

LISEM

Limburg Soil Erosion Model

Windows version 2.x

USER MANUAL

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Preface

This is a first draft of the manual for the new LISEM for windows, currently at version 2.1. It is a compilation of the website: <http://www.geog.uu.nl/lisem>, on which you can find the latest information.

LISEM started out as an erosion model that simulates overland flow, splash and rill erosion, with some extra features. More processes were added and the number of variables and choices in the interface became prohibitive because initially all combinations were allowed. Therefore it was decided to have different versions of LISEM that essentially consist of the *Basic* version plus an extra set of processes:



LISEM Basic: the original LISEM including parallel infiltration through different types of surfaces inside a gridcell, as well as grass strips and channels.



LISEM Wheeltracks: the basic version plus the ability to treat semi-permanent wheeltracks as a network of small channels.



LISEM Multiclass: the basic version with the erosion/deposition changed to a multiclass system with 6 sediment classes causing spatial changes in texture composition.



LISEM Nutrients: the basic version with the nutrient losses (N and P) in solution and in suspension, absorbed to the clay particles.



LISEM Gullies (EUROWISE): the basic version with incision in a multi-layered soil, in certain areas that are prone to gully, according to an empirical landscape analysis.

Not all of the theory and descriptions are included in this manual yet, only of the basic version and the gully version.

Victor Jetten, January 2, 2002

Reference:

Jetten, V. (2002). *LISEM user manual, version 2.x*. Draft version January 2002. Utrecht Centre for Environment and Landscape Dynamics, Utrecht University, The Netherlands. pp 48.

DISCLAIMER

No warranties, expressed or implied, are made that the computer programs described in this publication are free from errors or are consistent with any particular standard of programming language, or that they will meet a user's requirement for any particular application.

Contents

1	Introduction	5
2	LISEM BASIC - Theoretical framework	6
2.1	Rainfall.....	7
2.2	Interception	7
2.3	Infiltration	7
2.3.1	Swatre	8
2.3.2	Holtan method	9
2.3.3	Green and Ampt	11
2.3.4	Morel-Seytoux and Verdin.....	12
2.3.5	Subtraction of Ksat.....	12
2.4	Surface definition on a sub-gridcell level	12
2.5	Storage in micro depressions.....	12
2.5.1	Surface Storage in LISEM Version 1.63 and earlier	15
2.5.2	Overland flow and channel flow	17
2.6	Erosion and eposition	19
2.6.1	Splash detachment.....	19
2.6.2	Flow detachment and deposition.....	19
2.6.3	Channel detachment and deposition	21
3	LISEM-wheeltracks	22
4	LISEM-multiclass	22
5	LISEM-nutrients	22
6	LISEM-GULLIES (EUROWISE)	23
6.1	Introduction.....	23
6.1.1	Ephemeral gullies	23
6.1.2	Summer and winter gullies.....	26
6.2	Basic principles.....	26
6.2.1	Critical area analysis - theory.....	27
6.2.2	Critical area analysis - Implementation in LISEM	28
6.2.3	Ephemeral gully formation	30
6.2.4	Gully incision.....	32
7	THE INPUT DATABASE	33
7.1	PCRASTER.....	33
7.2	The input maps	34
7.2.1	Catchment maps.....	35
7.2.2	Vegetation maps.....	37
7.2.3	Soil surface maps	37
7.2.4	Infiltration related maps.....	39
7.2.5	Erosion/deposition related maps	43
7.2.6	Channels	43
7.3	Additional maps needed for EUROWISE	45
7.4	Rainfall data.....	47

8	The interface	48
8.1	Speed buttons & Tabs.....	49
8.2	Start tab	49
8.3	Basic maps	51
8.4	Output timeseries.....	53
9	LISEM output	54
9.1	Main output screen and totals	54
9.2	Hydrographs and sedigraphs	54
9.3	Erosion and deposition maps.....	55
9.4	Timeseries	56
10	References.....	57
11	Partners	59
	Appendix	60

1 INTRODUCTION

LISEM, the Limburg Soil Erosion Model, simulates the hydrology and sediment transport during and immediately after a single rainfall event in a small catchment. The model has been used so far in catchments between 10 and approximately 300 ha. LISEM is built to simulate both the effects of the current land use and the effects of soil conservation measures.

The model was originally made for the Province of Limburg, the Netherlands, to test the effects of grass strips and other small scale soil conservation measures on the soil loss. In the "Limburg" project, three catchments were fully equipped and monitored for 5 years by the local government (Waterboard Roer en Overmaas), the Free University of Amsterdam (Physical Geography), Alterra and the Utrecht University (Physical Geography). Although it can be used for planning purposes it is essentially a research tool because of its complexity.

The philosophy behind LISEM is that the model assumes nothing! An example: if a land use change is modelled there is no way of telling LISEM that it should change all the related variables because the crop is e.g. winter wheat and not sugar beet. The user must change all appropriate variables him/herself: infiltration variables, surface roughness, Manning's n etc. This gives the user more freedom and it is much clearer what happens in the simulation, however this also means that the user knows what he/she is doing.

Basic processes incorporated in the model are rainfall, interception, surface storage in micro-depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow (in man-made ditches), detachment by rainfall and throughfall, transport capacity and detachment by overland flow. Also, the influence of compaction (e.g. by tractor wheelings), small paved roads (smaller than the pixel size) and surface sealing on the hydrological and soil erosion processes is taken into account. The processes are described in detail in the theory section. The latest developments include the modelling of:

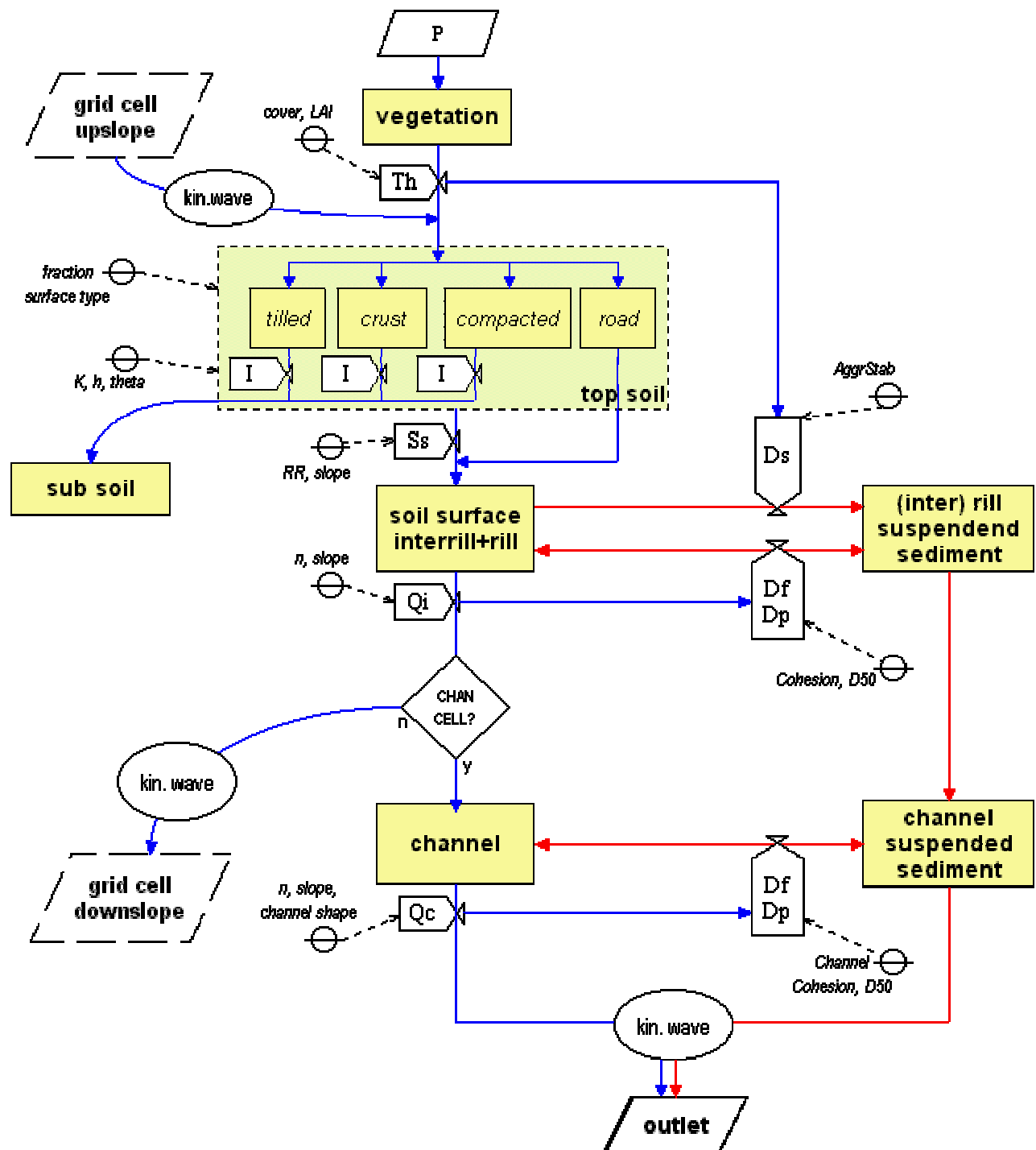
- wheel tracks as small channels,
- multiple sediment classes for erosion and deposition,
- the loss of P, NO₃ and NH₄ in solution and in suspension,
- the incision and formation of gullies

Although not directly visible to the user, the model is one of the first examples of a physically based model that is completely integrated in a raster Geographical Information System, [PCRaster](#) (van Deursen & Wesseling, 1992). The source code is a mix of C++ code, GIS operations, mathematical operations and hydrological functions (kinematic wave, Richards equation). No conversions are necessary between PCRaster and the model. All input and output maps are raster maps that can be easily displayed and treated with the PCRaster software.

2 LISEM BASIC - THEORETICAL FRAMEWORK

For each gridcell, rainfall and interception by plants are calculated, after which infiltration and surface storage are subtracted to give net runoff. Subsequently, splash en flow erosion and deposition are calculated using the stream power principle and the water and sediment are routed to the outlet with a kinematic wave procedure. Special cases can be defined for roads and compacted areas, and (man-made) channels can be taken into consideration.

Figure 2.1. Flow chart of LISEM BASIC.



2.1 Rainfall

LISEM uses rainfall intensities per time interval (so called break-point data). These are stored in an ASCII file. Data from multiple raingauges can be entered in an ASCII input data file with columns for each rainfall gauge. A map with areas having the raingauge ID number determines the spatial distributed rainfall input. This map can be based for example on Thiessen polygons or on a geomorphological analysis (assigning valleys to raingauges).

The rainfall is added to the current water height in each cell. However, the slope angle is taken into consideration: the rain falls on a horizontally projected surface while the actual terrain has a slope. Thus the rain is spread out over a larger area and the resulting water height is lower:

$$h = h + P \cdot \cos(a) \quad [2-1]$$

Where P is the rainfall depth in that timestep (mm) and a is the slope angle. The assumption here is that the slope is in one direction only, and the cell has a surface of $DX \cdot DX / \cos(a)$.

2.2 Interception

Interception by crops and vegetation is simulated by regarding the canopy as a simple storage as a simple storage. The cumulative interception during an event is calculated as (Aston, 1979):

$$S = c_p \cdot S_{max} \cdot \left[1 - e^{-k \cdot \frac{P_{cum}}{S_{max}}} \right] \quad [2-2]$$

where S is the cumulative interception (mm), P_{cum} is the cumulative rainfall (mm), k is a correction factor for vegetation density (equals $0.046 \cdot LAI$) and determines the rate with which S_{max} is reached, c_p is the fraction of vegetation cover and S_{max} is the canopy storage capacity (mm) estimated from the LAI (m^2/m^2), by Von Hoyningen-Huene (1981):

$$S_{max} = 0.935 + 0.498 \cdot LAI - 0.00575 \cdot LAI^2 \quad [2-3]$$

Note that the LAI represents the average leaf area of the fraction of the gridcell that is under vegetation. For example a gridcell with a single tree has a LAI of e.g. $6 m^2/m^2$, while the cover fraction c_p of the gridcell takes care of the fact that most of the cell is bare.

2.3 Infiltration

Infiltration can be calculated with various sub-models, according to the data available. Available are the Holtan (Beasley and Huggins, 1982), and Green and Ampt (Li et al., 1976) equations for one or two layers, or the SWATRE model, a finite difference solution of the Richard equation (Belmans et al., 1983; Feddes et al., 1978). The latter option includes vertical soil water transport and the change of matric potential in the soil during a rainfall event which can be examined by the user. The input is in the form of maps with soil hydrological properties such as initial moisture content, porosity and saturated conductivity. For each layer maps are defined. In case of the Richards equation, a map with soil profile types is linked to a series of tables with values for humidity, θ ; matrix potential, ψ ; and hydraulic conductivity, K.

The choice of infiltration model is mostly governed by the type of data available and the experience of the user. It should be noted that the models do not give the same results. Since initial water content and hydraulic conductivity are among the most sensitive input parameters of *LISEM* (De Roo et al., 1996b; Jetten et al., 1998), re-calibration is advisable when a different infiltration model is used.

Currently the following models are available:

1. Swatre (finite difference approximation of the Richards equation)
2. Holtan (as in the Answers model)
3. Green and Ampt for 1 and 2 layers
4. Morel and Seytoux
5. Subtraction of Ksat

2.3.1 Swatre

Infiltration and soil water transport in soils are simulated by a solution of the well known Richards equation, which combines the Darcy equation and the continuity equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} K(h) \left[\frac{\partial h}{\partial z} + 1 \right] \quad [2-4]$$

with:

K = the hydraulic conductivity (m/s);

h = the pressure (matric) potential (m);

θ = the volumetric water content (m³/m³);

z = the gravitational potential or height above a reference level (m);

t = time (s)

Using the soil water capacity $C(h) = d\theta / dh$ (the slope of the soil water retention curve $\theta(h)$), the unsaturated flow equation is derived:

$$C(h) \frac{\partial h}{\partial t} = \frac{\partial}{\partial z} K(h) \left[\frac{\partial h}{\partial z} + 1 \right] \quad [2-5]$$

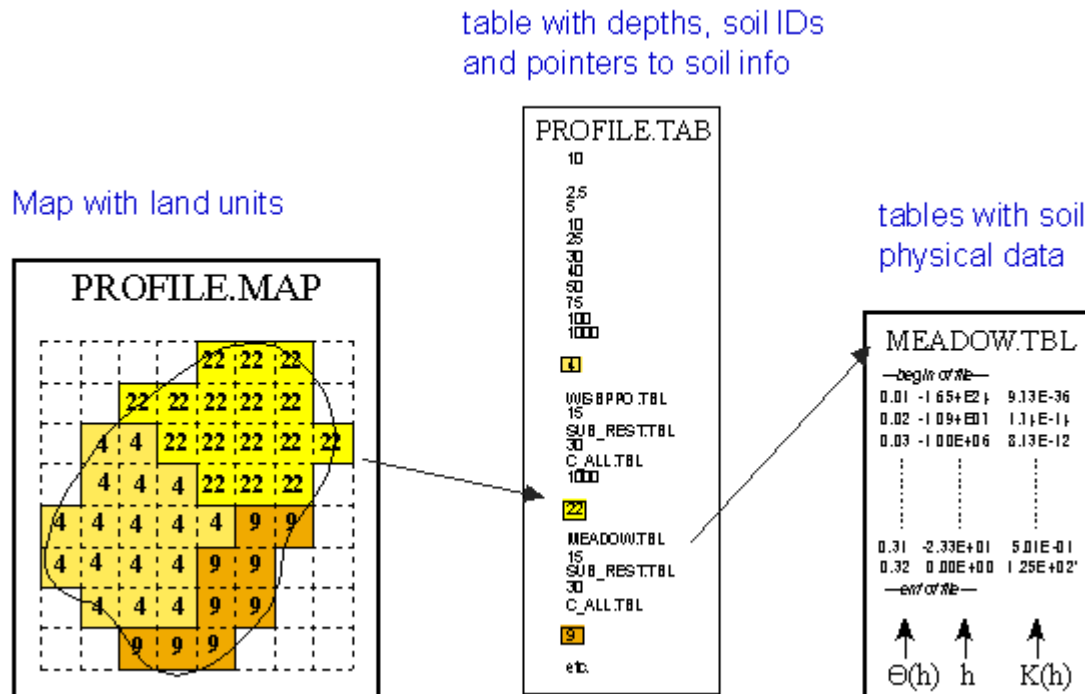
The Mualem/Van Genuchten equations (Mualem, 1976; Van Genuchten, 1980) can be used to predict the soil-water retention curves and the unsaturated hydraulic conductivity, which are needed to solve the equation above. However *LISEM* does not use these relations directly but requires the user to define the water retention curves and the K(h) curves as tables. The reasoning is that the measured curves hardly ever follow the Mualem-Van Genuchten relations exactly but usually deviate near saturation of the soil. Thus, for the catchments soil profile types are defined, and for each characteristic soil horizon, and for each horizon tables with the measured K-theta-h relations are required. The equations are solved by explicit linearisation using the so-called Thomas (tridiagonal) algorithm (see e.g. Remson et al., 1971). The submodel operates with a variable time increment depending on pressure head changes.

NOTE: SWATRE assumes that the nodes are not in the centre of the layers (as is common) but between the layers. Thus the user specifies the depth to the bottom of each layer (see section input database).

NOTE: The average hydraulic conductivity between the nodes can be calculated either as a arithmetic average ($0.5 \cdot \text{sum of } K_i \text{ and } K_{i+1}$), or as the geometric average ($\sqrt{K_i \cdot K_{i+1}}$). The choice is made in the user interface. This has a large influence as the geometric mean

favours the node with the lowest K value and the K(h) relationship is highly non-linear: compare $0.5 \cdot (1 + 0.01) = 0.5005$ with $\sqrt{1 \cdot 0.01} = 0.1$.

Figure 2.2. Data structure of the Swatire infiltration module.



2.3.2 Holtan method

For areas without detailed knowledge of the soil physics, different model versions with empirical infiltration equations can be used, using Green & Ampt and Holtan (e.g. Beasley & Huggins, 1982; de Roo, 1993). The Holtan model empirical (sub-)model is based on a storage concept. The main advantage of the model is the capability of recovery in soil infiltration capacity during periods of light or zero rainfall. The infiltration rate is expressed in terms of cumulative infiltration, initial soil water content and other soil variables:

$$f = FC + A * \left(\frac{S_t + DR - F}{TP * DF} \right)^P \quad [2-6]$$

with:

f = infiltration rate (mm/h);

FC = infiltration rate at steady state (mm/h);

A = the maximum possible increase in infiltration rate over the steady state rate, FC (mm/h);

S_t = storage potential of the soil (mm) above the impeding strata: total porosity (TP) minus the antecedent soil water (ASM):

$S = (1 - ASM) * TP * DF$;

DF = the effective depth to the impeding strata (control zone depth) (mm);

TP = total porosity (% volume);

ASM = antecedent soil moisture (% saturation);

DR = cumulative drainage (mm);

F = cumulative infiltration (mm);

P = dimensionless coefficient relating the rate of decrease in infiltration rate with increasing soil moisture content.

Huggins and Monke (1968) introduced an expansion of the model, assuming a relationship between percolation (or 'drainage') and soil water content. Using both equations, the recovery of infiltration rate as the result of a temporary interruption in rainfall can be predicted. They assume drainage when soil moisture content in the control zone exceeds field capacity:

$$dr = FC * \left(1 - \frac{S_t + DR - F}{(1 - FP) * TP * DF} \right)^r \quad [2-7]$$

with:

dr = percolation or 'drainage' rate (mm/h);

FP = field capacity (% saturation).

The major advantage of the Holtan model over other infiltration equations is the use of cumulative infiltration instead of time as the independent variable. This offers several advantages in catchment-hydrology simulation. Skaggs et al. (1969) evaluated several infiltration equations and concluded so. Using the Holtan equation, difficulties are not encountered in computing the infiltration rate at any time during a storm event, even when the water supply does not exceed the infiltration rate. Furthermore, because the Holtan model assumes a relationship between drainage and soil water content, the recovery of infiltration rate as the result of a temporary interruption in rainfall can be predicted.

The major difficulty with the Holtan equation is the control zone depth (DF). Holtan suggested that the depth to the first impeding layer should be used. If no impeding layer exists, a value equal to 0.25 to 0.75 of the A-horizon is advised (Beasley & Huggins, 1982). Beasley and Huggins remarked that of all of the variables used in the ANSWERS model, the DF is the least well defined and most arbitrary. Huggins and Monke (1966) found that the effective depth was highly dependent on both surface condition (crusting) and the cultural practices used in preparing the seed bed. De Roo and Riezebos (1992) also demonstrated the influence of crusting on the DF variable. Huggins and Monke (1968) suggested that the DF for deep soils can be determined by the depth necessary for the hydraulic gradient to approach unity. Skaggs et al. (1969) computed the control zone depth for fallow soils from the initial soil water content (ASM), the soil porosity (TP), and the volume of water that had infiltrated (F) at the time the infiltration rate reached a constant value:

$$DF = \frac{F_{sat}}{(1 - ASM) * TP} \quad [2-8]$$

with:

F_{sat} = Cumulative infiltration (mm) at saturation.

A major disadvantage of this method however, is that the DF variable is made a fitted variable instead of being physically measurable as the depth to the first impeding layer. Nevertheless, with this method, Holtan's equation gave an excellent fit ($r^2 = 0.988$, obtained using non-linear regression) to their experimental data. The Holtan infiltration model incorporates a minimum infiltration capacity (FC), which equals the saturated conductivity (Ks) of the topsoil. Because the Ks is always larger than zero, the model always allows for infiltration, even when the soil profile is saturated. Thus, using this sub-model, only Hortonian overland flow is simulated. Saturation overland flow is not simulated. Using the Swatre-based sub-models and the Green/Ampt submodels, one can simulate saturated overland flow.

2.3.3 Green and Ampt

Green and Ampt (1911) first applied the Darcy equation to the wetted zone in the soil, assuming that a distinct wetting front exist. They produced a one dimensional infiltration equation used and adapted by many researchers. Generally the equation has the following form:

$$i = k \left(t + \frac{\Omega}{I} \right) \quad [2-9]$$

and

$$I - \Omega \ln \left(t + \frac{I}{\Omega} \right) = kt \quad [2-10]$$

in which I = the infiltration rate (m/s), I = the accumulated infiltration over time (m), k = the hydraulic conductivity in the wetted zone (m/s), t = time since the start of the infiltration and Ω = potential head parameter (m). Note that k is not necessarily the saturated hydraulic conductivity but less according to Li et al. (1976). According to Fok and Hansen (1966) this parameter is defined as:

$$\Omega = (h_c + h_o)(\theta_w - \theta_i) \quad [2-11]$$

in which h_c = the average capillary suction head at the wetting front, h_o = the ponded head water level at the surface, θ_w = the water content of the wetted zone (may be smaller than the porosity) and θ_i = the antecedent moisture content. To get the infiltration rate at any time equation 2 has to be solved first for I and inserted into equation 1. This is usually done by iteration. Li et al. (1976) show that it is possible to use an explicit approximation by developing a power series expansion of the logarithmic term in equation 2. First the parameters are rewritten in their non-dimensional form:

$$I^* = \frac{I}{\Omega} ; t^* = \frac{kt}{\Omega} \text{ and } i^* = \frac{i}{k} \quad [2-12]$$

By using these parameters the equations are now rewritten as:

$$i^* = t + \frac{1}{I^*} \quad [2-13]$$

and

$$I^* - \ln(1 + I^*) = t^* \quad [2-14]$$

Replacing the logarithmic term with a power series and dropping the higher order terms yields a quadratic function that can be solved simply by retaining the positive root:

$$I^* = 0.5 \left[t^* + \sqrt{t^* (t^* + 8)} \right] \quad [2-15]$$

which can be rewritten in the dimensional form as:

$$dI = \frac{1}{2} \left[-(2I - kdt) + \sqrt{(2I - kdt)^2 + 8kdt(\Omega + I)} \right] \quad [2-16]$$

This is the relation used in LISEM whereby $dI > 0$ (if the solution is negative it has no meaning).

The Green and Ampt model is very sensitive to the choice of K_{sat} and initial moisture content. The initial assumption that the wetting front moves down as a wet body parallel to the surface with a speed dictated by the K_{sat} is not correct. Many researchers therefore suggested "field" variables: a "field porosity" or a field " K_{sat} ", or a suction at the wetting front that is not the matrix potential at a given time but a more soil property.

NOTE: This means that in practice the Green and Ampt solution needs calibration, either by decreasing the K_{sat} values or the storage capacity of the soil.

2.3.4 Morel-Seytoux and Verdin

not implemented yet

2.3.5 Subtraction of Ksat

The saturated hydraulic conductivity is subtracted from the net rainfall, simulating instant saturation in a simple way. This option can be used for testing and 'quick and dirty' estimates.

2.4 Surface definition on a sub-gridcell level

LISEM enables the simulation of several types of soil surfaces in a grid cell. These represent different soil structures. For small sized gridcells (< 100m²) this seems somewhat superfluous, but the gridcell size in LISEM is user defined and so the option is available.

The following surface types can be defined:

- normal soil surface (tilled)
- crusted
- compacted
- road (impermeable)
- grassstrips

Two maps with information are needed to do this:

1. For each surface type a map is needed that defines the fraction of a cell with that surface type. For instance where the crust fraction map has values > 0, LISEM assumes that it has to calculate a separate infiltration for the crusted surface fraction of the gridcell.
2. In order to do this LISEM needs a map for the saturated hydraulic conductivity of the crust (note that these names are optional). Note that the SWATRE infiltration module has a different data structure so the infiltration of different surface types is not done by a Ksat map but by specific soil physics tables. *All other parameters are assumed identical to the normal surface to avoid too many maps: the infiltration of e.g. a crust is not at all modelled in a physically based way and the separate ksat should be seen as a calibration variable.*

These surface types can be switched on and off in the interface without the need to change the maps. In this way scenarios can be modelled that simulate e.g. the effect of severe crusting or compaction.

The resulting water height at the surface is calculated as a weighted average of the normal infiltration and the infiltration of the area with a different soil structure, based of the fraction in the gridcell. Therefore the infiltration is averaged for each timestep.

2.5 Storage in micro depressions

The surface storage is not treated as a sharp threshold: runoff takes place before the water level reaches some threshold value of average surface storage. This is done because runoff at a micro-scale is a spatial process of ponds that fill up and overflow into each other. The

gridcell in LISEM represents an area of for instance 10x10 m² and before the average storage of this surface is filled the water at the edges of this area is moving downstream. The average depression storage can be measured at a given scale. The start value is more difficult and in LISEM a pragmatic approach is taken, based on the fraction of the surface that is ponded.

Surface storage is calculated using the Maximum Depression Storage (MDS). This is the threshold value of a given area above which surface micro depressions overflow: all depressions are connected to each other and to a point outside the reference area so that in principle each additional "drop" of water will flow outside the reference area. The MDS is determined by Kamphorst et al. (2000) from 221 digital elevation models of various types of micro relief, in a wide variety of agricultural circumstances and soil types. The analysis is based on DEMs of roughly 1m². Figure 1 shows the relation between the MDS and Random Roughness (RR). Originally the depression storage in LISEM was based on the work of Onstad (1984). Using the same form of equation Kamphorst et al. (2000) found ($R^2=0.88$, $n=221$):

$$MDS = 0.243RR + 0.010RR^2 + 0.012RRS \quad [2-17]$$

in which RR is the standard deviation of surface heights (cm) and S is the terrain slope (%). They tested 6 different roughness indices but found that the standard deviation of the heights gave the best relation with MDS (cm).

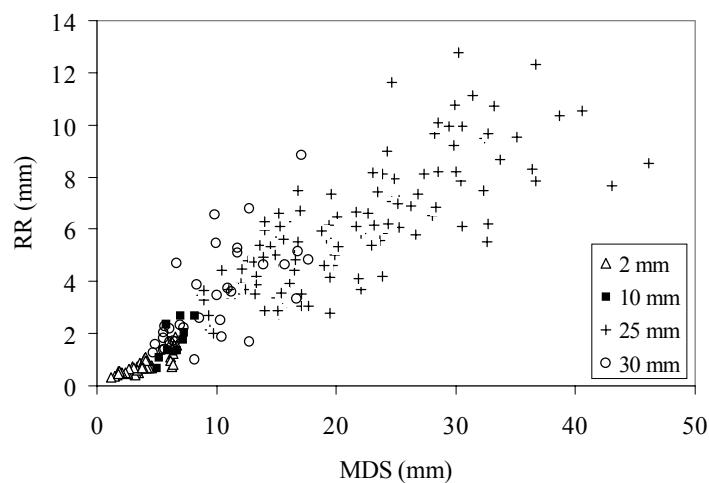


Figure 2.3. Non-linear relation between RR and MDS (Kamphorst et al., 2000), based on 221 DEMs of 1m² samples of a wide variety of surfaces. The difference in sampling distance is caused by the application of different tools in the various countries.

Apart from the water available for runoff, the roughness also determines width of the overland flow in LISEM. Rather than taking the cell width dx , the flow width (and hydraulic radius) is assumed linearly related to the fraction of ponded surface f_{pa} in the cell. The latter variable is related to the water depth at the surface h (mm) (Jetten and De Roo, 2001):

$$f_{pa} = 1 - \exp(-ah) \quad [2-18]$$

where a is an empirical factor between 0.04 and 1.8 for the roughness data set mentioned above. Figure 2 shows that the factor a appears to be strongly related to RR in mm ($R^2=0.99$, $n=362$):

$$a = 1.406 \cdot (RR)^{-0.942}$$

[2-19]

In which RR is in mm. Figure 3 shows the increase of ponded area with water height. Although not all the surfaces had a random roughness but showed also oriented roughness elements, the RR appeared to be the best roughness index to explain the variance in the dataset. Tortuosity based indices performed less as did the Linden -Van Dooren indices (Kamphuis et al., 2000).

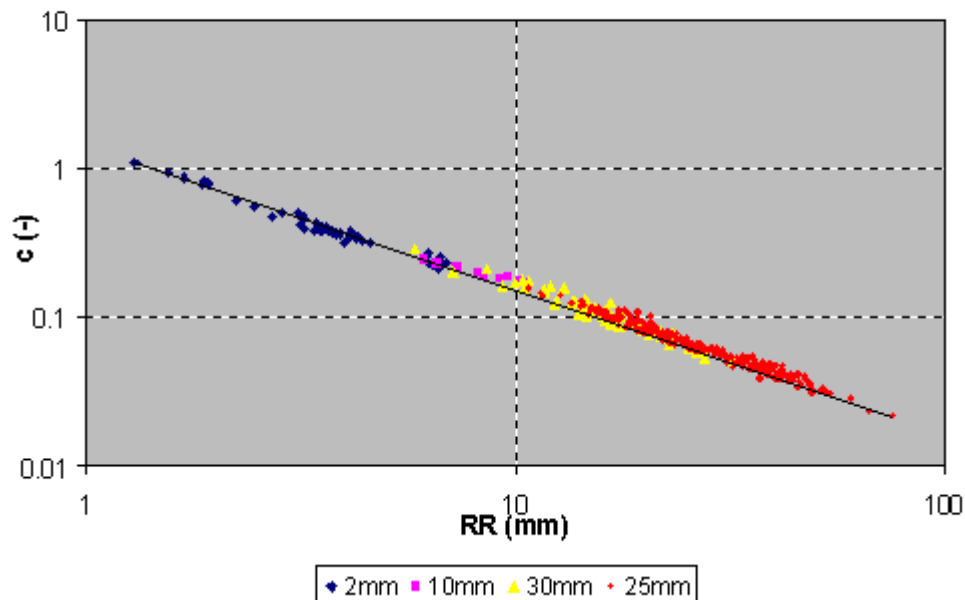


Figure 2.4. Ponded area shape factor a related to RR (Jetten and de Roo, 2001)

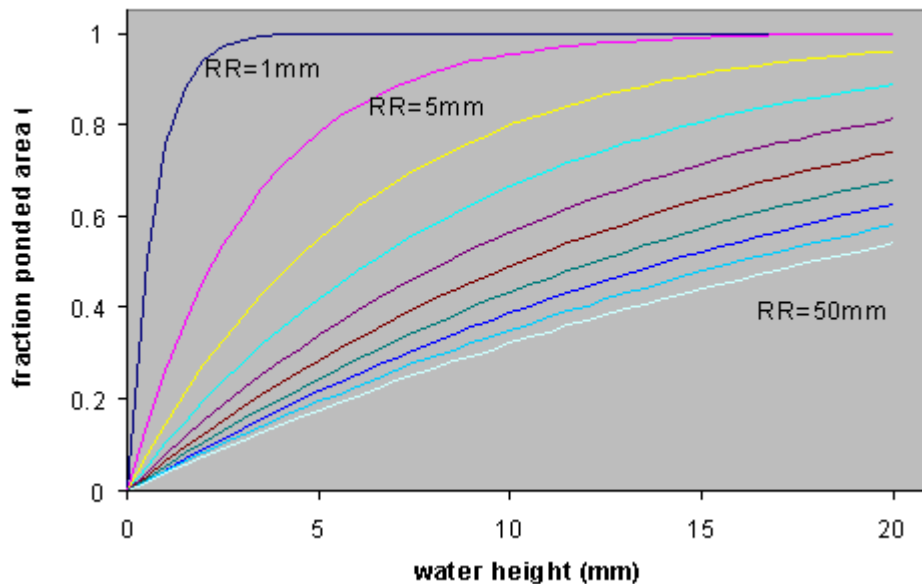


Figure 2.5. Ponded area fraction increase with water height for different values of RR (increase with 5 mm intervals).

Based on the MDS value and the fraction of ponded area the runoff before the water level reaches the MDS height is calculated as follows. It is assumed that the runoff starts if 10% of the surface is ponded so that the equation above for fpa reads:

$$0.1 = 1 - \exp(-a h) \quad [2-20]$$

which means that at $h = \ln(0.9)/-a$, runoff starts. If this threshold for h , called here Start Depressional Storage or SDS is larger than MDS, 0.9 of MDS is taken. Between this starting value "SDS" and the MDS value the runoff gradually increases in a non-linear way to reflect the observation that the surface usually consists of degraded aggregates which "release" little runoff until they are fully submerged. After the water level has passed MDS the runoff height increases linearly with water height:

$$\begin{aligned} h < \text{SDS} : \text{runoff} &= 0 \\ h > \text{SDS} : \text{runoff} &= (h - \text{SDS}) * (1 - \exp(-(h - \text{SDS}) / (\text{MDS} - \text{SDS}))) \end{aligned} \quad [2-21]$$

In fact this resembles a Gaussian curve ($1 - \exp(-x^2)$) as is seen in figure 4.

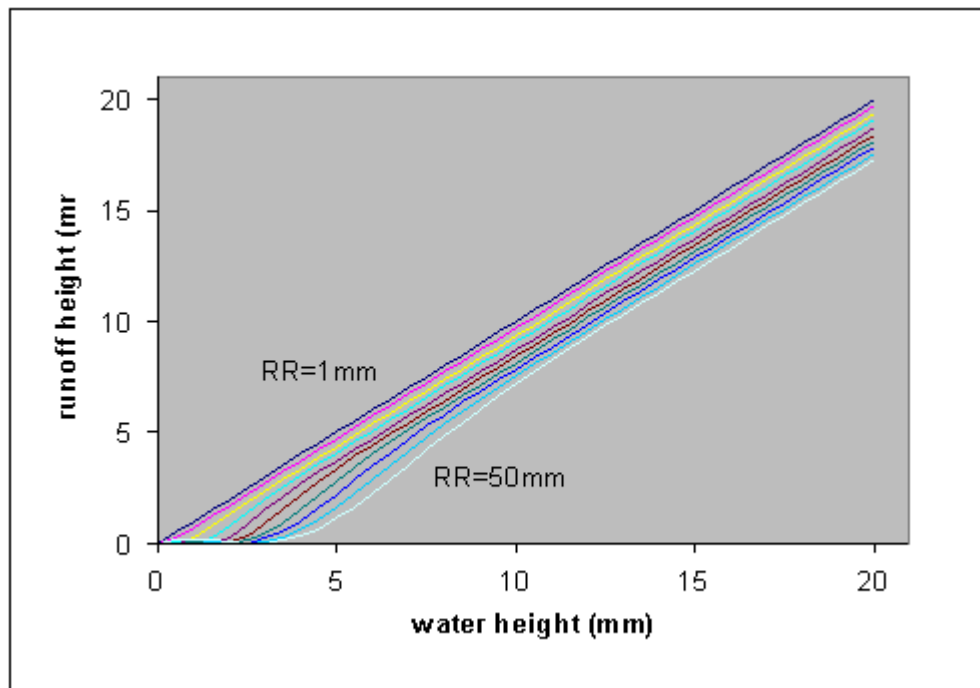


Figure 2.6. Increase of runoff height with with water height for different values of MDS and SDS (increase with 5 mm intervals).

2.5.1 Surface Storage in LISEM Version 1.63 and earlier

Version 1.63 and earlier

Storage in micro-depressions is simulated by a set of equations developed by Onstad (1984) and Linden et al. (1988). The variable Random Roughness is used as a measure of microrelief. Surface storage in depressions is simulated by (Onstad, 1984):

$$\text{RETMAX} = 0.112\text{RR} + 0.031\text{RR}^2 - 0.012\text{RRS}$$

with:
 RET_{MAX} = Maximum Depressional Storage (cm);
 RR = Random Roughness (cm);
 S = Slope gradient (%).

NOTE: in the Onstad equations the RR is calculated using the method of Almaras (1967), who eliminated the extreme 10% of the surface height readings and takes the $\ln$ of the values to normalise the dataset.

The rainfall excess (rainfall + overland flow - interception - infiltration) required to fill all depressions (RET_{RAIN} in cm) is calculated using the equation (Onstad, 1984):

$$RET_{RAIN} = 0.329RR + 0.073RR^2 - 0.018RRS$$

Moore & Larson (1979) identified three possible stages during a rainfall event:

- a) Micro-relief storage occurring, no runoff;
- b) Additional micro-relief storage accompanied by runoff;
- c) Runoff only with the micro-relief storage.

To determine the transition from stage a to stage b, the data of Onstad (1984) were re-analyzed. From this analysis the following equation was developed, simulating the starting point of runoff (RET_{START} in cm):

$$RET_{START} = 0.0527 RET_{MAX} RR - 0.0049S$$

Thus, during stage 1, all excess rainfall becomes depression storage. Then, from point RET_{START} to point RET_{MAX} both overland flow and further depressional storage occur, based on a linear filling of the depressions until RET_{MAX} . After RET_{MAX} , all excess rainfall becomes runoff. Thus, using these relationships the actual storage in depressions (RET in cm) can be calculated.

Also, using the same input data, the maximum fraction of the surface covered with water (FWA_{MAX}) can be calculated (Onstad, 1984):

$$FWA_{MAX} = 0.152RR - 0.008RR^2 - 0.008RRS$$

The actual fraction of the surface covered with water (FWA) is calculated using a relationship based on the work of Moore & Larson (1979) and Onstad (1984):

$$FWA = FWA_{MAX} (RET/RET_{MAX})^{0.6}$$

Ponded area is calculated according to the following equation:

$$FWA = 1 - \exp(-a WH/RET_{RAIN} * FWA_{max})$$

where a is a calibration factor, currently at -5, and WH is the water height of the water layer at the surface.

version 1.53 and earlier

In earlier versions the FWA was defined as a linear increase based on the stages 1, 2 and 3 described above. However the increase was defined in such a way that abrupt changes in fraction of ponded area were calculated with only a small increase in water height. Therefore the linear equations were replaced with the single exponential equation above.

Also in earlier versions, a part of the depressions was not included in the FWA because they were thought to be isolated. The effects of this was hardly noticeable and the fraction of depressions isolated was based on observations rather than a spatial analysis. Thus this variable became just an extra parameter to calibrate and it was removed from the source code in order to simplify depression storage. The fraction of isolated depressions (FWA_{ISO}) was calculated as follows:

Based on the findings of Linden et al. (1988), some depressions are (temporarily) isolated and do not contribute to overland flow. From their data it was determined that if the storage (RET) was less than 75% of the RETMAX, 20% of the depressions are isolated. If RET is between 75% and 100% of RETMAX then the following equation was derived:

$$FWA_{ISO} = 0.20 FWA (1 - 4(RET/RET_{MAX} - 0.75))$$

2.5.2 Overland flow and channel flow

A gridcell can have more than one type of surface: e.g. a road (smaller than DX) is impermeable, a wheeltrack is compacted and a field surface may be ponded or not. The infiltration characteristics vary according to the surface and the infiltration is calculated for each type. An average water height is then calculated for each gridcell, resulting in an average hydraulic radius with which the velocity is calculated. The field surface has a certain roughness and therefore only a part of the water will move.

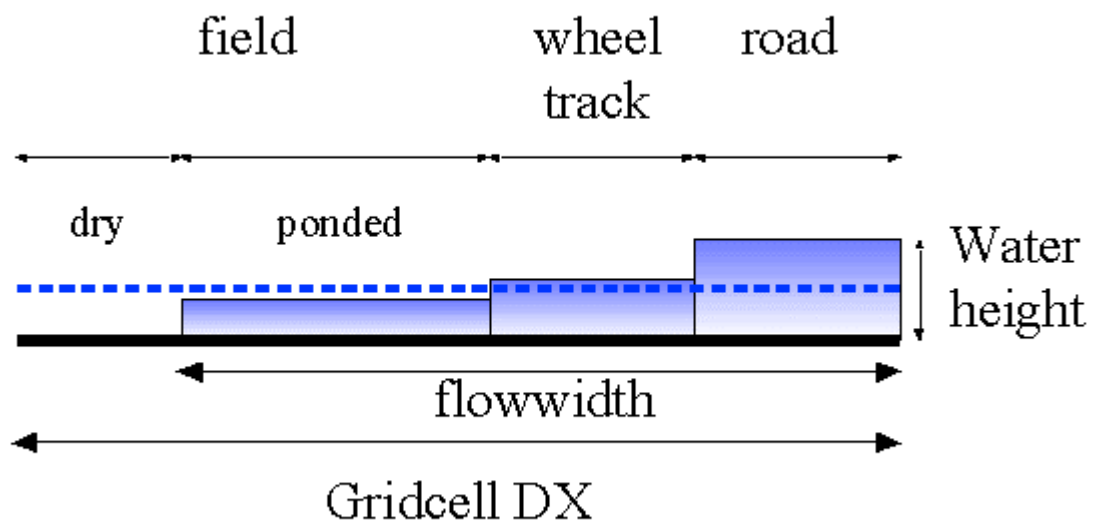


Figure 2.7. Calculation of average water height and flowwidth

The velocity V (m/s) is calculated with Manning's formula:

$$V = R^{2/3} * \text{sqrt}(S) / n \quad [2-22]$$

In which: R = hydraulic radius (m), calculated with the flowwidth and average water height(see figure 5); S = sine of the slope (fraction); n = Manning's n (dimensionless)

The discharge Q (m^3/s) per cell is then calculated with (Chow et al., 88):

$$A = \alpha Q^{\beta} \quad [2-23]$$

In which:

$$\alpha = \left((n / \sqrt{S} \cdot P)^{2/3} \right)^b \quad [2-24]$$

$b = 0.6$

A = wet cross section (m^2)

There is evidence that alpha is constant for small rills and independent of slope and resistance (Govers, 1997), because the flow will find a new equilibrium and uses its energy to form new rill dimensions, while the velocity does not change. Research is currently being done to see if this should be incorporated in LISEM.

For the distributed overland and channel flow routing, a four-point finite-difference solution of the kinematic wave is used together with Manning's equation. Procedures of the numerical solution can be found in Chow et al. (1988) and Moore & Foster (1990). The kinematic wave is done over the Local Drain Directions map that forms a network which connects cells in 8 directions.

Some cells may have a channel (ditch, gully) for which a separate kinematic wave is done (see fig 6). The cells that have a channel receive a part of the overland flow, depending on the velocity. Thus the velocity is considered the average velocity existing in the cell. The channel is considered to be in the center of the cell so that the distance from the edge to the channel is $0.5 \cdot (DX - \text{channel width})$. The part of the water that flows into the channel is therefore:

$$f = dt \cdot V / (0.5 \cdot (dx - cw)) \quad [2-25]$$

The channel width (cw in m) can increase during the run if the channel is not rectangular and the water level in it rises. In that case it cannot become larger than 0.9 of the cell width dx .

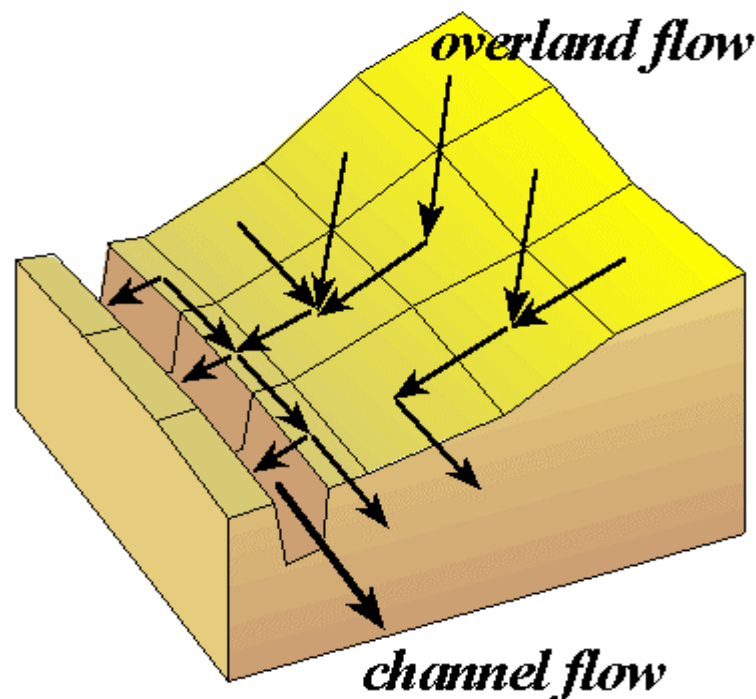


Figure 2.8. Overland and channel flow with LDD structure

2.6 Erosion and eposition

Detachment modelling is based on a generalised erosion-deposition as described by Morgan et al., (1992) and Smith et al (1994), and is identical to the EUROSEM model. It is assumed that the transport capacity concentration of the runoff reflects a balance between the continuous counteracting processes of erosion and deposition (D_p). Erosion is sum of splash detachment by rain drops (D_s), and flow detachment by runoff (D_f). The amount of sediment in suspension (e) is then calculated as:

$$e = D_s + D_f - D_p \quad [2-26]$$

2.6.1 Splash detachment

Splash detachment D_s (g.s^{-1}) is simulated as a function of soil aggregate stability, rainfall kinetic energy and the depth of the surface water layer. The kinetic energy can arise from both direct throughfall and drainage from leaves. Using splash tests the following general equation has been derived (unpublished data):

$$D_s = (2.82/A_s K_e \exp(-1.48 h) + 2.96).P.A \quad [2-27]$$

in which D_s is splash detachment (g.s^{-1}), A_s is the aggregate stability (median number of drops to decrease the aggregate by 50%), K_e is rainfall or throughfall kinetic energy (J.m^{-2}), h is the depth of the surface water layer (mm), P is the amount of rainfall or throughfall under the plant canopy in the timestep (mm), A is the surface over which the splash takes place (m^2). In LISEM splash detachment is calculated as the sum of all splash under and beside plants (throughfall and rainfall) and on ponded and dry areas:

$$\begin{aligned} D_{s_r\text{ponded}} : A &= (fpa)(1-\text{cover})A, \text{ and } K_e \text{ is } K_{e_r} \\ D_{s_t\text{ponded}} : A &= (fpa)(\text{cover})A, \text{ and } K_e \text{ is } K_{e_t} \\ D_{s_r\text{dry}} : A &= (1-fpa)(1-\text{cover})A, \text{ and } K_e \text{ is } K_{e_r} \\ D_{s_t\text{dry}} : A &= (1-fpa)(\text{cover})A, \text{ and } K_e \text{ is } K_{e_t} \end{aligned} \quad [2-28]$$

The kinetic energy of free rainfall and throughfall from the plant canopy as respectively:

$$\begin{aligned} K_{e_r} &= 8.95 + 8.44 \cdot \log(I) \\ K_{e_t} &= 15.8 \cdot \sqrt{h} - 5.87 \end{aligned} \quad [2-29]$$

where I is the rainfall intensity (mm/h) and h is the height of the plants (m). In equations 8a to 8d f is the splash delivery fraction, a user defined fraction that determines the amount of splashed soil that is transported through the air from the dry part of the gridcell to the wet part of the gridcell, so that it can be transported). This means that although most splash occurs on the dry part of the gridcell because of the exponential decrease of splash with water height, only a part of it will be transported.

2.6.2 Flow detachment and deposition

The ability of flowing water to erode its bed is assumed independent of the amount of material it carries and is only a function of the energy expended by the flow. Deposition takes place at a rate equal to wCV_s , where w is the width of flow (m), C is the sediment concentration in the flow (kg.m^{-3}) and V_s is the settling velocity of the particles (m.s^{-1}). The concentration at transport capacity (C_T) represents the sediment concentration at which the

rate of erosion by the flow and accompanying rate of deposition are in balance. In this condition the net rate of erosion is zero and Df equals the deposition rate ($wC_T V_s$). The equation for soil detachment by flow and deposition during flow, expressed in terms of settling velocity and transport capacity, then becomes:

$$D = Y(T_c - C)V_s w \quad [2-30]$$

in which D is Df or Dp (in kg.s^{-1}), T_c is the transport capacity of the flow (kg.m^{-3}) and Y is a dimensionless efficiency factor. The latter is included to account for the fact that the detachment will be limited by the cohesion of the soil material. The pick-up rate for cohesive soil therefore needs to be reduced by a coefficient whenever C is less than T_c . By definition, Y is 1 deposition takes place, i.e. when C is larger than T_c , and when erosion takes place it is calculated as (Rauws and Govers, 1988):

$$Y = u_{\min}/u_c = 1/(0.89 + 0.56Coh) \quad [2-31]$$

in which u_c and $u_{\min}$ are the critical shear velocity and the minimum critical shear velocity (cm.s^{-1}), and Coh is the cohesion of the wet soil determined with a Torvane (kPa). Cohesion by plant roots can be accounted for in LISEM by a second cohesion map that is added to the soil cohesion. Note that dx is added because the unit length of a spatial element in a raster environment becomes the grid cell size.

The transport capacity of overland flow is modeled as a function of unit stream power (Govers, 1990):

$$T_c = \delta_s c(w - w_c)^d \quad [2-32]$$

in which T_c is the volumetric transport capacity (kg.m^{-3}), δ_s is the material density (2650 kg.m^{-3}), w is the stream power (calculated as flow velocity*energy slope) and w_c is the critical stream power defined by Govers (1990) for a fairly wide range of materials to be approximately 0.4 cm.s^{-1} , c and d are experimental coefficients depending on the median texture (d_{50}) of the material. This equation describes the transport capacity in rills. In LISEM equation 9 becomes (with V in m/s and the sine of the slope S):

$$T_c = 2650 c(VS^{100} - 0.4)^d \quad [2-33]$$

Note that currently LISEM does not distinguish in its algorithms between interrill and rill erosion. In fact all erosion is assumed to be rill erosion, although there are no rills defined as such. Water simply flows from cell to cell following a drainage network (see below). Currently the definition of a separate rill network is under development and then rill and interrill transport capacity can be differentiated. LISEM uses the median of the texture (d_{50}) as input to represent spatial variability of grain sizes. The model calculates the corresponding coefficients a and b based on work of Govers (1990):

$$\begin{aligned} c &= [(D_{50} + 5)/0.32]^{-0.6} \\ d &= [(D_{50} + 5)/300]^{0.25} \end{aligned} \quad [2-34]$$

NOTE: originally these equations are valid for materials with a grain size diameter larger than $32 \mu\text{m}$.

There are two checks carried out in LISEM to avoid the calculation of an incorrect Df or Dp . The amount of erosion or deposition in a timestep depends on the settling velocity V_s . With a too large timestep it may happen that all sediment has already settled before the end of

the timestep. Therefore the deposition is never more than the amount of sediment in suspension:

$$D_p = \min(\text{sediment}, D_p) \quad [2-35]$$

In the case of detachment, the amount of detached soil cannot be more than the remaining carrying capacity of the flow (Q in m^3/s):

$$D_f = (T_c - C) Q \, dt \quad [2-36]$$

The net sediment in suspension is transported between gridcell with the kinematic wave.

2.6.3 Channel detachment and deposition

Erosion and deposition in channels is treated in the same way as these processes on land. There is no separate detachment equation LISEM, although the stream power concept was initially developed for rills. The same formulas are used, but with the hydraulic radius, velocity, discharge and transport capacity are based on channel maps for cross sectional shape, bed-gradient and Manning's n . The detachment efficiency is calculated with the channel cohesion.

3 LISEM-WHEELTRACKS

to be done

4 LISEM-MULTICLASS

to be done

5 LISEM-NUTRIENTS

to be done

6 LISEM-GULLIES (EUROWISE)

6.1 Introduction

In the MWISED project (EU ENV4-CT97-0687), Modeling Within Storm Erosion Dynamics, LISEM was extended to cope with the incision and formation of ephemeral gullies. The model was presented under the name **EUROWISE**, which is used here. EUROWISE is synonym to *LISEM-gullies*.

EUROWISE was designed not to need much more data for gully incision than the original LISEM. Incision can be modelled in a physically deterministic way by using shear stress of the flow along the sides and bottom of the gully and compare it to the shear strength of the profile. This would require a complete knowledge of the soil cohesion and variation of cohesion with depth, and the capability of simulating the flow conditions in detail. Although this can be done technically, such a model is very difficult to verify and the data would have to be extrapolated from a few measurements to a large extent. A different approach was chosen here: first flow incision takes place in certain areas only, derived from field observations, and secondly when incision takes place the width of the gully is based on an empirical relationship with the discharge. The amount of erosion is based on the more deterministic erosion and deposition equations in LISEM, such as described in the LISEM BASIC section.

6.1.1 Ephemeral gullies

The following text is copied from the thesis: "A spatial and temporal analysis of the characteristics, importance and prediction of ephemeral gully erosion" by Jeroen Nachtergaele (2001), who cooperated in the MWISED project.

Problems related to the definition of ephemeral gullies are two-fold. (1) Traditionally ephemeral gullies have been defined in the way they differ from rills and (classical) gullies. Such 'negative' definition is rather vague and open to discussion since it states what an ephemeral gully is not instead of expressing the essential nature of this erosion feature. (2) As it is often the case with newly defined concepts, many synonyms or nearly-synonyms have been used to describe this erosion feature. In what follows, it is attempted to define ephemeral gully erosion and its related erosion features in such a way that it is at least clear what within this study is understood by the term ephemeral gully erosion.

Rill erosion is defined as erosion in numerous small channels that are uniformly distributed across the slope and that can be obliterated by tillage (Hutchinson and Pritchard, 1976). According to the Soil Science Society of America (1997) rill erosion is characterized by numerous and randomly occurring small channels of only several centimetres in depth. Rills form on sloping fields, mainly on cultivated soils. Rills can follow tillage marks, or they may develop much like a drainage network of rivers in a large basin (Foster, 1986).

(Classical) gully erosion is defined as erosion in channels that are too deep to cross with farm equipment (Hutchinson and Pritchard, 1976). According to the USDA Soil Conservation Service (1966), classical gullies are channels formed by concentrated flow of water, removing upland soil and parent material and of a size to large to be obliterated by normal tillage operations.

Bank gullies form where a concentrated flow zone, a rill or an ephemeral gully crosses and erodes an earth bank, e.g. a terrace, a river bank (Poesen, 1993; Poesen and Hooke, 1997). Bank gullies may develop upslope by head-cut migration.

Ephemeral gully erosion was first comprehensively discussed by Foster (1986). The introduction of ephemeral gullies as a separate erosion class resulted from the fact that in the 1980's soil conservationists in the US became progressively aware that if only rills and classical gullies are considered in soil erosion assessments, an important erosional area and source of sediment within fields is being overlooked (Foster, 1986). The topography of most fields causes runoff to collect and concentrate in a few major natural waterways before leaving the fields. Erosion occurring in these channels is what is known as ephemeral gully erosion (Foster, 1986). The 'ephemeral' nature of this erosion feature results from the fact that ephemeral gullies are ploughed in and tilled across annually (or more frequent), therefore restoring the original hollow, but leaving a potential zone for subsequent ephemeral gully erosion. Poesen (1993) added to the view of Foster (1986) that ephemeral gullies may also form where overland flow concentrates along (or in) linear landscape elements (e.g. drill lines, plough furrows, parcel borders, access roads).

Definition-wise, incisions in linear landscape elements can be classified as rills since their formation is associated with the micro-relief generated by tillage or landforming operations (Haan et. al, 1994). However, incisions in linear landscape elements are a form of concentrated flow erosion that will never develop in a standard USLE runoff plot used to quantify interrill and rill erosion. According to the original idea behind the introduction of ephemeral gully erosion as a separate erosion class (Foster, 1986), it seems sound to consider incisions in linear landscape elements as part of ephemeral gully erosion. Synonyms used to describe (erosion due to) ephemeral gullies are: concentrated flow erosion (Foster, 1986; Auzet et al., 1995), talweg erosion (Papy and Souchère, 1993), thalweg gullies (De Ploey, 1990), megarills (Foster, 1986), rills in valley floors (Evans and Cook, 1987), valley-bottom rills (Boardman, 1992).

With respect to the differences between rill, ephemeral gully and (classical) gully erosion, it is clear that ephemeral gullies and classical gullies can be discerned based on their persistence. In contrast to the permanency of classical gullies, ephemeral gullies are short-lived. Definitions of ephemeral and classical gullies often refer to the means by which these gullies are (resp. are not) obliterated (i.c. normal tillage operations). Defining the exact operation or equipment, however, is less relevant since this is variable in both space and time. Relevant is the fact that, once formed, a classical gully evolves by erosion of the gully floor, head-cut migration and erosion of the gully walls, which implies a combination of processes (e.g. water erosion and mass movement). As ephemeral gullies form, are disguised and potentially form again on the same spot, their evolution requires mainly a repetition of the incision process, while the relative importance of head-cut migration and erosion of the gully walls is less significant.

Differences between rills and ephemeral gullies are not always very clear. Foster (1986) gives two firm arguments to distinguish rills from gullies. (1) Flow in rills is usually classified as a part of overland flow that is assumed to occur uniformly across a slope even though it is concentrated in rills. In contrast, flow in ephemeral gullies is clearly channelized. Also, erosion due to rills will affect the entire slope, while erosion due to ephemeral gullies is much more confined. However, net erosion due to rills/ephemeral gullies should be assessed by taking into account the combined effect of water erosion (formation) and tillage erosion (removal). (2) Subsequent ephemeral gullies will occur in the same spot, while the position of rills is variable from time to time since it is strongly influenced by micro-topography (e.g. tillage marks). In addition to the arguments of Foster (1986), it can be remarked that rills and gullies also differ in the way they contribute to the drainage pattern of a watershed. While rills are usually limited by field borders, ephemeral gullies often extend over multiple fields. In terms of erosion this implies that rills normally only redistribute soil within one field, whereas ephemeral gullies transport soil material to completely different parts of the watershed. The difference between rills and ephemeral gullies with respect to

the way they affect a watershed's hydrology, is also clearly illustrated by Steegen et al. (2000). They showed that there exists a positive relation between ephemeral gully development in a given watershed and measured suspended sediment concentrations at the outlet of that watershed for comparable rainfall events. In other words, ephemeral gullies do not only act as sediment sources, but once established they also function as efficient sediment transport ways. Despite the aforementioned arguments, there still exists a small overlap between rills and ephemeral gullies. For example, when a slope shows several clear rills, that concentrate gradually downslope and finally form a clear ephemeral gully (Figure 1), where should the critical point between rill and ephemeral gully be placed? It is clear that there exists a transition zone between rills and ephemeral gullies. While an overlap between the two cognate concepts does not impede the existence of each individual concept, problems may arise when assessing rills/ephemeral gullies in the field. In order to have an objective measure to distinguish rills from gullies in such dubious cases, Poesen (1993) proposed a critical cross-section of 929 cm² or one square foot, a criterion first used by Hauge (1977). Within this study this criterion was used to ensure that the data sets assessed in all study areas and by all persons involved are fully comparable.

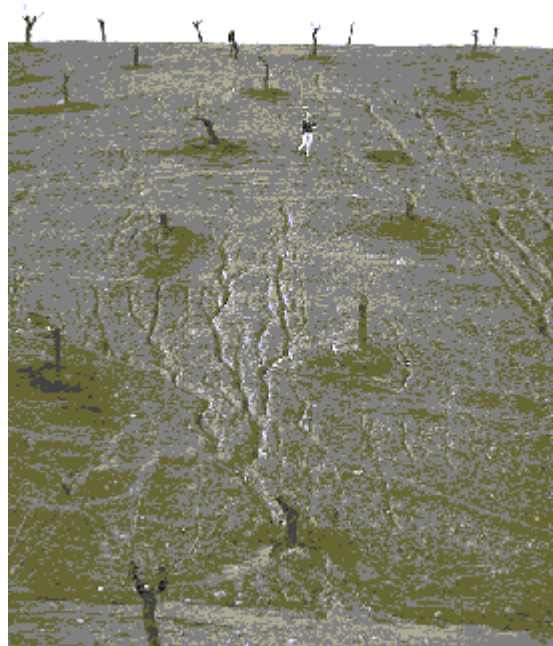


Figure 6.1. Photograph illustrating a transition from rill to ephemeral gully erosion (January 1998, Guadalentin, south-east Spain, foto: J.Nachtergaele)

Finally, questions about the true need for a distinction between rills and ephemeral gullies can often be heard from the side of soil erosion modellers. First of all the need for such a distinction with respect to erosion modelling originates from the fact that some erosion models explicitly state that they (only) cover interrill and rill erosion (e.g. USLE). What falls beyond the scope of these models needs to be named and defined since it requires another model or modelling approach. Concerning the erosion processes involved, modellers often raise that rills and ephemeral gullies can be treated equally since the initiation of both linear erosion features require soil material to be detached and transported by flowing water.

6.1.2 Summer and winter gullies

The cross section criterion can be applied to classify both so called "summer gullies" in central Belgium (shallow and very wide), and winter gullies (deep and narrow), as ephemeral gullies (figure 2).



Figure 6.2. winter (left) and summer gully (right) in Belgium (photos: I. Takken, KU Leuven)

EUROWISE has to be able to simulate both types of gullies: shallow gullies that widen when more erosion takes place and deep gullies that deepen and stay narrow. The difference is caused by the soil cohesion: in summer the situation is often a seedbed above a more compacted layer and sideways erosion encounters less resistance and costs less energy.

6.2 Basic principles

EUROWISE is an extension of LISEM: a feedback loop is added whereby the simulated flow detachment is recalculated to a loss of soil volume and causes a decrease of the surface height in the digital elevation model. This in its turn causes a change in local slope and flow path, which influences the erosion in the next time step.

The modelling of gully incision and formation takes a three step approach:

1. An analysis of the landscape to determination likely locations of a gully as a result of one or more rainfall events, called here "critical areas". These areas are selected on the basis of topographic features such as slope and upstream drainage area.
2. The simulation of splash and flow detachment on a physically deterministic basis everywhere in the catchment, using the principles of the LISEM BASIC.
3. Incision and change in gully dimensions as a result of flow detachment inside the critical areas, using an empirical discharge-width relationship. The rest of the catchment is assumed to have rill erosion only, which is not causing gullying. This is an extension of the code to simulate the incision in a 2 layer soil based on bulk density and cohesion, and an empirical width-discharge relationship.

6.2.1 Critical area analysis - theory

The position of the gullies is determined as the areas where topological critical thresholds are exceeded. The algorithms in this section are based on the work of Nachtergaele et al., 2001. He found that ephemeral gullies in the Belgian loessbelt and the Spanish Guadelantine area often occur on the same locations. These zones of likely incision, termed "critical areas" here, can be derived from an analysis of the area contributing runoff (A) to a given location, and the local slope of that location (S). Different types of critical thresholds for the Belgian loess belt are found in the literature. For the EUROWISE model, four empirical critical threshold values are evaluated:

- Critical threshold value according to Vandaele (1996)

$$S \cdot A^{0.4} > 0.5 \quad [6-1]$$

- Critical threshold value according to Moore et al. (1988)

$$S \cdot A > 18 \text{ and } \ln\left(\frac{A}{S}\right) > 6.8 \quad [6-2]$$

- Critical threshold value according to Vandaele et al. (1996)

$$S > 0.025 \cdot \left(\frac{A}{10000}\right)^{-0.4} \quad [6-3]$$

- Critical threshold value according to Desmet and Govers, (1997)

$$S \cdot A^{0.4} > 0.72 \quad [6-4]$$

The critical threshold values are area specific. The equation of Moore et al., (1988) is a more uniform relationship whereby $A \cdot S > 18$ is related to the erosive power concentrated Hortonian overland flow, while the relation " $\ln(A/S) > 6.8$ " is assumed to be a measure of soil saturation and therefore is more related to the process of saturated overland flow. According to Poesen et al. (1997), gully development in the Belgian loess belt is essentially caused by concentrated Hortonian overland flow. Therefore Moore's equation was considered at first less appropriate for the area.

After analysis it appeared that a second threshold is needed (Nachtergaele, 2001): when a critical area is defined according to the algorithms above, the contributing area will soon dominate the analysis and all area towards the outlet will be seen as critical. Thus a second threshold is needed to give a lower boundary that will make the gully formation stop. For the Belgian loessbelt it was shown that no gullying occurred on the lower slopes and thalwegs when the slope angle decreased below 4%. Below this angle deposition processes become dominant.

6.2.2 Critical area analysis - Implementation in LISEM

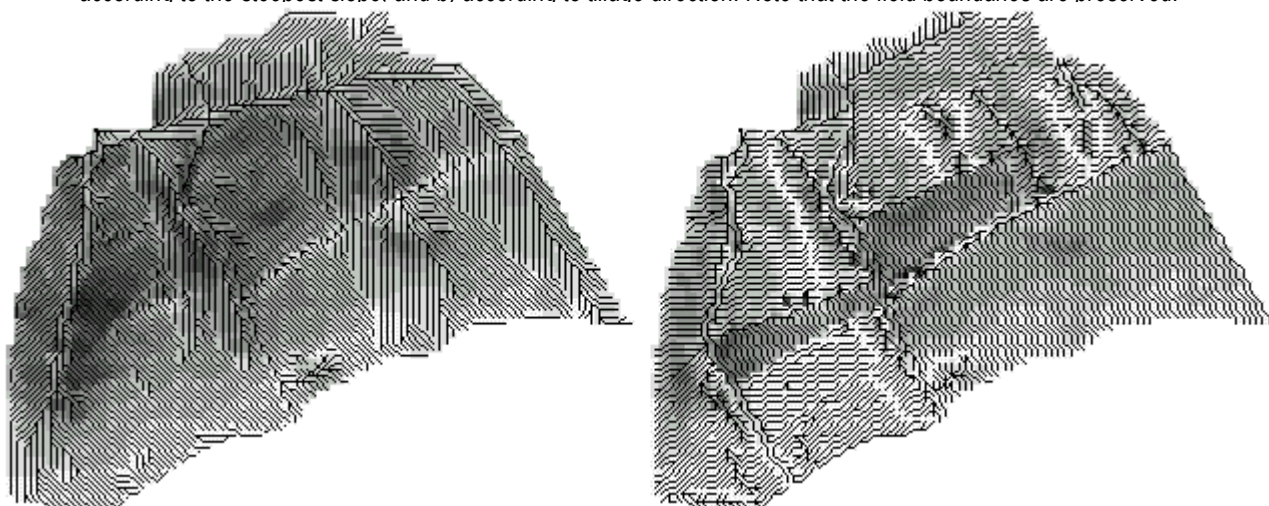
Since the EUROWISE model uses raster maps created with the Geographical Information System PCRaster (Van Deursen and Wesseling, 1998). This GIS combines the regular spatial expression of any GIS with a modelling language that enables the analysis of flow of material over a landscape and is therefore very suitable for this work package. The language follows simple rules that can be combined in a "script", a kind of macro that is executed with a compiler (PCRCALC.EXE). In PCRaster a network can be generated from the digital elevation model (DEM) that defines the direction of flow over the landscape. The network is called LDD, the Local Drain Direction. The LDD can be made directly from the DEM by using the steepest angle of flow (see figure 1). To delimit critical areas, the contributing area draining towards a given point has to be generated. In PCRaster the command to do this is:

```
ups.map = accuflux(ldd.map, cellarea());
```

This command accumulates the cellarea over the network and gives therefore in each cell of the output map the cumulative area of all cells draining towards that cell, so e.g. the value of the outlet of the catchment has the total area of the whole catchment above the outlet. This is the PCRaster equivalent of the variable A in the algorithms above.

In an agricultural environment the direction of flow is often the tillage direction (at least for a part of the year). Takken (2001) in her work on the influence of tillage on runoff, created a PCRaster script to generate automatically a valid LDD based on the tillage direction per field, while including features such as headlands, dead furrows and topography where necessary. (see Fig. 3). It can be seen that the effect is very different: the concentration zones follow the field pattern much more in the right hand image than in the left hand image (Fig. 4). The main concentration lines are formed by the four small side valleys. The slope is calculated by taking the difference in elevation between a grid cell and the cell towards it drains, divided by the distance.

Figure 6.3. PCRaster LDD maps for a 40ha catchment (Limburg, NL): a) drainage direction (lines) and slope (grayscale) according to the steepest slope, and b) according to tillage direction. Note that the field boundaries are preserved.



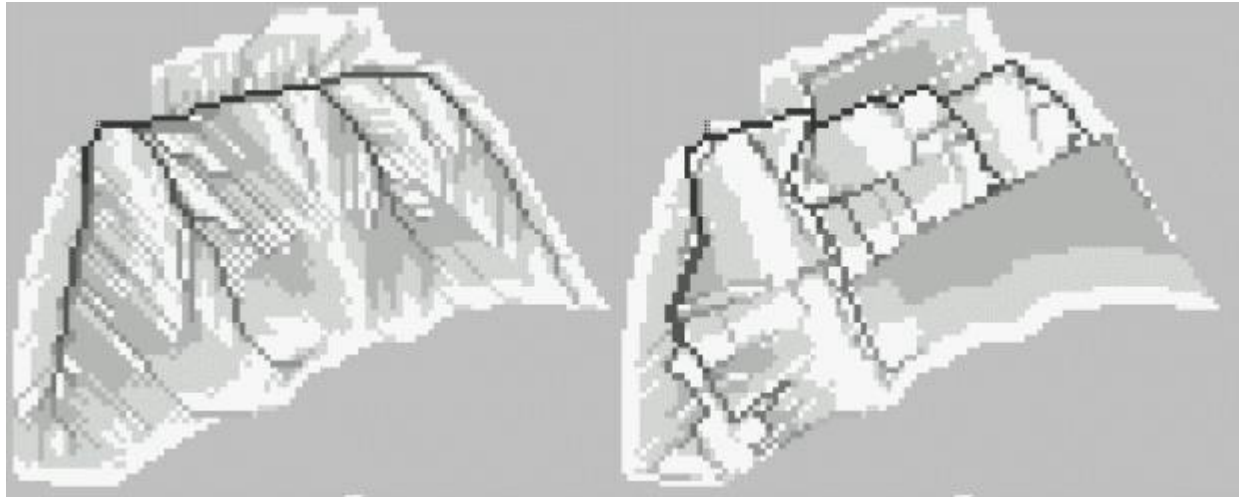


Figure 6.4. PCRaster contributing area from accuflux (identical to variable A in the critical zone algorithms, see text): a) patterns using the steepest slope, and b) patterns using the according the tillage direction.

However, the implementation of the above algorithms in PCRaster needs a certain interpretation of the thresholds. Firstly, when the algorithms are implemented directly the critical area is calculated on a cell to cell basis. That means that if a cell has a local slope angle that does not meet the criteria, that cell may not be seen as a critical cell. This causes fractioning of the critical zone. It must therefore be assumed that once a gully starts forming it will not stop at a single location and continue downslope of that location simply because the local slope is not sufficient. Therefore a more continuous zone has to be created. Secondly, the gully formation will not continue endlessly and the algorithms show a dominance of the drainage area A above the local slope S. In reality gully formation may stop because the gradient at the bottom of the slope is low and deposition occurs. This has been observed for the Belgium loess belt although not for the Mediterranean area.

The implementation in PCRaster is done as follows:

- 1) A critical zone is made according to the algorithms
- 2) the map edge is excluded from the zone because the flow path created in PCRaster will consider the map edge as a boundary (so often a gully will form there);
- 3) This zone is accumulated along the network to give a continuous area;
- 4) A critical threshold slope angle is applied when necessary (depending on the area);
- 5) Isolated "critical" pixels are removed;
- 6) Isolated "non-critical" pixels are classified as "critical" if the pixels upstream and downstream are also "critical" (repair holes in the critical zone).

```
=====begin of file=====
#####
# Critical area analysis #
#####
binding
# INPUT MAPS
Dem=dem.map;
Fcrit1 = fcrit1.map;
Fcrit2 = fcrit2.map;
Fcrit3 = fcrit3.map;
Fcrit4 = fcrit4.map;
Fcrit5 = fcrit5.map;

initial
# SURFACE TOPOLOGY
# create ldd
```

```

report Ldd=lddcreate(Dem,1E25,1E25,1E25,1E25);
# create upstream area and slope map
Upstream=accuflux(Ldd,cellarea());
Slope=max(slope(Dem),0.001);
B=celllength();
# COMPUTE CRITICAL THRESHOLDS
# critical threshold according to Vandaele, 1996
report Fcrit1=if((Slope*((Upstream/B)**0.4)) gt 0.5 and Slope gt
0.04,0,nominal(10));
# critical threshold according to Moore et al., 1988
report Fcrit2=if(Slope*(Upstream/B) gt 18 and ln((Upstream/B)/(Slope)) gt
6.8,0,nominal(10));
# critical threshold according to Vandaele et al., 1996
report Fcrit3=if(Slope gt (0.025*((Upstream/10000)**-0.4)),0,nominal(10));
# critical threshold according to Desmet and Govers
report Fcrit4=if((Slope*((Upstream/B)**0.4)) gt 0.72,0,nominal(10));
# critical threshold according to Vandaele et al., 1997, Portugal
report Fcrit5=if(Slope*(Upstream/B) gt 40 and ln((Upstream/B)/(Slope)) gt
9.8,0,nominal(10));
=====end of file=====

```

An example: critical areas for the Kinderveld test site (BE)

Figure 5 shows 6 images of the Kinderveld test area near Leuven (BE) where gullies were monitored in the MWISED project (see introduction). The test site has a size of 13.7 ha and a grid cell size of 5x5 m. The measured gullies are shown as a black line while the white areas are the 5 critical areas susceptible to gully erosion. It can be seen that all critical areas include the gullies except for algorithm 5 which begins too far downslope. Also the figure shows that the algorithms 1 and 3 produce too large areas while 2 and 4 are closer to reality. Since the main overland flow process is Hortonian overland flow, criteria 4 seems to give the best result.

6.2.3 Ephemeral gully formation

The section above results in a water flux and sediment flux on the surface, that is distributed using the kinematic wave principle. The sediment is a result of erosion which may or may not cause gully formation, depending on the location in the field. As is explained above the gullying is assumed to take place ONLY in the critical areas. The following approach is taken to simulate the incision processes.

Gully width

The gully formation, i.e. the deepening of the critical area, is not necessarily over the whole grid cell width: the gully width depends on the peak discharge of the runoff in a non-linear way: $w = a \cdot Q^b$. The parameters a and b are predefined for Belgium from laboratory and field observations.

For areas which exceeds the critical threshold value, gully width is calculated according to the relation: $W = a \cdot Q_{\text{peak}}^b$, with a and b as empirical constants, W is the gully width in meters and Q_{peak} is the peak discharge of the runoff in m^3/s . For the Belgium loess belt these relationships are found by KULEUVEN for different kind of gullies in field and in laboratories: the best relation is:

$$W = 2.51 \cdot Q^{0.412}$$

[6-5]

Note that the user can define the parameters a and b in the interface.

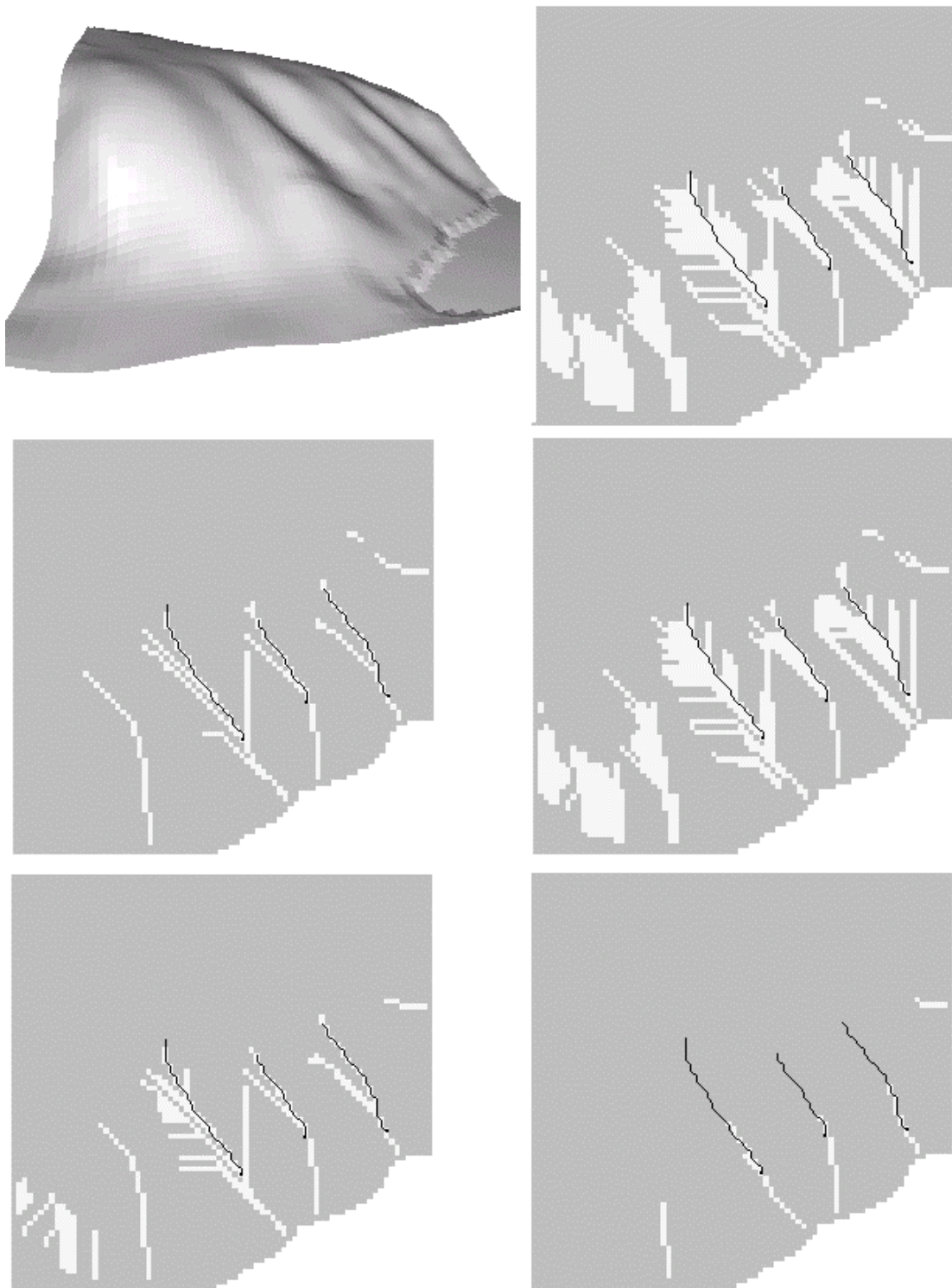


Figure 6.5. Critical areas according to the 5 algorithms (white). The lines are the actual mapped gullies.

The gully width has to be initialized in order for the erosion to start. A sensitivity analysis shows that this value is not very sensitive and an arbitrary value of 0.1 m is chosen. The width of the gullies increases with increasing runoff discharge till the point of the maximum peak discharge (Fig. 6). At that point gully width is assumed to be constant.

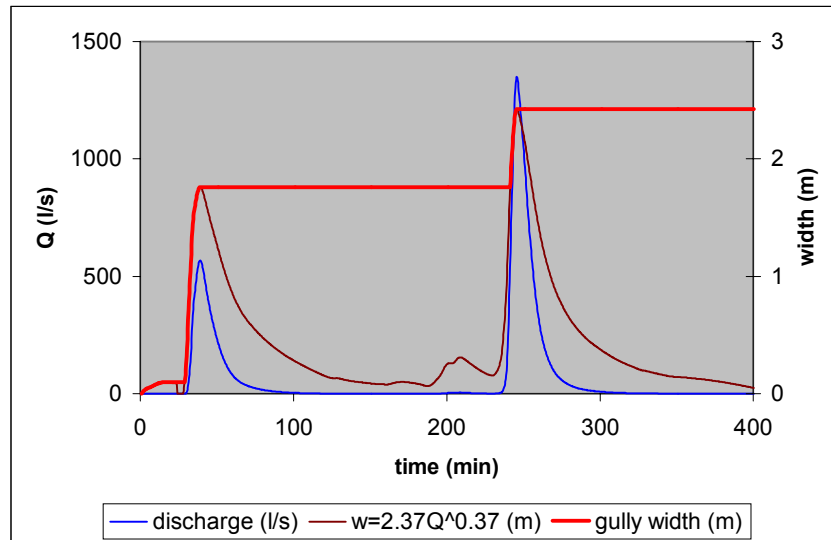


Figure 6.6. Simulated gully width when the peak discharge is passing a pixel which exceeds the critical threshold.

6.2.4 Gully incision

For each gridcell and timestep the processes above result in the water discharge Q ($\text{kg}\cdot\text{m}^{-3}$), the corresponding gully width w (m) and the sediment discharge Q_s (kg). The eroded mass of the soil is recalculated to a depth depending on the situation:

1. Homogeneous soil: only the depth d of the gully increases over the gully width w using the amount of flow detachment Df and the bulk density D of the soil: $d = Df/(w \cdot dx \cdot D)$.

Note that these parameters are represented by maps that can be spatially variable, only the depth is assumed homogeneous.

2. Two layers: in case the soil has a compacted layer with a higher cohesion (e.g. a plough layer), both the gully width and depth have to be adjusted. In this case the gully often becomes shallow and wide because the sideways erosion is easier than the downward erosion. This effect is not accounted for in the Q - w relationship. Thus the following system is devised: if the depth of the gully reaches the second layer AND the water level in the gully still "touches" the first layer the flow detachment is divided over the walls and bottom of the gully as follows:

$$Df_x = \frac{2h}{P_w} \cdot Y_1 \cdot (T_c - C) \cdot V_s \cdot w \cdot dx \quad [6-6]$$

$$Df_y = \frac{w}{P_w} \cdot Y_2 \cdot (T_c - C) \cdot V_s \cdot w \cdot dx$$

where: h is the water depth (m), P_w is the wet perimeter (m), and Y_1 and Y_2 are the efficiencies based on the cohesions of the 1st and 2nd layer. The gully width w and depth d are increased according to:

$$w = w + Df_x / w \cdot dx \cdot \rho_1 \quad [6-7]$$

$$d = d + Df_y / w \cdot dx \cdot \rho_2$$

The gully width cannot become larger than the grid cell width. During the calculations the digital elevation model changes. For each time step a new DEM is calculated in the dynamic loop of PC Raster. This new DEM is derived from old DEM with subtraction of the erosion or addition of the sedimentation. Changes in the DEM causes changes in local drain direction (LDD), which allows fluctuations in the stream pattern of the gullies.

7 THE INPUT DATABASE

The input database consists of a series of raster maps created with or converted to the GIS PCRaster. Furthermore LISEM needs event based (so called breakpoint) data of rainfall intensity for one or more rainstorms. Note that LISEM does not yet simulate evapotranspiration so that this is not taken into consideration when dry periods between rainfall events are calculated.

In the next sections you will find an overview of the input data and the commands needed to create them with PCRaster. Note that a PCRaster script file is available from the website which generates the complete input dataset from a few basic maps.

7.1 PCRASTER

All input and output maps in LISEM are in the format of the PCRaster Geographical Information System. PCRaster is a **free** GIS is produced by PCRaster environmental software, and can be obtained through their website:



There you will find a complete list of functions, research and coding examples and literature. PCRaster is not only a normal GIS but a generic programming language for dynamic landscape modelling. If you are interested in using PCRaster for modelling purposes, a distance learning course is available through the internet: <http://pcraster.geog.uu.nl/mutate>.

PCRaster is used in two contexts here:

1. LISEM is largely built in a mixture of PCRaster commands and C++
2. The modelling capabilities of PCRaster are used to create the input maps with one or more macros (scripts).

LISEM is developed in an environment that is a mix of C++ and PCRaster libraries. A large part of the source code is written in the macro language of PCRaster. The advantage of this close integration is primarily for the model developer: the PCRaster macro-language includes a powerful 'calculator' that is able to parse virtually any mathematical or logical equation. Equations that are commonly found in erosion models can be typed almost literally from a text to include them into the model. An example: the Manning's equation can be written in PCRaster as a string that is given to a 'calculator' (the statements are translated to C++ at compilation):

```
V=if(n gt 0, R^(2/3)*sqrt(max(slope(DEM), 0.001))/n,0);
```

where V, R, DEM and n are raster maps, and slope is the GIS operation to calculate the gradient from the DEM but it cannot be smaller than 0.001. The instruction is carried out for all cells in the raster maps. As a precaution, the logical "if" statement sets the Velocity to 0 where n is 0. The advantage of this approach is that the code is very compact and that several developers can work with the code at the same time, without the need of knowing a higher programming language such as C++ or Pascal.

Note that for processes where iteration is required (such as the kinematic wave and Richard's type infiltration) special functions are developed. The advantage for the user lies in the fact that the output maps of runoff and erosion/deposition can be viewed directly with PCRaster without the need of conversions.

PCRaster can also be used to create input maps using separate statements for each map, examples of which are given in the "input maps" section. These commands have the general syntax:

```
pcrcalc [options] out.map = in.map...
```

where a large number of operations are available for the in.map. Note that PCRaster is very strict on the variable types which have to be specified explicitly if the type of resulting map is ambiguous. The types are:

- boolean = 0/1
- directional = 0-360
- ldd = network direction (1-9)
- nominal = class integer
- ordinal = class integer
- scalar = real value

Alternatively all input maps can be created in one operation with the script that can be found on the LISEM website. The script is run with the command:

```
pcrcalc -f lisemmaps.mod
```

which produces the LISEM input maps based on 4 basic catchment maps.

NOTE: PCRaster has no capabilities of digitizing maps. It can however import maps from IDRISI and ARC-INFO (basic Arc-grid format). Also PCRaster has extensive capabilities of geostatistical interpolation.

7.2 The input maps

All input and output maps in LISEM are in the format of the PCRaster GIS. This raster GIS is produced by PCRaster environmental software, and can be obtained through their website, where you will find a complete list of functions and examples.

LISEM needs a minimum of 24 maps depending on the input options selected in the interface (e.g. enabling the simulation of ditches requires additional maps, and some infiltration options require more maps than others). If needed all maps can be derived from 4 base maps:

digital elevation model,

land use,

soil type and

impermeable areas such as tarred roads (this is needed because the road can be narrower than the gridcell size and LISEM needs to know what type of soil or land use exists adjacent to the road).

All input data can be derived from these four base maps, but of course other sources can be used to make the input maps (geostatistical interpolation, remote sensing etc.).

The spatial input data for LISEM can be structured as follows:

1. Catchment maps
2. Vegetation maps
3. Soil surface maps
4. Infiltration related maps
5. Erosion/deposition related maps
6. Channels

In this part all input maps are listed with the PCRaster commands to make them. Since PCRaster is also capable of running macros and even spatial models, all commands given here are combined in a script, so that the complete database can be constructed in one go. The script can be downloaded from the website.

NOTE: the map names given here are NOT compulsory but can be specified individually by the user in the interface. However, to enable compatibility with the older versions of LISEM the map names used here are the default names. Also the extension ".map" is NOT compulsory, just convenient.

7.2.1 Catchment maps

The actual digital elevation model is not used in LISEM, only maps derived from it. This has the advantage that a number of important maps such as the surface drainage network (called Local Drain Direction or LDD in PCRaster) and Gradient are not automatically derived with GIS operations, but can be supplied by the user.

Map name	Contents	Type	Unit	Range
LDD	Local drain direction	ldd		1-9 (see below)
AREA	Catchment boundaries	boolean		1
ID	Area covered by raingauges	nominal		1- n (= # of raingauges)
GRAD	Slope gradient (sine of slope angle)	scalar	-	must be > 0 and <= 1
OUTLET	Location of outlet and suboutlets	nominal		0-3

LDD: Local Drain Direction, this map gives for each cell the direction of the surface runoff (the number correspond to a keypad on your keyboard: 1=drainage to lower left, 6 is drainage to the right etc.) the number 5 is reserved for the catchment outlet. Note that this map cannot contain local depressions, the entire catchment has to drain towards the outlet. PCRaster provides commands that can automatically generate such a map, with removal of the local depressions ('pits') based on constraints given by the user. In this case the LDD is based on the steepest slope. The command is:

```
pcrcalc ldd.map=lddcreate(dem.map,1e10,1e10,1e10,1e10)
```

The 4 large values are thresholds to remove the pits and create a continuous LDD.

It is also possible to generate a valid LDD map based on the tillage direction. A PCRaster macro has been constructed by Takken et al. (2000) that combines major topographic concentration lines with tillage direction per field, including 'headlands' and 'dead furrows'.

NOTE: errors with LISEM related to the kinematic wave where MVs are reported (missing values) are often because the LDD does not have the same dimensions as the other maps.

AREA: all maps are checked against this map for the number and location of non-missing value cells. If maps do not have the same size and number of valid cells, an error occurs.

```
pcrcalc area.map=catchment(ldd.map, pit(ldd.map))
```

GRAD: this is the gradient in the direction of the LDD. *PLEASE NOTE: this must be the SINE of the slope (not the tangent).* Because the slope can occur in the denominator of various algorithms, it cannot be 0 (zero). Use the slope command to create the slope from the DEM:

```
pcrcalc grad.map=slope(dem.map)
```

or make a gradient map with the tangent of the slope in the direction of the flow (it has to be covered with the slope derived from the DEM to account for edge cells):

```
pcrcalc grad.map=(dem.map-  
upstream(ldd.map, dem.map))/downstreamdist(ldd.map)  
pcrcalc grad.map=cover(grad.map, slope(dem.map))
```

convert this map to a sine and make sure it is larger than 0::

```
pcrcalc grad.map=sin(atan(max(0.001, grad.map)))
```

ID: this map can be made in various ways, using Thiessen Polygons or zones based on relief. The numbers in this map must correspond to the number of rain gauges in the rainfall file. An example is to create a map according to Thiessen polygons from a map with pixels that have the numbers of the rain gauges:

```
pcrcalc id.map=nominal(spreadzone(gauge.map, 0, 1))
```

Alternatively the relief can be taken more into account by taking the slope as a weighing factor:

```
pcrcalc id.map=nominal(spreadzone(gauge.map, 0, grad.map))
```

or by using the mean elevation line between two gauges as a separation line (gauges have id numbers 1, 2 and 3 here, dem is a map):

```
pcrcalc a1 = maptotal(if(p1 eq 1, dem, 0))  
pcrcalc a2 = maptotal(if(p2 eq 2, dem, 0))  
pcrcalc a3 = maptotal(if(p3 eq 3, dem, 0))  
pcrcalc a4 = (a1+a2)/2  
pcrcalc a5 = (a2+a3)/2  
pcrcalc id.map = nominal(if(dem lt a4, 1, if(dem lt a5 and dem  
ge a4, 2, 3)))
```

NOTE: that the gauges must be situated inside the ldd.map area otherwise it will not be included in the spread operation.

OUTLET: a map with values 0 (background) and 1 which is the main outlet. On this cells a hydrograph and sedigraph are stored as ASCII files. Two additional cells can be given (numbers 2 and 3 compulsory) to store hydrographs and sedigraphs for additional locations (e.g. sub catchments). The main outlet is found by:

```
pcrcalc outlet.map=pit(ldd.map)
```

7.2.2 Vegetation maps

Vegetation and/or crops are mainly used by the interception and splash erosion processes in LISEM. The maps are usually made by reclassifying the field boundary map. vegetation influences also the soil cohesion for which a separate map must be defined (see below). Note that LISEM has never been tested for forest areas and should be used with care in these circumstances.

Map name	Contents	Type	Unit	Range
LAI	Leaf area index	scalar	-	0-12
PER	Fraction of soil covered by vegetation	scalar	-	0-1
CH	Vegetation height	scalar	m	0-30

LAI: leaf area index, used to calculate the storage capacity of the canopy. The value represents the LAI of the vegetated part of the gridcell. For instance if a grid cell has a single tree with a LAI of 6 in it, the LAI of that cell is 6.

PER: fraction of soil cover by canopy, but also litter or other types of soil cover (except for stones).

CH: crop height, used to calculate throughfall kinetic energy in the splash erosion part.

These maps can be made in similar operations if a table is available that has as the first column the id numbers of the landuse map-units, and in the other columns values for the LAI, cover fraction and vegetation height (the option "--matrixtable" is needed because of the table layout conventions in PCRaster):

```
pcrcalc --matrixtable lai.map = lookupscalar(landuse.map, 1,
veg.tbl)

pcrcalc --matrixtable per.map = lookupscalar(landuse.map, 2,
veg.tbl)

pcrcalc --matrixtable ch.map = lookupscalar(landuse.map, 3,
veg.tbl)
```

The table may look like this (four landuse types with different IDs not necessarily sequential):

```
=====begin of file=====
1   0   0.1   0
2   1.2  0.3   0.3
4   1.23 0.35  0.4
16  6.1  0.95  1.8
=====end of file=====
```

NOTE: LISEM assumes no logic in this table! It will not check if a LAI of 6 is combined with a cover fraction of 0.

7.2.3 Soil surface maps

This is a mixed category with maps that determine several processes: infiltration, surface storage, overland flow (velocity). In an agricultural catchment these maps are based on the landuse mostly, or on a combination of landuse and soils. Note that in a crop rotation cycle these values will change according to for instance crusting stage, soil cover and tillage operation.

It also includes different *types of surface* for which the processes are calculated separately.

Map name	Contents	Type	Unit	Range
N	Manning's n	scalar	-	0.001 - 10
RR	Random Roughness	scalar	cm	0.05 - 20
STONEFRC	Fraction covered with stones	scalar	-	0 - 1
CRUSTFRC	Fraction cover with a crust	scalar	-	0 - 1
ROADWIDT	width of impermeable roads	scalar	m	0-cellsize

N: Surface resistance to flow, expressed as Manning's n.

RR: 'random roughness' used here as the standard deviation of the micro relief heights (do not use transformations to obtain a more 'normal' distribution).

STONEFRC: fraction of stones for which no splash erosion is calculated (used only in this process).

CRUSTFRC: fraction of the soil crusted. On gridcells with non-zero values the infiltration is calculated according to soil physical properties supplied by the user, depending on the infiltration option chosen.

ROADWIDT: width of impermeable roads for which no infiltration is calculated (is used in all infiltration modules).

```
pcrcalc --matrixtable n.map = lookupscalar(landuse.map, 1,
surface.tbl)

pcrcalc --matrixtable rr.map = lookupscalar(landuse.map, 2,
surface.tbl)

pcrcalc --matrixtable stonefrc.map = lookupscalar(landuse.map,
3, surface.tbl)

pcrcalc --matrixtable crustfrc.map = lookupscalar(landuse.map,
4, surface.tbl)

pcrcalc roadwidt.map = scalar(if (roads.map neq 0, *width*,
0))
```

where "surface.tbl" is a table such as used with the vegetation related maps, and *width* is a value for the road width in m.

7.2.4 Infiltration related maps

There are currently 6 infiltration options in LISEM, based on 3 different models. Depending on the choice of the user in the interface, a different set of input maps is needed.

- a) no infiltration: no maps needed
- b) SWATRE (including crusts, wheel tracks and grass strips)
- c) Holtan/Overton
- d) Green & Ampt: 1 and 2 layers and additional surface types
- e) Morell-Seytoux & Verdin

a) No infiltration

The entire catchment is assumed impermeable. Can be used for testing.

b) SWATRE

To operate the SWATRE infiltration module, the user has to set up a series of maps and tables with soil physical properties that describe the profile (max 20 layers) of each land unit. These can be e.g. soil type units or fields or parts of fields.

Map name	Contents	Type	Unit	Range
PROFILE.INP	ASCII lookup file describing soil profiles of map units			
name.TBL	ASCII tables with soil physical data			
PROFILE.MAP	map with profile ID numbers	nominal	-	>= 1
PROFCRST.MAP	map with ID number of crust profiles	nominal	-	>= 1
PROFWHL.MAP	ID number of wheel track profile	nominal	-	>= 1
PROFGRAS.MAP	ID number of grass strip profile	nominal	-	>= 1
HEADOUT.MAP	locations of matric potential output	nominal	-	0, 1-4
INITHEAD.001 ...INITHEAD.0nn	positive initial matric potential of each soil layer	scalar	cm	0..100000

PROFILE.INP: when the SWATRE infiltration model is used LISEM needs a 3D structure of the soil. This structure is described in the text file PROFILE.INP. In this file the number of nodes are given for the solution of the Richards equation (using a finite difference approximation) and their depths. These are independent of the actual soil horizons. NOTE that the node depths are used in LISEM as boundaries between simulation layers (not centres). Below the nodes the soil profiles are given (see syntax below) with 'pointers' to the names of the tables describing the soil physical relations (pF curve and hydraulic conductivity curve) of a particular soil type.

NOTE that in this file ALL information is stored, including that of the units for crusts, wheel tracks and grass strips. So if these features are simulated the file PROFILE.INP has to be adjusted to reflect their presence.

The file PROFILE.INP has the following layout:

```
=====          Begin of file =====
14              number of soil layers

2.5            1:depth of boundary between first and second layer (cm)
5              2:depth of boundary between second and third layer
10             3: etc.
15
20
25
30
40
50
60
70
80
90
100            14: depth of final soil layer (cm)

1              description of map unit 1. Used in Swatre if
ASCRP.TBL      the name of the soil physics table to be used
15             the depth down to which the above table is used (cm)
SUB REST.TBL   use this table for depth 15-30
30
C ALL.TBL
100

2              description of map unit 2. Used in Swatre if
ASCRP A.TBL    etc.
15
SUB REST.TBL
30
C ALL.TBL
100

3              etc
ASCRP C.TBL
15
SUB REST.TBL
30
C ALL.TBL
100
=====          End of file =====
```

name.TBL: in the soil above three horizons are defined, each of them with separate soil physical characteristics, referring to the specific tables. The horizons used here are: 0-15 cm, 15-30 cm and 30-100 cm. The tables used for these layers contain 3 columns: soil moisture content (theta, fraction), pressure head (h in cm), and unsaturated conductivity (k in cm/day). An example:


```

0.01  -4.86E+24   1.95E-21
0.02  -1.04E+07   1.64E-11
0.03  -9.02E+05   2.12E-09
0.04  -2.15E+05   3.63E-08
.....etc.
0.31  -3.19E+01   6.74E-01
0.32  -2.33E+01   9.89E-01
0.33  -1.54E+01   1.54E+00
0.34   0.00E+00   5.69E+01

```

PROFILE.MAP: a map based on soils, fields or a combination, with ID numbers that are used to look up the corresponding soil physics tables in PROFILE.INP.

PROFCRST.MAP: a map with ID numbers on those places where there is a crust, to look up the soil profiles for crusted soils in the file PROFILE.INP. The areas that are crusted are defined in CRUSTFRC.MAP. There can be more crust profiles if there are for instance more crop types with a different developing surface. Simply include more crust profile descriptions in PROFILE.INP.

PROFGRAS.MAP: a map with ID numbers corresponding to the soil profile for grass strips. The area where strips are present are given in GRASSWID.MAP.

PROFWHL.MAP: a map with ID numbers corresponding to the soil profile for wheel tracks. The area where tracks are present are given in WHEELWID.MAP. Note that there are more maps to define wheeltracks.

HEADOUT.MAP: map with up to four cells numbered 1 to 4 (de rest having value 0). When the option matric output is checked in the infiltration options of the input menu, an ASCII table with matric potential for each layer at each timestep is created.

INITHEAD.001 - INITHEAD.020: initial matric potential for each layer (if for instance you have defined 6 layers in PROFILE.INP, there are 6 maps 001 to 006). The values are positive matric potentials in cm.

c) Holtan/Overton

The Holtan infiltration model is a one layer empirical model. The maps need no further description. Note that the extra infiltration options (wheel tracks, crusts and grass strips) are not implemented for the Holtan model.

Map name	Contents	Type	Unit	Range
FC	infiltration rate saturation	scalar	mm/h	0-100
A	difference initial and saturation rate	scalar	mm/h	0-100
TP	soil porosity	scalar	cm ³ /cm ³	0.01-0.60
DF	depth infiltration control zone	scalar	mm	0.001-300
P	coefficient infiltration equation	scalar	-	0.4-0.8
ASM	initial soil moisture content	scalar	-	0.20-1
FP	soil moisture at field capacity	scalar	-	0.40-0.90

d) Green & Ampt, 1 and 2 layers and additional surface types

G&A demands the hydraulic properties of the first layer. NOTE that the soil depth is only of consequence if the option "impermeable sub soil" is checked, meaning that the soil storage is limited to the product of the moisture deficit and the depth: $(\theta_{s1} - \theta_{t1}) \cdot \text{soildep1}$. If this option is not checked the soil is assumed of unlimited depth and at moisture content θ_{t1} for its entire depth.

Map name	Contents	Type	Unit	Range
KSAT1	Saturated hydraulic conductivity	scalar	mm/hr	0-1000
THETAS1	Saturated volumetric soil moisture content	scalar	-	0-1
THETA1	Initial volumetric soil moisture content	scalar	-	0-1
PSI1	Soil water tension at the wetting front	scalar	cm	0-1000
SOILDEP1	Soil depth	scalar	mm	0-1000

G&A1: Additional surfaces

In addition separate ksat maps have to be defined for crusted soils, wheel tracks or grass strips. These maps are required when any (or all) of the extra options in the infiltration options menu are checked.

Map name	Contents	Type	Unit	Range
KSATWT	wheeltrack Ksat, used with infiltration option "include wheel tracks"	scalar	mm/hr	0-1000
KSATGRAS	grass strip Ksat, used with infiltration option "include grass strips"	scalar	mm/hr	0-1000
KSATCRST	crust Ksat, used with infiltration option "include crusts"	scalar	mm/hr	0-1000

NOTE: in addition the user has to define the maps WHEELWID.MAP, GRASSWID.MAP and/or CRUSTFRC.MAP.

These options are only used for the first layer of the Green and Ampt module. If a 2 layer Green and Ampt is used, the second layer will be identical for all option.

G&A2: Two layer Green & Ampt

Requires all maps of Green and Ampt 1 layer plus an identical set for 2nd layer. The depth of the second layer (soildep2) is only of consequence when the "impermeable sub-soil" option is checked (see remark above).

Map name	Contents	Type	Unit	Range
KSAT2	see KSAT1	scalar	mm/hr	see KSAT1
THETAS2	see THETAS1	scalar	-	see THETAS1
THETA2	see THETA1	scalar	-	see THETA1
PSI2	see PSI1	scalar	cm	see PSI1
SOILDEP2	see SOILDEP1	scalar	mm	see SOILDEP1

e) Morel-Seytoux & Verdin

Not implemented yet.

7.2.5 Erosion/deposition related maps

Erosion and deposition in LISEM is based on the deficit transport capacity (capacity surplus equals deposition and transport deficit equals erosion). The particles in flow have a settling velocity that is estimated by the settling velocity of the median fraction (D50 in μm). To calculate more sediment classes the LISEM-MULTICLASS SEDIMENT version has to be used.

Map name	Contents	Type	Unit	Range
AGGRSTAB	Aggregate stability	scalar	-	0.00001-200; -1
COH	Cohesion of bare soil	scalar	kPa	COH+COHADD $\geq$ 0.196
COHADD	Additional cohesion by roots	scalar	kPa	COH+COHADD $\geq$ 0.196
D50	D50 value of the soil	scalar	μm	(advise:) 25-300

AGGRSTAB: aggregate stability is used for the splash erosion. It is the median number of the drops needed to decrease the size of the aggregates by half on a sieve (LOWE test).

COH: Cohesion of the soil (kPa) measured with a torvane. The cohesion value is used in an empirical formula to decrease the transport deficit with a factor between 0 (no erosion) and 1 (cohesionless soil).

COHADD: Additional cohesion (kPa) to be added by the user to simulate the effect of plant roots on the soil strength. Note that this is a calibration value as the Torvane test is not suited to measure the effect of roots.

D50: median of the texture of the soil (μm) used to simulate the settling velocity. This value determines strongly the deposition.

WARNING: if water with sediment with e.g. D50=25 flows over a gridcell with a D50=150, all sediment will deposit, even if the sediment in flow has a D50 that is less. To avoid these kind of effects use a homogeneous D50 map or better use the version LISEM MULTICLASS SEDIMENT.

7.2.6 Channels

Channels in LISEM are meant to be man-made ditches with a width much smaller than the grid cell (typically a ditch of less than 1.5 m wide in a grid cell of 10x10 m). The channel network **MUST** be a continuous network connected to the outlet. Water that enters the channel in LISEM does not come out again (the channels do not overflow) and if the channels are not connected to the outlet they are effectively sinks. LISEM does a separate kinematic wave for the channel.

Simulations can also be done considering a concentrated flow line, such as a thalweg, to be a channel. The PCRaster operation `accuflux` can be used to determine a channel based on the ldd:

```
pcrcalc chanmask.map = scalar(if(accuflux(ldd,cellarea()) lt
10000, 1))
```

This command creates a mask of a channel (having value 1 as the channel and MV outside) based on the contributing area: all cells that have 10000 m² of drainage area upstream are considered a channel. The mask itself is not used in LISEM but it can be used to create the channel input maps:

CAUTION: The channel form (hydraulic radius) and resistance (Manning's n) determine to a large extent the shape of the hydrograph. Channels are considered impermeable.

Map name	Contents	Type	Units	Range
LDDCHAN	Local drain direction of channel network	ldd		1-9
CHANGRAD	Channel gradient	scalar	-	0.0001-10 6)
CHANMAN	Manning's n for the channel	scalar	-	0.001-0.6
CHANCOH	Cohesion of the channel bed	scalar	kPa	> 0.196
CHANWIDT	Width of channel	scalar	m	0-cellwidth
CHANSIDE	Channel cross section shape	scalar	-	0-10

LDDCHAN: the LDD map based on the channel mask alone. This map can only have one pit that has to be the same as the pit (outlet) of the LDD. A way to create this map is:

```
pcrcalc
lddchan.map=lddcreate(dem*chanmask.map,1e10,1e10,1e10,1e10)
```

CHANGRAD: the gradient of the channel bed based on the channel mask alone. A way to create this map is:

```
pcrcalc changrad.map=slope(dem*chanmask.map)
```

CHANMAN: the Manning's n (resistance to flow of the channel). Usually this is not known and a literature value (ditches with vegetation) is assumed. If the channel is used to simulate a thalweg, the manning's n of the land use could be used (n.map, see above):

```
pcrcalc chanman.map=n.map*chanmask.map
```

CHANCOH: the cohesion (kPa) of the channel bed, resistance to flow erosion. Usually this is not known and a literature value (ditches with vegetation) is assumed, or of a concrete channel is simulated, a very high cohesion could be assumed. If the channel is used to simulate a thalweg, the cohesion of the land use could be used (coh.map and cohadd.map, see above):

```
pcrcalc chancoh.map=(coh.map+cohadd.map)*chanmask.map
```

CHANWIDT: the channel bed width in m. Because the channel shape is not necessarily rectangular, the top width at water level, and the hydraulic radius, is calculated from the side angle and the water height in the channel. This value should be smaller than the grid cell

width (not more than 90% of the cell width). The width is usually a field measured value (*width*):

```
pcrcalc chanwidth.map=if (chanmask.map ne 0, *width*)
```

CHANSIDE: tangent of the angle between the channel side and the vertical: 0 is a rectangular channel, 1 is a side angle of 45 degrees, 10 is a very wide channel (84 degrees). Note that the width of the top of the water level depends on this side angle, if the water rises the stream becomes wider, but it cannot become wider than the gridcell.

```
pcrcalc chanside.map=if (chanmask.map ne 0, 0)
```

7.3 Additional maps needed for EUROWISE

All input and output maps in LISEM are in the format of the PCRaster GIS. This raster GIS is produced by PCRaster environmental software, and can be obtained through their website, where you will find a complete list of functions and examples.

In order to run EUROWISE (LISEM-GULLIES) a few additional maps are needed, on top of the regular maps needed with the LISEM BASIC version.

Note that the names are not compulsory but default in the current version. They can be changed individually in the interface.

EUROWISE needs a Digital Elevation model for the critical area assessment, and a few additional maps that define the structure of the layers to be eroded.

Map name	Contents	Type	Unit	Range
DEM	Digital elevation model	scalar	m	0- top of Mount Everest
GULWIDTH	Initial width of gully	scalar	m	must be > 0
GULLYMAN	Resistance of gully bottom	scalar	-	0.001-0.6
BULKDENS	Bulk density first layer	scalar	kg/m3	must be > 1000
GULDEP2	Depth to second layer	scalar	cm	must be > 0
GULCOH2	Cohesion of second layer	scalar	kPa	must be > 0.2
GULBD2	Bulk density second layer	scalar	kg/m3	must be > 1000

DEM: Digital elevation model, used to delimit the critical areas according to the algorithm chosen in the interface by the user. The analysis is done inside EUROWISE.

GULWIDTH: initial width of the gully for those areas where incision takes place (in practice this is the critical area). This parameter is maybe not necessary and will disappear in the future based on a sensitivity analysis of various areas.

```
pcrcalc gulwidth.map=????????????
```

GULLYMAN: resistance to flow at the bottom of the gully based on Manning's n. This will be purely based on assumptions, but a value is needed (like the "channel" maps in the lsem basic version)

```
pcrcalc gullyman.map=????????????????
```

BULKDENS: this map can be made by interpolation of measured values or by reclassifying a soil or land use map. The classification can be done with a lookup table as is explained in the LISEM BASIC input map section (soil surface maps):

```
pcrcalc bulkdens.map=lookupscalar(unit, soil.tbl, 1)
```

where soil.tbl is a text file containing bulk density values of each map unit.

NOTE: that the gauges must be situated inside the ldd.map area otherwise it will not be included in the spread operation.

GULDEPTH: the depth to a second layer with a higher bulk density and cohesion. Although in reality there can be a gradual increase in bulk density, EUROWISE assumes an abrupt change to simulate the situation of a loose seedbed on a more compact sub-soil. This map determines to a large extent whether the widening of the gully. The depth can be assumed constant:

```
pcrcalc guldepth.map=scalar(if (unit.map eq 1,8,12))
```

gives a map with a depth of 8 cm for unit 1 and 12 cm for all other units. Also a random change (noise) around a mean value could be assumed:

```
pcrcalc guldepth.map=scalar(0.01*normal(1)+0.08)
```

gives a map with a depth of 8 cm with a normal distributed noise that has a standard deviation of 1 cm.

GULCOH2: Cohesion of the second layer, see the map COH.MAP.

GULBD2: see the bulk density map above.

7.4 Rainfall data

The file containing the rainfall data is in ASCII-format and can have any name. The rainfall file should have the following structure (the second column is for explanation only and should be ignored in the real file).

```

=====begin of file=====
RUU CSF TIMESERIE INTENSITY NORMAL 1    Fixed text, 1 indicates the number of
                                         raingauges
station_1                                name of gauge 1, if more gauges are
                                         present then put each name on a
                                         seperate line.
                                         empty line, required!
0.000 00.00
20.00 60.00                                indicate 60 mm/hours rainfall intensity
                                         from minute 0 to 20
250.0 00.00
=====end of file=====

```

If two or more rain gauges are used, e.g. 3 (referring to the numbers used in ID.MAP), the file should have the following structure:

```

=====begin of file=====
RUU CSF TIMESERIE INTENSITY NORMAL 3
station_1
station_2
station_3
955.00 0.00 00.00 0.00
960.00 2.53 20.00 0.50
960.30 2.51 10.00 0.50
960.90 2.49 05.63 0.50
961.97 2.44 10.00 0.50
965.87 2.27 60.00 6.66
1300.00 0.00 00.00 0.00
=====end of file=====

```

The first column is: time (in minutes). The second column is the rainfall intensity (in mm/h) of rain gauge number 1, the third column is the intensity of raingauge number 2 etc.

So, from time 955 to 960 (minutes), the rainfall intensity at raingauge 1 is 2.53 mm/h. From time 965.87 to time 1300 there is no rainfall.

Important:

The last time entered should be large enough to allow all runoff to reach the catchment outlet. This time should be equal to or larger than the time at which the simulation is stopped, specified in the interface.

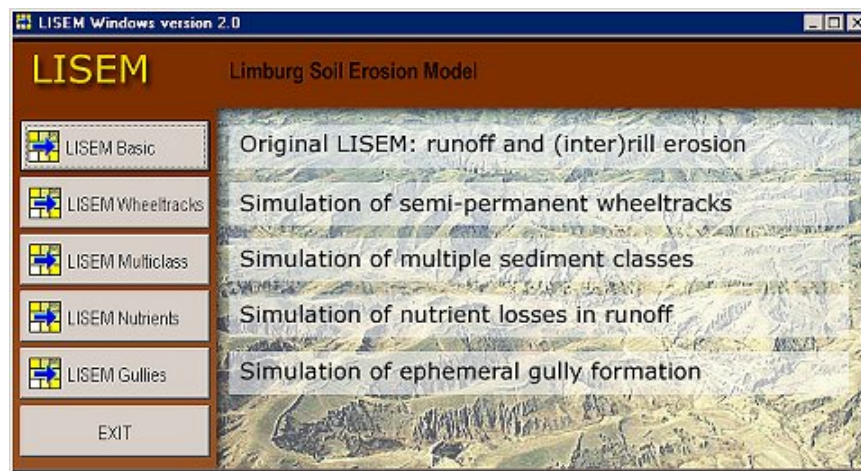
Note: the rainfall file is not in standard PCRaster format. This format was an experimental format and is only used in LISEM. It may change in the future.

8 THE INTERFACE

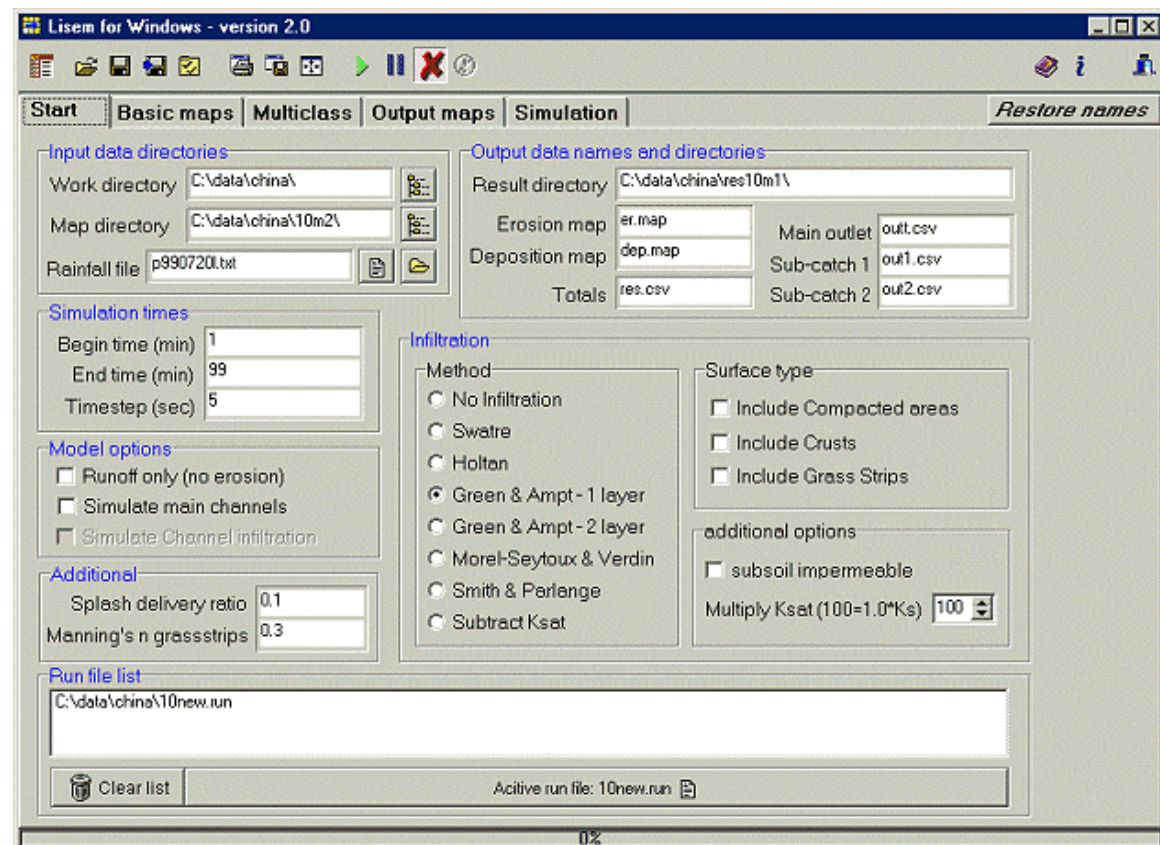
The five version of LISEM are contained in a single executable:

lisemwin.exe

When it does not exist, a file lisemwin.ini is created in which the last workspace is saved. LISEM opens with the following screen:



Pressing one of the buttons will generate a LISEM interface that only contains the options needed to run that particular version of LISEM. The basic interface looks as follows:

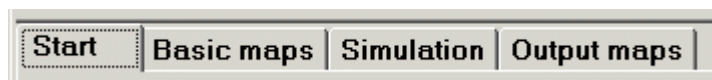


8.1 Speed buttons & Tabs

The icons on top of the interface are:

- load a run file
- save a run file
- save a run file under a different name
- save the directory name of the workspace in the **lisemwin.ini** file
NOTE that the lisemwin.ini file also contains the LISEM Type (0 = Basic, 1=Wheeltracks etc.) and the names upto 4 runfiles (full path-names needed). If the variable LisemType = -1, LISEM starts with the opening screen (top picture), else it starts straight away with the input screen, and starts executing the runfiles in the list.
- dump the active (visible) screen to a printer (e.g. the simulation screen)
- dump the active screen to a GIF file
- resize the screen so that it is entirely visible (800x600 pixels)
- the icons:  are the run buttons:
 - the arrow executes the run-file list
 - the pause icon pauses the run and it can be resumed with the arrow
 - the cross halts the current run and starts the next
 - the last symbols halts all runs

On the top of the screen a number of tabs are visible:



1. Start : general directories and options
2. Basic Maps : input map names
 - Swatre infiltration options
3. Simulation : water balance totals, hydrograph and sedigraph
4. Output maps : output timeseries

8.2 Start tab

Input directories

Names of workspace, input directories and rainfall file. Clicking on the icons brings up a directory tree to change the dir or it can be types. Clicking on the "text page" icon brings up a window with the rainfall file for inspection (not edit).

Output directories

Specification of the output directories and file names. The result directory is made automatically if it doesn't exist. Limit the number of runoff map characters: the runoff maps are stored as: try00010.500, try00010.750 etc. with simulation time minutes before the dot and fractions of minutes as extension. Selecting the PCRaster timeseries option creates sequential map names: try0000.001, try0000.002 etc.

The runoff maps are optionally stored as discharge (l/s) or unit discharge (l/s/m).

The erosion (positive values) and deposition (negative values) maps are stored in tonnes/ha.

Simulation time

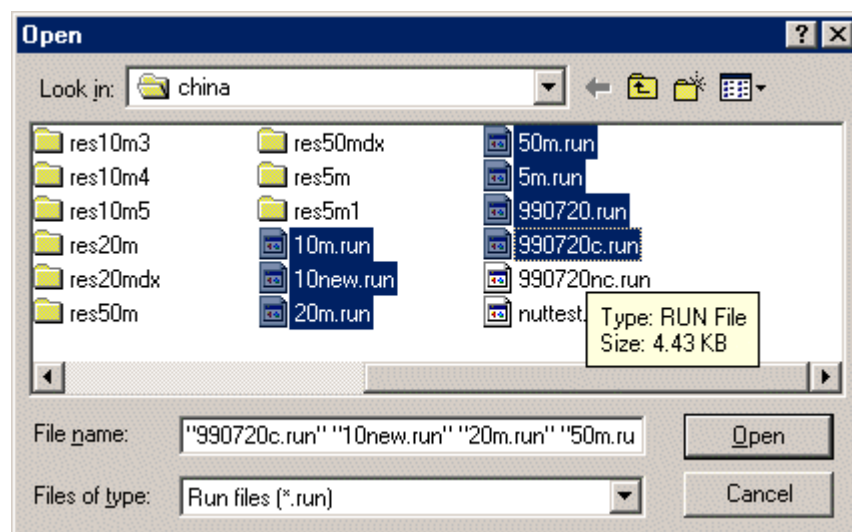
Begin and end times of the simulation in *minutes*: these have to be present in the rainfall file. The timestep is in *seconds*: be sure to make it not too large (in general equal to the gridcell size in m). A good rule of thumb is to use simulation intervals in sec that are 0.2-2 times the grid cell size in m. Do not make it too small either, this causes instabilities (apparently!). A smaller timestep results in a higher peak because of a greater accuracy of the kinematic wave solution.

Output times

Definition of output times to store the runoff timeseries. There are two options: give an interval (e.g. every 4 timesteps) or define individual timesteps.

Runfile list

List of runfiles loaded with the 'load file' button. More files are added until the "trashcan" button is pressed and the list is emptied. LISEM will start executing the runfiles one by one. *DOUBLE CLICKING* on a runfile name will activate it and load the options stored in it. The list of runfiles is executed from the file you double clicked to the end of the list. You can select several run files in the "file open" window by holding 'shift' or 'ctrl' and pointing the mouse.



An example of a run file is given in the **appendix**. It can be edited by hand but the variable names should not be edited because LISEM uses them to recognize the them.

Model options

- No erosion, runoff only: all erosion calculations are skipped.
- Simulate main channels: channel calculations are done, additional maps are required.
- Channel infiltration: ponded infiltration in channel using simple subtraction of a Ksat map. The infiltration will stop if the storage (given in mm) is filled up. Additional maps needed: CHANKSAT.MAP and CHANSTOR.MAP.

NOTE: this option does not work properly at the moment!

Additional options

A few parameters in LISEM do not need to be defined in a spatial way but as a single constant in the interface:

- **Splash delivery ratio:** the relative amount of sediment that is splashed from the dry part of a gridcell to the wet part of a grid cell so that it can be transported. The remainder of the splash sediment settles again as splash deposition.
- **Manning's n grass strips:** a large Manning's n value is given here to simulate the friction of flow on a grass strip. As the strip is generally smaller than a gridcell, the surrounding Manning's n is given in the Manning's n map, while the strip itself is specified here.

Surface types

Activating this option will enable the user to define surface types that "occupy" only a fraction of the pixel. This influences infiltration and in the case of grass strips also the flow resistance. At least two additional maps are needed: one that defines for each cell the fraction of the cell containing this type (e.g. `crustfrc.map` contains values 0-1) and other maps that define the infiltration characteristics (e.g. `ksatcrst.map` tell LISEM how much the `ksat` is for the crusted fraction of a cell). When the SWATRE infiltration model is chosen the structure is different).

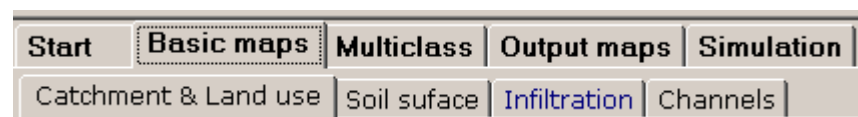
Infiltration

Clicking on an infiltration model will activate certain map input options. Additional choices for infiltration are:

- subsoil impermeable: the layer below the last layer (depends on the infiltration method) infiltration zone is assumed impermeable. Thus the soil will gradually fill up. *This has not been tested for the Holtan equation (option 3)*
- callibration Ksat: the Ksat value in the soil physics tables (see SWATRE) or in the `ksat` maps (other infiltration methods) is multiplied by this factor: $Ks_{new} = Ks_{table} * factor/100$.

8.3 Basic maps

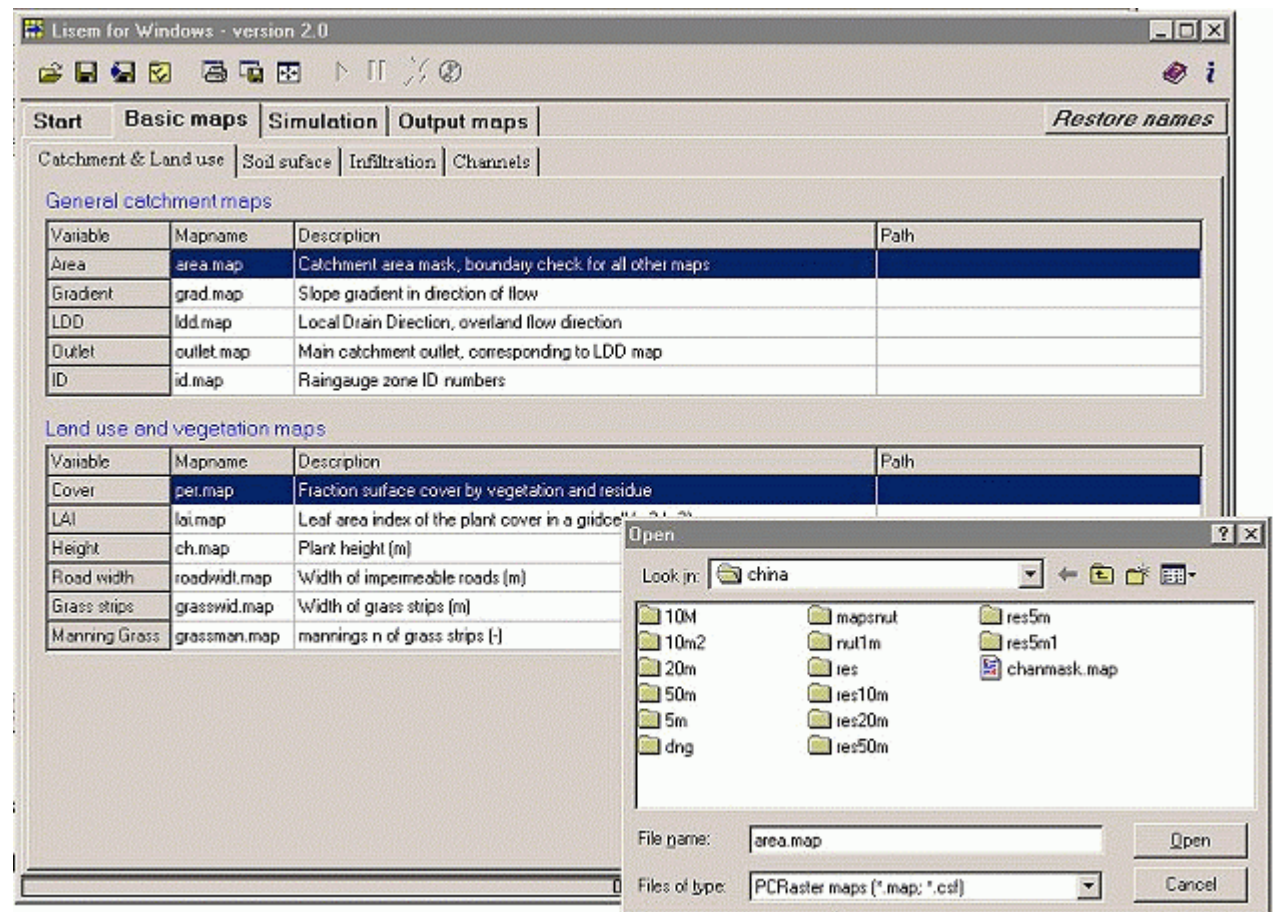
LISEM Basic needs a series of input maps organized as described in the "input maps" section:



Catchment and land use etc.

In these windows the maps can be selected. The run file contains a complete list of maps and their paths so it is easier to adapt an existing run-file of a different project than clicking on each map name in turn. Clicking on a name opens a directory window and the name field can be linked to a specific map. There are no compulsory names in LISEM but a series of default names are used that date from LISEM versions that did not have this name

selection feature. Thus old databases can still be used. The *restore names* button will replace all mapnames with their defaults, and will fill up empty places.



Similar screen exist for the other categories. Note that when the maps are not selected the mapnames are grayed out and not accessible (e.g. swatre maps are grayed out when Green and Ampt is selected).

SWATRE options

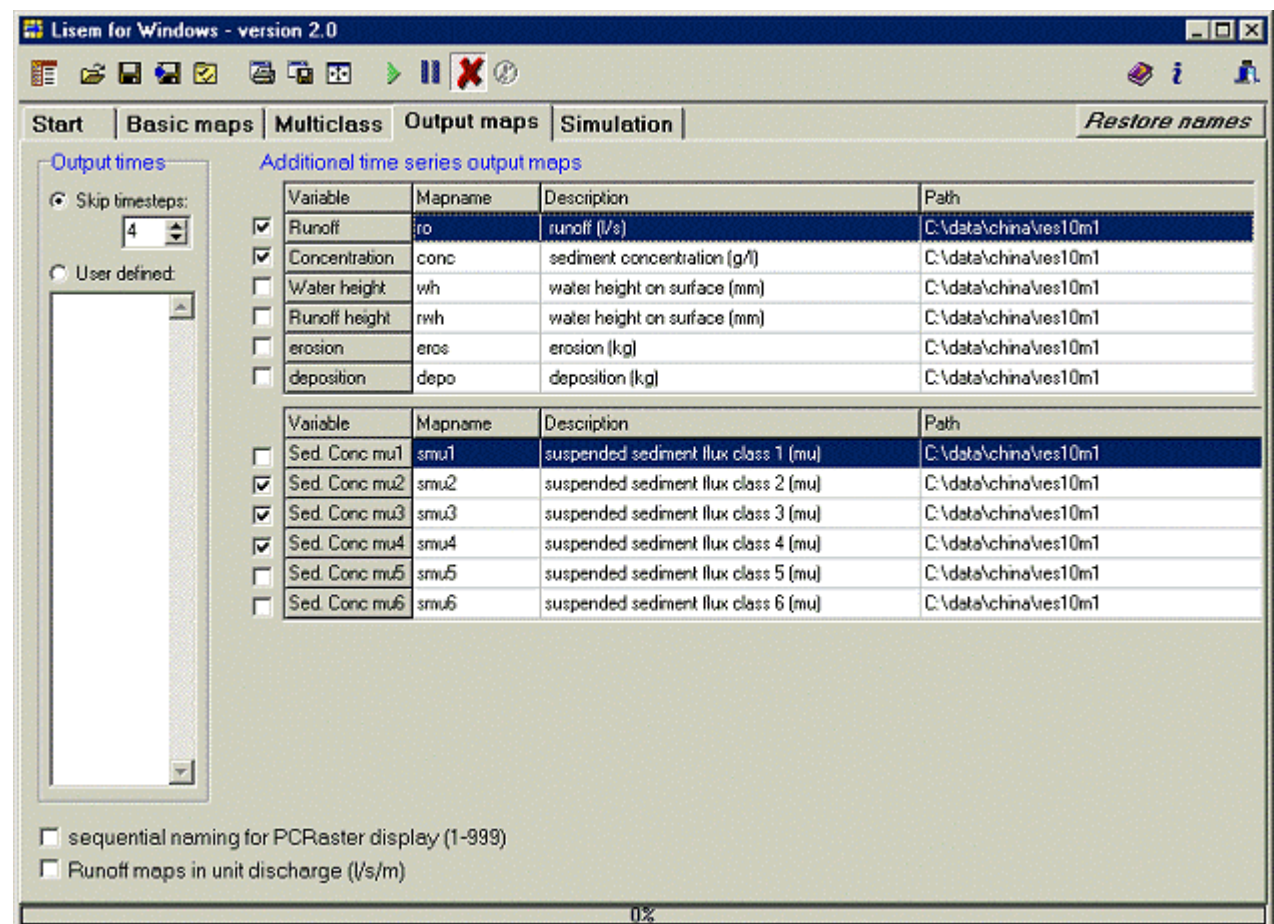
1. minimum timestep: to adjust for mass balance errors SWATRE calculates internally with a flexible timestep, smaller than the timestep used in LISEM. The timestep cannot become smaller than the value given here. A smaller value gives greater accuracy. Generally 1 sec gives sufficient accuracy.
NOTE: in old LISEM versions (older than version 1.60) this value was given in days because SWATRE was initially designed for daily timesteps. This has been changed to seconds for ease of use. In the run file this value is still in days to have downward compatibility.
2. save matric head: this option needs a map "headout.map" that has numbered locations. For these locations ascii tables are written with the temporal change of the hydraulic head during the run.
3. geometric mean: the average conductivity K between nodes is calculated as: $K_{avg} = \sqrt{K_i * K_{i-1}}$, else the average K is calculated as: $K_{avg} = (K_i + K_{i-1})/2$
NOTE: the conductivity between the surface and the first node is always calculated with the geometric mean (Feddes et al, 1978).

8.4 Output timeseries

The results of LISEM can be stored in "timeseries" these are maps that give a flux or status at regular intervals or at timesteps chosen by the user (type a series of timesteps in minutes in the "user defined" area). Simply select the type of output you want. Depending on the LISEM types chosen, additional timeseries can be stored (second list in picture below).

The maps are stored in the "result" directory given by the user in the "Start" screen.

The maps are stored as: name0001.250; name0006.500 etc. for the output at 1 min 15 seconds or respectively 6 minutes and 30 seconds. In order to have compatibility with PCRaster, which stores the maps by timestep number (name0000.001, name0000.002,...etc), the "store as PCRaster timeseries" can be chosen. Additionally the runoff can be stored in unit discharge: l/sec/m flow width.

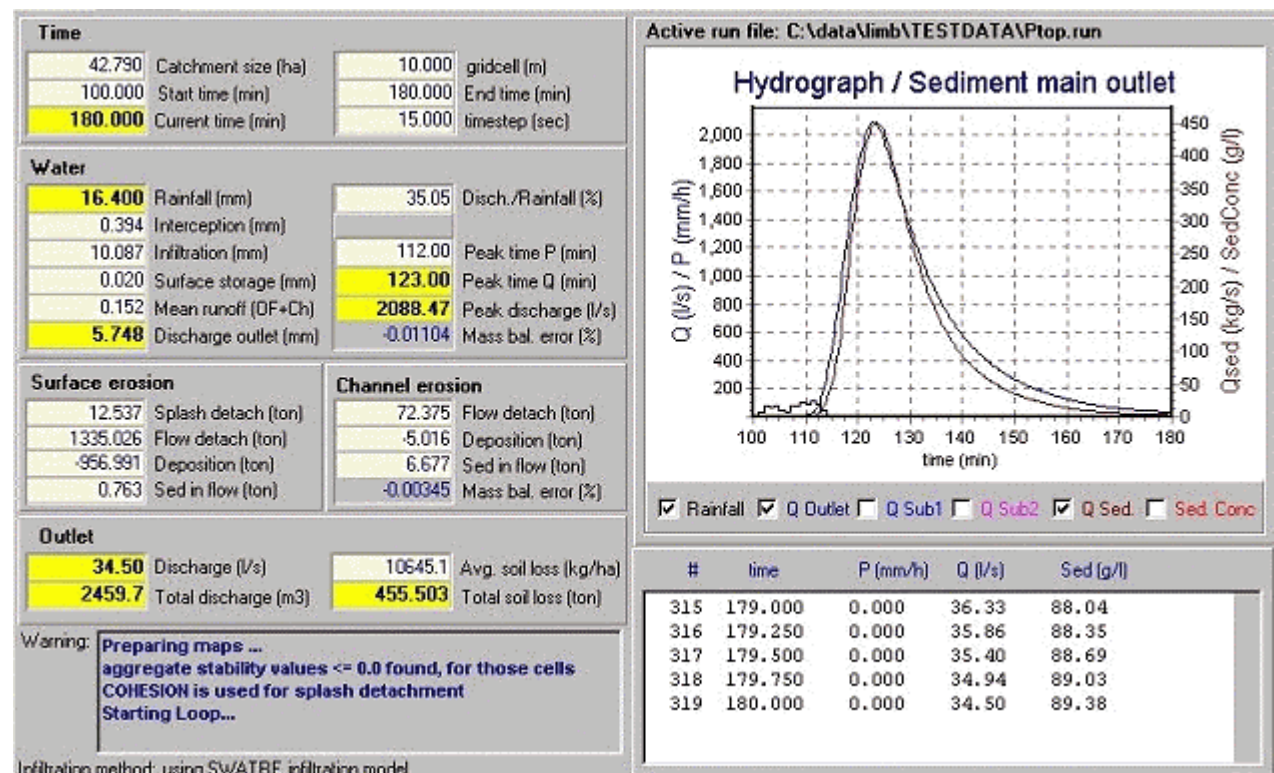


9 LISEM OUTPUT

LISEM generates a wide variety of outputs that enables the user to evaluate any erosion scenario in detail. Not only total values of the water balance variables and of erosion, deposition and soil loss from the catchment are given, also so called "timeseries" can be generated, which are a series of output maps at regular intervals or at times chosen by the user. These timeseries can be shown in the display (2D) or aguila (3D) program of PCRaster as a sequence of images, giving the impression of a film of the variable.

9.1 Main output screen and totals

The picture below shows the output screen with total values of all water balance variables, as well as erosion, deposition and soil loss. The hydrograph, sedigraph and sediment concentration as shown as graphs.



9.2 Hydrographs and sedigraphs

Hydrographs and sedigraphs of up to three locations (usually the outlet and two subcatchments) can be stored as comma delimited files, that is one of the standard input formats of MS- Excel (extension ".csv", see example below). The names of these files are specified on the LISEM start screen. Below is the basic output. If LISEM multiclass is chosen all suspended sediment classes are stored as separate columns.

```

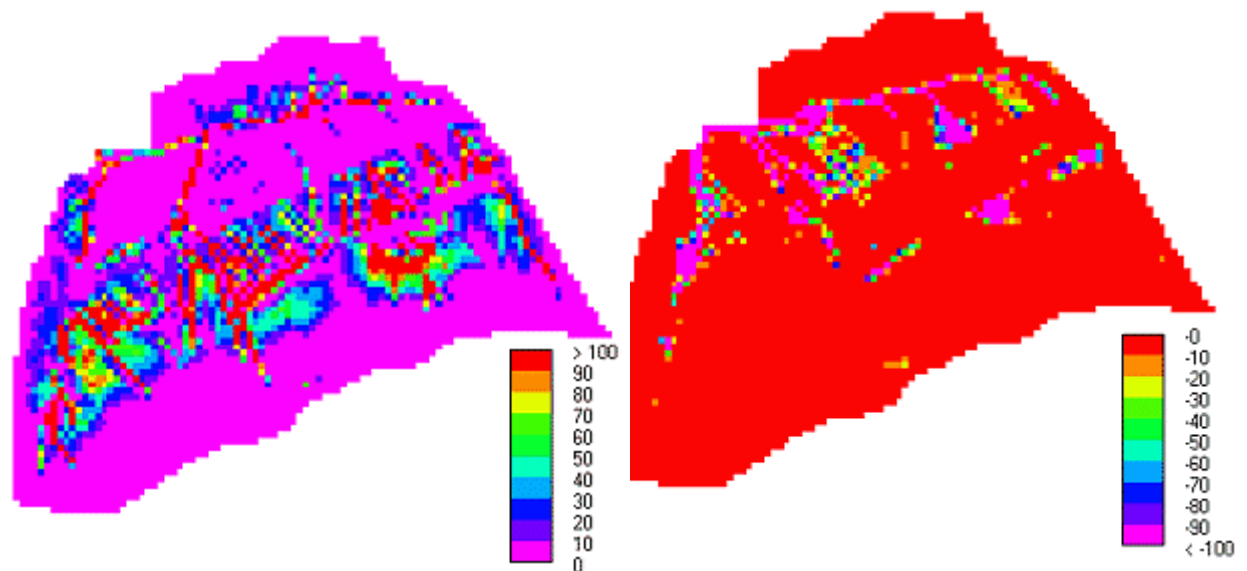
=====begin of file=====
"t","P","Q","Qsed","Conc"
"min","mm/h","l/s","kg/s","g/l"
1,0,0,0,0
1.25,19.4628,0,0,0
1.5,19.4628,0,0,0
1.75,19.4628,0,0,0
2,19.4628,0.0724395,0.00968105,0
2.25,26.0608,0.794583,0.0718342,0
2.5,26.0608,1.28849,0.124497,0
2.75,26.0608,2.47899e-05,3.29806e-07,10.6319
3,26.0608,5.47828e-05,4.03354e-07,4.90999
3.25,50.9473,0.0129043,0.00328798,216.454
3.5,50.9473,0.0361977,0.0108857,266.185
3.75,50.9473,0.0408011,0.00957935,212.618
4,50.9473,0.0749616,0.010196,124.569
4.25,66.2244,0.138133,0.0152438,102.085
etc.
=====end of file=====

```

Example hydrograph data, stored as comma delimited file.

9.3 Erosion and deposition maps

LISEM produces two maps that contain the erosion (positive values) and deposition (negative values) in PCRaster format. The names of these files are specified on the LISEM start screen. The values are expressed in tonnes/ha, and represent the total erosion/deposition in a gridcell (including channels and/or wheel tracks). In case of multiclass erosion the values are the sums of the erosion and deposition of all the texture classes. Note that It is not so easy to interpret these maps as material that is eroded somewhere in the catchment may deposit further downstream. Below an example is shown of these output maps, left is erosion (mostly in the thalweg), right is deposition (on the slopes).



9.4 Timeseries

The following timeseries output maps can always be generated:

- runoff as discharge in (l/s) or unit discharge (l/s/m)
- water height at the surface (mm)
- runoff height (mm)
- concentration of suspended sediment (g/l)
- erosion (ton/ha)
- deposition (ton/ha)

LISEM Wheeltracks has the same output map options, except that the discharge and runoff/water height will include the flow in the wheeltracks.

LISEM Multiclass has as additional output the timeseries of suspended sediment concentration of all 6 classes.

LISEM Nutrients has as additional output the timeseries of the NO₃, NH₄ and P losses in solution, suspension and infiltration, as well as the suspended clay concentration.

LISEM Gullies has as additional output the timeseries of the gully with, depth and volume.

10 REFERENCES

note: these references are copied from LISEM literature and not checked yet !

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11 PARTNERS

The LISEM project is an ongoing project with input of many organizations. The model is constantly improved (hopefully) and expanded in EU projects. The following institutions contribute or have contributed to its development. The development is in charge of Dr. Victor Jetten



Universiteit Utrecht

Victor Jetten, Rudi Hessel and Daniel van der Vlag, Department of Physical Geography, Utrecht University (NL)



Cees Wesseling, PCRaster environmental software



ALTERRA

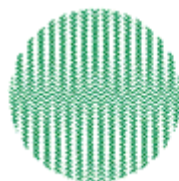
Coen Ritsema, Jannes Stolte and Simone van Dijck, Alterra (NL)



Ad de Roo, JRC (IT)



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University of Amsterdam, Physical Geography

APPENDIX

The Run file

All options and map names of a single run are stored in the "run" file which can be edited by hand. These include the names and option for all LISEM types, wheeltracks, multiclass sediment etc. Where no values are found, default values are used. The rainfall file and maps are stored with their full path names so they are linked individually and can be found in different directories (e.g. infiltration maps for different seasons).

```
=====begin of file=====
[LISEM for WINDOWS run file]
```

```
[Work Directory]
WorkDir=C:\data\china
```

```
[Input]
Map Directory=C:\data\china\10m2\
Table Directory=C:\data\china\10m2\
Rainfall Directory=C:\data\china\
Rainfall file=p9907201.txt
```

```
[Output]
Result Directory=C:\data\china\res10m1\
Main results file=res.csv
Outlet 1 file=outt.csv
Outlet 2 file=out1.csv
Outlet 3 file=out2.csv
Erosion map=er.map
Deposition map=dep.map
```

```
[Simulation times]
Begin time=1
End time=99
Timestep=5
```

```
[General options]
No Erosion simulation=0
Include main channels=0
Channel Infiltration=0
```

```
[Additional options]
Grassstrip Mannings n=0.3
Splash Delivery Ratio=0.1
```

```
[Infiltration]
Method=3
Include wheeltracks=0
Include grass strips=0
Include crusts=0
Ksat calibration=100
Impermeable sublayer=0
SWATRE internal minimum timestep=
Matric head files=0
Geometric mean Ksat=0
```

```

[Output]
Runoff maps in l/s/m=0
Timeseries as PCRaster=0
Regular runoff output=1
Output interval=4
User defined output=0
Output times=
CheckOutputMaps=1,1,0,0,0,0
CheckOutputMapsNUT=0,1,0,1,0,0,0,0,0
CheckOutputMapsMC=0,1,1,1,0,0,0,0,0
CheckOutputMapsGUL=1,1,0,0,0,0

[Texture classes]
ClassMu=2,16,32,53,75,105
TCCal=

[map names]

[Catchment]
area=C:\data\china\10m2\area.map
grad=C:\data\china\10m2\grad.map
ldd=C:\data\china\10m2\ldd.map
outlet=C:\data\china\10m2\outlet.map
ID=C:\data\china\10m2\id.map

[Landuse]
cover=C:\data\china\10m2\per.map
lai=C:\data\china\10m2\lai.map
ch=C:\data\china\10m2\ch.map
road=C:\data\china\10m2\roadwidt.map
grasstrip=C:\data\china\10m2\grasswid.map

[Erosion]
coh=C:\data\china\10m2\coh.map
cohadd=C:\data\china\10m2\cohadd.map
aggrstab=C:\data\china\10m2\aggrstab.map
d50=C:\data\china\10m2\d50.map

[Surface]
rr=C:\data\china\10m2\rr.map
manning=C:\data\china\10m2\n.map
crustfrc=C:\data\china\10m2\crustfrc.map
compfrc=C:\data\china\10m2\compfrc.map
stonefrc=C:\data\china\10m2\stonefrc.map

[InfilHoltan]
A=C:\data\china\10m2\A
FP=C:\data\china\10m2\FP
P=C:\data\china\10m2\P

[InfilExtra]
ksatcrst=C:\data\china\10m2\ksatcrst.map
ksatcomp=C:\data\china\10m2\ksatcomp.map
ksatgras=C:\data\china\10m2\ksatgras.map

[InfilGA2]
ksat2=C:\data\china\10m2\ksat2.map
psi2=C:\data\china\10m2\psi2.map
thetas2=C:\data\china\10m2\thetas2.map

```

```
thetai2=C:\data\china\10m2\thetai2.map  
soildep2=C:\data\china\10m2\soildep2.map
```

```
[InfilGA1]  
ksat1=C:\data\china\10m2\ksat1.map  
psi1=C:\data\china\10m2\psi1.map  
thetas1=C:\data\china\10m2\thetas1.map  
thetail=C:\data\china\10m2\thetail.map  
soildep1=C:\data\china\10m2\soildep1.map
```

```
[InfilSmith]  
ksat1=C:\data\china\10m2\ksat1.map  
psi1=C:\data\china\10m2\G1.map  
thetas1=C:\data\china\10m2\thetas1.map  
thetail=C:\data\china\10m2\thetail.map  
soildep1=C:\data\china\10m2\soildep1.map
```

```
[InfilMorel]  
ksat1=C:\data\china\10m2\ksat1.map  
psi1=C:\data\china\10m2\G1.map  
thetas1=C:\data\china\10m2\thetas1.map  
thetail=C:\data\china\10m2\thetail.map  
soildep1=C:\data\china\10m2\soildep1.map
```

```
[InfilSwatre]  
profinp=C:\data\china\10m2\profile.inp  
profmap=C:\data\china\10m2\profile.map  
profcrst=C:\data\china\10m2\profcrst.map  
profwltr=C:\data\china\10m2\profwltr.map  
profgras=C:\data\china\10m2\profgras.map  
inithead=C:\data\china\10m2\inithead  
headout=C:\data\china\10m2\headout.map
```

```
[Channelinfil]  
chanksat=C:\data\china\10m2\chanksat.map  
chanstor=C:\data\china\10m2\chanstor.map
```

```
[Channels]  
lddchan=C:\data\china\10m2\lddchan.map  
chanwidth=C:\data\china\10m2\chanwidth.map  
chanside=C:\data\china\10m2\chanside.map  
changrad=C:\data\china\10m2\changrad.map  
chanman=C:\data\china\10m2\chanman.map  
chancoh=C:\data\china\10m2\chancoh.map
```

```
[Wheeltrack]  
lddwheel=C:\data\china\10m2\lddwheel.map  
wheelnbr=C:\data\china\10m2\wheelnbr.map  
wheelwidth=C:\data\china\10m2\wheelwid.map  
wheeldepth=C:\data\china\10m2\wheeldep.map  
wheelgradient=C:\data\china\10m2\wheelgrd.map  
wheelman=C:\data\china\10m2\wheelman.map  
wheelcohesion=C:\data\china\10m2\wheelcoh.map  
ksatwt=C:\data\china\10m2\ksatwt.map
```

```
[Texture]  
fractionmu0=C:\data\china\10m2\mu0.map  
fractionmu1=C:\data\china\10m2\mu0.map  
fractionmu2=C:\data\china\10m2\mu0.map
```

```
fractionmu3=C:\data\china\10m2\mu0.map  
fractionmu4=C:\data\china\10m2\mu0.map  
fractionmu5=C:\data\china\10m2\mu0.map
```

```
[NutsP]  
pcont=C:\data\china\10m2\pcont.map  
psolute=C:\data\china\10m2\psolut.map  
pefficiency=C:\data\china\10m2\peff.map  
psorp=C:\data\china\10m2\Psorp.map  
pconv=C:\data\china\10m2\Pconv.map
```

```
[NutsNO3]  
no3cont=C:\data\china\10m2\NO3cont.map  
no3solute=C:\data\china\10m2\NO3solut.map  
no3efficiency=C:\data\china\10m2\NO3eff.map  
no3sorp=C:\data\china\10m2\NO3sorp.map  
no3conv=C:\data\china\10m2\NO3conv.map
```

```
[NutsNH4]  
nh4cont=C:\data\china\10m2\nh4cont.map  
nh4solute=C:\data\china\10m2\nh4solut.map  
nh4efficiency=C:\data\china\10m2\nh4eff.map  
nh4sorp=C:\data\china\10m2\NH4sorp.map  
nh4conv=C:\data\china\10m2\NH4conv.map
```

```
[NutsBD]  
bulk=C:\data\china\10m2\bulkdens.map
```

```
[Gully]  
dem=C:\data\china\10m2\dem.map  
gullyn=C:\data\china\10m2\gullyman.map  
bulkdens1=C:\data\china\10m2\bulkdens.map  
gullydep=C:\data\china\10m2\soilDep2.map  
gullycoh=C:\data\china\10m2\coh2.map  
bulkdens2=C:\data\china\10m2\bulkden2.map
```

```
[OutputNut]  
outpsolut=C:\data\china\res10m1\NPsol  
outpsus=C:\data\china\res10m1\NPsus  
outpinf=C:\data\china\res10m1\NPinf  
outnh4solut=C:\data\china\res10m1\NNH4sol  
outnh4sus=C:\data\china\res10m1\NNH4sus  
outnh4inf=C:\data\china\res10m1\NNH4inf  
outNO3solut=C:\data\china\res10m1\NNO3sol  
outNO3sus=C:\data\china\res10m1\NNO3sus  
outno3inf=C:\data\china\res10m1\NNO3inf  
outno3inf=C:\data\china\res10m1\smul
```

```
[Output]  
outrunoff=C:\data\china\res10m1\ro  
outconc=C:\data\china\res10m1\conc  
outwh=C:\data\china\res10m1\wh  
outrwh=C:\data\china\res10m1\rwh  
outeros=C:\data\china\res10m1\eros  
outdepo=C:\data\china\res10m1\depo
```

```
[OutputGul]  
outguld=C:\data\china\res10m1\guld  
outgulw=C:\data\china\res10m1\gulw
```

```
outgula=C:\data\china\res10m1\gula
outgulf=C:\data\china\res10m1\gulf
outguldem=C:\data\china\res10m1\dem
```

```
[OutputMC]
outmu1=C:\data\china\res10m1\smu1
outmu2=C:\data\china\res10m1\smu2
outmu3=C:\data\china\res10m1\smu3
outmu4=C:\data\china\res10m1\smu4
outmu5=C:\data\china\res10m1\smu5
outmu6=C:\data\china\res10m1\smu6
=====end of file=====
```