down-slope strip. In the highland agricultural areas of Thailand (Mark Hoey, 1988), the total soil loss in these systems is about 3% to 10% of that of traditional cropping systems (mono-cropping systems). The effect of grass strip on soil conservation is similar to that of terraces. In fact, the strip cropping and grass strip systems are similar to the inter-cropping systems, the main difference being that the strips are as shallow as possible, the main crop strips are as wide as possible, and the strip system is suitable for machine production systems, especially in western European countries where most farming activities are done by machines.

### 2.2.4 Grass

Grass, especially as the permanent grassland, provides the highest possible coverage, even during the off-season. Grass can reduce splash to a minimum because of the very high densities of plant stems and roots near and in the surface soil, even though it cannot significantly decrease the runoff. On sandy loam soil, total soil losses in permanent grass systems are 0.7% and 2% of those in fallow and continuous corn systems respectively (Persant, et al., 1988). Xu Peng and Su Fen (1988) also reported considerable effects of grass on soil erosion control: in a hilly area with red earth soil, three months old grass reduced runoff by 30% and sediment yield by 78% compared to the barren land.

### 2.2.5 Trees, forestry, agroforestry

Trees, forestry or agroforestry can assist in soil erosion control in three ways: maintenance of the soil's erosion resistance, reduction of runoff, and ground surface cover (Young, 1988). If a desired coverage is achieved, these systems can reduce soil erosion by more than 70% (Thai Phien, 1988, Xu Peng and Su Fen, 1988).

### 2.2.6 Economic effects of conservation land use systems

Some measures for soil erosion control may cause economic loss. However, many successful examples indicate that the appropriate measure can improve the income of farmers as well as provide efficient control of soil erosion. In China, Guo Tingfu (1988) has proved that after the land use system was changed from a conventional to a soil erosion control system, a remarkable economic benefit could been obtained. At the same time, the yield of some crops also increased.

### 2.2.7 Summary

The measures discussed above have different effects on water and soil conservation. Some measures efficiently reduce water discharge, while others can efficiently reduce the sediment yield. The effects vary with the places and the soil types where they are introduced. Therefore, the planning or alternation of land use has to consider soil conditions such as the type and erodibility of soil, topographical conditions, present level of erosion, management measures and agricultural activities. Combined use of the various measures discussed above is the best way to optimize the best effects on water and soil conservation.

# Chapter 3
# Study Area, Data Collecting and Processing

Groesbeek in the Netherlands, the study area, is gently sloping and comprises various forms of agricultural land. In the present study, the effects of the time step used in LISEM on the simulation results was calibrated according to the general concepts of simulation modeling. In addition, the effects of the time step and the initial soil hydraulic pressure head on simulation results was studied by comparing simulation results with results measured in the study area. LISEM was also used to evaluate the effects of alternative land use systems on water and soil conservation according to the simulation results. In order to pursue these research purposes, rainfall, soil and crop data were collected, and these data were carefully processed by using PC-Raster, ARC/INFO, Appia, and other programs.

## 3.1 Study area

### 3.1.1 Introduction to Groesbeek

The study area, Groesbeek, in the Netherlands, has a total surface area of 3.2 $km^2$ (Table 3.1), divided into four sub-catchments (Figure 3.1). The surface area of the sub-catchments ranges from 45.6 ha to 111.6 ha. The relative altitude is below 53 m. There are regular problems with water runoff and soil erosion. The area is gently sloping; about 67% of total area has slopes with a gradient less than 5%. Only 7.2% of the area is somewhat steeper (slope>10%) mainly around the water basins. The water basins are used to collect runoff and sediment.

Table 3.1: Surface area per gradient category and sub-catchment at the Groesbeek study area

| Slope (%) | Catchment1 (ha) | Catchment 2 (ha) | Catchment 3 (ha) | Catchment 4 (ha) | Total (ha) | Percent (%) |
|---|---|---|---|---|---|---|
| 0 ~ 2 | 23.9550 | 16.0300 | 11.3275 | 31.0050 | 82.3175 | 25.70 |
| 2 ~ 5 | 23.0400 | 30.5200 | 35.6375 | 42.3300 | 131.5275 | 41.07 |
| 5 ~10 | 15.9375 | 16.2925 | 25.7200 | 25.4200 | 83.3700 | 26.03 |
| >10 | 4.1225 | 3.5300 | 2.4950 | 12.9075 | 23.0550 | 7.20 |
| Total | 67.0550 | 66.3725 | 75.1800 | 111.6625 | 320.2700 | 100.00 |

### 3.1.2 Soil type and current land use system

Soil types in the Groesbeek study area include sand, loamy sand, sandy loam, light loam and loam soils, according to a soil analysis report by W.H. Leenders and A.G. Beekman (1996). We generally classified these soil types into two groups, sandy soil and loess soil in order to simplify the data processing and input. In this area, most of the soil can be classified into the loess group, covering about 82% of the total area (Table 3.2). Sandy soil is mainly found in catchment 1. Catchment 4 includes only loess soil.

Table 3.2: Surface area of soil types at the Groesbeek study area

| Soil types | Catchment 1 (ha) | Catchment 2 (ha) | Catchment 3 (ha) | Catchment 4 (ha) | Total (ha) | Percent (%) |
|---|---|---|---|---|---|---|
| Sand | 53.9725 | 1.8175 | 0.7150 | 0.000 | 56.5050 | 17.64 |
| Loess | 13.0825 | 64.5550 | 74.4650 | 111.6625 | 263.7650 | 82.36 |
| Sub-total | 67.0550 | 66.3725 | 75.1800 | 111.6625 | 320.2700 | 100.00 |

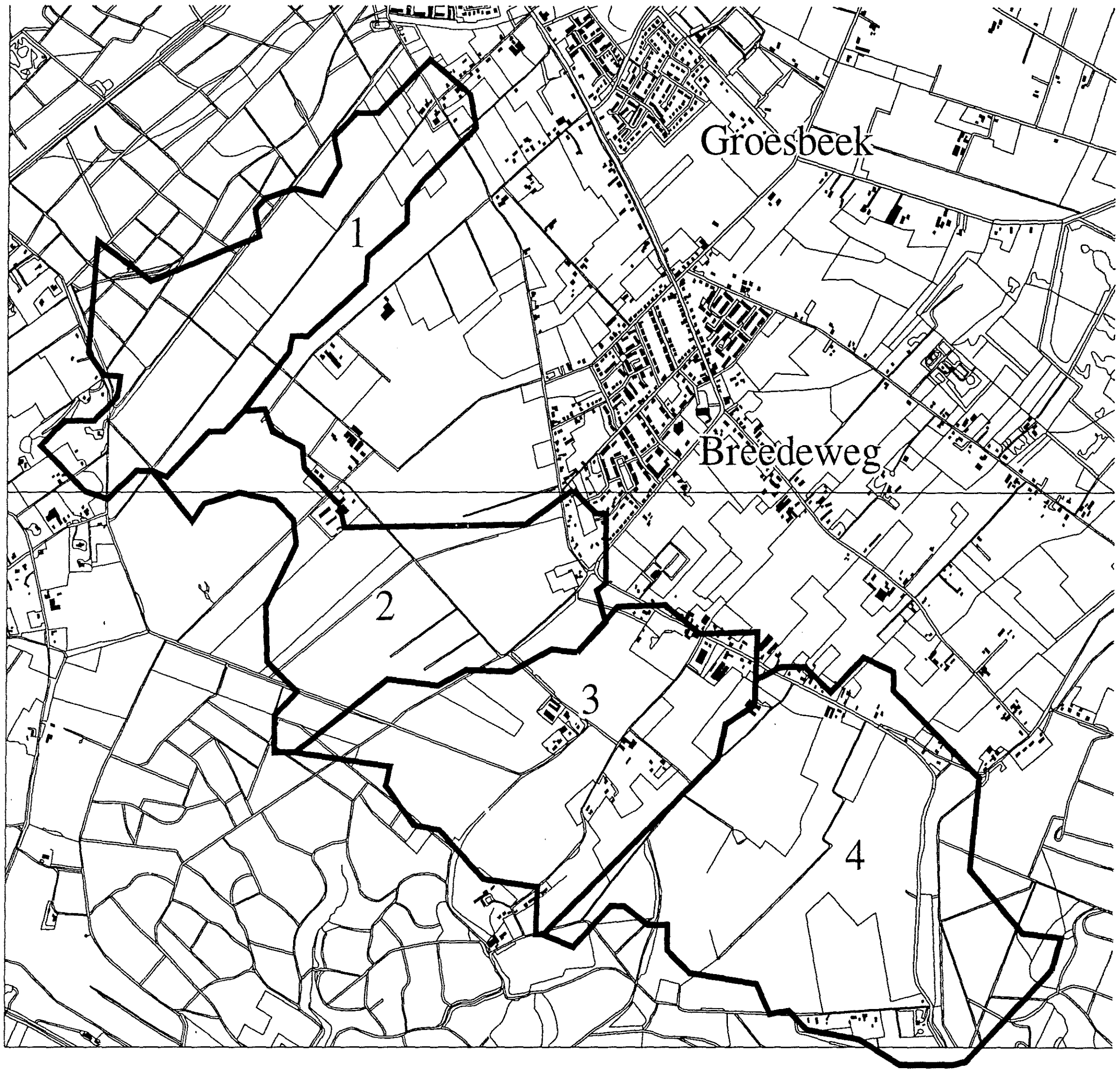


Figure 3.1: The study area
**1**: Sub-catchment 1; **2**: Sub-catchment 2;
**3**: Sub-catchment 3; **4**: Sub-catchment 4.

Arable farming is the main land use pattern in the Groesbeek study area, covering about 49% of the total area (Table 3.3). Forest, gardens and bush, which can be regarded as natural elements in this area, cover about 8.5%. The water basin for collecting runoff and sediment covers 0.3%. Maize is the main crop, covering about 16% of the total area. The second main crop are potatoes, sometimes combined with beans, covering about 13% of the total area. Nearly 5% of the total area is used as nursery for garden trees. The small trees usually stay there for 3 to 5 years. This does not help to control erosion because small trees cannot completely cover the soil surface for a long time. The area includes several dairy farms, whose grassland covers near 25% of the total area. This is very helpful for soil and water conservation, and also contributes to the variety of the landscape. Quite a large proportion of the area is used for maize, potato, potato/bean and winter wheat (about 38% of total area). This implies a high erosion risk, especially in winter and early spring, due to the low soil coverage.

Table 3.3 : Current land use in the study area at Groesbeek

| Land use Types | Catchment 1 (ha) | Catchment 2 (ha) | Catchment 3 (ha) | Catchment 4 (ha) | Total (ha) | Percent (%) |
|---|---|---|---|---|---|---|
| Water basin | 0.3275 | 0.0000 | 0.5725 | 0.0000 | 0.9000 | 0.28 |
| Maize | 4.2650 | 10.0000 | 20.5750 | 15.8125 | 50.6525 | 15.82 |
| Vegetable | 0.6975 | 0.5625 | 0.0000 | 0.0000 | 1.2600 | 0.39 |
| Small tree | 13.3875 | 0.0000 | 0.0825 | 0.5950 | 14.0650 | 4.39 |
| Winter wheat | 8.1700 | 2.9225 | 5.6475 | 13.4575 | 30.1975 | 9.43 |
| Asparagus | 6.9975 | 0.0425 | 0.0000 | 0.0000 | 7.0400 | 2.20 |
| Scorzonera | 3.4625 | 0.0000 | 0.9825 | 0.8350 | 5.2800 | 1.65 |
| Carrot | 0.5300 | 0.0000 | 0.0000 | 0.0000 | 0.5300 | 0.17 |
| Sugar-beet | 2.2125 | 2.8500 | 0.0525 | 8.6100 | 13.7250 | 4.29 |
| Out-area[1] | 2.2300 | 2.4675 | 1.1175 | 28.5200 | 34.3350 | 10.72 |
| Grassland | 3.7050 | 37.7850 | 16.0500 | 22.2000 | 79.7400 | 24.90 |
| Others | 4.5650 | 0.0000 | 0.0000 | 0.0000 | 4.5650 | 1.43 |
| Gardens | 0.4375 | 2.4950 | 4.1500 | 1.9525 | 9.0350 | 2.82 |
| Unpaved roads | 2.8250 | 0.5800 | 1.0025 | 1.4725 | 5.8800 | 1.84 |
| Paved roads | 0.1675 | 0.8750 | 1.4225 | 1.4375 | 3.9025 | 1.22 |
| Bush | 0.2100 | 0.5575 | 0.5200 | 0.3075 | 1.5950 | 0.50 |
| Potato/bean[2] | 0.0000 | 1.4900 | 12.3150 | 10.7375 | 24.5425 | 7.66 |
| Potato | 0.0000 | 2.6075 | 10.1350 | 4.2725 | 17.0150 | 5.31 |
| Forest | 12.8650 | 1.1375 | 0.5550 | 1.4525 | 16.0100 | 5.00 |
| Total | 67.0550 | 66.3725 | 75.1800 | 111.6625 | 320.2700 | 100 |

## 3.2 Data collection

The use of LISEM to analyze water erosion and to evaluate the land use system on the risk of water erosion requires four types of data: 1. rainfall intensity data; 2. soil physical and hydraulic data; 3. crop and land use data; 4. runoff and sediment data to calibrate LISEM.

### 3.2.1 Rainfall data

One rainfall meter has been installed in the study area to measure and record rainfall directly. The study used data from four single rainfall events, two in the summer and two in the winter, which were entered into LISEM to evaluate land use systems. One rainfall event from 28 October 1998 was used to calibrate the time step and the initial soil hydraulic pressure head.

The original data (Table 3.4) include date, time and cumulative rainfall. Rainfall intensity and cumulative rain time were calculated using equation 3.1[3] in Excel sheet, after which an ASCII file of rainfall input was made (Appendix 7).

$$IR_T = \frac{0.2}{((T+t)-(T_P+t_p))\times 24} \quad \text{..........(3.1)}$$

$IR_T$: Rainfall intensity at time T (mm/h)
T: Recording day at time T (-);
$T_p$: Previous recording data of time T(-);
t: Recording time at Time T (-);
$t_p$: Previous recording time of time T (-).

[1] Most of this is forestry and bush, while a very small part consists of houses and gardens.
[2] Used for potatoes one year and for beans the next.
[3] In equation 3.1, 0.2 is amount of rainfall between two adjacent records that was determined particularly. 24 is the coefficient of time change from day to hour.

Table 3.4: Original rainfall data

| Date | Time | Cumulative rain (mm) | Rain intensity (mm/h) |
|---|---|---|---|
| 24/8/98 | 12.45:35 | 0.0 | 0.0 |
| 24/8/98 | 13:35:42 | 0.2 | 0.24 |
| 24/8/98 | 13:45:32 | 0.4 | 1.22 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 25/8/98 | 2:06:57 | | - |

Note: Columns one to three from rainfall meter.
Fourth column from equation 3.1.

### 3.2.2 Soil physical and hydraulic data

Soil physical and hydraulic data are major data for running LISEM, which can be obtained from laboratory analysis and field measurements.

#### *3.2.2.1 Soil saturated hydraulic conductivity*

The constant head method introduced by J. Stolte (1997) was used to measure the soil saturated hydraulic conductivity. In this methods, a constant water level is maintained on top of an undisturbed soil sample. The volume of water that percolates through the sample is measured over time. The soil sample is first kept in a water vessel, in which the water level is about one-third to one-fourth of the height of the soil sample, for two days to four weeks, until the sample is saturated. Soil samples with high clay content need more time. The saturated soil sample is then placed on the measuring platform. The percolating water is collected and the outflow is weighed in time using an electronic balance with an accuracy of 0.1%. Three measurements are used to calculate the mean saturated conductivity after the steady state is reached, i.e., when three successive measurements differ by 2% or less. The mean saturated hydraulic conductivity can now be calculated using Equation 3.2. The final data are shown in appendix 1.

$$K_s = \frac{V}{t \times A} \times \frac{l}{l+d} \quad ............(3.2)$$

$K_s$: Saturated hydraulic conductivity (cm/d);
V: Mean outflow ($cm^3$ or gram);
T: time (days);
A: Surface area of soil sample ($cm^2$);
l: Height of soil sample (cm);
d: Thickness of sate water layer (cm).

#### *3.2.2.2 Soil unsaturated conductivity and water retention characteristic*

In the laboratory, Wind's evaporation method was used to measure the original soil unsaturated conductivity and water retention characteristic. The soil samples were taken undisturbed from the study field and were wetted to near saturation. The samples were then allowed to dry by evaporation from the top surface. Pressure heads were measured at different depths in the sample by using a tensometer. At known times, the decrease in mass of the sample and the pressure heads were recorded. The experiment ended when air entered the uppermost tensometer. After the sample had been dried, its water content during the experiment was calculated. The Appia program, developed by the Staring

Center, was used to calculate the soil unsaturated conductivity and water retention characteristic. The resulting data are included in Appendix 2.

### *3.2.2.3 Soil cohesion*

Some data were measured directly in field using "Torvane". Other data were from a case study of Limburg. Appendix 3 presents the available data for the spring and winter seasons.

### *3.2.2.4 Additional soil cohesion due to crops*

The roots of the vegetation or crop are responsible for extra soil cohesion, whose cohesion value depends on the density of the crop roots. Most additional cohesion data were obtained from a previous the study in Limburg. Others were estimated by comparing the crop characteristics and cultivation methods with those of winter wheat, sugarbeet, potato, maize and grassland, which were already known. All data used in LISEM are shown in appendix 3.

### *3.2.2.5 Median grain size of the soil (D50)*

Soil particle data were obtained from a soil analysis report by W.H. Leenders and A.G. Beekman (Table 3.5). D50 is the median grain size of top soil in μm, a parameter which is used to calculate the transport capacity of overland flow in LISEM. D50 data are also presented in appendix 3.

Table 3.5: Soil particle fractions for the Groesbeek study area

| Soil type | <2 μm | 2~16 μm | 16~50 μm | 50~75 μm | 75~105 μm | 105~150 μm | 150~210 μm | >210 μm | D50 μm |
|---|---|---|---|---|---|---|---|---|---|
| Sand | 3.5 | 5.8 | 28.3 | 2.8 | 2.0 | 3.6 | 11.3 | 42.7 | 222.5 |
| | 2.1 | 5.2 | 9.3 | 1.3 | 1.2 | 4.0 | 11.4 | 67.6 | |
| Loess | 10.1 | 9.6 | 57.9 | 8.7 | 1.7 | 1.9 | 2.5 | 7.5 | 122 |

### **3.2.2.6** *Soil profile and soil type*

Soil profile was roughly described in five layers (Appendix 9) on the basis of an analysis report by W.H. Leenders and A.G. Beekman (Table 3.). It was combined with the soil unsaturated conductivity tables to obtain the soil profile input file. On the basis of the soil type data, the soil type map was generated by the ARC/INFO program.

Table 3.6: Soil profile at Groesbeek study area

| Sandy soil | | | | Loess soil | | | |
|---|---|---|---|---|---|---|---|
| Layer (cm) | Clay (%) | Loam (%) | D50 (μm) | Layer (cm) | Clay (%) | Loam (%) | D50 (μm) |
| 0 ~ 30 | 3.0 | 28.3 | 222.5 | 0 ~ 30 | 10.0 | 78.0 | 122 |
| 30 ~ 50 | 3.0 | 31.2 | 220.0 | 30 ~ 48 | 11.0 | 84.0 | -- |
| 50 ~ 75 | 3.0 | 31.3 | 205.0 | 48 ~ 75 | 16.0 | 86.0 | -- |
| 75 ~ 90 | 3.0 | 30.0 | 217.5 | 75 ~ 90 | 12.0 | 77.0 | -- |
| 90 ~ 120 | 2.5 | 6.0 | 345.0 | 90 ~ 120 | <4.0 | 5.0 | 390.0 |

### 3.2.3 Crop and land use data

Numerical crop data, such as crop height (CH), and crop coverage (PER), and land use data, such as land surface random roughness, Manning's N and the width of tractor wheels were converted into maps by PC-Raster. These maps were used directly in the LISEM simulation process.

#### *3.2.3.1 Crop height*

Crop height could easily be measured by means of a ruler at different growth periods. In our case, only the crop height data for the winter period were from measured, while the data for the spring were taken from a previous the study in Limburg (Appendix 4).

#### *3.2.3.2 Crop leaf area index (LAI)*

LAI was not measured due to time limitations. Most crop LAI data were obtained from the Limburg study, others were obtained from "Simulation Reports CABO-TT" (E.R. Boons-Prins, et al., 1993) or by estimating on the basis of cultivation practice and comparing the crops to other crops whose LAI were known. All available data for spring and winter periods are listed in appendix 4.

#### *3.2.3.3 Crop coverage*

Crop coverage was calculated using equations 3.3, 3.4, 3.5 and 3.6, which were converted from equations developed by De Roo et al. (1994). Small tree coverage were measured by ruler in the field. Forest and grassland coverage were from the Limburg data. Others were estimated by comparing the crops to other crops whose coverage was known. All available data are also presented in appendix 4.

$$PER_w = \frac{CH_w + 0.0933}{1.27} \quad \text{..........} \quad (3.3)$$

$$PER_s = -\frac{1}{1.2}\ln\left(1 - \frac{CH_s}{0.7723}\right) \quad \text{..........} \quad (3.4)$$

$$PER_m = \frac{CH_m + 0.0362}{4.13} \quad \text{..........} \quad (3.5)$$

$$PER_p = -\frac{1}{1.2}\ln\left(1 - \frac{CH_p}{0.7999}\right) \quad \text{..........} \quad (3.6)$$

$PER_w$: Coverage of winter wheat; $CH_w$: Crop height of winter wheat;
$PER_m$: Coverage of maize; $CH_m$: Crop height of maize;
$PER_s$: Coverage of sugarbeet; $CH_s$: Crop height of sugarbeet;
$PER_p$: Coverage of potato; $CH_p$: Crop height of potato.

#### *3.2.3.4 Land use system*

The coordinates of field blocks (parcels) were recorded when measuring the elevation of the study area, using GPS. Field surveys and recording yielded the current land use data. The ARC/INFO program translated the data into a map, which was then converted into an ASCII-file. This ASCII-file was entered into the PC-Raster program for conversion into a PC-Raster map for use in LISEM. This process was repeated for the production of a new land use scenario map.

### *3.2.3.5 Land surface random roughness*

The Limburg data were used for the various land use types (appendix 4).

### 3.2.4 Topographical data

The elevation data for the study area were measured by GPS and converted into a DEM (Digital Elevation Map) map by the PC-Raster program. The DEM map was not used directly in LISEM, but provided the basic map to generate LDD, slope (or gradient), area, and channel maps.

### 3.2.5 Data for calibration

Some equipment was installed at the study area to measure the runoff and sediment in sub-catchment 1 (Appendix 9). These data were used to determine the simulation time step and initial soil hydraulic pressure head in order to get reliable results.

## 3.3 Data processing and input files

Most data had to be converted into maps using the PC-Raster and ARC/INFO programs; others, such as rainfall intensity, soil physic data and soil profile were translated into ASCII-files. Running LISEM required 24 maps, while a further 36 maps were selectively used for the infiltration simulation method. In our case, the "SWATRE" method was used to simulate the infiltration, which required the profile map, wheel track profile map, soil hydraulic pressure head out map and initial hydraulic pressure head for each soil layer map. This meant that 41 maps were necessary for each sub-catchment, each land use scenario and each season.

### 3.3.1 Basic maps

The Digital Elevation Map (DEM), land use map, and soil maps are basic maps which were obtained in the process of data collecting.

The Sub-catchment map was also very important map because there may be several sub-catchments in one study area, some sub-catchments are purpose study area, while others may not be purpose study area . It was derived from DEM by using group equation 3.8 in the PC-Raster environment. Subsequently, new DEM, land use and soil maps of the purpose sub-catchment were generated by using group equation 3.9. Finally, all maps used in LISEM were produced by combining these basic maps and the numerical data in the PC-Raster program.

```
pcrcalc tldd.map=lddcreate(Wdem.map,1e35,1e35,1e35,1e35)
pcrcalc tcatch.map=catchment(tldd.map,pit(tlld.map))
pcrcalc subcatch.map=tcatch.map eq A                    ......(3.8)
```

Wdem.map: DEM of whole area, it is made by ARC/INFO in data collection section;
tldd.map: Temporary ldd map;
tcatch.map: Temporary catchment map;
subcatch.map: Purpose sub-catchment map;
A: The number of purpose sub-catchment in temporary catchment map.

```
pcrcalc dem.map=if(boolean(subcatch.map), Wdem.map)
pcrcalc land.map=if(boolean(subcatch.map), Wland.map)
pcrcalc soil.map=if(boolean(subcatch.map), Wsoil.map)    .......... (3.9)
```

dem.map: DEM of purpose sub-catchment;
land.map: Land use map of purpose sub-catchment;
soil.map: Soil map of purpose sub-catchment;
Wland.map: Land use map of whole area, it is made by ARC/INFO in data collection section;
Wsoil.map: Soil map of whole area, it is made by ARC/INFO in data collection section;

### 3.3.2 Basic tables

All data except for rainfall and soil profile had to be translated into two appropriate types of ASCII tables using the data in Appendices 3 and 4. In Table 3.7, the first column lists land use types, the second column the data. The data include one of crop leaf area index (lai.tbl), crop coverage (per.tbl), crop height (ch.tbl), land surface random roughness (rr.tbl), Manning's N [1](n.tbl), road width (roadwidt.tbl) and tractor wheel width (wheelwid.tbl). In table 3.8[2], the first column lists land use types, the

Table 3.7: ASCII table of crop variable

| | |
|---|---|
| 1 | 1.86 |
| 2 | 0.11 |
| 3 | 0.19 |
| . | . |
| . | . |
| 20 | 0.55 |

Table 3.8: ASCII table of crop and land variable

| | | |
|---|---|---|
| 1 | 2 | 1.50 |
| 1 | 3 | 3.32 |
| 2 | 2 | 2.70 |
| 2 | 3 | 2.85 |
| . | . | . |
| . | . | . |
| 20 | 3 | 3.32 |

second column soil types and the third column the data. The data include one of soil aggregate stability (aggrstab.tbl), soil cohesion (coh.tbl), crop additional cohesion (cohadd.tbl), D50 (d50.tbl), soil profile number (profile.tbl), tractor wheel profile number (profwltr.tbl) and the stone fraction in the soil surface (stonefrc.tbl). A total of 13 tables were prepared.

Two other special tables are also very important. Table 3.9 was used to produce an outlet map (outlet.tbl). Table 3.10 was used to generate a soil pressure head out map (headout.tbl).

Table 3.9: Coordinates of outlet points

| | | |
|---|---|---|
| $X_1$ | $Y_1$ | 1 |
| . | . | . |
| . | . | . |
| . | . | . |
| $X_5$ | $Y_5$ | 5 |

Note: Basin outlet point must be number 1. The maximum number of outlet points is 5. First column is x-coordinate, second column is y-coordinate, third column is number of outlet points.

Table 3.10: Coordinates of pressure head out points

| | | |
|---|---|---|
| $X_1$ | $Y_1$ | 1 |
| . | . | . |
| . | . | . |
| . | . | . |
| $X_6$ | $Y_6$ | 6 |

Note: First point must be basin outlet point. There are 6 points in all. First column is x-coordinate, second column is y-coordinate, third column is number of points.

[1] Manning's N is a roughness coefficient reflecting the resistance to overland and channel flow.
[2] Soil types, 2 = sandy soil, 3 = loess soil.

### 3.3.3 Making input maps in PC-Raster

The 41 maps used directly in LISEM were produced by combining the basic maps and tables whose generation was described above.

#### *3.3.3.1 Morphological maps of the drainage basin*

Table 3.11 presents morphology maps of the drainage basin, based on the basic maps and tables. The program presented in appendix 10 was used to generate these maps, and they do not change as long as the location of the study area is not changed.

Table 3.11: Input maps of drainage basin morphology

| Name of maps | Brief description | Basic maps | Basic tables |
|---|---|---|---|
| area.map | Defines simulation area of purpose sub-catchment with value 1; values outside this area have to be defined as "missing values". | ldd.map | |
| id.map | Defines the area where rainfall data is available. Grid squares in the area have a number, those outside grid squares are "missing values". | area.map | |
| ldd.map | Expresses the local drain directions. Grid squares in area have numbers from 1 to 9. Outside grid squares are "missing values". | dem.map | |
| grad.map | Indicates the slope gradient. The value should be between 0.0001 and 10. Outside grid squares are "missing values". | dem.map | |
| outlet.map | Defines the runoff outlet points. The maximum number of outlet points is 5. The first outlet point must be the basin outlet point. Grid squares of outlet points have numbers, other grid squares have value 0. Those outside the area have to be classified as "missing values". | ldd.map | outlet.tbl |
| roadwidt.map | Indicates the width of roads. Grid squares located on roads have a value that does not exceed the size of the grid squares. Other grid squares are classified as "missing values". | land.map | |

#### *3.3.3.2 Channel variables maps*

Table 3.12 lists the maps required for channel variables. These maps do not change as long as the location of the study area is not changed. Channels in the study area include natural channels made by erosion and man-made channels. In the Groesbeek study area, there is only one man-made channel, which is very narrow and short, and is not indicated on the land use map. There are no natural channels in this area. These maps were prepared using the program presented in appendix 10.

#### *3.3.3.3 Crop, soil and land use variables maps*

Crop, soil and land use maps vary with the soil types and land use systems. Unlike the drainage basin morphological maps and channel variables maps, they change with any change in the land use system, even if the location of the study area and the soil types do not change. Table 3.13 shows crop, soil and land use variables maps. They were generated using the program presented in appendix 11.

Unfortunately, repeated conversion leads to some errors in PC-Raster, even with the same basic tables and maps. Therefore, the program presented in appendix 12 had to be used to produce the final maps, particularly in the study comparing the effects of soil conservation on different land use options. This program includes a correcting section, which can eliminate the errors.

Table 3.12: Input maps for channel variables in LISEM

| Name of maps | Brief description | Basic maps |
|---|---|---|
| chanwidt.map | Indicates the width of the channel bottom in meters. Values range from 0 to any positive[1]. In the area, grid squares without a channel have the value 0. Those outside the area are classified as "missing values". | ldd.map |
| changrad.map | Shows the gradient of channel. Grid squares located min the channel have values from 0.0001 to 10. All other grid squares are classified as "missing values". | ldd.map, grad.map |
| chanside.map | Expresses the tangent of the angle of the channel side with the vertical. Grid squares located within the channel have values from 0 to 10. All other grid squares are classified as "missing values". | ldd.map |
| chancoh.map | Cohesion of channel surface. Grid squares located within the channel have positive values. All other grid squares are classified as "missing values". | ldd.map |
| chanman.map | Manning's N of channel surface. Grid squares located within the channel have values from 0 to 0.6. All other grid squares are classified as "missing values". | ldd.map |
| lddchan.map | Indicates the LDD of the channel. Grid squares located within the channel have numbers from 1 to 9. All other grid squares are classified as "missing values". | ldd.map |

#### *3.3.3.4 Maps for SWATRE sub-models*

Maps of the soil profile, soil profile at tractor wheel track, soil pressure head out and initial soil hydraulic pressure head are required for the SWATRE sub-model. The number of initial soil hydraulic pressure head maps must equal the number of soil layers in the description file of the soil physical profile. Table 3.14 presents these maps and the basic maps and tables to produce them. Profile.map, profwltr.map and headout.map were produced using the program presented in appendix 11 or 12. Inithead.a maps were generated using the program presented in appendix 13.

### 3.3.4 Soil hydraulic physical tables for SWATRE sub-model

Soil hydraulic physical tables are used directly in the SWATRE sub-model; they express the relations between soil water content, pressure head and water conductivity. In these tables, the first column shows soil moisture content values in $cm^3/cm^3$, calculated from residual point to saturated point. The second column shows the pressure head in cm and negative values. The third column lists the hydraulic conductivity values in cm/day (Appendix 5). The figure of hydraulic conductivity in the last line of the hydraulic physical table indicates the saturated hydraulic conductivity; it was calculated on the basis of the figures in appendices 1 and 2 with the help of equation 3.10[2].

$$SC = \frac{SC_s + 2 \times SC_e}{3} \quad \text{.........} \ldots (3.10)$$

SC: Saturated conductivity used in soil physical tables;

$SC_s$: Saturated conductivity measured by constant water head method;

$SC_e$: Saturated conductivity measured by evaporation method and fixed by Appia program.

---

[1] The total width of channel and road is not allowed to exceed the size of the grid squares. The width of the channel may increase due to erosion during simulating process. It must also be made sure that the total width of roads and new channels is still smaller than the size of the grid squares. If not, LISEM will stop running.

[2] This experiential equation was taken from the Limburg study.

Table 3.13: Crop, soil and land use variables maps used in LISEM

| Name of maps | Brief description | basic maps | basic tables |
|---|---|---|---|
| lai.map | Shows the leaf area index of crops. Grid squares inside study area have values 0 or positive. Those outside the area are classified as "missing values". | land.map | lai.tbl |
| per.map | Shows the soil coverage by vegetation. Grid squares inside study area have values from 0 to 1.0. Those outside the area are classified as "missing values". | land.map | per.tbl |
| rr.map | Shows the random roughness of land surface in cm. Grid squares inside study area have values from 0.001 to 10. Those outside the area are classified as "missing values". | land.map | rr.tbl |
| ch.map | Shows the height of vegetation in m. Grid squares inside study area have values from 0 to 30. Those outside the area are classified as "missing values". | land.map | ch.tbl |
| aggrstab.map | Shows the soil aggregate stability. Grid squares inside study area have values from 0.001 to 200. Those outside the area are classified as "missing values". | land.map | aggrstab.tbl |
| coh.map | Shows the soil cohesion in KPa. Grid squares inside study area have values 0 or positive. Those outside the area are classified as "missing values". | land.map<br>soil.map | coh.tbl |
| cohadd.map | Shows the crop additional cohesion in KPa. Grid squares inside study area have values 0 or positive. Those outside the area are classified as "missing values". | land.map<br>soil.map | cohadd.tbl |
| n.map | Shows Manning's N for the soil surface. Grid squares inside study area have values from 0.001 to 0.6. Those outside the area are classified as "missing values". | land.map | n.tbl |
| d50.map | Shows soil d50 values in µm. Grid squares inside study area have values from 2 to 2000. Those outside the area are classified as "missing values". | soil.map | d50.tbl |
| stonefrc.map | Shows the stone fraction of the soil. Grid squares inside study area have values from 0 to 1.0. Those outside the area are classified as "missing values". | land.map | stonefrc.tbl |
| wheelwid.map | Shows the width of tractor wheel tracks in m. Grid squares inside study area have values from 0 to grid size. Those outside the area are classified as "missing values". | land.map | wheelwid.tbl |
| grasswid.map | Shows the width of the grass strip or waterways in m. Grid squares inside study area have values from 0 to grid size. Those outside the area are classified as "missing values". | land.map | |

Table 3.14: Input maps for SWATRE sub-model

| Name of maps | Brief description | basic maps | basic tables |
|---|---|---|---|
| profile.map | Shows the number of soil profile types. Grid squares in study area have positive integers. Those outside the area are classified as "missing values". | land.map<br>soil.map | profile.tbl |
| profwltr.map | Shows the number of soil profile types of tractor wheeling tracks. Grid squares in study area have positive integers. Those outside the area are classified as "missing values". | land.map<br>soil.map | profwltr.tbl |
| headout.map | Shows the location of detailed soil hydraulic pressure head out. Grid squares located out points have positive integers from 1 to 6, others in study area have value 0. Those outside the area are classified as "missing values". | area.map<br>ldd.map | headout.tbl |
| inithead.a[1] | Shows the initial soil hydraulic pressure head of each soil layer. Grid squares in study area have negtive integers. Those outside the area are classified as "missing values". | area.map | |

[1] a is a number like 001, 002, ..., 014,...; the numbers must correspond to the numbers of the soil layers in the description file of the soil physical profile.

### 3.3.5 Input files

#### *3.3.5.1 Soil profile file*

Profile.inp is an ASCII file. It describes the soil physical profile (Appendix 6). It includes the depth of each soil layer in cm, the numbers of the soil profile types which are indicated in profile.map, and the names of soil physical tables.

#### *3.3.5.2 Rainfall files*

The original rainfall data from the rain gauges should be calculated using equation 3.1. An ASCII file can then be made for every single rain event as shown in appendix 7.

## 3.4 Running file for LISEM

In order to run LISEM, the running file should be carefully prepared, using the MS-DOS or WINDOWS editor. This file contains all the information required for the simulation, such as the directories where the data, tables and maps can be found and the results can be stored (Appendix 8).

# Chapter 4
# The Effects of Time Step and Initial Soil Hydraulic Pressure Head on Results in LISEM

In LISEM, several factors significantly affect the accuracy of the simulation. The most important of these factors are the time step and the initial soil hydraulic pressure head (ISHPH). Since the time step can not be changed during the simulation process, and ISHPH is the starting point for the calculation of the soil moisture and infiltration in SWATRE sub-model, several pre-runs are necessary to determine the appropriate time step and initial soil hydraulic pressure head so as to reduce the probability of significant differences between simulated and measured results to below 1%.

## 4.1 Some input data for testing time step and ISHPH

The rain intensity data was obtained at 8 and 11 o'clock on 28th October, 1998 (appendix 12). Data on crop and soil variables is shown in appendices 3 and 4. Data on crop and soil variables were converted into maps using the methods introduced in chapter 3. Cell size in all maps is 5 meters, corresponding to the width of some parcels in the field.

## 4.2 Evaluation methods

In order to evaluate the results of simulation for different time steps and ISHPH values, two methods were used.

1) Realistic error: this is the result of $X^2$-test, comparing simulation and measurement results (Equation 4.1). It should be smaller than 6.635 in order to ensure that the probability of significant differences is below 1%.

$$RE = \frac{(M_r - S_r)^2}{M_r} \quad ........... (4.1)$$

RE: Result of $X^2$-test comparing measurement and simulation results;
$M_r$: Measurement results;
$S_r$: Simulation results.

2) Relative error: this is the result of a $X^2$-test of simulation results for different time steps or ISHPH values (Equation 4.2). The probability of a significant difference between two test results is smaller than 1% if $X^2$ is smaller than 6.635.

$$REE = \begin{cases} \frac{(R_n - R_{n+1})^2}{R_n} & (R_n \geq R_{n+1}, n = 1,2,...,8) \\ \frac{(R_n - R_{n+1})^2}{R_{n+1}} & (R_n < R_{n+1}, n = 1,2,...,8) \end{cases} \quad ........... (4.2)$$

REE: Result of $X^2$-test
$R_n$: Results of $N^{th}$ test;
$R_{n+1}$: Results of $(N+1)^{th}$ test.

## 4.3 Effects of time step on LISEM simulation results

According to the LISEM manual, the time step in seconds should not be larger than the cell size of the maps in meters which is general rule of LISEM. In fact, the time step can be made large or small according to the accuracy tolerated.

In the present case, time steps of 5 seconds, 10 seconds, 20 seconds, 40 seconds, 80 seconds, 120 seconds and 180 seconds were tested. The soil hydraulic pressure head is – 70 cm, and all other factors were the same for all time steps.

### 4.3.1 Results and analysis

#### *4.3.1.1 Total runoff*

The total water discharge (runoff) increased as the time step increased (Figure 4.1), but it decreased as the time step exceeded a value which is about 25 times the theoretical time step (5 seconds). The peak value was found at about 120 seconds (which is 24 times the theoretical time step).

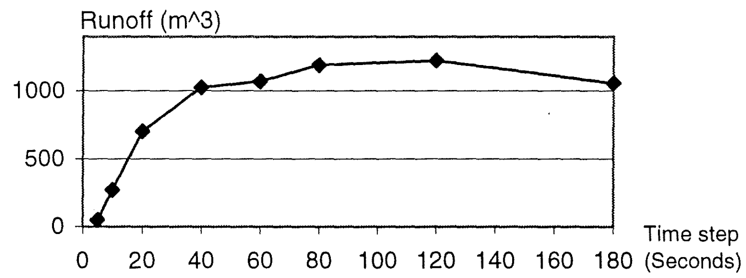


Figure 4.1: Change in total runof at different time steps

RE decreased as the time step increased (Table 4.1). For small time steps, the error was very large, so these results could not be accepted for practical purposes, unlike the results obtained with time steps between 40 and 60 seconds.

According to REE, the results did not change significantly when the time step was changed from 40 to 60 seconds and from 80 to 120 seconds, though there were significant differences between the results of 60 and 80 seconds. This results cannot be explained by general concept of simulation model. However, compared with RE, simulation results could be used to evaluate the effects on water and soil conservation of various land use systems and measures, because the relative error caused by time step for various land use systems and measures could be eliminated if time step was same.

Table 4.1: Difference in total runoff between measurement and simulation data

| Time step (seconds) | 5 | 10 | 20 | 40 | 60 | 80 | 120 | 180 |
|---|---|---|---|---|---|---|---|---|
| Measured data ($m^3$) | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 |
| Simulation data ($m^3$) | 48.48 | 270.95 | 703.79 | 1026.39 | 1071.73 | 1189.77 | 1222.80 | 1055.51 |
| RE | 951.46 | 574.44 | 112.05 | 0.37 | 0.62 | 19.97 | 29.82 | 0.08 |
| REE | 1020.89 | | 147.87 | | 13.00 | | 26.51 | |
| | | 691.46 | | 2.00 | | 0.92 | | |

It can be concluded that the results are acceptable for time steps between 40 and 60 seconds, if total runoff is the only result considered.

#### *4.3.1.2 Soil movement*

The change in average soil loss in the simulation process corresponds to that in total runoff. The highest average soil loss was found at a time step of 40 seconds. Average soil loss increased sharply for time steps between 5 and 40 seconds, then decreased slowly (Figure 4.2). The change in total soil loss with increasing time step reflects that in average soil loss.

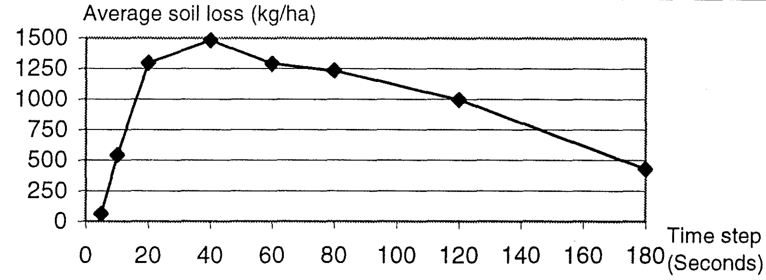

Figure 4.2: Change in average soil loss at different time steps

Splash detachment did not change significantly with increasing time step, but flow detachment and deposition decreased with increasing time step (Table 4.2). These factors showed a significant linear relation with time step (for flow detachment: $R^2$=0.7889 > 0.6961 (P0.01); for deposition: $R^2$=0.6631>0.62 (P0.05)) .

Table 4.2: Soil movement at different time steps

| Time step (second) | Splash detachment (ton) | Flow detachment (ton) | Deposition (ton) | Total soil loss (ton) | Total soil movement (ton) | REE of total soil movement | | Soil movement balance error (%) |
|---|---|---|---|---|---|---|---|---|
| 5 | 11.94 | 209.34 | 217.00 | 4.27 | 221.28 | 26.72 | | 0.187 |
| 10 | 12.01 | 286.17 | 261.83 | 36.35 | 298.18 | | 0.08 | 0.003 |
| 20 | 12.17 | 290.76 | 215.99 | 86.87 | 302.93 | 59.47 | | 0.083 |
| 40 | 12.32 | 182.87 | 95.78 | 99.29 | 195.19 | | 11.64 | 0.113 |
| 60 | 12.37 | 140.62 | 66.34 | 86.49 | 152.99 | 1.79 | | 0.183 |
| 80 | 12.41 | 124.90 | 54.22 | 82.88 | 137.31 | | 8.86 | 0.241 |
| 120 | 12.49 | 94.09 | 39.45 | 66.79 | 106.58 | 19.82 | | 0.514 |
| 180 | 12.39 | 57.08 | 40.00 | 28.87 | 69.47 | | | 2.030 |

There was also a significant linear relation between flow detachment and deposition ($R^2$=0.8635>0.6961(p0.01)), but the rate of decrease in flow detachment with increasing time step was higher than that of deposition. Flow detachment and deposition determine the amount of total soil loss and average soil loss, while differences in decrease rates between detachment and deposition cause changes in soil loss. Therefore, flow detachment is the main indicator of soil loss.

Table 4.2 shows the soil movement balance error, which changed very little with increasing time step. It remained within the acceptable range, although the error was somewhat large at a time step of 180 seconds. On the whole, time step does not affect the balance of soil movement. However, the REEs of total soil movement remained within the acceptable range of time step between 10 and 20 seconds and between 60 and

80 seconds. In addition, the total soil movement increased with increasing of time step when time step is below 20 seconds, it then decreased with increasing time step.

Total soil loss did not change significantly when time step was changed from 20 to 120 seconds, but a significant difference was found when it was changed from 5 to 20 seconds and from 120 to 180 seconds. A change from 60 to 80 seconds produced no significant change of average soil loss. Total and average soil loss did not change significantly when time step was from 60 and 80 seconds.

#### *4.3.1.3 Peak runoff and peak time*

Peak runoff also increased with increasing time step, but decreased at very large time steps (Table 4.3). There were no significant differences for time steps between 40 seconds and 120 seconds, especially compared to the measured data (405.53 l/s). Unfortunately, the error was very large for very small or very large time steps. According to the simulation data, the acceptable time step is 40 to 120 seconds.

Table 4.3 : Peak runoff and peak time at different time steps

| Time step (seconds) | Data types | 5 | 10 | 20 | 40 | 60 | 80 | 120 | 180 |
|---|---|---|---|---|---|---|---|---|---|
| Peak runoff (l/s) | Measured | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 |
| | Simulation | 46.48 | 117.10 | 310.40 | 389.64 | 388.27 | 401.43 | 388.56 | 323.30 |
| | RE | 317.89 | 205.14 | 22.31 | 0.62 | 0.74 | 0.04 | 0.71 | 16.6 |
| | REE | 107.30 | | 19.90 | | 0.45 | | 13.17 | |
| | | | 319.09 | | 0.01 | | 0.43 | | |
| Peak time (minutes) | Measured | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 |
| | Simulation | 79.33 | 81.50 | 91.33 | 84.67 | 85.00 | 85.33 | 88.00 | 90.0 |
| | RE | 0.17 | 0.03 | 0.81 | 0.03 | 0.04 | 0.06 | 0.29 | 0.57 |
| | REE | 0.06 | | 0.52 | | 0.01 | | 0.05 | |
| | | | 1.19 | | 0.01 | | 0.09 | | |

The time step also affected the time when the peak runoff occurred (Table 4.3). In fact, the REE always remained within the acceptable range, which means that the peak time did not appear to change when time step was changed from very small to very large. However, RE exceeded the acceptable range at time steps of 20 seconds and larger than 120 seconds. Suitable time steps are between 40 and 120 seconds as regards peak runoff and peak time.

#### *4.3.1.4 Runoff evolution*

Simulated runoff varied greatly for different time steps (Figure 4.3 A~H). A comparison with the measured data shows that the larger the time step, the greater the similarity in the runoff process. The numbers of runoff peaks fell from several to only one peak as the time step was increased from 5 seconds to 180 seconds. Unfortunately, the graph of the runoff change in the simulation process did not accurately match the shape of the graph based on the data measured over the same period.

The graphs shows that results obtained with time steps between 40 and 80 seconds are acceptable under field conditions, meaning many crops, fairly small parcels, various management practices and low homogeneity of soil conditions.

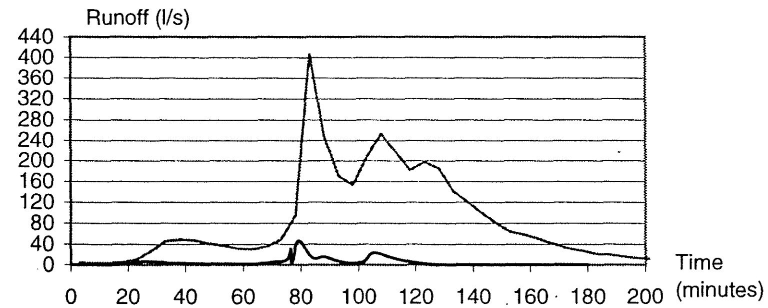


Figure 4.3A: Evolution process of runoff when time step is 5 seconds

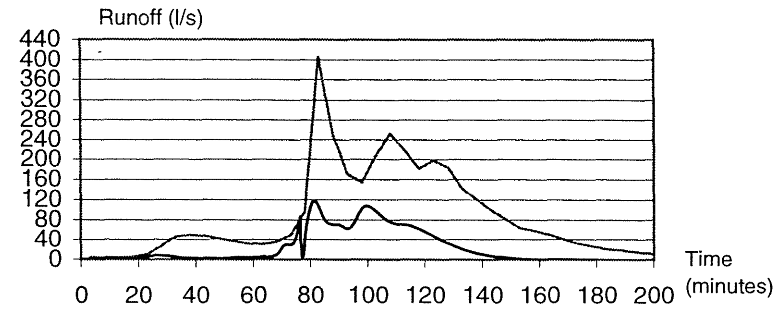


Figure 4.3B: Evolution process of runoff when time step is 10 seconds

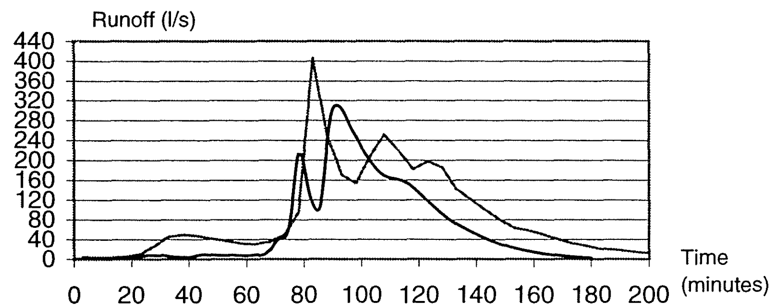


Figure 4.3C: Evolution process of runoff when time step is 20 seconds

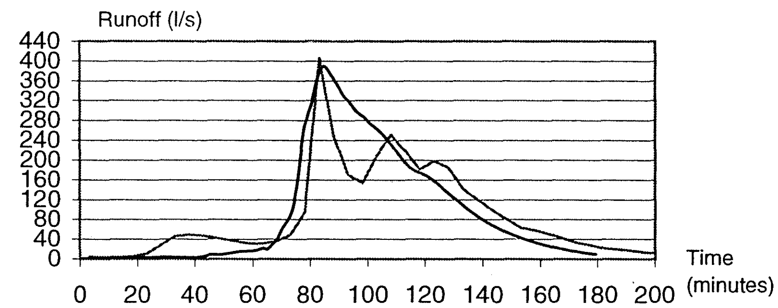


Figure 4.3D: Evolution process of runoff when time step is 40 seconds

Note: ———— Measuring data; ———— Simulating data

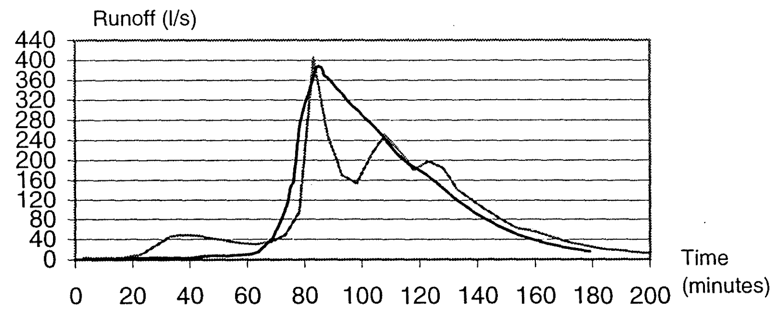


Figure 4.3E: Evolution process of runoff when time step is 60 seconds

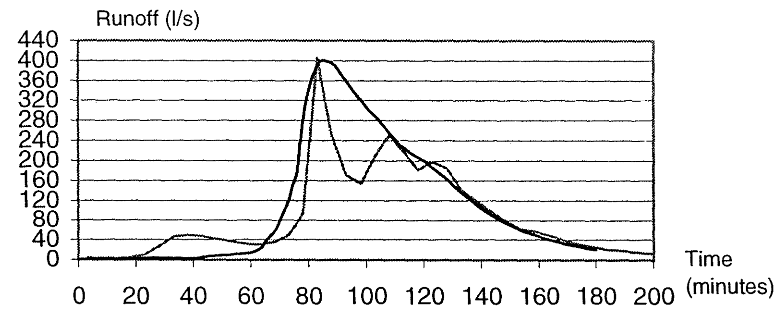


Figure 4.3F: Evolution process of runoff when time step is 80 seconds

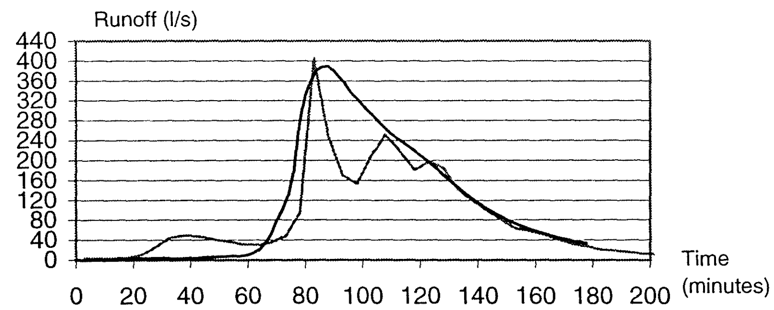


Figure 4.3G: Evolution process of runoff when time step is 120 seconds

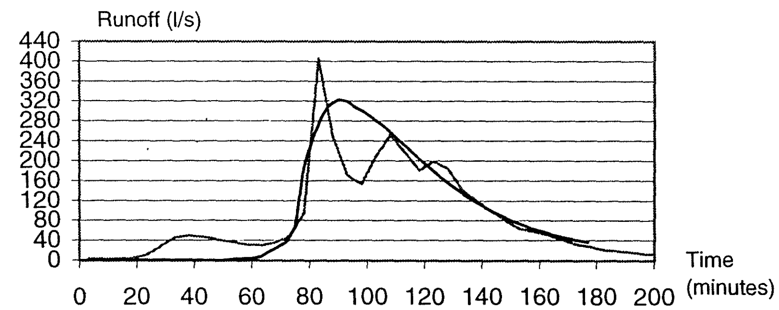


Figure 4.3H: Evolution process of runoff when time step is 180 seconds

Note: ———— Measuring data; ———— Simulating data

### 4.3.2 Conclusions on time step

The time step is a very important factor in LISEM, which can be changed before the simulation process is started, but is fixed during the simulation process. The following conclusions could be drawn from several runs using the same input data and maps.

1. According to the general concept of simulation models (P.A. Leffelaar, 1993), the differences in the results for different time steps should be small as the time step becomes small meaning that the time step does not affect the simulation results. In the present case, however, they tended to be large for small time steps. These results cannot be explained by the general concept of the effect of time step in simulation models. It is possible that LISEM still contains some bugs, which would have to be eliminated in the future.
2. Time step significantly affected the results of total runoff, runoff peak value and peak time, number of runoff peaks, average soil loss and total soil loss. Their values initially increased with increasing time step, then decreased when time step was future increased. In addition, peak time appeared to be delayed as the time step increased. As regards the differences of simulation results between time steps, time step did not affect significantly simulation results only if time step was between 60 and 80 seconds.
3. Comparing the simulation data with the measured data, the error in the total runoff, peak runoff value and peak time was found to be very large when the time step was equal to or smaller than the theoretical time step (in this case, 5 seconds) and when it became very large (larger than 24 times the theoretical time step). The probability of difference was generally smaller than 1% when time step was between 40 and 80 seconds.
4. Time step did not affect the amount of splash detachment. Equations 2.12, 2.13 and 2.14 shows that the splash rate may be different for different time steps, but the total splash amount is determined by some unchangeable factors such as crop height, crop coverage and crop leaf area. Moreover, the amount of splash was relatively small, about 4% to 18% of total soil movement.
5. Flow detachment was the main contributor to soil movement; the relative changes in the amount of flow detachment and deposition determined the amount of soil loss.
6. On the basis of a comparison between the simulated data and the measured data on runoff, peak runoff, peak time and soil loss, and the significance of the differences with the simulation results, 60 seconds was chosen as the fixed time step to be used in the process of selecting a land use system.

## 4.4 Initial soil hydraulic pressure head

Initial soil hydraulic pressure head (ISHPS) is used in the SWATRE sub-model of LISEM where it is the starting point of the whole simulation process. It is a dynamic variable, and it is difficult to get its accurate value just at the start of the rainfall event. In LISEM, this problem was solved by making several runs under different assumptions for the initial soil hydraulic pressure head. The appropriate ISHPH was then chosen on the basis of the results of the simulation.

The time step was 60 seconds, which was the fixed time step chosen above. All other input data and maps were the same, while initial soil hydraulic pressure head was the variable factor. Rainfall data was the same which was used in the time step test section.

Six different values of the initial pressure head were tested, they are –25cm, -50cm, -70cm, -80cm, -100cm and –200cm.

### 4.4.1 Results and analysis

#### 4.4.1.1 *Total runoff*

The total runoff decreased as ISHPS was changed from –25cm to –200cm (Figure 4.4); the relationship between total runoff and ISHPS was linear ($R^2$=0.9482>0.7648 (P0.01)).

A comparison between simulated data with measured data (Table 4.4) shows that RE and REE were very large at high and low ISHPH values. As far as RE is concerned, the result would be acceptable only around –70cm ISHPH. As regards REE, unlike the effects of time step on total runoff, the results did not match even when the ISHPH was changed only lightly. Therefore, only a very narrow range of ISHPH is appropriate for correct results of the simulation.

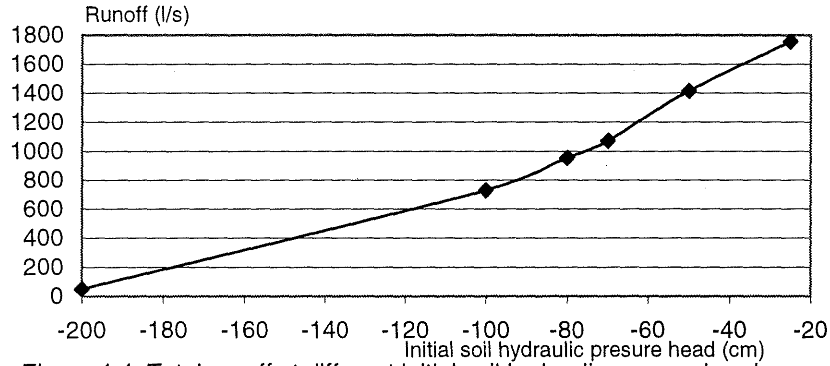

Figure 4.4: Total runoff at different initial soil hydraulic presure head

Table 4.4: Difference in total runoff between simulation and measured data

| ISHPH (cm) | -25 | -50 | -70 | -80 | -100 | -200 |
|---|---|---|---|---|---|---|
| Measured data ($m^3$) | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 | 1046.17 |
| Simulation data ($m^3$) | 1757.08 | 1414.41 | 1071.73 | 955.74 | 729.70 | 50.76 |
| RE | 483.10 | 129.62 | 0.62 | 7.82 | 95.73 | 947.11 |
| REE | 83.02 | | 14.08 | | 178.90 | |
| | | 109.57 | | 70.02 | | |

#### *4.4.1.2 soil movement*

The average soil loss increased slowly and then decreased sharply when ISHPH was decreased from very high to very low (Figure 4.5). It reached its peak value around on ISHPH value of –70cm.

Table 4.5 shows the soil movement. Like time step, ISHPH did not affect splash detachment, but it did affect flow detachment and soil deposition. There was a significant relationship between ISHPH and flow detachment ($R^2$=0.9486 > 0.7648 (P0.01)), and between ISHPH and soil deposition ($R^2$=0.7170>0.6937 (P0.05)). Flow detachment and soil deposition decreased with decreasing of ISHPH. The REE of flow detachment was apparent except for ISHPH values between –70cm and –80cm. The

REE of average soil loss was also significant except for ISHPH values between –25 and –50 cm. However, total soil loss was not significantly different except at very low ISHPH. As regards soil movement, therefore, the suitable ISHPH is between –70cm to –80cm.

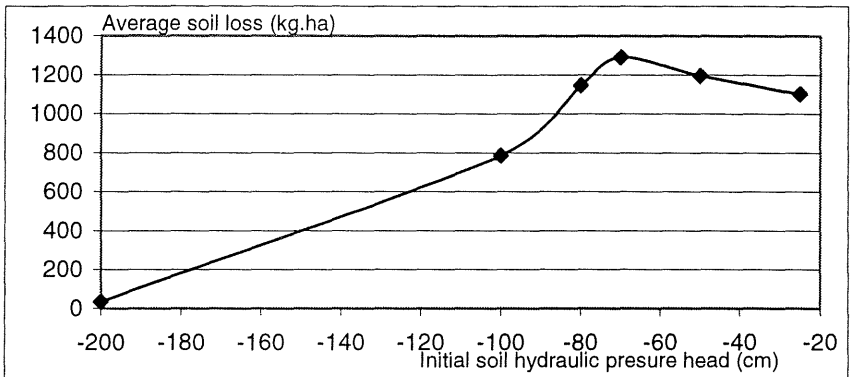

Figure 4.5: Average soil loss at different initial soil hydraulic presure head

Table 4.5: Soil movement at different ISHPH values

| ISHPH (cm) | Splash detachment (ton) | Flow detachment (ton) | Deposition (ton) | Total soil loss (ton) | Total soil movement (ton) | REE of total soil movement | | Soil movement error (%) |
|---|---|---|---|---|---|---|---|---|
| -25 | 12.37 | 224.83 | 161.28 | 73.92 | 237.20 | 9.26 | | 0.84 |
| -50 | 12.37 | 182.73 | 106.37 | 80.21 | 194.74 | | 11.39 | 4.37 |
| -70 | 12.37 | 140.62 | 66.34 | 86.49 | 152.99 | 1.29 | | 0.10 |
| -80 | 12.33 | 127.24 | 62.51 | 76.93 | 139.57 | | 8.43 | 0.09 |
| -100 | 12.26 | 95.96 | 55.37 | 52.75 | 109.22 | 279.0 | | 0.09 |
| -200 | 11.99 | 13.27 | 22.89 | 2.36 | 25.26 | | | 0.00 |

#### 4.4.1.3 *Peak runoff and peak time*

Peak runoff generally decreased with decreasing ISHPH, but it was slightly higher at on ISHPH of –70cm than at a value of –50cm (Table 4.6). The values of RE and REE shows that the results for peak runoff can really only be accepted at ISHPH values higher than –70cm.

Table 4.6: Peak runoff and peak time at different ISHPH values

| Items | Data types | ISHPH -25 | ISHPH -50 | ISHPH -70 | ISHPH -80 | ISHPH -100 | ISHPH -200 |
|---|---|---|---|---|---|---|---|
| Peak runoff (l/s) | Measured | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 | 405.53 |
| | Simulation | 401.25 | 353.30 | 388.27 | 338.25 | 259.26 | 21.20 |
| | RE | 0.05 | 6.73 | 0.74 | 11.16 | 52.16 | 364.24 |
| | REE | 6.51 | | 7.39 | | 2673.00 | |
| | | | 3.15 | | 24.06 | | |
| Peak time (minutes) | Measured | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 | 83.12 |
| | Simulation | 102 | 93 | 85 | 85 | 85 | 79 |
| | RE | 4.29 | 1.17 | 0.04 | 0.04 | 0.04 | 0.20 |
| | REE | 0.87 | | 0.00 | | 0.46 | |
| | | | 0.75 | | 0.00 | | |

The peak time tended to be earlier at lower values of ISHPH, bringing it close to the true peak time derived from measured data. The RE and REE values shows that ISHPH does not significantly affect the peak time.

#### *4.4.1.4 Runoff process*

During the simulation period, the runoff process shows major differences at different ISHPH values (Figure 4.6A~F). The number of peaks shows irregular changes high ISHPH values such as –25cm or –50cm as well as of low ISHPH values, such as 100cm, there were several peaks. At –25cm the last peak was higher than any previous peak. Only one peak was found at ISHPH values of –70cm and –80cm.

However, the process did not match the actual runoff process at all ISHPH values tested. Comparing all graphs in figure 4.5, the processes at ISHPH values of –70cm and –80cm are the closest to the measured process. Perhaps the best value is –70cm.

### 4.4.2 Conclusions on initial soil hydraulic pressure head

1. ISHPH significantly affected the simulation results regarding total runoff, peak runoff, peak time, average soil loss, total soil loss, flow detachment and soil deposition. There is a very narrow range of suitable ISHPH values at which simulated runoff matched measured total runoff.
2. There were positive linear relationships between ISHPH on the hand total runoff, flow detachment and soil deposition on the other. Changing ISHPH caused irregular changes in the numbers of runoff peaks. Total soil loss and average soil loss first increased to peak point, then decreased as ISHPH was further increased. The true peak time could be approximated at a wide range of ISHPH values, although there were slight differences.
3. As was also found for time step, the runoff process could not be matched by adjusting ISHPH.
4. There were not significant difference on total soil erosion and peak runoff when ISHPH was between –70 and –80 cm.
5. Considering all effects on soil erosion of ISHPH, the best ISHPH value is –70cm.

## 4.5 Summary

1. The results of the time step test shows that some bugs may exist in the LISEM, so LISEM will need to be continuously improved in the future. However, it can still be used to evaluate the effects on soil conservation of various land use systems, because the relative effects are much more important than the absolute effects in the evaluating of land use options, and the relative effects of various land use system were not affected by time step.
2. Summarizing the results of our test for time step and initial soil hydraulic pressure head, it can be concluded that the appropriate time step and initial soil hydraulic pressure head are 60 seconds and –70cm respectively. These can be used as initial values to simulate the effects of different land use systems on soil conservation. Since the data we used for rainfall, crops and soil variables were for the winter period, these initial values can only be used to simulate the winter situation.
3. It took an large amount of time to find the appropriate time step and initial soil hydraulic pressure head. On the other hand, it would be difficult to find the best values for time step and initial soil hydraulic pressure head by changing these values manually. These are the main reasons for the generally large simulation error.

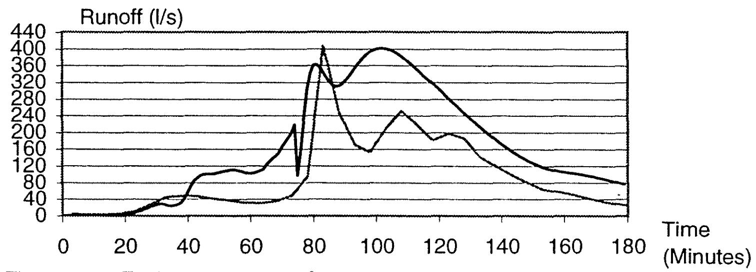

Figure 4.6A Evolution process of runoff when intial presure head is -25cm

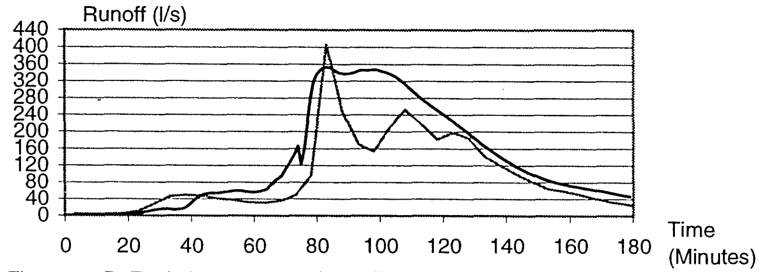

Figure 4.6B Evolution process of runoff when intial presure head is -50cm

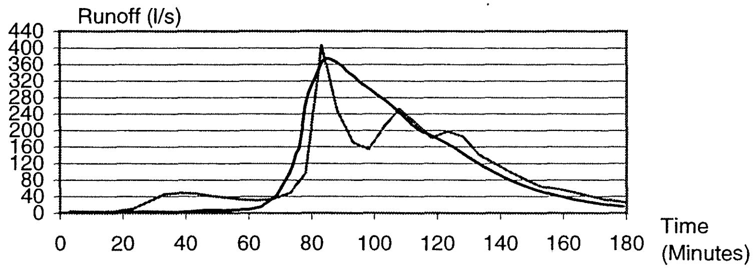

Figure 4.6C Evolution process of runoff when intial presure head is -70cm

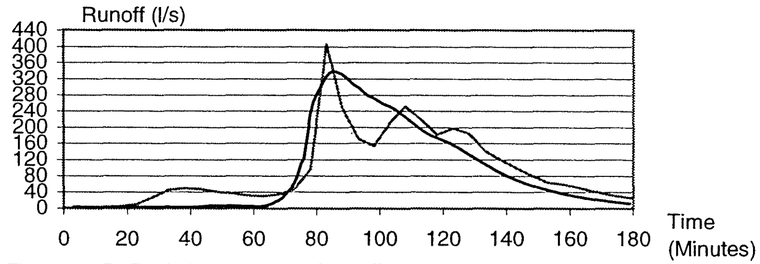

Figure 4.6D Evolution process of runoff when intial presure head is -80cm

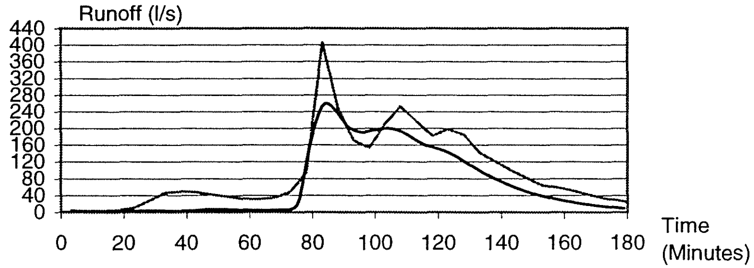

Figure 4.6E Evolution process of runoff when intial presure head is -100cm

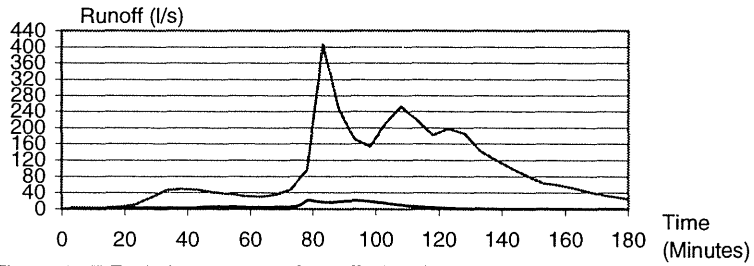

Figure 4.6F Evolution process of runoff when intial presure head is -200cm

Note: ———————— Measuring data ———————— Simulating data

Therefore, it will be necessary to develop LISEM from fixed time step to changeable time step, so that the best time step can be chosen automatically by the program.

4. It will also be necessary to add some sub-models such as evaporation and crop growth to make LISEM continuous. The realistic initial soil hydraulic pressure head could then be simulated by the program. LISEM could then be used to study soil erosion on scales ranging from one farm to regional level, and as a tool for regional land use planning.

# Chapter 5
# Evaluation of Land Use Systems for Soil Erosion Control

There are four sub-catchments in the Groesbeek study area. This paper only presents the results of first sub-catchment due to limited amount of time available. The first sub-catchment has a surface area of 67.055 ha. Relative altitude is less than 53 m (Figure 5.1), and sandy soil covers 80.5% of the total area. In the first sub-catchment, six land use systems (including the current land use system) are developed. These land use systems were evaluated on the basis of the LISEM simulation results.

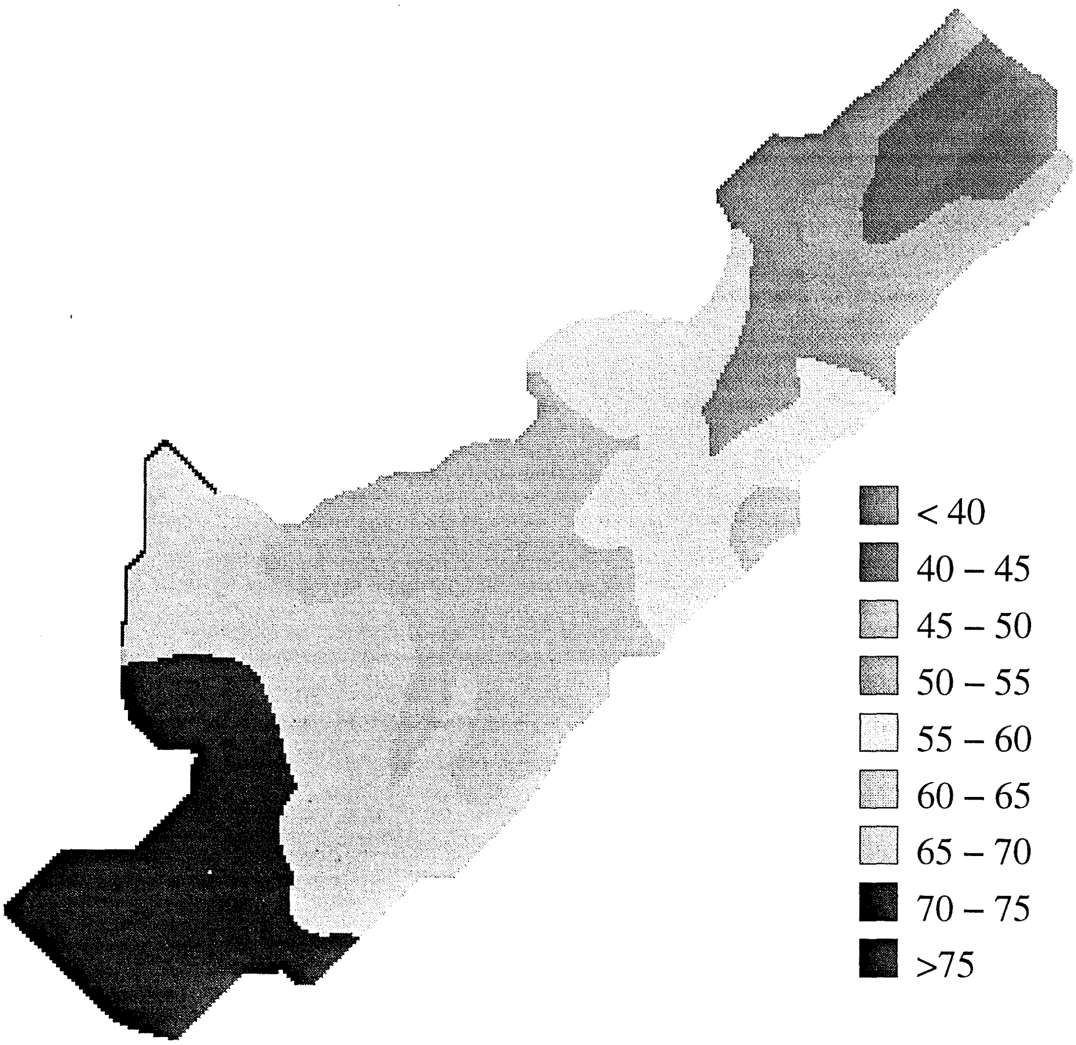


Figure 5.1: The topography of catchment 1
Note: The altitude is in meter.

## 5.1 Development of alternative land use systems

In order to reduce runoff and sediment yield, as well as to beautify and diversify the landscape of the Groesbeek study area, several alternative land use options needed to be formulated. Crop and land use data for the various land use options were converted into input data and maps of LISEM. The LISEM simulation results were used to evaluate the alternative land use options. Soil erosion figures were utilized as critical figures in the process of evaluation. The alternative land use systems were assessed on there ability to achieve the following aims:

1. Reducing water discharge and sediment yield (soil loss) at the basin outlet point;
2. Reducing the total soil erosion and soil deposition within the catchment;
3. Not reducing farmers' income too much;
4. Some improvement of the landscape.

The main aims were 1 and 2, and the present study only examined the effects of land use systems on water and soil conservation. These effects also included to a certain extent partially the effects of tillage, residues and manure management, etc.. Random roughness, Manning's N, soil cohesion and crop additional cohesion were changed by changing land use types. These parameters show the comprehensive effects of crop types, tillage, residues and manure management methods based on crops.

The new or alternative land use options have been developed by experts on soil conservation, administrators of the local community and land owners. Some plans of the local community for nature and landscape, farmers' views and soil erosion control have been considered in the alternative land use options. Five land use options[1] , including the current use system were formatted after a meeting of soil conservation experts, the administrators of the local community and farmers.

## 5.2 Introduction of land use systems

In the catchment studied arable land is the main land use type. In scenarios 2, 3, 4 and 5, some soil and water conservation measures are introduced into this area, but they do not change the basic land use type. Scenario 6 changes arable land into dairy land.

### 5.2.1 Scenario 1

Scenario 1 is the current land use system, which has been introduced in chapter 3 (Table 5.1).

### 5.2.2 Scenario 2

This involved certain management measures. There is no difference between scenarios 1 and 2 during the spring period. In the winter, maize, scorzonera, carrot and sugarbeet fields are used for green manure, with the green manure crop (Yellow mustard) area covering 15.6% of the total area (Figure 5.2 and Table 5.1).

### 5.2.3 Scenario 3

According to the land use plans of the local community, a natural area will be added to scenario 2 to formulate new land use system (Figure 5.3). The location and size of the natural area is described in the land use plans developed by the local community. The natural area can be used for grass, shrubs, flowers, etc. Its size is 1.11 ha, only 1.7% of

[1] In this paper, scenario 1 to 4 land use options are from this meeting. Scenario 5 and 6 are formatted according to purposes of research.

the total catchment area; 0.50 ha. is from small tree field, 0.03 ha. is from winter wheat field, 0.49 ha is from asparagus field and 0.09 ha is from scorzonera (Table 5.1). Just as in scenario 2, maize, scorzonera, carrot and sugarbeet field are used for green manure during the winter.

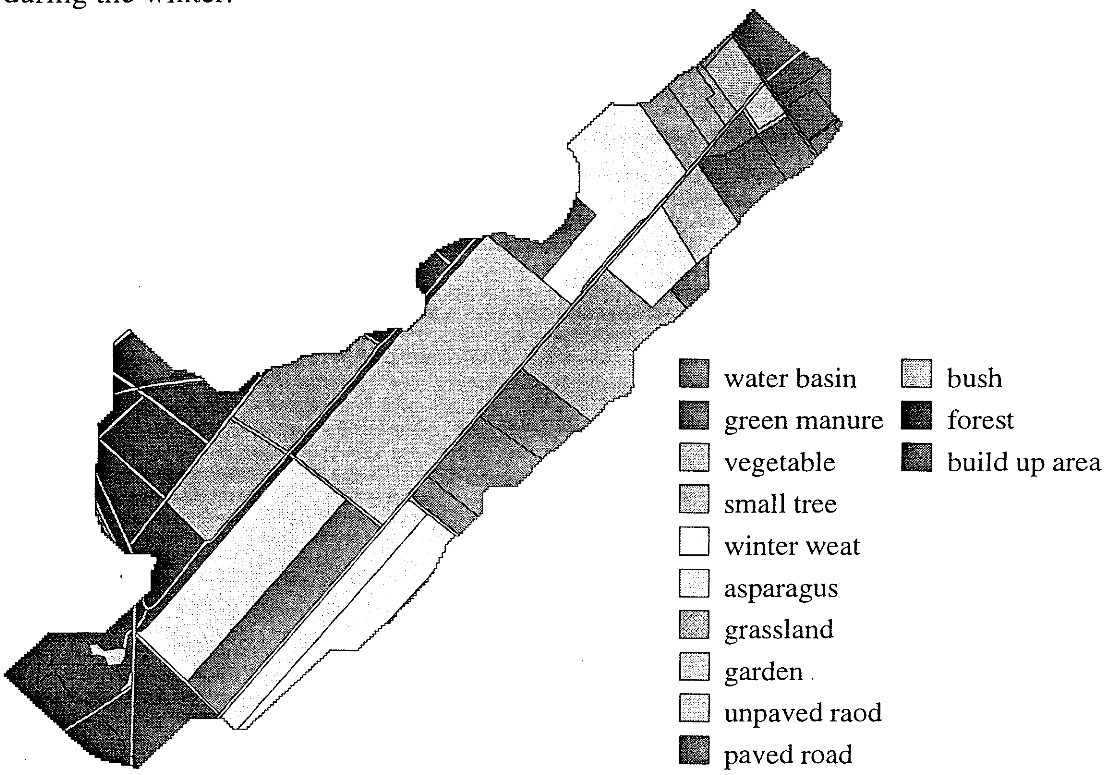


Figure 5.2: Map for scenario 2 in winter

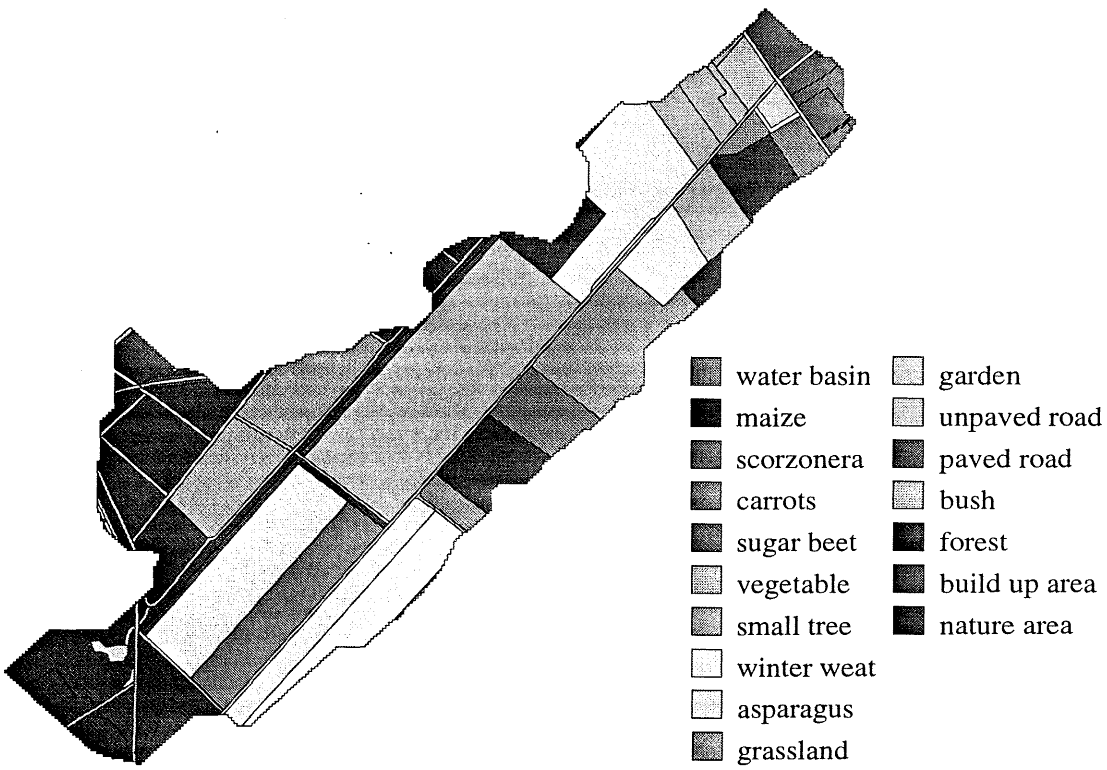


Figure 5.3: Map for scenario 3

### 5.2.4 Scenario 4

Some grass strips are added to scenario 3. The distance between the grass strip is 200 meters on a direction perpendicular to that of the slopes, the width of the strips is 5 meters and strips follow as much as possible the parcel borders (Figure 5.4). The total area of grass strips is 0.83 ha, only 1.23% of the total area. 0.335 ha is from small tree field, 0.268 ha is from winter wheat field, 0.095 ha is from asparagus field, 0.055 ha is from scorzonera field, and 0.078 ha is from grassland field (Table 5.1). Like scenario 2, maize, scorzonera, carrot and sugarbeet fields are used for green manure during the winter.

### 5.2.5 Scenario 5

Based on the current land use system, grass strips with a width of 1.5 meters wide are added at two sides of all the roads (Figure 5.5). About 0.8 ha (1.22% of the total area) is used for grass strips (Table 5.1). Otherwise, this scenarios is the same as scenario 1.

### 5.2.6 Scenario 6

Based on the current land use system, all arable land is changed into grassland (Figure 5.6). The area of grassland thereby increases to 43.4 ha, i.e., is 64.7% of the total area (Table 5.1).

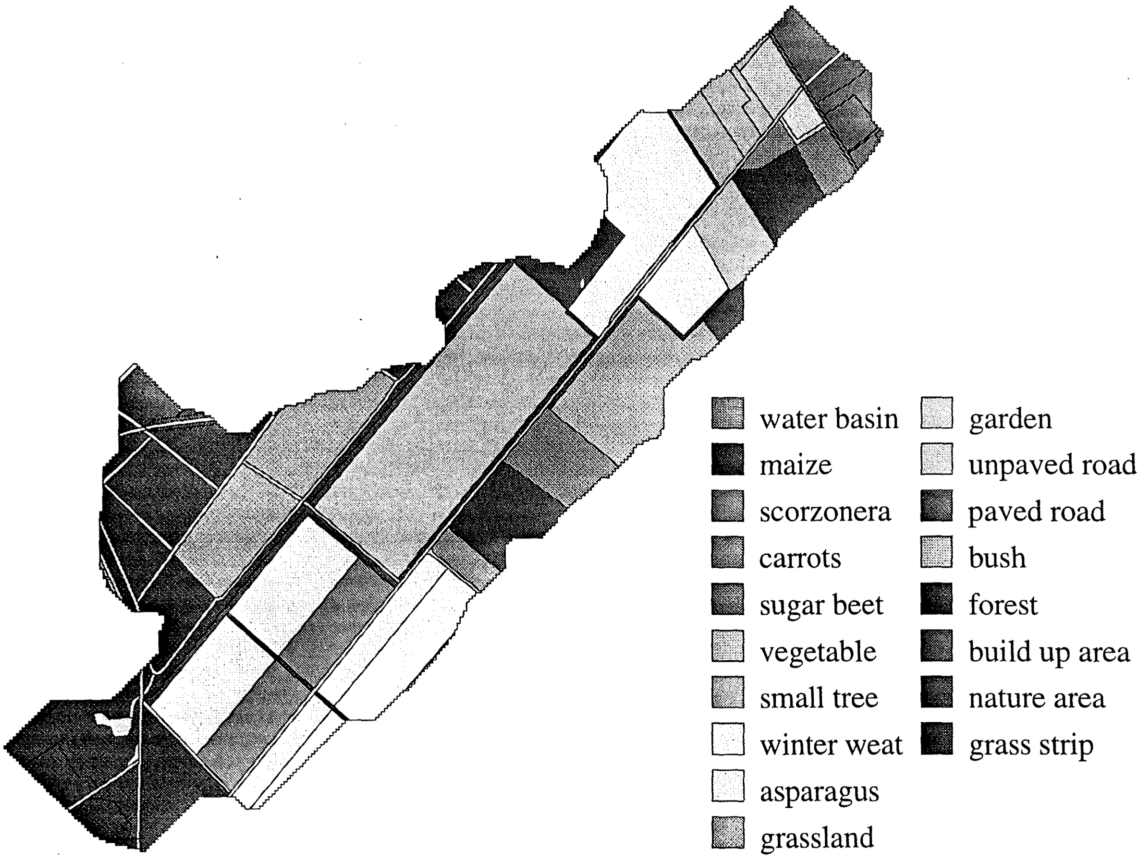


Figure 5.4: Map for scenario 4

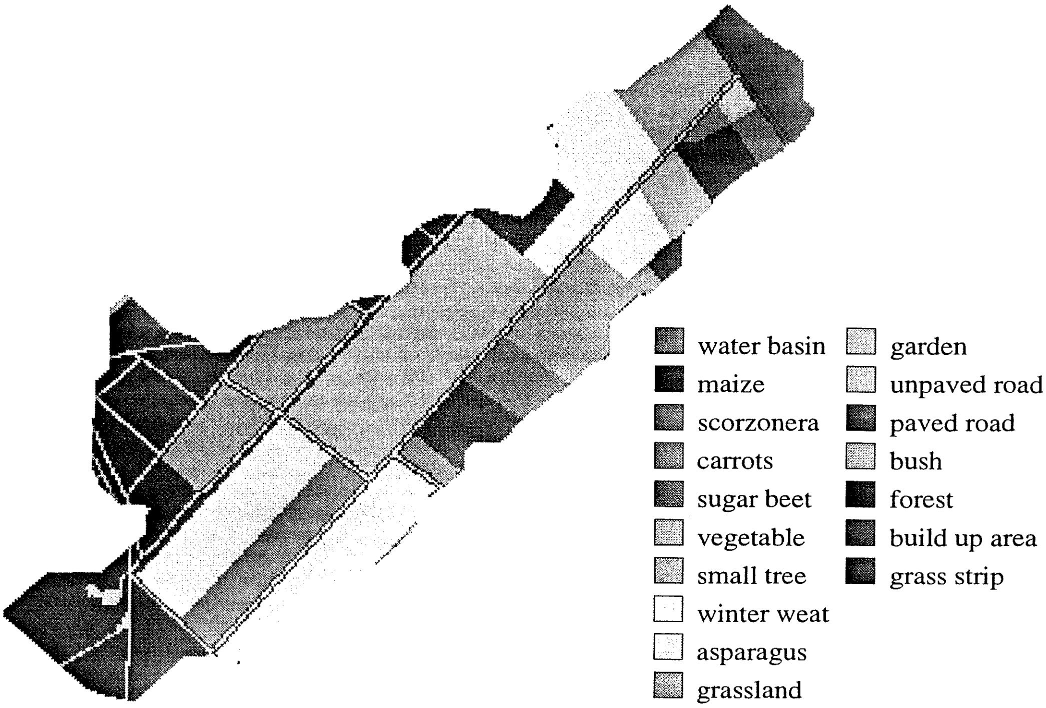


Figure 5.5: Map for scenario 5

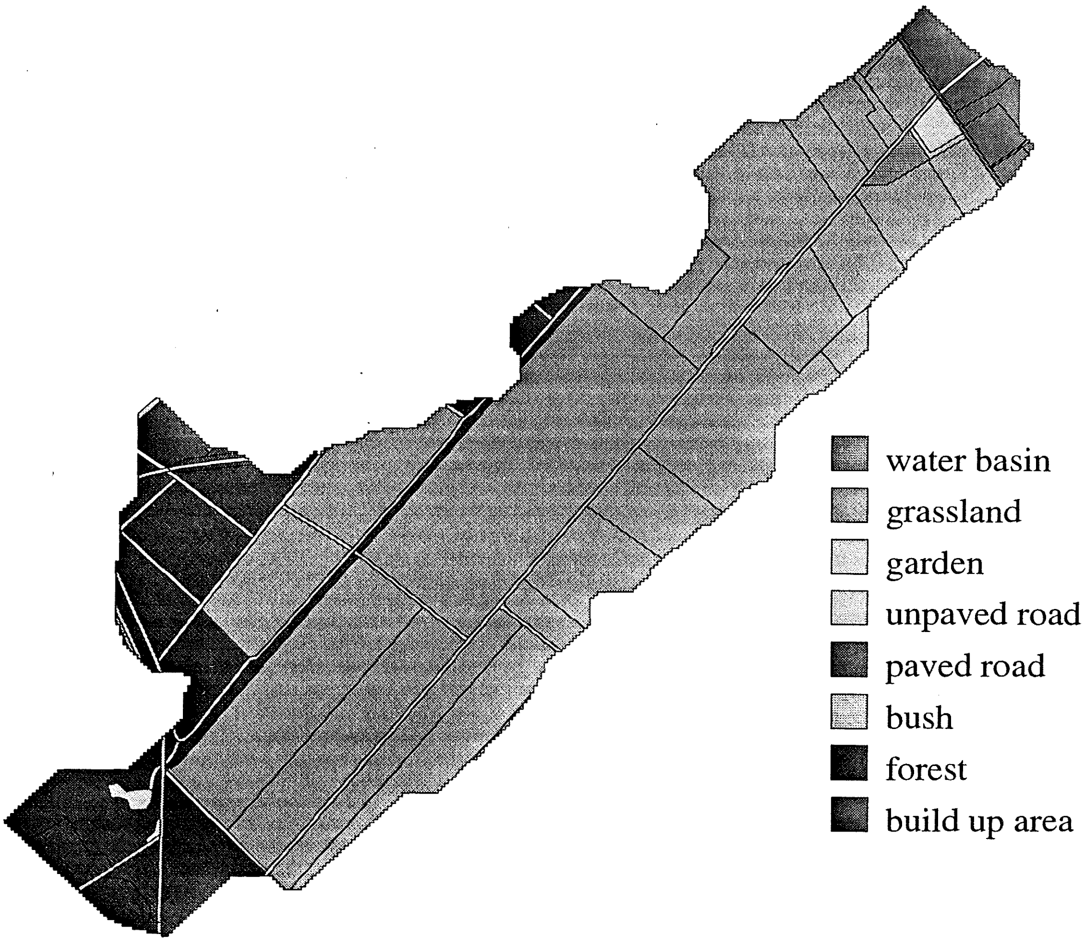


Figure 5.6: Map for scenario 6

Table 5.1: Area (ha) and percentage (%) of the total area for all various land use types in 6 different scenarios

| Land use types | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | | Scenario 5 | | scenario 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % |
| Water basin | 0.3250 | 0.48 | 0.3250 | 0.48 | 0.3250 | 0.48 | 0.3250 | 0.48 | 0.3175 | 0.47 | 0.3250 | 0.48 |
| Maize | 4.2650 | 6.36 | 4.2650 | 6.36 | 4.2650 | 6.36 | 4.2650 | 6.36 | 4.2700 | 6.37 | 0.00 | 0.00 |
| Vegetable | 0.6975 | 1.04 | 0.6975 | 1.04 | 0.6975 | 1.04 | 0.6975 | 1.04 | 0.6800 | 1.01 | 0.00 | 0.00 |
| Small trees | 13.3875 | 19.96 | 13.3875 | 19.96 | 12.8850 | 19.22 | 12.5500 | 18.72 | 13.2975 | 19.83 | 0.00 | 0.00 |
| Winter wheat | 8.1700 | 12.18 | 8.1700 | 12.18 | 8.1425 | 12.14 | 7.8750 | 11.74 | 8.1450 | 12.15 | 0.00 | 0.00 |
| Asparagus | 6.9975 | 10.44 | 6.9975 | 10.44 | 6.5075 | 9.70 | 6.4125 | 9.56 | 6.9350 | 10.34 | 0.00 | 0.00 |
| Scorzonera | 3.4625 | 5.16 | 3.4625 | 5.16 | 3.3775 | 5.04 | 3.3225 | 4.95 | 3.4150 | 5.09 | 0.00 | 0.00 |
| Carrot | 0.5300 | 0.79 | 0.5300 | 0.79 | 0.5300 | 0.79 | 0.5300 | 0.79 | 0.5225 | 0.78 | 0.00 | 0.00 |
| Sugarbeet | 2.2125 | 3.30 | 2.2125 | 3.30 | 2.2125 | 3.30 | 2.2125 | 3.30 | 2.2050 | 3.29 | 0.00 | 0.00 |
| Build up area | 2.2300 | 3.33 | 2.2300 | 3.33 | 2.2300 | 3.33 | 2.2300 | 3.33 | 2.2325 | 3.33 | 2.2300 | 3.33 |
| Grassland | 3.7050 | 5.53 | 3.7050 | 5.53 | 3.7050 | 5.53 | 3.6275 | 5.41 | 3.7275 | 5.56 | 4.34275 | 64.76 |
| Others | 4.5650 | 6.81 | 4.5650 | 6.81 | 4.5650 | 6.81 | 4.5650 | 6.81 | 4.4800 | 6.68 | 4.5650 | 6.81 |
| Garden | 0.4375 | 0.65 | 0.4375 | 0.65 | 0.4375 | 0.65 | 0.4375 | 0.65 | 0.4275 | 0.64 | 0.4375 | 0.65 |
| Unpaved road | 2.8250 | 4.21 | 2.8250 | 4.21 | 2.8250 | 4.21 | 2.8250 | 4.21 | 2.8250 | 4.21 | 2.8250 | 4.21 |
| Paved road | 0.1675 | 0.25 | 0.1675 | 0.25 | 0.1675 | 0.25 | 0.1675 | 0.25 | 0.1675 | 0.25 | 0.1675 | 0.25 |
| Bush | 0.2100 | 0.31 | 0.2100 | 0.31 | 0.2100 | 0.31 | 0.2100 | 0.31 | 0.2000 | 0.30 | 0.2100 | 0.31 |
| Forest | 12.8650 | 19.19 | 12.8650 | 19.19 | 12.8650 | 19.19 | 12.8650 | 19.19 | 12.3925 | 18.48 | 12.8650 | 19.19 |
| Natural area | 0.00 | 0.00 | 0.00 | 0.00 | 1.1100 | 1.66 | 1.1100 | 1.66 | 0.00 | 0.00 | 0.00 | 0.00 |
| Grass strip | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.8275 | 1.23 | 0.00 | 0.00 | 0.00 | 0.00 |
| Grass strip beside road | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.8150 | 1.22 | 0.00 | 0.00 |
| Total | 67.0550 | 100.0 | 67.0550 | 100.0 | 67.0550 | 100.0 | 67.0550 | 100.0 | 67.0550 | 100.0 | 67.0550 | 100.0 |

## 5.3 Input maps and data

The data presented in appendices 3 and 4 were converted into maps by means of the methods introduced in chapter 3. Two groups of input maps were generated, one for the spring period, the other for winter period. Data of soil physical tables for the various profile types are presented in appendices 1 and 2.

Four rain events are used to simulate soil erosion (Appendix 7). Two rain events with rain frequencies of once in 2 years and 25 years respectively (SR2 and SR25) were used for spring (May/June), and two rain events with rain frequencies of once in 2 years and 25 years respectively (WR2 and WR25) were used for winter period (November /December). The amount and peak intensity of rain in the 25 year frequency were higher than these in the 2 year frequency (Table 5.2).

Table 5.2: The rain amount and peak rain intensity

| Period | Occurrence frequency | Total rainfall | | Highest intensity | |
|---|---|---|---|---|---|
| | | Amount (mm) | Ratio | intensity (mm/h) | Ratio |
| Spring | 2 years | 13.30 | 1.00 | 81.6 | 1.00 |
| | 25 years | 23.60 | 1.78 | 141.6 | 1.74 |
| Winter | 2 years | 10.00 | 1.00 | 26.0 | 1.00 |
| | 25 years | 16.30 | 1.63 | 41.2 | 1.59 |

In accordance with the results of chapter 4, the time step for the simulation was set at 60 seconds for all scenarios and rain events. The initial soil hydraulic pressure head of –70cm which results from chapter 4 was used for all scenarios in the winter period. We were unable to calibrate the initial soil hydraulic pressure head for the spring period, due to the lack of measured data[1]. Therefore, we used –500cm as the initial soil hydraulic pressure head to simulate the soil erosion situation in spring.

## 5.4 LISEM runs

In all, 24 LISEM runs were made (6 scenarios times 4 rain events). All pre.run files made using the methods introduced in chapter 3, were combined into one bat-file, after which the computer automatically simulated soil erosion for each individual scenario.

## 5.5 Results[2]

### 5.5.1 Total runoff (water discharge)

The total water discharge was found to be decreased by the new land use options during spring and winter (Figure 5.7). The effects of reduction depended on the measures introduced in the scenarios and rain events (Table 5.3). The relative reduction in the water discharge compared to scenario 1 became lower as the rain intensity and the amount of rainfall increased. Although the amount and the peak intensity of rain with a 25 year frequency were 1.78 and 1.74 times for spring rain events, and 1.63 and 1.59 times for winter rain events as those for rain with 2 year frequency (Table 5.2), the total discharges increased 5.2 to 14.5 times.

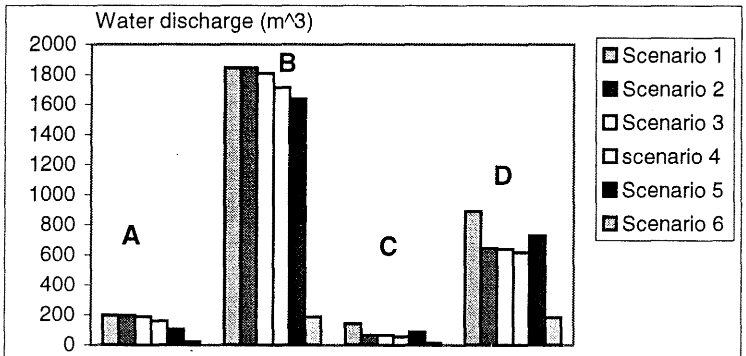


Figure 5.7: Total water discharge of scenarios and rain events

Table 5.3: Total water discharge (m3) and reduction compared with scenario 1 (%)

| Rain event | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Discharge | 198.97 | 198.97 | 187.42 | 159.47 | 105.85 | 21.47 |
| | Reduction (%) | 0.00 | 0.00 | 5.81 | 19.85 | 46.80 | 89.21 |
| WR2 | Discharge | 143.56 | 67.30 | 66.82 | 54.96 | 87.74 | 12.61 |
| | Reduction (%) | 0.00 | 53.12 | 53.45 | 61.71 | 38.88 | 91.22 |
| SR25 | Discharge | 1844.75 | 1844.75 | 1808.11 | 1714.09 | 1636.67 | 187.47 |
| | Reduction (%) | 0.00 | 0.00 | 1.99 | 7.08 | 11.28 | 89.84 |
| WR25 | Discharge | 889.90 | 644.55 | 639.52 | 617.58 | 725.63 | 184.39 |
| | Reduction (%) | 0.00 | 27.57 | 28.14 | 30.60 | 18.46 | 79.28 |

[1] This study was started at end of June, therefore, we have not any measuring data from spring time.
[2] Assumed error caused by time step were same for all scenarios and rain events.

Comparing scenarios 2, 3, 4, 5 and 6 with scenario 1, scenario 2 was unable to reduce water discharge in spring, as scenarios 1 and 2 produced similar results for the spring. However, changing bare land to green manure land had significant effects, since this measure reduced water discharge by more than 20%. Scenarios 3 and 4 had some additional effects on the reduction of the total water discharge in the spring period, but the effects were less than 20% in scenario 4 and less than 6% in scenario 3. These low reduction percentages resulted from the fact that the size of the area changed to natural area and grass strips were only 1.66% to 2.99% of the total area. Scenario 5 had significant effects on the reduction of the total water discharge for light rain[1], e.g. low amounts and intensity of rainfall, but its effects declined sharply for heavy rainfall. Scenario 6 was able to greatly decrease the total water discharge by 79% to 92%, and the rate of reduction remained over 79%, although its effect also fell for very heavy rainfall.

### 5.5.2 Total soil loss (sediment yield)

Soil loss is the amount of soil removed from the catchment area by outflow. It is one of the important critical figures in evaluating the effects of alternative land use options. Total soil loss depends on the amount and intensity of rainfall and on the measures used in the scenarios (Figure 5.8 and Table 5.4). The total soil loss for the 25 year frequency rainfall was found to be 8 to 33 times that for 2 year frequency rainfall.

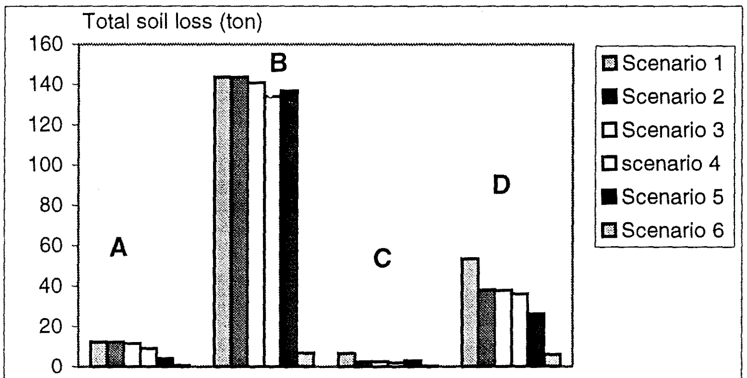


Figure 5.8: Total soil loss of scenarios and rain events
A: SR2; B: SR25; C: WR2; D: WR25.

Scenario 2 did not reduce total soil loss in spring, but had a significant effect during winter time, reducing total soil loss after winter rain events to 28% to 62% of the value in scenario 1. Sowing green manure thus has apparent effects on soil erosion control although its impact is restricted to the winter period. Scenario 3 had only minor effect on total soil loss, reducing by less than 6.7%. It hardly had any effect at heavy rain events, reducing soil loss by less than 2%. Scenario 4 reduced total soil loss by 3.5 ~ 28%, and its effect was quite low at heavy rain events. The efficiency of scenario 5 in reducing total soil loss was found to be highly variable, its relative reduction ranging from near 5% for heavy rain events to 66.7% for light rain events. Scenario 6 had considerable effect, especially for light rain events, with a total soil loss near zero. It was able to reduce total soil loss by more than 88% even for heavy rain.

[1] Comparing rain events of 2 and 25 years happening frequency, light rain means the amount and intensity of rain are relative low, and heavy rainfall means the amount and intensity are relative high.

Table 5.4: Total sediment yield in tons and reduction produced by the various scenarios (%)

| Rain event | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Sediment | 12.33 | 12.33 | 11.50 | 8.96 | 4.11 | 0.63 |
| | Reduction (%) | 0.00 | 0.00 | 6.69 | 27.35 | 66.69 | 94.89 |
| WR2 | Sediment | 6.63 | 2.52 | 2.50 | 1.93 | 3.03 | 0.30 |
| | Reduction (%) | 0.00 | 62.00 | 62.30 | 70.93 | 54.25 | 95.42 |
| SR25 | Sediment | 143.70 | 143.70 | 140.85 | 134.07 | 136.88 | 6.80 |
| | Reduction (%) | 0.00 | 0.00 | 1.98 | 6.70 | 4.75 | 95.27 |
| WR25 | Sediment | 53.32 | 37.94 | 37.64 | 36.03 | 26.14 | 6.02 |
| | Reduction (%) | 0.00 | 28.83 | 29.40 | 32.42 | 50.98 | 88.71 |

### 5.5.3 Total soil erosion (splash and flow detachment)

In the process of water erosion, soil can be moved from its original site by splash, overland flow or channel flow detachment. Channel flow detachment only occurs at the basin outlet point[1]. In fact, there is no channel in the study catchment, so the channel detachment is zero, which means that the soil movement is caused by splash and overland flow detachments. The sum of splash and overland flow detachment indicates the total amount of soil erosion in the soil erosion process. Part of the detached soil remains in catchment area, while the rest leaves the catchment area, the latter represents the real loss of soil from the catchment and is called soil loss or sediment yield (Table 5.4).

Table 5.5 presents the total amounts of soil moved. Splash detachment hardly differed for scenarios 1, 2, 3, 4 and 5, although there were significant differences between rain events. The total soil erosion was reduced mainly by reducing the amount of overland flow detachment. Light rain events caused minor total soil erosion.

Table 5.5: Total soil erosion, splash and overland flow detachment in tons

| Rain event | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Splash detachment | 7.55 | 7.55 | 7.36 | 7.25 | 7.46 | 0.53 |
| | Flow detachment | 29.76 | 29.76 | 26.86 | 24.06 | 17.02 | 2.63 |
| | Total soil erosion | 37.31 | 37.31 | 34.22 | 31.31 | 24.49 | 3.16 |
| | Reduction (%) | **0.00** | **0.00** | **8.28** | **16.09** | **34.37** | **91.52** |
| WR2 | Splash detachment | 6.72 | 6.70 | 6.50 | 6.38 | 6.65 | 0.57 |
| | Flow detachment | 18.32 | 10.53 | 10.18 | 9.00 | 12.54 | 1.46 |
| | Total soil erosion | 25.04 | 17.23 | 16.68 | 15.38 | 19.20 | 2.03 |
| | Reduction (%) | **0.00** | **31.18** | **33.39** | **38.59** | **23.33** | **91.91** |
| SR25 | Splash detachment | 13.13 | 13.13 | 12.82 | 12.62 | 12.96 | 1.05 |
| | Flow detachment | 288.82 | 288.82 | 282.72 | 268.77 | 263.69 | 15.30 |
| | Total soil erosion | 301.95 | 301.95 | 295.54 | 281.39 | 276.65 | 16.35 |
| | Reduction (%) | **0.00** | **0.00** | **2.12** | **6.81** | **8.38** | **94.59** |
| WR25 | Splash detachment | 11.53 | 11.45 | 11.13 | 10.94 | 11.45 | 0.95 |
| | Flow detachment | 105.15 | 79.26 | 77.61 | 73.93 | 78.75 | 9.71 |
| | Total soil erosion | 116.68 | 90.71 | 88.74 | 84.87 | 90.20 | 10.66 |
| | Reduction (%) | **0.00** | **22.26** | **23.95** | **27.27** | **22.69** | **90.86** |

[1] This point was used as a channel, since LISEM requires a channel even if there is no real channel in the catchment.

Scenario 6 not only greatly reduced overland flow detachment, but also caused major reduction of splash detachment, so it reduced the total amount of soil movement by more than 90%. Scenario 2 did not reduce total soil erosion during the spring period, but it did decrease the total soil erosion by more than 20% in winter. The reduction caused by scenario 3 was less than 34%, while causing very little reduction for heavy rainfall in spring. The effects of scenario 4 reduced total soil erosion by less than 39%, though its effect in winter was much better than that in spring. Scenario 5 reduced total soil erosion by between 8% and 35%, while its effects was better than that of scenarios 3 and 4 in spring. In contrast, the reduction achieved by scenario 5 was poorer than those produced by scenario 2, 3 and 4 in winter.

### 5.5.4 Soil deposition in the catchment

Soil deposition in the catchment is the amount of soil that is eroded by splash and flow detachment and then deposited in a different place within the catchment area. This soil is not lost from the catchment area. This parameter shows the capacity of land use types and scenarios to catch moving soil. The catching capacity (CC) for moving soil is defined by Equation 5.1.

$$CC = \frac{Dep}{TSM} \times 100 \quad ............(5.1)$$

CC: Catching capacity to moved soil (%);
Dep: Soil deposition (ton);
TSM: Total soil erosion (ton).

Scenarios 2, 3, 4, 5 and 6 decreased the soil deposition, except scenario 5 for rain events a with 25 year frequency in winter. The soil deposition in scenario 6 was less than 10% of that in scenario 1 (Table 5.6). The linear relationship between soil deposition and flow detachment has already been proven in chapter 4. The decrease in the amount of soil deposited after the implementation of certain measures is caused by the decrease in flow detachment. Therefore, we cannot evaluate the effects of the scenarios on the control of soil loss purely on the basis of the soil deposition figures.

However, the soil deposition data can be used to calculate CC, which is quantitative parameter used to evaluate scenarios. Compared to scenario 1, the catching capacity for moving soil generally increased after the introduction of certain erosion control measures (Table 5.6). Scenario 3 did not improve the CC obtained in scenario 2, neither in spring nor in winter. Scenarios 4, 5 and 6 enhanced the CC compared to scenarios 1 and 2. In particular, scenario 6 increased CC by 12.8% and 7.5% relative to scenarios 1 and 2 respectively. Introducing green manure in winter was found to increase CC by 7% to 16%. Comparing scenarios 1 and 6, scenario 6 significantly improved CC in spring for light rain (nearly 20%), while CC was reduced 20.7% for heavy rainfall in winter.

Table 5.6: The deposition of soil (ton) and catching capacity (%)

| Rain event | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Deposition | 24.98 | 24.98 | 22.72 | 22.35 | 20.38 | 2.53 |
| | CC (%) | **66.96** | **66.96** | **66.39** | **71.39** | **83.23** | **80.08** |
| WR2 | Deposition | 18.41 | 14.71 | 14.18 | 13.45 | 16.15 | 1.72 |
| | CC (%) | **73.51** | **85.36** | **85.00** | **87.44** | **84.15** | **85.00** |
| SR25 | Deposition | 158.19 | 158.19 | 154.59 | 147.18 | 139.64 | 9.54 |
| | CC (%) | **52.39** | **52.39** | **52.31** | **52.31** | **50.47** | **58.36** |
| WR25 | Deposition | 63.31 | 52.73 | 51.07 | 48.79 | 63.96 | 4.59 |
| | CC (%) | **54.26** | **58.13** | **57.54** | **57.49** | **70.91** | **43.01** |
| Average of CC (%) | | ***59.46*** | ***62.43*** | ***62.17*** | ***64.04*** | ***65.71*** | ***67.11*** |

### 5.5.5 The evolution process of runoff and soil concentrations in the water flow

Instantaneous runoff and soil concentrations in the water flow changed within the simulation period (Figures 5.9 to 5.12), but the changes in runoff and soil concentrations were not synchronous. The peak time for runoff (PTR) is the moment at which the highest runoff occurs, while the peak time for soil concentration (PTSC) is the moment at which the water flow contains the highest soil concentrations (Tables 5.7 and 5.8). Peak times and amounts of runoff indicate the water storage capacity for the various scenarios. Peak values for soil concentration mirror the capacity to prevent detachment.

In all scenarios, PTRs preceded PTSCs in SR2, but the reverse situation was found for in SR25. In WR2, the PTR in scenario 1 followed PTSC, but in other scenarios PTRs preceded PTSCs. In WR25, the PTRs for all scenarios except scenario 6 preceded PTSCs.

Peak runoff values for scenarios 2, 3 4, 5 and 6 were lower than that in scenario 1; scenario 6 in particular reduced it by more than 5 times. However, peak values for soil concentration in the water flow in scenarios 2, 3 and 4 were lower than that of scenario 1 for the light rain events of SR2 and WR2 and slightly higher for the heavy rain events of SR25 and WR25. Scenarios 5 and 6 efficiently lowered the peak value for soil concentration in the water flow compared the other scenarios.

Within same rain event, the numbers of peaks for runoff and soil concentration in the water flow were the same for scenarios 1 to 5 (Figures 5.9 to 5.12), while the evolution of runoff and soil concentrations in the water flow was similar except for scenarios 4 and 5 in SR2. Within the same scenario and rain event, the numbers of peaks was the same for runoff and soil concentration. The evolution was also similar, except that soil concentration in the water flow fell to zero later than that of runoff. In addition, there were differences for different rain events.

Table 5.7: Peak value (l/s) and peak time (minutes) for runoff

| Rain events | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Peak value | 169.13 | 169.13 | 165.38 | 140.28 | 73.18 | 31.19 |
| | Peak time | 19.00 | 19.00 | 20.00 | 13.00 | 15.00 | 13.00 |
| WR2 | Peak value | 70.38 | 40.85 | 40.85 | 30.58 | 41.33 | 11.04 |
| | Peak time | 49.00 | 51.00 | 51.00 | 54.00 | 60.00 | 37.00 |
| SR25 | Peak value | 741.75 | 741.75 | 737.30 | 680.84 | 646.14 | 115.15 |
| | Peak time | 24.00 | 24.00 | 24.00 | 24.00 | 23.00 | 15.00 |
| WR25 | Peak value | 450.62 | 325.79 | 325.79 | 292.92 | 345.68 | 63.16 |
| | Peak time | 43.0 | 42.0 | 42.0 | 43.0 | 46.0 | 56.0 |

Table 5.8: Peak value (g/l) and peak time (minutes) for soil concentrations in the water flow

| Rain events | Items | Scenario 1 | Scenario 2 | Scenario 3 | scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| SR2 | Peak value | 84.34 | 84.34 | 83.63 | 70.46 | 44.40 | 37.52 |
| | Peak time | 27.00 | 27.00 | 27.00 | 15.00 | 16.00 | 15.00 |
| WR2 | Peak value | 62.83 | 48.72 | 48.74 | 45.81 | 38.55 | 32.01 |
| | Peak time | 39.00 | 55.00 | 55.00 | 59.00 | 41.00 | 39.00 |
| SR25 | Peak value | 96.06 | 96.06 | 96.50 | 97.05 | 88.28 | 40.71 |
| | Peak time | 11.00 | 11.00 | 11.00 | 11.00 | 31.00 | 22.00 |
| WR25 | Peak value | 66.28 | 67.13 | 67.02 | 67.37 | 44.86 | 39.68 |
| | Peak time | 33.00 | 62.00 | 63.00 | 67.00 | 31.00 | 40.00 |

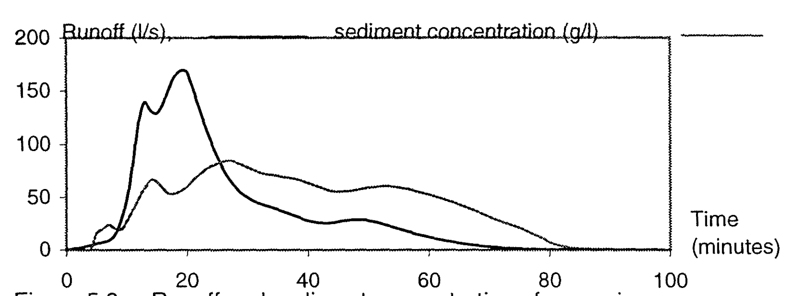

Figure 5.9a: Runoff and sediment concentration of scenario 1, spring period, 2 years frequence rainfall

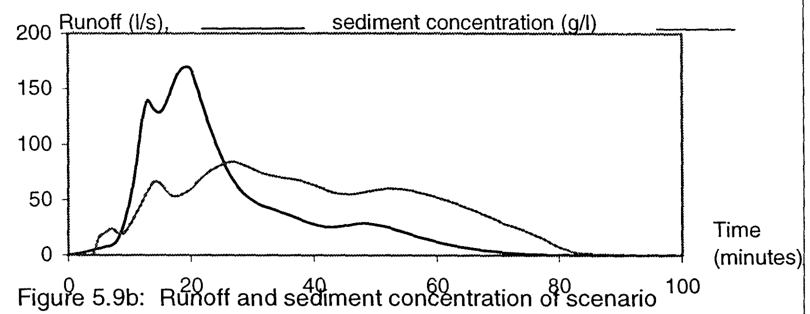

Figure 5.9b: Runoff and sediment concentration of scenario 2, spring period, 2 years frequence rainfall

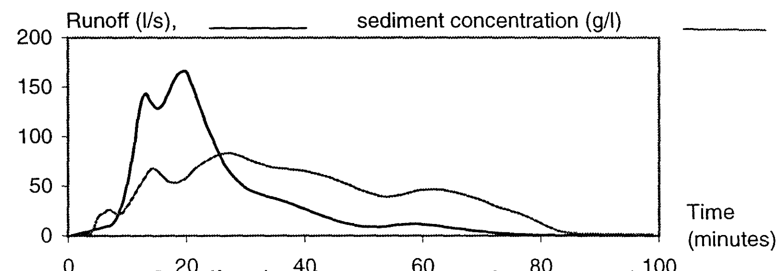

Figure 5.9c: Runoff and sediment concentration of scenario 3, spring period, 2 years frequence rainfall

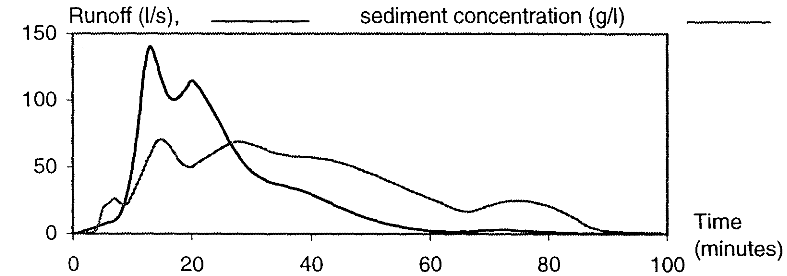

Figure 5.9d: Runoff and sediment concentration of scenario 4, spring period, 2 years frequence rainfall

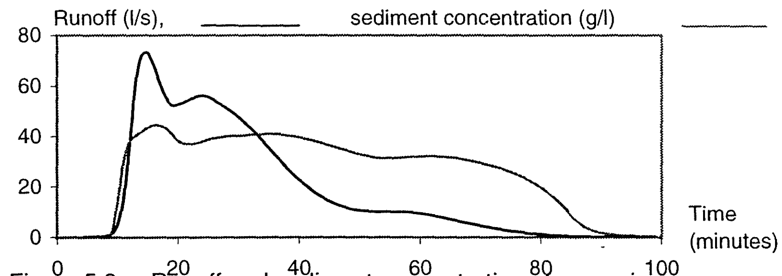

Figure 5.9e: Runoff and sediment concentration of scenario 5, spring period, 2 years frequence rainfall

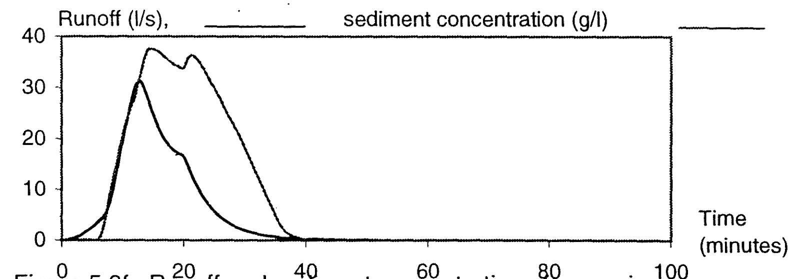

Figure 5.9f: Runoff and sediment concentration of scenario 6, spring period, 2 years frequence rainfall

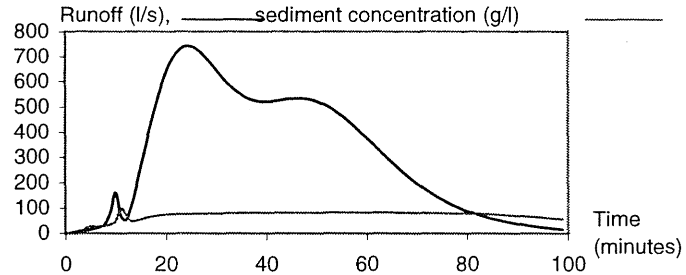


Figure 5.10a: Runoff and sediment concentration of scenario 1, spring period, 25 years frequence rainfall

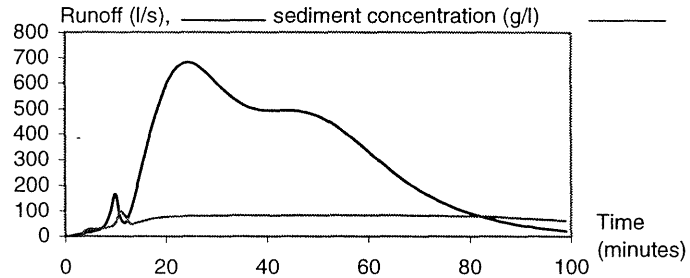


Figure 5.10b: Runoff and sediment concentration of scenario 2, spring period, 25 years frequence rainfall

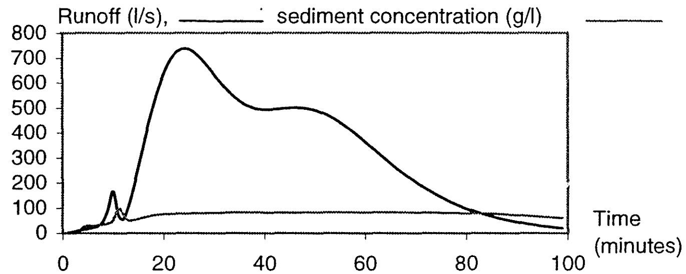


Figure 5.10c: Runoff and sediment concentration of scenario 3, spring period, 25 years frequence rainfall

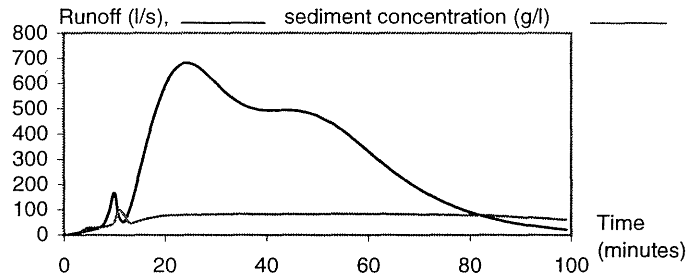


Figure 5.10d: Runoff and sediment concentration of scenario 4, spring period, 25 years frequence rainfall

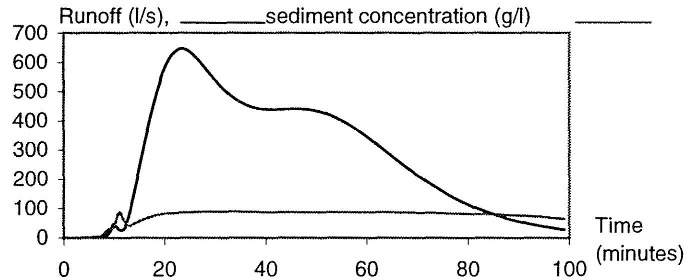


Figure 5.10e: Runoff and sediment concentration of scenario 5, spring period, 25 years frequence rainfall

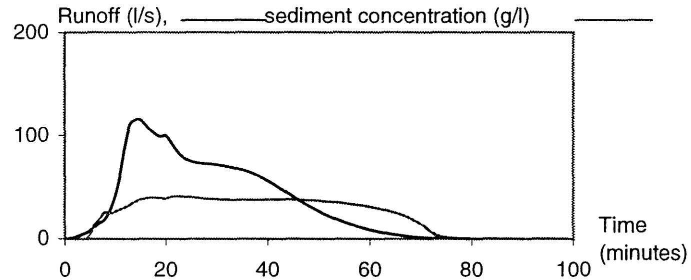


Figure 5.10e: Runoff and sediment concentration of scenario 5, spring period, 25 years frequence rainfall

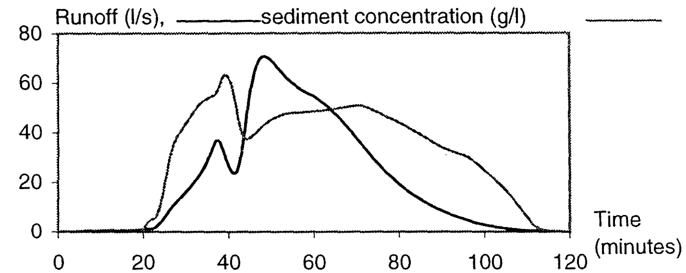


Figure 5.11a: Runoff and sediment concentration of scenario 1, winter period, 2 years frequence rainfall

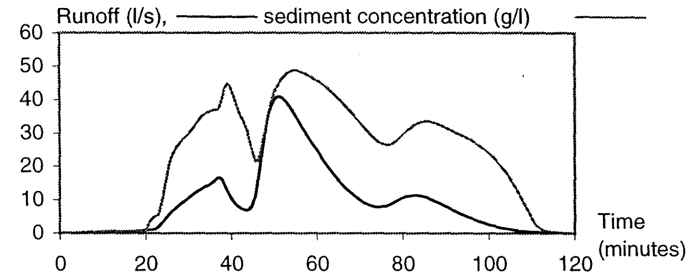


Figure 5.11b: Runoff and sediment concentration of scenario 2, winter period, 2 years frequence rainfall

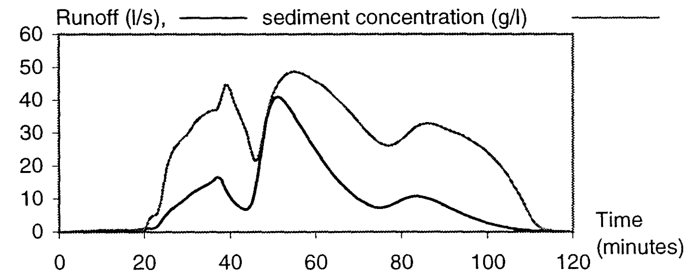


Figure 5.11c: Runoff and sediment concentration of scenario 3, winter period, 2 years frequence rainfall

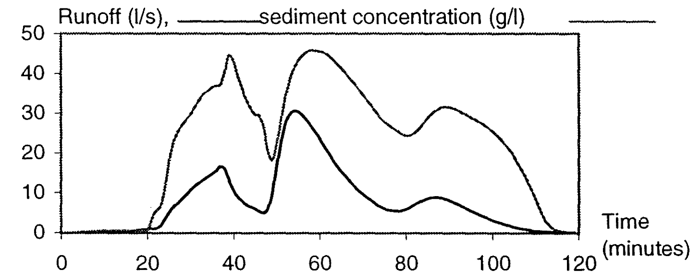


Figure 5.11d: Runoff and sediment concentration of scenario 4, winter period, 2 years frequence rainfall

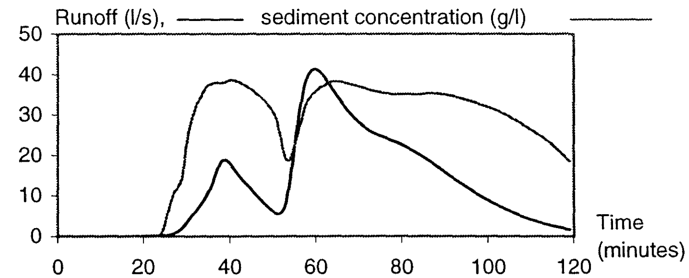


Figure 5.11e: Runoff and sediment concentration of scenario 5, winter period, 2 years frequence rainfall

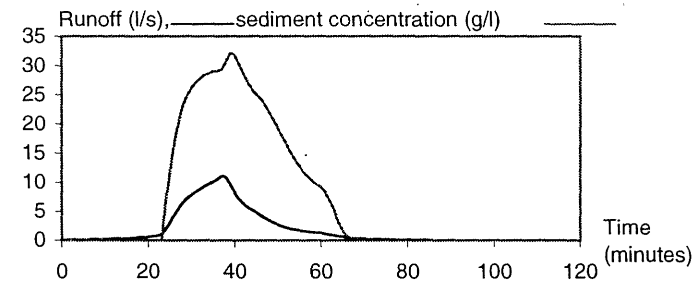


Figure 5.11f: Runoff and sediment concentration of scenario 6, winter period, 2 years frequence rainfall

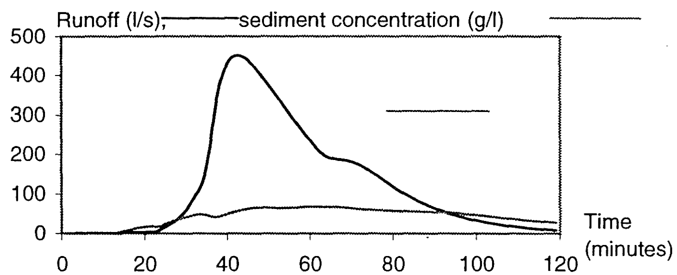


Figure 5.12a: Runoff and sediment concentration of scenario 1, winter period, 25 years frequence rainfall

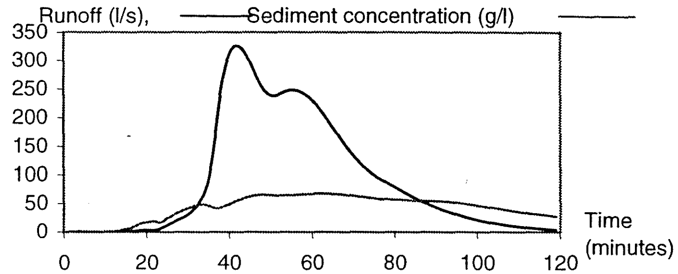


Figure 5.12b: Runoff and sediment concentration of scenario 2, winter period, 25 years frequence rainfall

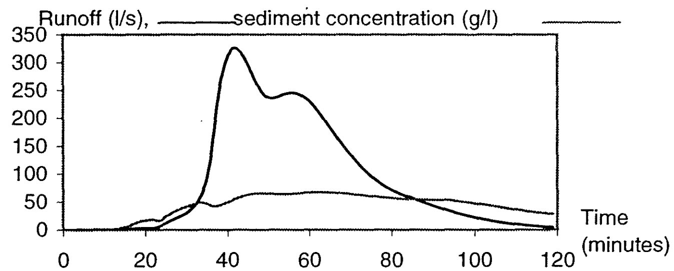


Figure 5.12c: Runoff and sediment concentration of scenario 3, winter period, 25 years frequence rainfall

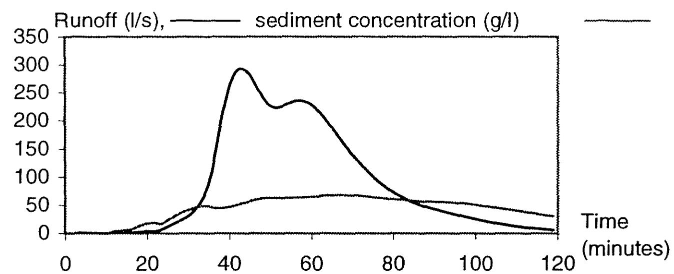


Figure 5.12d: Runoff and sediment concentration of scenario 4, winter period, 25 years frequence rainfall

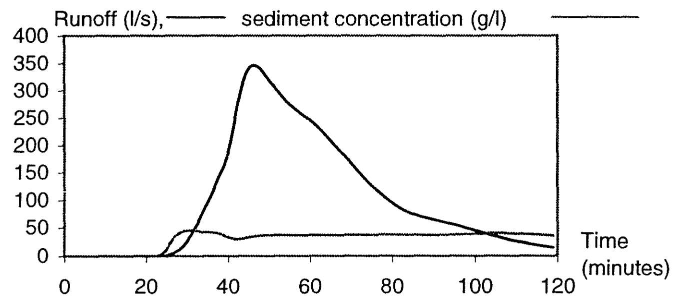


Figure 5.12e: Runoff and sediment concentration of scenario 5, winter period, 25 years frequence rainfall

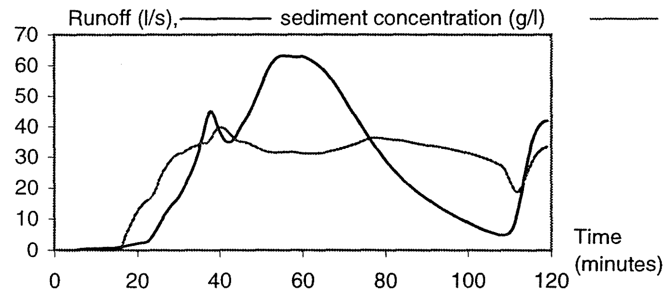


Figure 5.12f: Runoff and sediment concentration of scenario 6, winter period, 25 years frequence rainfall

## 5.6 Analysis and discussion

### 5.6.1 Recommended land use scenarios

Compared to scenario 1, scenario 2 would only lead to considerably decreased water erosion only in winter, while the water erosion situation in spring would remain exactly the same as in scenario 1. We do not think scenario 2 could meet the purpose of water and soil conservation over the years as a whole. It could be used as a emergency measure to reduce soil loss in winter.

Scenario 3 would have considerably effects on water and soil conservation, and would be more efficient than scenario 2, especially in spring. However it could not produce significant change to the landscape as a whole, since natural area is only 1.7% of the total area, it is quite small.

Scenario 4 would involve the use of natural area and grass strips. Grass strips in the field not only reduce soil erosion, but also constitute a natural element according to the concept of integration of nature and agriculture (Smeding, 1997). Grass strips provide shelter and hiding places for animals such as birds and predators, while certain wild flowers also can grow in them. Grass strips can diversify and beautify the landscape. They can be combined with natural area to form a good natural network because the spaces of these natural elements are smaller than 400 m. The combination would cover nearly 3% of total area and match the desired area for nature. However, in this network, some grass strips would still be independent, and the network would not be connected to houses, gardens, woodlands and wetlands. Scenario 4 could satisfy the purpose regarding water and soil conservation, but the potential for natural functions would not be completed used.

In scenario 5, grass strips were located beside both sides of the roads. They could also be used as natural elements. They would constitute a natural network which diversifies and beautifies the landscape. This network would be connected to other natural elements in the catchment, which means the potential for natural functions could be fully developed, even though its area is quite small. However, the locations could not change unless the locations of the roads were changed. The soil deposition on these strips would cause them to grow to a level which makes them into obstacles for agricultural activities. We have assumed that all soil deposition in catchment are averagely distributed over the grass strips only, while in fact, soil deposition does not only happen on grass strips, and distribution is not average. Whether in rain with 2 year frequency or in rain with 25 year frequency, the increase of elevation of surface over grass strips was very slightly (less than 0.94 cm a year). Therefore, land need to be levelled by more than every 20 years. In fact, this type of grass strips could not harm the agricultural activities, and it is not a temporary measure.

Scenario 6 would change the land use type totally. Its effect on water and soil conservation was the best of the six scenarios. However, it would have great agro-technical and socio-economic consequences, and may not be acceptable to the farming community.

In summary, scenarios 4, 5 and 6 could meet the aims of water and soil conservation in this catchment, and they might be used in the future. If the land has to retain its use as arable land, scenarios 4 and 5 could be used. Scenario 4 would be better than scenario 5 since it is better able to meet the main purpose, i.e., water and soil conservation.

### 5.6.2 Effects of green manure on soil and water conservation

In winter, maize, sugarbeet, scornozera and vegetable land becomes bare, and the erosion risk increases sharply. Severe soil and water loss may happen if heavy rainfall happens during this period. If green manure were introduced to cover the bare land, the risk of soil erosion could be decreased significantly.

Compared to bare land, green manure crop can cover land for 95%, leaf area index reaches 1.36, and random roughness is increased by 30.9%. Green manure enlarges the water storage capacity. The water discharge is reduced by 53.1% in light rain events, and still decreased by 27% even in heavy rainfall. Green manure increases soil cohesion by 67.2%, while crop additional cohesion rises from 0 to 1.12 KPa, and Manning's N is increased by 25%. The velocity of overland flow is decreased because of the increase in random roughness and Manning's N, so that the detachment capacity of the overland flow is decreased (Hairsine, et al, 1992). Green manure also increases protection against detachment and the catching capacity for moving soil. In light rain, green manure reduces flow detachment and soil deposition within the catchment by 42.5% and 20% respectively, increases the catching capacity by 16%. In heavy rain, flow detachment and deposition are reduced by 24.6% and 16.7% respectively. Finally, total soil loss is decreased by 62% in light rain and 28.8% in heavy rain.

Splash detachment does not change because green manure is too high to affect the rainfall's splash energy. Equation 2.15 shows that only when the crop height is below than 0.13 m, the KE (kinetic energy) of leaf drainage is smaller than 0, it can cause a significant change in the splash rate. Since the actual crop height is 0.26 m, however, the splash detachment is not really decreased.

In addition, green manure can delay the peak time of soil concentration in the water flow by near 100%, while its peak value is reduced by 22.5% in light rain and increased by 1.3% in heavy rain. Green manure also decreases the peak value of runoff, by 42% in light rain and by 27.7% in heavy rain, but it has no significant effect on the peak time of runoff. Green manure does not cause significant changes in the evolutions of runoff and soil concentration in the water flow compared to bare land.

### 5.6.3 Effects of natural area on soil and water conservation

In the catchment studied, part of the land covered with small tree, winter wheat, asparagus and Scorzonera land (Table 5.1) are changed into natural area, covering only 1.7% of the total catchment area. Since the natural area consists largely of grassland, the saturated hydraulic conductivity would be higher than that of land covered by small trees land, and the water storage capacity of the soil would be increased. The natural area would cause great increases in soil cohesion and crop additional cohesion, enhancing protection against erosion.

Natural area would reduce total water discharge by 2% to 6% in spring, but its effect would be less than 0.7% in winter. It would also decrease the sediment yield by 0.7% ~ 7%, the reductions in spring being 2% in heavy rain and 6.7% in light rain. In winter, natural area could reduce sediment yield by less than 0.7%, so there would be no significant reduction of sediment yield or total soil loss.

Nor would such an area significant reduction of splash detachment, because the reduction rate would be less than 3.5%. The crop height would be smaller than 0.13 m, so splash rate would be significantly reduced. Unfortunately, natural area would cover only 1.7% of the total area, so the total reduction in splash detachment would be less than 3.5%. However, its reduction of splash detachment would be by 0.9% ~ 2.8% more than that of green manure, even though its area is only one tenth.

The introduction of a natural area would not significantly reduce overland flow detachment in heavy rain in winter, although, it could reduce overland flow detachment by 9.7% in light rain in spring. There would be no significant reduction of soil deposition within the catchment and the catching capacity would not be considerably enhanced. In addition, natural area in the catchment studied would hardly affect the evolution process of runoff and soil concentrations in the water flow.

The small magnitude of the effects that the natural area on water and soil conservation can be explained as follows.

1. The area is quite small and is concentrated in one continuous part of the catchment (Figure 5.3), so it could only control or reduce soil erosion and water discharge over a very small area. hence its effect would be very limited.
2. 80% of natural area is located parallel to the down-slopes, weakening its effect on water and soil conservation.
3. 50% of natural area is sited at the border of the catchment, again weakening its water and soil conserving effects.

### 5.6.4 Effects of grass strip soil and water conservation

The water and soil conservation effects of grass strips depend on their direction relative to the down-slopes, the width of the grass strips and the spaces between the strips (van Dijk, et al, 1996). In the Groesbeek catchment studied, two types of grass strips were evaluated by LISEM. One type of grass strips (A) is situated in the field (See description of scenario 4), the other (B) is located on both sides of all the roads (See description of scenario 5).

Grass strips in the field can reduce total water discharge by 2.5 ~ 14.0%, while those alongside the road can decrease it by 11.3 ~ 46.8%. Type B reduces water discharge about 3 times as strongly as type A. Both types reduce discharge 2 to 4 times as much in light rain as in heavy rain, and their effects in spring are better than in winter.

As regards the reduction in total soil loss (sediment yield), type A reduces it by 4.3 ~ 22.8%, and it efficiently decreases sediment yield even in heavy rain, while type B causes a 4.8 ~ 67% reduction. It is very helpful for water and soil conservation practice that type B can reduce the sediment yield by more than 50% in both light and heavy rain in winter. The reduction of the sediment yield caused by type B is similar to the results of the previous study in Southern Limburg (Netherlands), but the effects of type A is much lower.

Just like green manure and the introduction of natural area measures, neither type of grass strips significantly reduces splash detachment. However, both type of grass strips significantly reduce overland flow detachment by 5 ~ 43%. The reduction in total soil erosion by type B is 8 ~ 35%, which is 2 to 4 times that of type A.

Type A increases the catching capacity for moving soil by 2.9 ~ 7.5% in light rain, but it yields no improvement in heavy rain, even decreasing the catching capacity by 0.2% in heavy rain in spring. Type B can strengthen the catching capacity by 12% to 19% in light rain, but just like type A, it reduce the catching capacity in heavy rain in spring by 1.8%.

Summarising, both types of grass strips would have effects on water and soil conservation, with B being more efficient than A.

The large differences between grass strips A and B can be explained as follows:

1. Unpaved road covers 4.21% of the total area, thus constituting a relatively large part of the catchment. This road has a sandy soil base (Figure 3.1). Rain water on the unpaved road cannot be stored or infiltrated into the sub-soil, so it flows from roads into fields or down the slopes, contributing to a strong water flow. Unfortunately, the soil cohesion of the unpaved roads in this catchment is quite low and there is nothing to protect the surface of the roads or to reduce the water flow and erosion. Finally, unpaved roads contribute too much water and soil to the water discharge, leading to soil loss. Type B not only store part of water and catch part of the soil washed away from the fields, but are also very helpful in storing part of the water and catching almost all of the soil washed away from unpaved roads. By contrast, type A cannot store water or catch soil washed away from unpaved roads in time. As a result, the water and soil mix into the water flow from the fields to form large water flows, thus increasing the erosion. That is why in this particular catchment, type B are more efficient for water and soil conservation than A. However, the capacities of type B to store water and catch soil washed from fields and roads is limited by their narrow strip. Type B cannot store all the water and soil washed from roads and fields in heavy rain, which explains the lower catching capacity in heavy rain.
2. The total length of type B grass strips is about 5430 m, while that of type A is only 1655 m, which means type B can control a much large area than type A.

In summary, grass strips would have considerable effects on water and soil conservation. However, since the water storage capacity of grass strips is limited, their effects on water and soil conservation would decrease sharply in heavy rain.

### 5.5.6 Effects of grassland on soil and water conservation

In the sub-catchment studied, grassland would cover 64.76% of the total area if all arable lands were converted into grassland (See scenario description). This would mean an additional 39.7 ha of grassland. Grassland greatly increases soil cohesion, crop additional cohesion, crop coverage, Manning's N, random roughness, and saturated hydraulic conductivity of some parcels (See Appendices 1, 2, 3, 4).

Comparing grassland with the current arable land system, grassland greatly reduces the total water discharge, sediment yield, soil movement and soil deposition within the catchment, and significantly increases the catching capacity for moving soil. Its effects depend on rain events and seasons.

Grassland decreases the total water discharge by 79.3 ~ 91.2%, with an average of 89.6%. The total water discharge is less than 2.8 $m^3$/ha. It reduces sediment yield by 88 ~ 96%, with an average reduction rate of 93.6%. The resulting sediment yield is 4.5 ~ 102 kg/ha.

Unlike green manure, natural area or grass strips, grassland can greatly reduce splash detachment as well as overland flow detachment. Both types of detachment would be reduced by more than 90%. As a result, total soil erosion would be reduced to less than 17 ton, which is only 6 ~ 10% of that of the current arable land system. The average of total soil erosion would be decreased to 47 ~ 244 kg/ha.

If the arable land is turned into grassland, soil deposition within the catchment would be only 6.9% of that under the current arable land system. Soil deposition would be 25.7 ~ 141.2 kg/ha. Moreover, grassland would increase the catching capacity by 13%.

Figures 5.9 to 5.12 and tables 5.7 and 5.8 show that grassland would completely change the evolution process of runoff and soil concentration in the water flow. The peak values for runoff would decreased by 81 ~ 86%, while those of the soil concentration in the water flow would be reduced by 40 ~ 60%.

Green manure and grassland would have similar effects in winter if their areas are the same.

Summarising, grassland would have excellent effects on water and soil conservation, particularly as regards the sediment yield which would be decreased to near zero. This means there would hardly be any soil erosion in grassland, even in a sandy soil area. If we compare the data obtained in the present study with those of some earlier studied, we find that the effects of grassland on sandy soil are less produced than those obtained on loess or clay soil. On the other hand, the effects on gently sloping area are better than on hilly areas.

## 5.7 Conclusions

1. On the basis of their effects on water and soil conservation, Scenarios 4, 5 and 6 are suitable for future use to address the purposes of reduction of water discharge and sediment yield, and improvement of the landscape.
2. In the catchment studied, sandy soil covers about 80% of the total area. Measures such as adding grass strips or natural area, and using green manure in winter would reduce water discharge and soil loss. However, the ideal effects on water and soil conservation, reducing water discharge to a minimum and soil loss to near zero, are difficult to reach by these means. The best effects can be achieved by changing arable land to dairy land. This would especially avoid soil loss.
3. The introduction of a natural area would have little effect on water and soil conservation, especially in winter. The small magnitude of the effects results from the small area occupied by the natural area and the fact that most of natural area is

situated in a direction parallel to down-slopes, while half of it is located at the border of the catchment.

4. Using green manure in winter can reduce water discharge, sediment yield, and soil deposition within the catchment by 20%. Green manure would also increase the catching capacity for moving soil. Its effects on water and soil conservation are close to that of an equal area of grassland.
5. Grass strips, whether located in field parcels or alongside of roads, have significant effects on water and soil conservation. They are able to reduce sediment yield, water discharge, soil movement and soil deposition by 2% to 35%, and increase the catching capacity by 2% to 20%. In the catchment studied, the effects on water and soil conservation of grass strips along both sides of roads would be better than those of grass strips located in field parcels.
6. Grassland is able to decrease water discharge, sediment yield, soil deposition and soil movement to about 10% of those of arable land. In fact, for a situation with a rainfall frequency of once every 2 years, total soil loss is less than 0.63 tons, which is virtually no soil loss at all.
7. Compared to green manure and grassland, the effects on water and soil conservation of natural area or grass strips are rather disappointing, unless large area are converted from their present use. Grass strips do, however reduce water discharge and soil erosion per unit area much more efficiently than grassland or green manure. Therefore, grass strips would be very useful in addressing the aims of water and soil conservation.
8. The grassland introduced in scenario 6 would significantly change the evolution of runoff and the soil concentration in the water flow. In spring, with light rain, the introduction of natural area of the implementation of scenario 3 would not significantly change the evolution of the runoff and the soil concentration in the water flow. Grass strips ( scenarios 4 and 5) are able to change the evolution process, but there is a significant difference between grass strips in field parcels and those alongside the roads. However, in spring, with heavy rain, the introduction of a natural area or grass strips could result in marked change in the evolution processes. In winter, the evolution processes would be similar among scenarios 2, 3, and 4, and considerably different from scenario 1. The evolution processes after the introduction of grass strips side the roads or in scenario 5 would be different from that resulting from the implementation of other measures or scenarios.
9. Scenarios 4, 5 and 6, involving measures such as grass strips and natural area have the potential to achieve water and soil conservation over long period of time. By contrast, the use of green manure is a temporary measure, which cannot reduce water discharge or soil loss during the spring period. None of the measures and scenarios discussed in the present paper would efficiently reduce erosion on the unpaved roads. The introduction of natural area or of grass strips would have some effect on the diversification of the landscape.
10. Lack of time has prevented us from developing any more scenarios. Nor were we able to study the changes in the effects on water and soil conservation of the changing the surface area and location of the natural area or the width, size and location of the grass strips. LISEM allows such parameter to be easily studied, but the simulation would take too much time. The total simulation time depends on the total area, the grid size, the number of land use types and especially the rainfall intensity.

# Chapter 6
# Utilization of LISEM in China

China is still a largely agricultural country. Nearly 80% of the total population live in the rural area, and 60% of the labor force are employed in agriculture. But China's land area of 9.6 million square kilometers has high proportion of hills, mountains, and hot, dry basins that are unsuitable for agricultural cultivation, so that only about 11 percent of the land area is under cultivation, e.g. arable land (Paul M. Howard, 1981). Part of agricultural lands is located in the tropical, and subtropical hilly areas and the loess plateau. These areas are highly prone to erosion. The population of China currently numbers nearly 1.3 billion, and about 5 ~ 10% of the food supply is covered by imports from the international market. Agriculture in China tends to intensify in order to fill the food supply gap and reduce imports. These intensive agricultural activities undoubtedly increase the risk of soil erosion, especially that of the water erosion caused by rainstorms which are frequent in these areas. One of most important aspects of policy development is therefore to define an appropriate land use system to reduce the risk of soil erosion and to maintain a reliable agricultural production.

Figure 6.1: Map of China.

Note: China has 108 million hectares of cultivated land, mostly in the Northeast, North China, and Middle-Lower Yangtze plains, the Pearl River (Zhujiang) Delta and the Sichuan Basin.

## 6.1. Rainfall and topographical characteristics of the water erosion area in China

The water erosion situation in a particular area is determined by many factors, and the process is quite complicated. However, rainfall and topographical characteristics are very important factors. The basic conditions for water erosion are that the amount and intensity of the rainfall have to be high enough to cause erosion, and that the land has to be sloping. The loess plateau area and the tropical and subtropical hilly and mountain areas all meet these basic conditions.

### 6.1.1 Rainfall characteristics

The erosive potential of a shower of rain is mainly determined by the amount of rain and the intensity of the shower. The rainfall in southern China and the Loess plateau of northern China possesses the characteristics to cause severe soil erosion.

The general characteristics of the rain pattern on the loess plateau in northern China include the following (Jiang Deqi, 1986, Zhu xiao-mo, 1988, Jing Ke, 1988):
1. The amount of rainfall is 600 mm/year in the southeastern part of the plateau and gradually decreases to 200 mm/years in the northern and northwestern parts.
2. 50% to 70% of these rainfalls in the months of July, August and September.
3. The rainfalls mostly in heavy to very heavy showers. During such showers 10 ~ 80% of the total amount of rain can fall, while the intensity can be up to 120 mm/hour.

Rainfall patterns in the tropical and sub-tropical area in southern China can be characterized as follows (Woo et al., 1997, Chen Jiazheng, 1988, Xu peng and Su Fen, 1988):
1. The spatial variation in the rainfall regime is related to the variability of the rainfall generating process in southern China. The rainfall is more than 2000 mm/year in the south-east, and decreases gradually to 1000 ~ 1200 mm/year in the western part of southern China.
2. The winter is a relatively dry season. Air flow is outward from the continent, and the prevailing dry air mass brings about low precipitation. Reversal of the monsoonal air flow begins in spring, and the frequent passage of frontal systems over southern China gives rise to frequent rain events.
3. In coastal, eastern and part of the central areas middle of southern China, heavy rainfall is frequently associated with tropical depressions and typhoon events. In the western part, heavy rainfall is frequently associated in warm and wet flow from the Indian Ocean.
4. Heavy rainfall events in southern China are confined to the period between May and September. During heavy rainfall, the highest rain intensity is frequently over 70 mm/h, and this may continue for several days.

### 6.1.2 Topographical characteristics

The loess plateau of China has a surface of 530,000 $km^2$, most of which is covered in loess, while the remaining part consists of rocky hills, mountain ranges and alluvial plains. In this area, very steep slope, with gradients exceeding 15%, are still used as arable land. Generally, two types of landscape exist in this area:

1. The actual plateau, which can be divided into two sub-types:
   1) Terrace like, gradually descending plains, with relatively light erosion The soil erosion is relative light.
   2) Flat plateaus intersected by large and deep gullies. This is steep area with very heavy soil erosion.
2. Hills, which can also be divided into two sub-types:
   1) Elongated ridges, with steep slopes and occasional deep gullies.
   2) Rounded hills, most of which have been developed into terraces for intensive agriculture.

Most of southern China consists of severely weathered hills, forming a rolling topography, with hill slopes meeting the flat valley bottoms at abrupt angles (Sheng et al., 1997). The low hills, high hills, and paddy plains form a fluctuating topography. The relative altitude of the hills ranges from less than 50 meters to over than 200 meters. Hilly areas occupy 10 ~ 40% of the total area. Most steep slopes, where the gradient is smaller than 20%, are used for agricultural cultivation due to the population pressure. About half of the hills have been developed into terraces and are intensively used as arable land.

## 6.2. Current water erosion situation in China

As indicated, the rainfall and topographical conditions met conditions for soil erosion. Soil erosion always occurs if agricultural activities are not suitable for the topographical, soil and climatic conditions and exceed the tolerance of the local ecosystem.

In China, soil erosion has been an obstacle to the agricultural and national economy. Account for 78% of the more than 200 poverty counties located in the severe soil erosion area. Water erosion mainly occurs in the sub-tropical, tropical and loess plateau areas. The process of water erosion causes soil and soil nutrition loss, and decreases soil productivity. Nowadays, the total area subject to water erosion is 1.7 million square kilometers, which is 17.7% of the total land area, and is accounted for about 642,000 km2 (about 60.8% of arable land and 37.8% of water erosion area) in cultivated land. Soil erosion has resulted in serious land degradation in many areas. Organic material may be completely lost from the soil, and in some cases the entire topsoil has disappeared, exposing the bedrock, particularly in mountainous and hilly areas. This Phenomenon is called rocky desertification, and lead to complete loss of productivity.

The main cause of the severe soil erosion is the inappropriate agricultural activities, such as overgrazing, deforestation, changing grassland into arable land, and clear cultivating methods. The high population pressure in particular forces farmers to use their land more intensively and to develop new arable land in areas which are not suitable for such uses. In these areas, therefore, the urgent tasks include changing the structure of the agricultural system and formulating optimal land use systems in order to achieve the purpose of ecologically safe agriculture. addressing this purpose requires the advanced tools to analyze the soil erosion situation and to evaluate the land use system.

## 6.3 Current utilization of LISEM in China

As discussed in Chapters 2 and 3, LISEM can be used to evaluate the effects on water and soil conservation of land use system. It is hypothesized an optional tool to pursue the above purpose in China.

LISEM is a new model, which has so far been used twice in China. A study to calibrate LISEM for the steep areas in China is in progress. A second research project, in the terraced area of China, has started. After these researches, the LISEM is expected to be utilized in China widely.

The aim of the project called "EROCHINA" is to find optimal land use and conservation strategies acceptable to both policy-makers and farming families under the present socio-economic conditions, and to improve the sustainability of land use in China. This also involves a participatory approach to soil and water conservation planning, and the integration of soil erosion modeling and land evaluation on the loess plateau in northern China. LISEM will be used as a policy-making tool to improve the sustainability of land use. The model will be extended to include gully erosion, as gullies are a familiar phenomenon on the Loess Plateau in northern China.

## 6.4 Prospects for the utilisation of LISEM in China

As indicated in chapters 2, 3 and 5, LISEM is a very helpful tool to study water erosion and to evaluate land use systems for water erosion control. In southern China, especially the eastern and coastal parts, topographical characteristics are small hills with gent slopes, and rainfall heavy and seasonal. These basic characteristics are similar to those of Limburg and Groesbeek in the Netherlands. However, soil erosion in these areas is due to intensive agriculture, and inappropriate land use systems accelerate the water erosion. The situation of soil erosion in these areas of China is more serious than that in Netherlands. LISEM may be used to evaluate and select land use systems although the difference at the soil erosion situation. Certainly, some small researches are necessary in order to get some critical figures used in LISEM, such as initial soil hydraulic pressure head.

However, for southeastern China and part of southwestern China , the use of LISEM faces some difficulties. As discussed in chapters 2 and 3, the slope will affects the roughness, the water storage of surface land, the velocity of overland flow, the detachment amount. At the terrace hilly area, it is a question for LISEM how to express the slope of terrace place and between terraces, and the grid size match the terrace and reflect the slope between two terrace play a very important role, because the soil erosion mainly occurs at the slope between terraces. According to equations 2.6 to 2.9, if the slope is not correct, the water storage is wrong. Then the results of overland flow are wrong. Finally, the simulation results are not correct.

For northern China, especially in the steep zone of the Loess plateau, as well as in southwestern China, the high hills and mountains have very steep slopes. Equations 2.6 to 2.9 are based on the gently slope of Limburg. Are they suitable for use in steep areas? So far, we are unable to confirm this.

The high population pressure in China make it necessary to pursue high yield production methods in order to match the supply of food and raw materials with the demand. How to achieve the two aims of ecological safety and high production is a major task for Chinese water and soil conservation experts. LISEM can be used to evaluate the effects on water and soil conservation measures of the current land use systems, and alternative options, but LISEM cannot evaluate the productivity of land, production of crop systems, and agro- and socio-economy. It means LISEM could not be used independently to optimize land use systems for Chinese situation. Other research approaches such as Multiple Goal Linear Programming are necessary.

## 6.5 Discussion

Due to the complex topographical and climatic conditions, LISEM can be directly used in some places of China, especially in gently sloping areas. However, in other parts of China, such as terraced areas and steep zones, it will be necessary to calibrate and modify LISEM before it can be widely used in China.

Due to the special socioeconomic conditions of China, LISEM by itself cannot completely solve China's problems of water and soil conservation. It could be perfected if it can be connected to other models, so that it not only evaluate the water erosion, but also evaluate the ecological, sociological aspects. LISEM can provide the spatial data on soil erosion, which is very important in formulating the appropriate land use system, and different land use types and management measures can be introduced according to the soil erosion situation in order to achieve the highest production as well as the lowest erosion.

So far, LISEM can only simulate the soil erosion situation during a single rain event, it is difficult to use this model to evaluate the effects of land use systems on water and soil conservation over long periods such as one year or one growth cycling. If it can be connected with crop growth and evaporation simulation programs, it can be used to evaluation the water and soil conservation capacity of land use systems over long time. The results of evaluation is more reliable than that of only one rain event.

# Appendices

**Appendix 1:** Saturated Conductivity by constant water head method (unit: cm/d)

| Land use | Soil types | First July | First July | average | August 6 | August 6 | average |
|---|---|---|---|---|---|---|---|
| Sugar-beet | Sand | 267.92 | 360.43 | 314.18 | 509.82 | 397.40 | 453.61 |
| | Loess | 402.89 | 135.34 | 269.12 | 0.641 | | 0.641 |
| Maize | Sand | 952.44 | 1083.37 | 1017.91 | 981.94 | | 981.94 |
| | Loess | 66.13 | 96.98 | 81.56 | 6.16 | 7.47 | 6.82 |
| Grass | Sand | 261.05 | 319.70 | 290.38 | 8.02 | 13.12 | 10.57 |
| | Loess | 31.85 | 30.02 | 30.94 | 4.08 | 23.85 | 13.97 |
| Tree | Loess | 230.11 | 96.12 | 163.12 | 72.31 | 65.28 | 68.80 |
| Wheat | Sand | 192.06 | 365.06 | 278.56 | 85.11 | | 85.11 |
| Potato | Loess | | | | 98.35 | 70.22 | 79.79 |
| Bare soil | Loess | | | | 200.19 | 269.71 | 234.95 |

(continue)

| Land use | Soil types | September 23 | September 23 | average |
|---|---|---|---|---|
| Wheat | Sand | 126.21 | 92.12 | 109.17 |
| | Loess | 174.17 | 40.14 | 107.16 |
| Bean | Loess | 60.19 | 65.21 | 62.70 |

**Appendix 2:** Soil hydraulic physics data

| Crop (land use) | Date | Theta-R ($cm^3/cm^3$) | Theta-S ($cm^3/cm$) | Alpha | n | l | Ks (cm/d) | Table | Note |
|---|---|---|---|---|---|---|---|---|---|
| Sugar-beet | 17/6 | 0.01 | 0.37 | 0.0324 | 1.496 | -2.299 | 136.882 | b-1a | |
| (sand soil) | 17/6 | 0.01 | 0.38 | 0.0199 | 1.624 | -1.000 | 100.000 | b-1b | |
| Sugar-beet | 17/6 | 0.01 | 0.409 | 0.0042 | 1.650 | -0.406 | 42.348 | b-2a | |
| (loess soil) | 17/6 | 0.01 | 0.400 | 0.0039 | 1.815 | -1.000 | 12.383 | b-2b | |
| Maize | 17/6 | 0.01 | 0.357 | 0.0107 | 1.945 | -1.000 | 28.388 | m-2a | |
| (loess soil) | 17/6 | 0.01 | 0.417 | 0.0111 | 1.574 | -0.286 | 11.196 | m-2b | |
| Bean | 6/8 | 0.000 | 0.362 | 0.0092 | 1.722 | -1.000 | 30.000 | Bean1a | |
| (loess soil) | 6/8 | 0.01 | 0.384 | 0.0199 | 1.484 | -2.736 | 79.681 | Bean1b | |
| Tree | 17/6 | 0.01 | 0.370 | 0.0184 | 1.669 | -2.336 | 43.648 | t-1a | |
| (sand soil) | 17/6 | 0.01 | 0.427 | 0.0459 | 1.415 | -3.471 | 74.138 | t-1b | |
| Wheat | 17/6 | 0.01 | 0.445 | 0.0395 | 1.439 | -2.829 | 127.281 | wp-1a | |
| (sand soil) | 17/6 | 0.01 | 0.400 | 0.0354 | 1.446 | -1.000 | 238.055 | wp-1b | |
| Maize | 6/8 | 0.02 | 0.310 | 0.0128 | 1.771 | -2.356 | 29.094 | m-p2a | |
| (loess soil) | 6/8 | 0.10 | 0.440 | 0.0104 | 1.789 | -1.789 | 34.631 | m-p2b | |
| | 6/8 | 0.05 | 0.430 | 0.0171 | 1.509 | -3.337 | 8.946 | m-p2c | |
| Maize | 6/8 | 0.10 | 0.384 | 0.0085 | 1.513 | -2.877 | 21.597 | m-s2a | 12~20 cm |
| (loess soil) | 6/8 | 0.10 | 0.345 | 0.0062 | 1.972 | -2.103 | 13.791 | m-s2b | 12~20 cm |
| Wheat | 6/8 | 0.05 | 0.425 | 0.386 | 1.430 | -1.202 | 143.263 | w-1b | |
| (sand soil) | 6/8 | 0.05 | 0.415 | 0.391 | 1.425 | -2.751 | 230.450 | w-1a | |
| Maize | 6/8 | 0.10 | 0.375 | 0.0062 | 1.957 | -2.526 | 24.980 | m-d2a | 50~58 cm |
| (loess soil) | 6/8 | 0.10 | 0.320 | 0.0035 | 2.781 | -1.736 | 9.792 | m-d2b | 50~58 cm |
| Wheat | 23/9 | 0.10 | 0.410 | 0.0041 | 2.021 | -2.294 | 6.841 | ww-2a | Harvested |
| (loess soil) | 23/9 | 0.10 | 0.380 | 0.0031 | 2.082 | -0.333 | 6.711 | ww-2b | Harvested |
| Potato | 23/9 | 0.10 | 0.437 | 0.0042 | 1.839 | -0.747 | 11.983 | Pw-a | Harvested |
| (loess soil) | 23/9 | 0.10 | 0.425 | 0.0035 | 1.782 | -0.568 | 12.655 | Pw-b | Harvested |
| Grot2 | 23/9 | 0.10 | 0.374 | 0.0025 | 2.111 | 0.000 | 9.544 | Grpt2c | 45~53 cm |
| (loess soil) | 23/9 | 0.10 | 0.390 | 0.0033 | 2.005 | -0.897 | 10.139 | Grot2d | 45~53 cm |
| Grob13 | 23/9 | 0.10 | 0.435 | 0.0054 | 1.816 | 0.500 | 10.000 | Grpb1a | 5~13 cm |
| (loess soil) | 23/9 | 0.10 | 0.420 | 0.0035 | 2.082 | -0.235 | 12.470 | Grob1b | 5~13 cm |
| Wheat (sand soil) | 23/9 | 0.05 | 0.430 | 0.0142 | 2.357 | -2.141 | 17.010 | ww-1a | Harvested |
| Bean (loess soil) | 23/9 | 0.03 | 0.400 | 0.0166 | 1.783 | -2.566 | 28.337 | Beanwa | Harvested |
| Bare (sand soil) | 23/9 | 0.05 | 0.338 | 0.103 | 2.277 | -1.915 | 31.531 | Bareb | |
| Sand soil | | 0.02 | 0.38 | 0.0214 | 2.075 | 0.039 | 15.56 | sandd | Sub and deep soil |
| Forest | 23/9 | 0.10 | 0.580 | 0.0154 | 1.820 | -0.677 | 58.263 | f-1a | |
| | 23/9 | 0.10 | 0.580 | 0.0154 | 1.820 | -0.677 | 58.263 | f-1b | |

Note: Data presented in this table are results from Appia that use data from evaporation method to fix hydraulic characteristics of soil.

**Appendix 3:** The soil and crop variables data for September/October (or for calibration)

| Land use types (crops) | Code of land use types | Soil types | Soil cohesion (Kpa) | Crop additional cohesion (Kpa) | D50 (μm) | Code of soil profile tpyes | Stone fraction | Code of tractor wheel track profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 3.32 | 3.32 | 222.5 | 41 | 0 | 19 |
| | 1 | 3 | 3.32 | 3.32 | 122.0 | 42 | 0 | 20 |
| Maize | 2 | 2 | 1.34 | 0.00 | 222.5 | 43 | 0 | 19 |
| | 2 | 3 | 1.34 | 0.00 | 122.0 | 44 | 0 | 20 |
| Vegetable | 3 | 2 | 1.50 | 0.75 | 222.5 | 45 | 0 | 19 |
| | 3 | 3 | 1.50 | 0.75 | 122.0 | 46 | 0 | 20 |
| Trees | 4 | 2 | 2.70 | 2.03 | 222.5 | 47 | 0 | 19 |
| | 4 | 3 | 3.73 | 2.80 | 122.0 | 48 | 0 | 20 |
| Winter wheat | 5 | 2 | 1.34 | 0.00 | 222.5 | 1 | 0 | 19 |
| | 5 | 3 | 1.34 | 0.00 | 122.0 | 50 | 0 | 20 |
| Asparagus | 6 | 2 | 1.87 | 1.40 | 222.5 | 45 | 0 | 19 |
| | 6 | 3 | 1.87 | 1.40 | 122.0 | 46 | 0 | 20 |
| Scorzonera | 7 | 2 | 1.50 | 0.75 | 222.5 | 45 | 0 | 19 |
| | 7 | 3 | 1.50 | 0.51 | 122.0 | 46 | 0 | 20 |
| Carrots | 8 | 2 | 1.50 | 0.75 | 222.5 | 45 | 0 | 19 |
| | 8 | 3 | 1.50 | 0.75 | 122.0 | 46 | 0 | 20 |
| Sugar-beet | 9 | 2 | 1.50 | 0.75 | 222.5 | 45 | 0 | 19 |
| | 9 | 3 | 1.50 | 0.75 | 122.0 | 46 | 0 | 20 |
| Build up area | 10 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 10 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Grass | 11 | 2 | 3.32 | 3.32 | 222.5 | 41 | 0 | 19 |
| | 11 | 3 | 3.32 | 3.32 | 122.0 | 42 | 0 | 20 |
| Others | 12 | 2 | 3.32 | 3.32 | 222.5 | 41 | 0 | 19 |
| | 12 | 3 | 3.32 | 3.32 | 122.0 | 42 | 0 | 20 |
| Garden | 13 | 2 | 3.32 | 3.32 | 222.5 | 41 | 0 | 19 |
| | 13 | 3 | 3.32 | 3.32 | 122.0 | 42 | 0 | 20 |
| Unpaved road | 14 | 2 | 3.32 | 3.32 | 222.5 | 15 | 0 | 19 |
| | 14 | 3 | 3.32 | 3.32 | 122.0 | 16 | 0 | 20 |
| Paved road | 15 | 2 | 9999 | 9999 | 222.5 | 17 | 0 | 19 |
| | 15 | 3 | 9999 | 9999 | 122.0 | 18 | 0 | 20 |
| Bush | 16 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 16 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Potato/bean | 17 | 2 | 1.00 | 0.00 | 222.5 | 3 | 0 | 19 |
| | 17 | 3 | 1.00 | 0.00 | 122.0 | 32 | 0 | 20 |
| Potato | 18 | 2 | 1.00 | 0.00 | 222.5 | 3 | 0 | 19 |
| | 18 | 3 | 1.00 | 0.00 | 122.0 | 32 | 0 | 20 |
| Forest | 19 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 19 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Natural area | 20 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 20 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |
| Grass strip | 21 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 21 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |

The soil and crop variables data for May/June period, all scenarios

| Land use types (crops) | Code of land use types | Soil types | Soil cohesion (Kpa) | Crop additional cohesion (Kpa) | D50 (μm) | Code of soil profile types | Stone fraction | Code of tractor wheel track profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 1 | 3 | 3.32 | 3.32 | 122.0 | 2 | 0 | 20 |
| Maize | 2 | 2 | 1.00 | 0.25 | 222.5 | 3 | 0 | 19 |
| | 2 | 3 | 0.88 | 0.22 | 122.0 | 4 | 0 | 20 |
| Vegetable | 3 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 3 | 3 | 0.59 | 0.30 | 122.0 | 4 | 0 | 20 |
| Trees | 4 | 2 | 2.70 | 0.68 | 222.5 | 7 | 0 | 19 |
| | 4 | 3 | 0.93 | 0.23 | 122.0 | 8 | 0 | 20 |
| Winter wheat | 5 | 2 | 1.10 | 0.83 | 222.5 | 1 | 0 | 19 |
| | 5 | 3 | 1.00 | 0.75 | 122.0 | 10 | 0 | 20 |
| Asparagus | 6 | 2 | 1.00 | 0.50 | 222.5 | 1 | 0 | 19 |
| | 6 | 3 | 1.00 | 0.50 | 122.0 | 10 | 0 | 20 |
| Scorzonera | 7 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 7 | 3 | 0.59 | 0.30 | 122.0 | 4 | 0 | 20 |
| Carrots | 8 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 8 | 3 | 0.59 | 0.30 | 122.0 | 4 | 0 | 20 |
| Sugar-beet | 9 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 9 | 3 | 0.59 | 0.30 | 122.0 | 4 | 0 | 20 |
| Build up area | 10 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 10 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Grass | 11 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 11 | 3 | 3.32 | 3.32 | 122.0 | 28 | 0 | 20 |
| Others | 12 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 12 | 3 | 3.32 | 3.32 | 122.0 | 28 | 0 | 20 |
| Garden | 13 | 2 | 3.32 | 3.32 | 222.5 | 25 | 0 | 19 |
| | 13 | 3 | 3.32 | 3.32 | 122.0 | 26 | 0 | 20 |
| Unpaved road | 14 | 2 | 3.00 | 0.00 | 222.5 | 15 | 0 | 19 |
| | 14 | 3 | 3.00 | 0.00 | 122.0 | 16 | 0 | 20 |
| Paved road | 15 | 2 | 9999 | 9999 | 222.5 | 17 | 0 | 19 |
| | 15 | 3 | 9999 | 9999 | 122.0 | 18 | 0 | 20 |
| Bush | 16 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 16 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Potato/bean | 17 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 17 | 3 | 1.00 | 0.50 | 122.0 | 4 | 0 | 20 |
| Potato | 18 | 2 | 1.00 | 0.50 | 222.5 | 3 | 0 | 19 |
| | 18 | 3 | 1.00 | 0.50 | 122.0 | 4 | 0 | 20 |
| Forest | 19 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 19 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Natural area | 20 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 20 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |
| Grass strip | 21 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 21 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |

The soil and crop variable data for Winter period, scenarios 1, 5 and 6

| Land use types (crops) | Code of land use types | Soil types | Soil cohesion (Kpa) | Crop additional cohesion (Kpa) | D50 (μm) | Code of tractor wheel track profile types | Stone fraction | Code of soil profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 1 |
| | 1 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 2 |
| Bare | 2 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 2 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Vegetable | 3 | 2 | 1.50 | 0.75 | 222.5 | 19 | 0 | 3 |
| | 3 | 3 | 1.50 | 0.75 | 122.0 | 20 | 0 | 32 |
| Trees | 4 | 2 | 2.70 | 2.03 | 222.5 | 19 | 0 | 7 |
| | 4 | 3 | 3.73 | 2.80 | 122.0 | 20 | 0 | 8 |
| Winter wheat | 5 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 1 |
| | 5 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 10 |
| Asparagus | 6 | 2 | 1.87 | 1.40 | 222.5 | 19 | 0 | 1 |
| | 6 | 3 | 1.87 | 1.40 | 122.0 | 20 | 0 | 34 |
| Bare | 7 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 7 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Bare | 8 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 8 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Bare | 9 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 9 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Build up area | 10 | 2 | 2.35 | 1.76 | 222.5 | 19 | 0 | 25 |
| | 10 | 3 | 2.35 | 1.76 | 122.0 | 20 | 0 | 26 |
| Grass | 11 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 1 |
| | 11 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 28 |
| Others | 12 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 1 |
| | 12 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 28 |
| Garden | 13 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 25 |
| | 13 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 26 |
| Unpaved road | 14 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 15 |
| | 14 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 16 |
| Paved road | 15 | 2 | 9999 | 9999 | 222.5 | 19 | 0 | 17 |
| | 15 | 3 | 9999 | 9999 | 122.0 | 20 | 0 | 18 |
| Bush | 16 | 2 | 2.35 | 1.76 | 222.5 | 19 | 0 | 25 |
| | 16 | 3 | 2.35 | 1.76 | 122.0 | 20 | 0 | 26 |
| Bare | 17 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 17 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Bare | 18 | 2 | 1.34 | 0.00 | 222.5 | 19 | 0 | 3 |
| | 18 | 3 | 1.34 | 0.00 | 122.0 | 20 | 0 | 32 |
| Forest | 19 | 2 | 2.35 | 1.76 | 222.5 | 19 | 0 | 25 |
| | 19 | 3 | 2.35 | 1.76 | 122.0 | 20 | 0 | 26 |
| Natural area | 20 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 1 |
| | 20 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 30 |
| Grass strip | 21 | 2 | 3.32 | 3.32 | 222.5 | 19 | 0 | 1 |
| | 21 | 3 | 3.32 | 3.32 | 122.0 | 20 | 0 | 30 |

The soil and crop variable data for Winter period, scenarios 2, 3 and 4:

| Land use types (crops) | Code of land use types | Soil types | Soil cohesion (Kpa) | Crop additional cohesion (Kpa) | D50 (μm) | Code of soil profile type | Stone fraction | Code of tractor wheel track profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 1 | 3 | 3.32 | 3.32 | 122.0 | 2 | 0 | 20 |
| Green manure | 2 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 2 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Vegetable | 3 | 2 | 1.50 | 0.75 | 222.5 | 1 | 0 | 19 |
| | 3 | 3 | 1.50 | 0.75 | 122.0 | 36 | 0 | 20 |
| Trees | 4 | 2 | 2.70 | 2.03 | 222.5 | 7 | 0 | 19 |
| | 4 | 3 | 3.73 | 2.80 | 122.0 | 8 | 0 | 20 |
| Winter wheat | 5 | 2 | 1.34 | 0.00 | 222.5 | 1 | 0 | 19 |
| | 5 | 3 | 1.34 | 0.00 | 122.0 | 10 | 0 | 20 |
| Asparagus | 6 | 2 | 1.87 | 1.40 | 222.5 | 1 | 0 | 19 |
| | 6 | 3 | 1.87 | 1.40 | 122.0 | 34 | 0 | 20 |
| Green manure are | 7 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 7 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Green manure | 8 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 8 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Green manure | 9 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 9 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Build up area | 10 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 10 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Grass | 11 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 11 | 3 | 3.32 | 3.32 | 122.0 | 28 | 0 | 20 |
| Others | 12 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 12 | 3 | 3.32 | 3.32 | 122.0 | 28 | 0 | 20 |
| Garden | 13 | 2 | 3.32 | 3.32 | 222.5 | 25 | 0 | 19 |
| | 13 | 3 | 3.32 | 3.32 | 122.0 | 26 | 0 | 20 |
| Unpaved road | 14 | 2 | 3.32 | 3.32 | 222.5 | 15 | 0 | 19 |
| | 14 | 3 | 3.32 | 3.32 | 122.0 | 16 | 0 | 20 |
| Paved road | 15 | 2 | 9999 | 9999 | 222.5 | 17 | 0 | 19 |
| | 15 | 3 | 9999 | 9999 | 122.0 | 18 | 0 | 20 |
| Bush | 16 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 16 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Green manure | 17 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 17 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Green manure | 18 | 2 | 2.24 | 1.12 | 222.5 | 1 | 0 | 19 |
| | 18 | 3 | 2.24 | 1.12 | 122.0 | 36 | 0 | 20 |
| Forest | 19 | 2 | 2.35 | 1.76 | 222.5 | 25 | 0 | 19 |
| | 19 | 3 | 2.35 | 1.76 | 122.0 | 26 | 0 | 20 |
| Natural area | 20 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 20 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |
| Grass strip | 21 | 2 | 3.32 | 3.32 | 222.5 | 1 | 0 | 19 |
| | 21 | 3 | 3.32 | 3.32 | 122.0 | 30 | 0 | 20 |

**Appendix 4:** The crop variables data used in LISEM

The crop variable data for September/October period (or calibration)

| Land use types (crops) | Land use Code | Crop LAI | Crop coverage | Crop height (m) | Manning's N | Roughness (cm) | Road width (m) | Tractor wheel width (m) |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 1.86 | 0.95 | 0.05 | 207 | 0.99 | 0 | 0.0 |
| Maize | 2 | 0.00 | 0.00 | 0.00 | 120 | 0.97 | 0 | 0.0 |
| Vegetable | 3 | 2.89 | 0.80 | 0.34 | 127 | 1.32 | 0 | 0.00 |
| Trees | 4 | 2.60 | 0.45 | 0.62 | 264 | 0.97 | 0 | 1.50 |
| Winter wheat | 5 | 0.00 | 0.00 | 0.00 | 264 | 3.37 | 0 | 0.0 |
| Asparagus | 6 | 1.00 | 0.40 | 1.65 | 138 | 8.16 | 0 | 1.125 |
| Scorzonera | 7 | 2.89 | 0.80 | 0.34 | 124 | 1.32 | 0 | 0.64 |
| Carrot | 8 | 0.68 | 0.20 | 0.109 | 124 | 1.32 | 0 | 0.64 |
| Sugar-beet | 9 | 2.89 | 0.80 | 0.34 | 124 | 1.32 | 0 | 0.64 |
| Build up area | 10 | 11.0 | 0.95 | 15.0 | 300 | 1.36 | 0 | 0.0 |
| Grassland | 11 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Others | 12 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Garden | 13 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 4.0 | 0.0 |
| Unpaved road | 14 | 1.50 | 0.75 | 0.05 | 259 | 0.99 | 4.5 | 0.0 |
| Paved road | 15 | 0.0 | 0.0 | 0.0 | 10 | 0.05 | 0 | 0.0 |
| Bush | 16 | 11.0 | 0.95 | 5.0 | 300 | 1.36 | 0 | 0.0 |
| Potato/bean | 17 | 2.89 | 0.95 | 0.30 | 118 | 1.32 | 0 | 0.23 |
| Potato | 18 | 0.0 | 0.0 | 0.0 | 264 | 3.37 | 0 | 0.00 |
| Forest | 19 | 11.0 | 0.95 | 15.0 | 300 | 1.36 | 0 | 0.0 |
| Natural area | 20 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Grass strip | 21 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |

The crop variable data for May/June periods, all scenarios:

| Land use types (crops) | Land use Code | Crop LAI | Crop coverage | Crop height (m) | Manning's N | Roughness (cm) | Road width (m) | Tractor wheel width (m) |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 0 | 0.0 |
| Maize | 2 | 0.11 | 0.03 | 0.09 | 80 | 0.64 | 0 | 1.125 |
| Vegetable | 3 | 0.19 | 0.10 | 0.09 | 115 | 0.40 | 0 | 0.00 |
| Trees | 4 | 2.60 | 0.45 | 0.62 | 120 | 0.97 | 0 | 1.50 |
| Winter wheat | 5 | 1.08 | 0.35 | 0.35 | 123 | 0.90 | 0 | 0.24 |
| Asparagus | 6 | 0.00 | 0.00 | 0.00 | 135 | 8.16 | 0 | 0.23 |
| Scorzorrera | 7 | 0.19 | 0.10 | 0.09 | 115 | 0.40 | 0 | 0.64 |
| Carrot | 8 | 0.19 | 0.10 | 0.09 | 115 | 0.40 | 0 | 0.64 |
| Sugar-beet | 9 | 0.19 | 0.10 | 0.09 | 115 | 0.40 | 0 | 0.64 |
| Build up area | 10 | 11.0 | 0.95 | 15.0 | 300 | 1.36 | 0 | 0.0 |
| Grassland | 11 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 0 | 0.0 |
| Others | 12 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 0 | 0.0 |
| Garden | 13 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 4.0 | 0.0 |
| Unpaved road | 14 | 1.50 | 0.75 | 0.05 | 120 | 0.20 | 4.5 | 0.0 |
| Paved road | 15 | 0.0 | 0.0 | 0.0 | 10 | 0.05 | 0 | 0.0 |
| Bush | 16 | 11.0 | 0.95 | 5.0 | 300 | 1.36 | 0 | 0.0 |
| Potato/bean | 17 | 0.05 | 0.03 | 0.03 | 135 | 8.16 | 0 | 0.23 |
| Potato | 18 | 0.05 | 0.03 | 0.03 | 135 | 8.16 | 0 | 0.23 |
| Forest | 19 | 11.0 | 0.95 | 15.0 | 300 | 1.36 | 0 | 0.0 |
| Natural area | 20 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 0 | 0.0 |
| Grass strip | 21 | 1.86 | 0.95 | 0.05 | 227 | 0.70 | 0 | 0.0 |

The crop variable data for winter period of scenarios 1, 5 and 6

| Land use types (crops) | Land use Code | Crop LAI | Crop coverage | Crop height (m) | Manning's N | Roughness (cm) | Road width (m) | Tractor wheel width (m) |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Bare | 2 | 0.00 | 0.00 | 0.00 | 120 | 0.97 | 0 | 0.0 |
| Vegetable | 3 | 0.05 | 0.01 | 0.50 | 264 | 3.37 | 0 | 0.0 |
| Trees | 4 | 2.60 | 0.45 | 0.62 | 120 | 0.97 | 0 | 1.50 |
| Winter wheat | 5 | 0.05 | 0.02 | 0.01 | 127 | 1.10 | 0 | 0.24 |
| Asparagus | 6 | 0.50 | 0.20 | 1.65 | 138 | 1.32 | 0 | 1.125 |
| Bare | 7 | 0.00 | 0.00 | 0.00 | 120 | 0.97 | 0 | 0.00 |
| Bare | 8 | 0.00 | 0.00 | 0.00 | 120 | 0.97 | 0 | 0.00 |
| Bare | 9 | 0.00 | 0.00 | 0.00 | 120 | 0.97 | 0 | 0.00 |
| Build up area | 10 | 5.0 | 0.70 | 15.0 | 225 | 0.99 | 0 | 0.0 |
| Grassland | 11 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Others | 12 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Garden | 13 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 4.0 | 0.0 |
| Unpaved road | 14 | 1.50 | 0.75 | 0.05 | 120 | 0.20 | 4.5 | 0.0 |
| Paved road | 15 | 0.0 | 0.0 | 0.0 | 60 | 0.05 | 0 | 0.0 |
| Bush | 16 | 5.0 | 0.70 | 5.0 | 225 | 1.36 | 0 | 0.0 |
| Bare | 17 | 0.0 | 0.0 | 0.0 | 120 | 0.97 | 0 | 0.0 |
| Bare | 18 | 0.0 | 0.0 | 0.0 | 120 | 0.97 | 0 | 0.0 |
| Forest | 19 | 5.0 | 0.70 | 15.0 | 225 | 1.36 | 0 | 0.0 |
| Natural area | 20 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Grass strip | 21 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |

The crop variable data for winter period of scenarios 2, 3, and 4

| Land use types (crops) | Land use Code | Crop LAI | Crop coverage | Crop height (m) | Manning's N | Roughness (cm) | Road width (m) | Tractor wheel width (m) |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Green manure | 2 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Vegetable | 3 | 0.05 | 0.01 | 0.50 | 264 | 3.37 | 0 | 0.0 |
| Trees | 4 | 2.60 | 0.45 | 0.62 | 120 | 0.97 | 0 | 1.50 |
| Winter wheat | 5 | 0.05 | 0.02 | 0.01 | 127 | 1.10 | 0 | 0.24 |
| Asparagus | 6 | 0.50 | 0.20 | 1.65 | 138 | 1.32 | 0 | 1.125 |
| Green manure | 7 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Green manure | 8 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Green manure | 9 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Build up area | 10 | 5.0 | 0.70 | 15.0 | 225 | 0.99 | 0 | 0.0 |
| Grassland | 11 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Others | 12 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Garden | 13 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 4.0 | 0.0 |
| Unpaved road | 14 | 1.50 | 0.75 | 0.05 | 120 | 0.20 | 4.5 | 0.0 |
| Paved road | 15 | 0.0 | 0.0 | 0.0 | 60 | 0.05 | 0 | 0.0 |
| Bush | 16 | 5.0 | 0.70 | 5.0 | 225 | 1.36 | 0 | 0.0 |
| Green manure | 17 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Green manure | 18 | 1.36 | 0.55 | 0.26 | 150 | 1.27 | 0 | 0.64 |
| Forest | 19 | 5.0 | 0.70 | 15.0 | 225 | 1.36 | 0 | 0.0 |
| Natural area | 20 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |
| Grass strip | 21 | 1.86 | 0.95 | 0.05 | 259 | 0.99 | 0 | 0.0 |

**Appendix 5:** Soil physical data

Sample of soil physical table (First column is soil moisture content in $cm^3/cm^3$; second column is pressure head in cm and negative values; third column is hydraulic conductivity in cm/day):

| | | |
|---|---|---|
| 0.010 | -1.1E+0009 | 3.8E-0017 |
| 0.020 | -1.6E+0004 | 3.8E-0006 |
| 0.030 | -5.4E+0003 | 6.9E-0005 |
| 0.040 | -2.8E+0003 | 3.8E-0004 |
| 0.050 | -1.8E+0003 | 1.3E-0003 |
| 0.060 | -1.2E+0003 | 3.3E-0003 |
| 0.070 | -9.2E+0002 | 7.1E-0003 |
| 0.080 | -7.2E+0002 | 1.4E-0002 |
| 0.090 | -5.8E+0002 | 2.4E-0002 |
| 0.100 | -4.8E+0002 | 3.9E-0002 |
| 0.110 | -4.0E+0002 | 6.2E-0002 |
| 0.120 | -3.4E+0002 | 9.2E-0002 |
| 0.130 | -3.0E+0002 | 1.3E-0001 |
| 0.140 | -2.6E+0002 | 1.9E-0001 |
| 0.150 | -2.3E+0002 | 2.6E-0001 |
| 0.160 | -2.0E+0002 | 3.5E-0001 |
| 0.170 | -1.8E+0002 | 4.7E-0001 |
| 0.180 | -1.6E+0002 | 6.1E-0001 |
| 0.190 | -1.4E+0002 | 7.9E-0001 |
| 0.200 | -1.3E+0002 | 1.0E+0000 |
| 0.210 | -1.2E+0002 | 1.3E+0000 |
| 0.220 | -1.1E+0002 | 1.6E+0000 |
| 0.230 | -9.6E+0001 | 2.0E+0000 |
| 0.240 | -8.7E+0001 | 2.4E+0000 |
| 0.250 | -7.9E+0001 | 3.0E+0000 |
| 0.260 | -7.2E+0001 | 3.7E+0000 |
| 0.270 | -6.5E+0001 | 4.5E+0000 |
| 0.280 | -5.8E+0001 | 5.5E+0000 |
| 0.290 | -5.2E+0001 | 6.7E+0000 |
| 0.300 | -4.7E+0001 | 8.1E+0000 |
| 0.310 | -4.1E+0001 | 9.9E+0000 |
| 0.320 | -3.6E+0001 | 1.2E+0001 |
| 0.330 | -3.1E+0001 | 1.5E+0001 |
| 0.340 | -2.6E+0001 | 1.9E+0001 |
| 0.350 | -2.1E+0001 | 2.3E+0001 |
| 0.360 | -1.6E+0001 | 3.1E+0001 |
| 0.370 | -1.0E+0001 | 4.2E+0001 |
| 0.380 | 0.0E+0000 | 2.1E+0002 |

Note: The conductivity in last line is saturated conductivity from table below that is calculated by equation 3.10.

Name of soil physical input tables and saturated conductivity in tables for September/October (or calibration):

| Crop (land use) | Code of land use | Soil types | 0 ~10 cm soil layer * | 10 ~30 cm soil layer * | 30 ~100 cm soil layer * | 100-150cm soil layer * | 150-200cm soil layer * | Code of soil profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 210,g-1at.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 41 |
| | 1 | 3 | 192, g-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 42 |
| Maize | 2 | 2 | 47, ww-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 43 |
| | 2 | 3 | 40, ww-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 44 |
| Vegetable | 3 | 2 | 210, b-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 45 |
| | 3 | 3 | 78, b-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 46 |
| Trees | 4 | 2 | 72, t-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 47 |
| | 4 | 3 | 22, t-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 48 |
| Winter wheat | 5 | 2 | 190,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 5 | 3 | 61, spwwsc.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 50 |
| Asparagus | 6 | 2 | 210, b-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 45 |
| | 6 | 3 | 78, b-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 46 |
| Scorzonera | 7 | 2 | 242, b-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 45 |
| | 7 | 3 | 28, b-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 46 |
| Carrots | 8 | 2 | 242, b-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 45 |
| | 8 | 3 | 28, b-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 46 |
| Sugar-beet | 9 | 2 | 242, b-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 45 |
| | 9 | 3 | 28, b-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 46 |
| Build up area | 10 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 10 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grassland | 11 | 2 | 210,g-1at.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 41 |
| | 11 | 3 | 192, g-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 42 |
| Others | 12 | 2 | 210,g-1at.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 41 |
| | 12 | 3 | 192, g-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 42 |
| Garden | 13 | 2 | 210,g-1at.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 41 |
| | 13 | 3 | 192, g-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 42 |
| Unpaved road | 14 | 2 | 10, r-r1.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 15 |
| | 14 | 3 | 5, r-r2.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 16 |
| Paved road | 15 | 2 | 0, bouw.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 17 |
| | 15 | 3 | 0, bouw.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 18 |
| Bush | 16 | 2 | 78, busha.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 16 | 3 | 22, bushb.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Potato/bean | 17 | 2 | 80, bean1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 17 | 3 | 47, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Potato | 18 | 2 | 210, p-1b.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 18 | 3 | 68, p-2b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Natural area | 20 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 20 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |
| Forest | 19 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 19 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Natural area | 21 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 21 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |

Note: *: Number is saturated conductivity calculated by equation 3.10; soil physical table used in LISEM.

Name of soil physical input tables and saturated conductivity in tables for May/June periods of all scenarios:

| Crop (land use) | Code of land use | Soil types | 0 ~10 cm soil layer | 10 ~30 cm soil layer | 30 ~100 cm soil layer | 100-150cm soil layer | 150-200cm soil layer | Code of soil profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 1 | 3 | 10, orch.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 2 |
| Maize | 2 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 2 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Vegetable | 3 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 3 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Trees | 4 | 2 | 72, t-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 7 |
| | 4 | 3 | 22, t-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 8 |
| Winter wheat | 5 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 5 | 3 | 61, spwwsc.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 10 |
| Asparagus | 6 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 6 | 3 | 61, spwwsc.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 10 |
| Scorzonera | 7 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 7 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Carrots | 8 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 8 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Sugar-beet | 9 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 9 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Build up area | 10 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 10 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grassland | 11 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 11 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Others | 12 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 12 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Garden | 13 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 13 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Unpaved road | 14 | 2 | 10, r-r1.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 15 |
| | 14 | 3 | 5, r-r2.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 16 |
| Paved road | 15 | 2 | 0, bouw.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 17 |
| | 15 | 3 | 0, bouw.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 18 |
| Bush | 16 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 16 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Potato/been | 17 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 17 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Potato | 18 | 2 | 99.3, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 18 | 3 | 46.6, bean1a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 4 |
| Natural area | 20 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 20 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |
| Forest | 19 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 19 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Natural area | 21 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 21 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |

## Name of soil physical input tables and saturated conductivity in tables for winter period of scenarios 1, 5 and 6

| Crop (land use) | Code of land use | Soil types | 0 ~10 cm soil layer | 10 ~30 cm soil layer | 30 ~100 cm soil layer | 100-150cm soil layer | 150-200cm soil layer | Code of soil profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 1 | 3 | 10, orch.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 2 |
| Maize | 2 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 2 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Vegetable | 3 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 3 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Trees | 4 | 2 | 72, t-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 7 |
| | 4 | 3 | 22, t-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 8 |
| Winter wheat | 5 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 5 | 3 | 61, spwwsc.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 10 |
| Asparagus | 6 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 6 | 3 | 28.3,beanwa.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 34 |
| Scorzonera | 7 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 7 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Carrots | 8 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 8 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Sugar-beet | 9 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 9 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Build up area | 10 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 10 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grassland | 11 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 11 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Others | 12 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 12 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Garden | 13 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 13 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Unpaved road | 14 | 2 | 10, r-r1.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 15 |
| | 14 | 3 | 5, r-r2.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 16 |
| Paved road | 15 | 2 | 0, bouw.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 17 |
| | 15 | 3 | 0, bouw.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 18 |
| Bush | 16 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 16 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Potato/been | 17 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 17 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Potato | 18 | 2 | 31.5, bareb.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 3 |
| | 18 | 3 | 28.5, pw-b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 32 |
| Natural area | 20 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 20 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |
| Forest | 19 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 19 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grass strip | 21 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 21 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |

Name of soil physical input tables and saturated conductivity in tables for winter period of scenarios 2, 3 and 4

| Crop (land use) | Code of land use | Soil types | 0 ~10 cm soil layer | 10 ~30 cm soil layer | 30 ~100 cm soil layer | 100-150cm soil layer | 150-200cm soil layer | Code of soil profile types |
|---|---|---|---|---|---|---|---|---|
| Water basin | 1 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 1 | 3 | 10, orch.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 2 |
| Maize | 2 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 2 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Vegetable | 3 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 3 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Trees | 4 | 2 | 72, t-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 7 |
| | 4 | 3 | 22, t-2a.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 8 |
| Winter | 5 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| wheat | 5 | 3 | 61, spwwsc.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 10 |
| Asparagus | 6 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 6 | 3 | 28.3,beanwa.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 34 |
| Scorzonera | 7 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 7 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Carrots | 8 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 8 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Sugar-beet | 9 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 9 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Build up | 10 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| area | 10 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grassland | 11 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 11 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Others | 12 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 12 | 3 | 125,meadow.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 28 |
| Garden | 13 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 13 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Unpaved | 14 | 2 | 10, r-r1.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 15 |
| road | 14 | 3 | 5, r-r2.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 16 |
| Paved road | 15 | 2 | 0, bouw.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 17 |
| | 15 | 3 | 0, bouw.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 18 |
| Bush | 16 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 16 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Potato/been | 17 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 17 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Potato | 18 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 18 | 3 | 200,wogm.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 36 |
| Natural | 20 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| area | 20 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |
| Forest | 19 | 2 | 500, f-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 25 |
| | 19 | 3 | 500, f-1b.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 26 |
| Grass strip | 21 | 2 | 177,w-1a.tbl | 200, Sand1.tbl | 100, Sand2.tbl | 50,sand3.tbl | 10,sand4.tbl | 1 |
| | 21 | 3 | 130,Grass.tbl | 60, m-s2a.tbl | 25, m-d2a.tbl | 25,m-d2a.tbl | 9.8,m-d2b.tbl | 30 |

**Appendix 6:** Description file of soil profile (**profile.inp**) used in LISEM for all scenarios and periods:

| Sample | Explanation |
|---|---|
| 14 | Numbers of soil layers. |
| | |
| 2.5 | Depth of boundary between first and second layer in cm; |
| 5 | Depth of boundary between second and third layer in cm; |
| 10 | etc. |
| 15 | |
| 20 | |
| 25 | |
| 30 | |
| 40 | |
| 60 | |
| 70 | |
| 90 | |
| 100 | |
| 150 | |
| 200 | Depth of final soil layer in cm. |
| | |
| 1 | Code of profile type in profile.map; |
| w-1a.tbl | The name of soil physical table to be used; |
| 10 | The depth down to which the above table is used in cm; |
| sand1.tbl | etc. |
| 30 | |
| sand2.tbl | |
| 100 | |
| sand3.tbl | |
| 150 | |
| sand4.tbl | |
| 200 | |
| | |
| 2 | |
| orch.tbl | |
| 10 | |
| m-s2a.tbl | |
| 30 | |
| m-d2a.tbl | |
| 150 | |
| m-d2b.tbl | |
| 200 | |
| | |
| 3 | |
| bareb.tbl | |
| 10 | |
| sand1.tbl | |
| 30 | |
| sand2.tbl | |
| 100 | |
| sand3.tbl | |
| 150 | |
| sand4.tbl | |
| 200 | |
| | |
| 4 | |
| bean1a.tbl | |
| 10 | |
| m-s2a.tbl | |
| 30 | |

m-d2a.tbl
150
m-d2b.tbl
200

7
t-1a.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

8
t-2a.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

9
w-1a.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

10
spwwsc.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

15
r-r1.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

16
r-r2.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

17
bouw.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

18
bouw.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

19
Whl_all.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

20
whl_all.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

25
f-1a.tbl
10
sand1.tbl
30

sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

26
f-1b.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

28
meadow.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

30
grass.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

32
pw-b.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

34
beawa.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

36
wigm.tbl
10

m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

41
g-1at.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

42
g-2a.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

43
ww-1b.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

44
ww-2a.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

45
b-1b.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150

sand4.tbl
200

46
b-2b.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

47
t-1a.tbl
10
sand1.tbl
30
sand2.tbl
100
sand3.tbl
150
sand4.tbl
200

48
t-2a.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

50
spwwsc.tbl
10
m-s2a.tbl
30
m-d2a.tbl
150
m-d2b.tbl
200

**Appendix 7:** Rainfall input files used in LISEM.

Rain data for October period (or for calibration) ( First column is the cumulative time in minutes, second column is rainfall intensity in mm/h) :

```
RUU CSF TIMESERIE INTENSITY NORMAL 1
station_1

0.000          0.000
4.267          2.812
6.350          5.760
7.783          8.372
9.550          6.792
10.850         9.231
11.850         12.000
12.850         12.000
14.033         10.141
15.067         11.613
15.833         15.652
16.450         19.459
16.917         25.714
17.433         23.226
17.933         24.000
18.167         51.429
18.450         42.353
18.867         28.800
19.300         27.692
19.617         37.895
19.850         51.429
20.083         51.429
20.417         36.000
20.683         45.000
20.767         144.000
20.967         60.000
21.317         34.286
21.683         32.727
22.200         23.226
22.667         25.714
23.083         28.800
23.467         31.304
23.867         30.000
24.300         27.692
24.733         27.692
25.050         37.895
25.450         30.000
25.933         24.828
26.567         18.947
27.067         24.000
27.533         25.714
28.200         18.000
28.750         21.818
29.250         24.000
29.900         18.462
30.267         32.727
30.917         18.462
31.567         18.462
32.867         9.231
33.917         11.429
34.817         13.333
```

| | |
|---|---|
| 35.483 | 18.000 |
| 36.000 | 23.226 |
| 36.617 | 19.459 |
| 37.383 | 15.652 |
| 38.083 | 17.143 |
| 38.883 | 15.000 |
| 39.783 | 13.333 |
| 41.217 | 8.372 |
| 42.000 | 15.319 |
| 43.383 | 8.675 |
| 44.000 | 19.459 |
| 44.950 | 12.632 |
| 48.200 | 3.692 |
| 49.533 | 9.000 |
| 50.417 | 13.585 |
| 51.783 | 8.780 |
| 52.667 | 13.585 |
| 53.517 | 14.118 |
| 54.500 | 12.203 |
| 55.750 | 9.600 |
| 57.567 | 6.606 |
| 59.450 | 6.372 |
| 60.533 | 11.077 |
| 61.217 | 17.561 |
| 62.100 | 13.585 |
| 62.783 | 17.561 |
| 63.350 | 21.176 |
| 64.150 | 15.000 |
| 64.367 | 55.385 |
| 64.683 | 37.895 |
| 64.967 | 42.353 |
| 65.483 | 23.226 |
| 65.950 | 25.714 |
| 66.417 | 25.714 |
| 66.733 | 37.895 |
| 67.167 | 27.692 |
| 67.700 | 22.500 |
| 68.283 | 20.571 |
| 68.683 | 30.000 |
| 69.000 | 37.895 |
| 69.267 | 45.000 |
| 69.567 | 40.000 |
| 69.900 | 36.000 |
| 70.300 | 30.000 |
| 70.700 | 30.000 |
| 71.183 | 24.828 |
| 71.650 | 25.714 |
| 72.233 | 20.571 |
| 72.700 | 25.714 |
| 73.233 | 22.500 |
| 73.600 | 32.727 |
| 73.933 | 36.000 |
| 74.233 | 40.000 |
| 74.550 | 37.895 |
| 74.717 | 72.000 |
| 74.950 | 51.429 |
| 75.133 | 65.455 |
| 75.317 | 65.455 |
| 75.483 | 72.000 |
| 75.650 | 72.000 |
| 75.783 | 90.000 |

| | |
|---|---|
| 75.933 | 80.000 |
| 76.100 | 72.000 |
| 76.283 | 65.455 |
| 76.433 | 80.000 |
| 76.533 | 120.000 |
| 76.650 | 102.857 |
| 76.800 | 80.000 |
| 76.950 | 80.000 |
| 77.100 | 80.000 |
| 77.250 | 80.000 |
| 77.383 | 90.000 |
| 77.517 | 90.000 |
| 77.700 | 65.455 |
| 77.883 | 65.455 |
| 78.350 | 25.714 |
| 78.617 | 45.000 |
| 78.867 | 48.000 |
| 79.167 | 40.000 |
| 80.033 | 13.846 |
| 81.500 | 8.182 |
| 82.717 | 9.863 |
| 83.683 | 12.414 |
| 84.783 | 10.909 |
| 85.733 | 12.632 |
| 86.617 | 13.585 |
| 87.267 | 18.462 |
| 87.900 | 18.947 |
| 88.767 | 13.846 |
| 89.467 | 17.143 |
| 90.950 | 8.090 |
| 91.933 | 12.203 |
| 92.717 | 15.319 |
| 93.933 | 9.863 |
| 95.700 | 6.792 |
| 96.717 | 11.803 |
| 97.533 | 14.694 |
| 98.367 | 14.400 |
| 99.633 | 9.474 |
| 101.050 | 8.471 |
| 102.000 | 12.632 |
| 103.183 | 10.141 |
| 104.550 | 8.780 |
| 106.483 | 6.207 |
| 108.467 | 6.050 |
| 111.683 | 3.731 |
| 114.700 | 3.978 |
| 119.533 | 2.483 |
| 125.033 | 2.182 |
| 126.000 | 0.00 |
| 180.00 | 0.00_ |

## Rain data for spring period, all scenarios:

### *A: Shower happens every 2 years:*

```
RUU CSF TIMESERIE INTENSITY NORMAL 1
station_1

0.0     0.0
5.0    24.0
7.5    30.0
12.5   81.6
15.0   30.0
20.0   24.0
100.0   0.0_
```

### *B: Shower happens every 25 years:*

```
RUU CSF TIMESERIE INTENSITY NORMAL 1
station_1

0.0     0.0
5.0    41.4
7.5    58.8
12.5 141.6
15.0   58.8
20.0   41.4
100.0   0.0_
```

## Rain data for winter period, all scenarios:

### *A: Shower happens every 2 years:*

```
RUU CSF TIMESERIE INTENSITY NORMAL 1
station_1

0.0    0.0
15.0   3.6
22.5   6.8
37.5   26.0
45.0   6.8
60.0   3.6
120.0  0.0_
```

### *B: Shower happens every 25 years:*

```
RUU CSF TIMESERIE INTENSITY NORMAL 1
station_1

0.0     0.0
15.0    6.2
22.5   11.6
37.5   41.2
45.0   11.6
60.0    6.2
120.0   0.0_
```

**Appendix 8:** Sample of running control file (***.run**):

| *Sample* | *Explanation* |
|---|---|
| c:\data\groesbeek\catch1\scen2\spring | Direction where the input maps and files are located; |
| c:\data\groesbeek\alltables | Direction where soil physical tables are located; |
| c:\data\groesbeek\results\catch1\scen2s2 | Direction where output files and maps are located; |
| sum2y.dat | Name of rain file; |
| 0 | Starting time of simulation in minutes; |
| 100 | End time of simulation in minutes; |
| 60 | Time step of simulation in seconds; |
| 1 | Print option; |
| 1 | Infiltration method; |
| 0.000005 | Minimum time step for SWATRE in days; |
| 5 | Precision factor of SWATRE; |
| 0.00080903 | Settling velocity of sediment; |
| 0.4 | Critical unit stream power; |
| 0.1 | Splash delivery ration; |
| 0.200 | Manning's N for grass strip and waterways; |
| 0.4 | Expected rill width in m; |
| 0.4 | Critical velocity above which rill formed; |
| eros.map | |
| dep.map | |
| res.dat | Name of summary results file; |
| out.dat | Name of output file for basin outlet point; |
| out1.dat | Name of output file for other outlet point; |
| out2.dat | |
| n | End the output file; |
| y | Need the runoff maps; |
| 10 | Time in minutes for runoff maps; |
| 12 | |
| 14 | |
| 16 | |
| 20 | |
| 24 | |
| 100 | |
| 0 | End of runoff maps generation; |
| rn | First characters of name of runoff maps. |

**Appendix 9:** Measured data in field for calibration:

| Date | Time | Cumulative time (minutes) | Runoff level (cm) | Runoff level (m) | runoff (l/s) |
|---|---|---|---|---|---|
| 10/28/98 | 8:51:53 | 0.00 | 0.00 | 0.00 | 0.00 |
| 28-Oct-98 | 8:55 | 3.117 | 9.59 | 0.10 | 3.98 |
| 28-Oct-98 | 9:00 | 8.117 | 9.00 | 0.09 | 3.40 |
| 28-Oct-98 | 9:05 | 13.117 | 8.96 | 0.09 | 3.37 |
| 28-Oct-98 | 9:10 | 18.117 | 10.14 | 0.10 | 4.57 |
| 28-Oct-98 | 9:15 | 23.117 | 13.98 | 0.14 | 10.16 |
| 28-Oct-98 | 9:20 | 28.117 | 20.83 | 0.21 | 27.39 |
| 28-Oct-98 | 9:25 | 33.117 | 25.63 | 0.26 | 45.92 |
| 28-Oct-98 | 9:30 | 38.117 | 26.30 | 0.26 | 48.97 |
| 28-Oct-98 | 9:35 | 43.117 | 25.93 | 0.26 | 47.27 |
| 28-Oct-98 | 9:40 | 48.117 | 24.59 | 0.25 | 41.41 |
| 28-Oct-98 | 9:45 | 53.117 | 23.51 | 0.24 | 37.03 |
| 28-Oct-98 | 9:50 | 58.117 | 22.03 | 0.22 | 31.49 |
| 28-Oct-98 | 9:55 | 63.117 | 21.72 | 0.22 | 30.40 |
| 28-Oct-98 | 10:00 | 68.117 | 22.92 | 0.23 | 34.76 |
| 28-Oct-98 | 10:05 | 73.117 | 26.19 | 0.26 | 48.46 |
| 28-Oct-98 | 10:10 | 78.117 | 34.36 | 0.34 | 95.36 |
| 28-Oct-98 | 10:15 | 83.117 | 61.37 | 0.61 | 405.53 |
| 28-Oct-98 | 10:20 | 88.117 | 50.48 | 0.50 | 249.02 |
| 28-Oct-98 | 10:25 | 93.117 | 43.43 | 0.43 | 171.08 |
| 28-Oct-98 | 10:30 | 98.117 | 41.58 | 0.42 | 153.47 |
| 28-Oct-98 | 10:35 | 103.117 | 47.10 | 0.47 | 209.47 |
| 28-Oct-98 | 10:40 | 108.117 | 50.72 | 0.51 | 251.99 |
| 28-Oct-98 | 10:45 | 113.117 | 47.86 | 0.48 | 218.00 |
| 28-Oct-98 | 10:50 | 118.117 | 44.46 | 0.44 | 181.38 |
| 28-Oct-98 | 10:55 | 123.117 | 46.03 | 0.46 | 197.79 |
| 28-Oct-98 | 11:00 | 128.117 | 44.81 | 0.45 | 184.97 |
| 28-Oct-98 | 11:05 | 133.117 | 40.30 | 0.40 | 141.95 |
| 28-Oct-98 | 11:10 | 138.117 | 37.72 | 0.38 | 120.35 |
| 28-Oct-98 | 11:15 | 143.117 | 34.93 | 0.35 | 99.36 |
| 28-Oct-98 | 11:20 | 148.117 | 32.17 | 0.32 | 80.92 |
| 28-Oct-98 | 11:25 | 153.117 | 29.20 | 0.29 | 63.55 |
| 28-Oct-98 | 11:30 | 158.117 | 28.21 | 0.28 | 58.32 |
| 28-Oct-98 | 11:35 | 163.117 | 26.58 | 0.27 | 50.28 |
| 28-Oct-98 | 11:40 | 168.117 | 24.45 | 0.24 | 40.83 |
| 28-Oct-98 | 11:45 | 173.117 | 22.23 | 0.22 | 32.21 |
| 28-Oct-98 | 11:50 | 178.117 | 20.75 | 0.21 | 27.13 |
| 28-Oct-98 | 11:55 | 183.117 | 18.70 | 0.19 | 20.94 |
| 28-Oct-98 | 12:00 | 188.117 | 17.88 | 0.18 | 18.73 |
| 28-Oct-98 | 12:05 | 193.117 | 16.46 | 0.16 | 15.24 |
| 28-Oct-98 | 12:10 | 198.117 | 15.02 | 0.15 | 12.14 |
| 28-Oct-98 | 12:15 | 203.117 | 14.61 | 0.15 | 11.33 |
| 28-Oct-98 | 12:20 | 208.117 | 14.47 | 0.14 | 11.06 |
| 28-Oct-98 | 12:25 | 213.117 | 13.88 | 0.14 | 9.98 |
| 28-Oct-98 | 12:30 | 218.117 | 13.03 | 0.13 | 8.53 |
| 28-Oct-98 | 12:35 | 223.117 | 11.16 | 0.11 | 5.80 |
| 28-Oct-98 | 12:40 | 228.117 | 11.14 | 0.11 | 5.78 |
| 28-Oct-98 | 12:45 | 233.117 | 11.10 | 0.11 | 5.73 |
| 28-Oct-98 | 12:50 | 238.117 | 9.94 | 0.10 | 4.35 |
| 28-Oct-98 | 12:55 | 243.117 | 9.65 | 0.10 | 4.05 |
| 28-Oct-98 | 13:00 | 248.117 | 9.25 | 0.09 | 3.64 |

**Appendix 10:** PC-Raster program produces drainage basin morphological and channel maps (**DBM.BAT**):

```
pcrcalc ldd-tmp.map=lddcreate(dem.map,1e31,1e31,1e31,1e31)
pcrcalc ldd.map=lddmask(ldd-tmp.map,catchment*ldd-tmp.map,pit(ldd-tmp.map) eq 1)
pcrcalc area.map=boolean(if(boolean(ldd.map) then nominal(1)))
pcrcalc id.map=if(arae.map then nominal(1))
pcrcalc grad.map=if(slope(dem.map) lt 0.0001 then scalar(0.0001) else slope(dem.map))
col2map – clone dem.map –B outlet.tbl temp.map
pcrcalc outlet.map=cover(temp.map,pit(ldd.map))
pcrcalc roadwidt.map=lookupscalar(road.tbl,land.map)
pcrcalc temp.map=boolean(pit(ldd.map))
pcrcalc lddchan.map=if(temp.map,ldd.map)
pcrcalc changrad.map=if(temp.map,grad.map)
pcrcalc chanwidt.map=if(temp.map then scalar(BB) else scalar(0))
pcrcalc chancoh.map=if(temp.map then scalar(CC))
pcrcalc chanman.map=if(temp.map then scalar(DD))
pcrcalc chanside.map=if(temp.map then scalar(EE))
```

Note: BB is the width of channel bottom; CC is cohesion of channel surface, it is 3.32 for grass surface, and 9999 for paved surface; DD is Manning's N of channel surface, it is 0.23 for grass surface, and 0.01 for paved surface; EE is tangent of side of channel, it can be measured in field.

**Appendix 11:** PC-Raster program generates crop, soil and land use variables maps, maps for SWATRE:

```
pcrcalc lai.map=lookupscalar(lai.tbl,land.map)
pcrcalc per.map=lookupscalar(cover.tbl,land.map)
pcrcalc rr.map=lookupscalar(rr.tbl,land.map)
pcrcalc n.map=lookupscalar(n.tbl,land.map)
pcrcalc ch.map=lookupscalar(ch.tbl,land.map)
pcrcalc wheelwid.map=lookupscalar(wheelwid.tbl,land.map)
pcrcalc coh.map=lookupscalar(coh.tbl,land.map,soil.map)
pcrcalc cohadd.map=lookupscalar(cohad.tbl,land.map,soil.map)
pcrcalc profwltr.map=lookupnominal(profwltr.tbl,soil.map)
pcrcalc profile.map=lookupnominal(profile.tbl,land.map,soil.map)
col2map –clone area.map –B headout.tbl temp.map
pcrcalc headout.map=cover(temp.map,pit(ldd.map))
```

**Appendix 12:** PC-Raster program produces crop, soil and land use variables maps, maps for SWATRE. Correcting section eliminating errors includes in this program.

```
pcrcalc tlai.map=lookupscalar(lai.tbl,land.map)
pcrcalc tper.map=lookupscalar(cover.tbl,land.map)
pcrcalc trr.map=lookupscalar(rr.tbl,land.map)
pcrcalc tn.map=lookupscalar(n.tbl,land.map)
pcrcalc tch.map=lookupscalar(ch.tbl,land.map)
pcrcalc twheel.map=lookupscalar(wheel.tbl,land.map)
pcrcalc tcoh.map=lookupscalar(coh.tbl,land.map,soil.map)
pcrcalc tcohadd.map=lookupscalar(cohad.tbl,land.map,soil.map)
pcrcalc profwltr.map=lookupnominal(profwltr.tbl,soil.map)
pcrcalc profile.map=lookupnominal(profile.tbl,land.map,soil.map)
col2map –clone area.map –B headout.tbl temp.map
pcrcalc headout.map=cover(temp.map,pit(ldd.map))
pcrcalc lai1.map=if(land.map eq A or land.map eq B or land.map eq C then tlai.map else olai.map)
pcrcalc per.map=if(land.map eq A or land.map eq B or land.map eq C then tper.map else oper.map)
pcrcalc rr.map=if(land.map eq A or land.map eq B or land.map eq C then trr.map else orr.map)
pcrcalc ch.map=if(land.map eq A or land.map eq B or land.map eq C then tch.map else och.map)
pcrcalc coh.map=if(land.map eq A or land.map eq B or land.map eq C then tcoh.map else ocoh.map)
pcrcalc cohadd.map=if(land.map eq A or land.map eq B or land.map eq C then tcohadd.map else ocohadd.map)
pcrcalc n.map=if(land.map eq A or land.map eq B or land.map eq C then tn.map else on.map)
pcrcalc wheelwid.map=if(land.map eq A or land.map eq B or land.map eq C then twheel.map else owheel.map)
```

Note: A, B and C are codes of land use types which are changed in new land use option. A, B and C are also codes of land use types which are not changed when most land use types are changed. o*.map is the map from land use option that is used to compare the effects of soil conservation of new land use option, its name should be changed in WINDOWS Exploer one by one.

**Appendix 13:** PC-Raster program generate initial soil hydraulic pressure head:

```
areamap area.map;
timer 1 A 1;
dyniamic
 report inithead=if(area.map then scalar(B));
```

Note: A is number of soil layers; B is initial soil hydraulic pressure head in negative integer.

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