Soil erosion modelling: description and data requirements for the LISEM physically based erosion model.

by

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'Himalayan Degradation'.

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1. Introduction

About 80 percent of the population in the Himalayas depend on agriculture for their livelihood. The fact that the area is ecologically fragile and the extent to which the available land is being used makes the area susceptible to degradation. Deforestation is taking place due to a/o. the rapid growth of the population. This satisfies the need for more arable land in the region, but degrades the area. Development of the agricultural sector and sustainable management of the available natural resources is vital, particularly in the view of the increasing population pressure and widespread poverty.

The main objective of the project is to develop sustainable management strategies that are technically feasible, economically viable, and socially acceptable. In short the project goal is to develop strategies can be implemented and have positive influence on soil and forest sustainability.

How the different disciplines work together in this project can be seen in Figure 1. This figure shows how the different disciplines depend on each other and also depicts the way the data gathered by the different groups are used by other groups. This paper roughly describes the state-of-the-art about the physically based erosion model called LISEM, but it should be clear to the reader that the model only is the single wheel in a much larger machine. Not only soil erosion is important in the project, but also forestry, geography, agriculture, economy and social sciences.

To accomplish the goals set, it is necessary to join the disciplines mentioned in scientific research, technical as well as social and economic, and to strive to a step forward in putting scientific knowledge to work in practice.

Figure 1 General project approach.

2. Description of the LISEM soil erosion model.

2.1. *The role of LISEM in the project*

The final goal in this project is to come to sustainable management strategies. After being defined, these strategies could be implemented in practice and tested whether they work or not. This is a very time consuming process. In stead of implementing the strategies in practice, their effect can also be simulated using the LISEM computer model and the outcome evaluated. This is a much cheaper and faster solution.

As shown in Figure 1, LISEM is an integral part of the project. After evaluating input from the Socio-economic survey, a number of feasible management strategies are calculated by the LISEM model. The most promising scenario will be evaluated, and results will be used in the bio-economic modelling.

2.2. *The LISEM model*

The LISEM model is a ‘process based raster model that operates on catchment scale’ and limits itself to single rain events. These different terms will be explained in the following paragraphs.

2.3. *Process based*

In this case ‘process based’ means that the model incorporates all major physical processes that are involved in generating sediment and runoff. This means that no empirical relationships are used inside the model, and it implies that a large number of variables are needed to let the model run accurately.

2.4. *Event based*

The underlying processes used in the model are calculated on a time-step basis from the beginning of a single event to the end of the event. This time step can vary between 5 and 15 seconds. Only the time during a rain event is taken into account because this is supposed to be the time span that most of the soil degradation is taking place. An advantage of only calculating for rain events is that the model only has to do calculations for a limited time.

2.5. *Raster based*

The physical processes in question are looked at on a cell basis; in other words the catchment is divided into equally sized square cells. These cells are supposed to have certain characteristics that are uniform throughout the (x-y), but may vary in depth (z)(e.g. soil-physical characteristics). The outcome of the calculations done for a certain cell may have implications for its surrounding cells. When, e.g., for a certain cell water runoff is calculated, this water will be transported to the next cell according to the local flow direction.

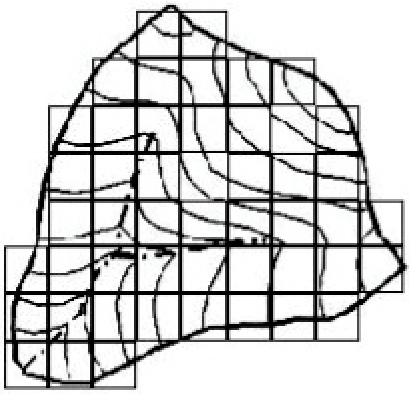


Figure 2 Example of a catchment divided onto grid cells using a uniform raster.

2.6. *Catchment scale*

The model calculations have to be done for a watershed. The final outcome of the model is a composition of all the different physical sub-models, and consists of a time series of water and sediment outflow at the outflow point of the selected catchment. Also a number of maps are generated that show water velocity across the surface, soil erosion and soil deposition. Since the model is designed to calculate its outflow for a single outflow point, it is naturally limited to a catchment having only one outlet. Also the complexity of the model is a limit to the catchment area, since the calculations are time consuming. All this limits the catchment size to about 25 km^2.

2.7. *How does LISEM operate?*

As said before, LISEM works on event basis. This means that LISEM starts its calculations at the moment it starts raining, or, only the rain data of the event that the user has selected is used in the calculations. The calculations continue until a certain time after the rain event has finished, which is also selected by the user. The status of the catchment at the beginning of the rain event (soil moisture distribution, land use, plant characteristics etc.) should be known to the model at the start of the rain event. This is because they influence the behaviour of the catchment with respect to runoff and erosion. After starting the model, LISEM starts calculating the infiltration, runoff and erosion for every cell separately, using the rain that falls on the surface area of every cell. After each time step, this results in a certain amount of infiltration, runoff and erosion (or deposition) for every cell. Dependent on the steepness and the flow direction of the cell, the ‘produced’ runoff and sediment is transported to the next cell. Then the next time step is calculated etc. This continues until the end time, defined by the user, is reached.

The runoff that is produced by all the cells, and that is not infiltrated somewhere in the catchment, leaves the catchment at the pre-defined outlet point. This also counts for the sediment: the sediment that is taken along with the water, and is not deposited somewhere in the catchment, leaves the catchment at the outlet point. Because runoff and erosion/deposition is known for each cell within the catchment, LISEM is able to produce an erosion/deposition map, where a spatial distribution is shown.

Since also, during the calculations, the water velocity across the surface is calculated, it is possible to generate maps that show the areas where runoff of water is most severe, and are therefore also susceptible to erosion. Another outcome of the model is the hydrograph and the sediment concentration in the hydrograph at the outlet of the catchment. Figure 3 shows the model windows and the hydrograph after a calculation run has finished.

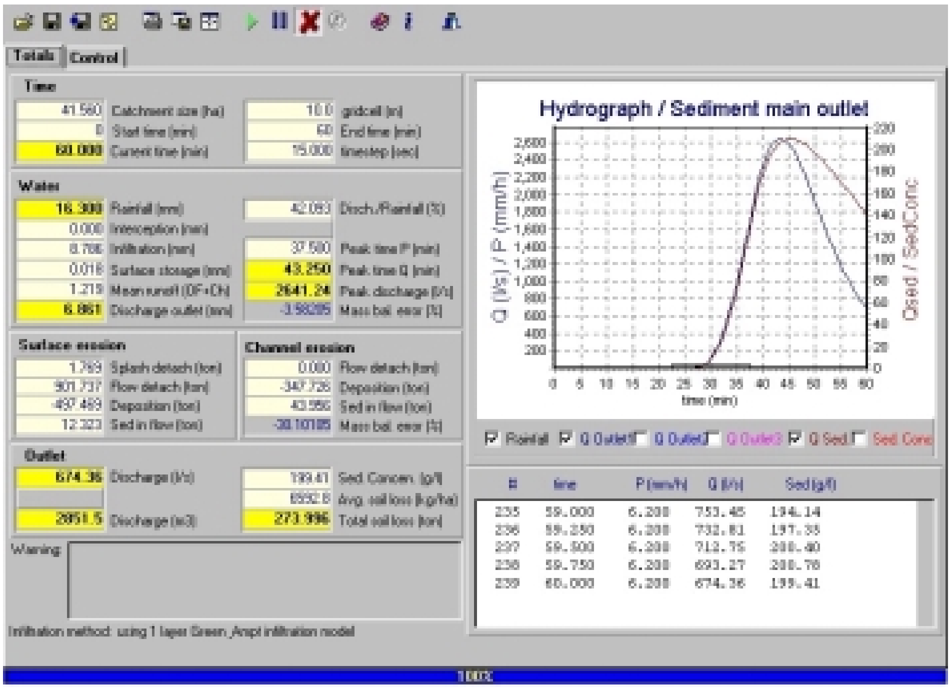


Figure 3 The LISEM model window after a calculation run.

2.8. *Calibration of the model for the selected catchment*

Before use, LISEM has to be specifically ‘fine-tuned’ for the catchment area where the model is being used. This is done by selecting the data of certain rain events, and slightly adjusting certain parameters, until the measured hydrograph and sedigraph for the specific event and the LISEM results match as close as possible. Now the model is calibrated for the specific catchment, and scenario calculations can be carried out.

2.9. *Final goal of the model: carrying out scenario calculations.*

The final goal of using the model is to define other land use in the catchment, and evaluating the effects of this altered land use in terms of soil and water loss. In order to do this, alternatives in land use should be defined in close co-operation with the farmers in the area. This is essential, since the farmers are the stakeholders that have to implement possible alternatives. In defining alternative land uses, not only the local farmers should be involved, but also agronomists who can evaluate the possible success of alternative crops on the (local) markets. Finally, soil scientists and crop/forest specialists should have their input in defining the scenario’s since they have the knowledge about reduction of water and soil loss that can be accomplished using certain alternative crops.

The outcome of the scenario analysis is then a balanced advice that is optimised between soil and water losses on the one side, and is still feasible for the local people to live from, or even improves their standards of living on the other side.

3. Parameters needed for running the LISEM model.

Table 1 lists all input data required to run LISEM using the SWATRE or Green & Ampt infiltration modules. Parameters (see column "Function" in Table 1) describe the catchment to be modelled with LISEM. All parameters are variable in 2-D or 3-D space due to spatial variation in a/o. soils, land use, land management and topography. Parameters are assumed constant during a simulated rain event. However, they may change between rain events due to weather, plant growth or land management. For the simulation of different rain events with LISEM, values of parameters that change between rain events should be adjusted. This applies especially to the parameters related to land use, erosion, the soil surface, infiltration and to wheel tracks (Table 1). Constants are constant over time and space during a simulated rain event. Rain intensity is the only input variable to LISEM, providing the input disturbance to catchment. Rainfall intensity varies in time, and also in space due to the type of rain event, wind or other meteorological influences, and topography.

Because LISEM is a dynamic[1] and distributed[2] model, it requires the variability of input parameters in space and time to be reflected in the model input. Therefore we should sample (measure or collect) input parameters in space and time according to their variability in these dimensions.
The parameters to be measured in the field and/or laboratory are listed in Table 1, together with recommended sampling dimensions for the HIMALAYAN DEGRADATION project. The column "sampling in space/time" denotes if sampling in space or in space and time is required to cover the variability of parameters for the purpose of running LISEM for different rain events. The recommended dimensions for sampling the spatial variability of the parameters are specified in the column "spatial sampling". 1-D means that the parameter is expected to vary along a linear element in the field, e.g. a grass strip, road or channel. 2-D means that variability in horizontal space of the parameters concerned is relevant to modelling with LISEM. "Horizontal space" is used here to refer to the surface of the entire catchment or parts of it. 3-D means that apart from variability in horizontal space, variability of the parameter in the soil profile ("at depth") is relevant to modelling with LISEM.

The parameters in Table 3 are selected for the field sampling and measurement campaign in the HIMALAYAN DEGRADATION project.

[1] Simulating processes, internal state variables and outputs for more than one moment in time
[2] Simulating processes, internal state variables and outputs at more than one place in space

Table 1 Complete set of input data for LISEM.

Description	Category	Function	LISEM name	Unit	Source
Digital elevation model	Catchment		dem.map	m	topographical map/GPS survey/aerial photographs
Soil map	Catchment		soil.map	-	soil map
Landuse map	Catchment		landuse.map	-	field mapping/remote sensing
Catchment area	Catchment	Constant	area.map	-	topographical map
Slope gradient	Catchment	Parameter	grad.map	sin(slope)	DEM
Drainage direction	Catchment	Parameter	ldd.map	-	DEM
Location of catchment outlet and sub-outlets	Catchment	Constant	outlet.map	-	DEM
Area covered by rain gauges	Catchment	Parameter	id.map	-	gauge positions/DEM
Rain intensity	Catchment	Input variable	#.txt	multiple	raingauge/meteo-station
Vegetation cover	Land use	Parameter	per.map	-	field measurement/remote sensing
Vegetation height	Land use	Parameter	ch.map	m	field measurement
Leaf area index	Land use	Parameter	lai.map	-	field measurement/remote sensing
Width of roads	Land use	Parameter	roadwidt.map	m	topographical maps/field measurement
Width of grass strips	Land use	Parameter	grasswid.map	m	field measurement
Manning's n of grass strips	Land use	Parameter	-	-	literature
Aggregate stability	Erosion	Parameter	aggrstab.map	-	field measurement
Cohesion added by roots	Erosion	Parameter	cohadd.map	KPa	calibration
D50	Erosion	Parameter	d50.map	10-6 m	field measurement/soil survey
Splash delivery ratio	Erosion	Constant	-	-	literature
Random roughness	Soil surface	Parameter	rr.map	cm	field measurement
Manning's n	Soil surface	Parameter	n.map	-	field measurement/literature
Coverage stones	Soil surface	Parameter	stonefrc.map	-	field measurement
Coverage crusts	Soil surface	Parameter	crustfrc.map	-	field measurement
Coverage compacted areas	Soil surface	Parameter	compfrc.map	-	field measurement/field mapping
Soil profile composition	Infiltration (SWATRE)	Parameter	profile.inp	cm (depth)	field measurement/soil map
Soil profile map	Infiltration (SWATRE)	Parameter	profile.map	-	field mapping/soil map
Crust profile map	Infiltration (SWATRE)	Parameter	profcrst.map	-	field mapping
Wheel track profile map	Infiltration (SWATRE)	Parameter	profwltr.map	-	field mapping
Grass strip profile map	Infiltration (SWATRE)	Parameter	profgras.map	-	field mapping
Compacted profile map	Infiltration (SWATRE)	Parameter	profcomp.map	-	field mapping
Initial soil water potential	Infiltration (SWATRE)	Parameter	inithead.00x	cm	field measurement/soil moisture content
Reporting points soil water potential	Infiltration (SWATRE)	Parameter	headout.map	-	field mapping/GPS

Table 2 Continuation of Table 1

Description	Category	Function	LISEM name	Unit	Source
K-h-theta relationships	Infiltration (SWATRE)	Parameter	#.tbl	multiple	laboratory measurement
Saturated hydraulic conductivity	Infiltration (Green & Ampt)	Parameter	ksat1/2.map	mm/h	field/lab measurement
Wetting front soil water potential	Infiltration (Green & Ampt)	Parameter	psi1/2.map	cm	literature
Saturated soil moisture content	Infiltration (Green & Ampt)	Parameter	thetas1/2.map	-	field/lab measurement
Initial soil moisture content	Infiltration (Green & Ampt)	Parameter	thetai1/2.map	-	field/lab measurement
Soil depth	Infiltration (Green & Ampt)	Parameter	soildep1/2.map	mm	field measurement
Saturated hydr. cond. of grass strips	Infiltration (Green & Ampt)	Parameter	ksatgras.map	mm/h	field/lab measurement
Saturated hydr. cond. of crusts	Infiltration (Green & Ampt)	Parameter	ksatcrst.map	mm/h	field/lab measurement
Saturated hydr. cond.of compacted	Infiltration (Green & Ampt)	Parameter	ksatcomp.map	mm/h	field/lab measurement
Channel bed storage	Channels	Parameter	chanstor.map		calibration
Channel width	Channels	Parameter	chanwidt.mao	m	field measurement
Manning's n channel bed	Channels	Parameter	chanman.map	-	calibration/literature
Cohesion channel bed	Channels	Parameter	chancoh.map	kPa	field measurement/calibration
Drainage direction channels	Channels	Parameter	lddchan.map	-	topographical map/field mapping/DEM
Side slope channels	Channels	Parameter	chanside.map	-	field measurement
Slope gradient of channel beds	Channels	Parameter	changrad.map	m/m?	DEM
Width of wheel tracks	Wheeltracks	Parameter	wheelwid.map	m?	field measurement
Number of wheel tracks	Wheeltracks	Parameter	Wheelnbr.map	-	Field measurement
Depth of wheel tracks	Wheeltracks	Parameter	wheeldep.map	?	field measurement
Manning's n of wheeltracks	Wheeltracks	Parameter	wheelman.map	-	field measurement/literature
Cohesion of wheel tracks	Wheeltracks	Parameter	wheelcoh.map	kPa	field measurement
Drainage directions of wheel tracks	Wheeltracks	Parameter	lddwheel.map	-	field mapping
Number of wheel tracks per cel	Wheeltracks	Parameter	wheelnbr.map	-	field mapping
Slope gradient of wheel tracks	Wheeltracks	Parameter	wheelgrd.map	?	DEM/drainage directions of wheel tracks
Saturated hydr. cond. of wheel tracks	Wheeltracks	Parameter	ksatwt.map	mm/h	field/lab measurement
Soil texture fractions (6)	Multiclass	Parameter	mu#.map	-	laboratory measurement
Cohesion	Erosion	Parameter	coh.map	Kpa	field measurement
Additional calibration	**Category**	**Function**	**LISEM name**	**Unit**	**Source**
Outflow at the outlet of the catchment	Calibration	Parameter	-	l/s, m^3/s	Field measurement
Sediment concentration of outflow	Calibration	Parameter	-	g/l	Field measurement

Table 3 Parameters for LISEM to be measured in the field or in the laboratory and suggested dimensions of sampling for the HIMALAYAN DEGRADATION project. S=space, T=time; 1-D: along a linear feature; 2-D: over land unit, 3-D: over land unit and in depth.

Description	**Category**	**Sampling in space/time**	**Spatial sampling**
Rain amount / rain intensity	Parameter	S/T	2-D
Vegetation cover	Land use	S/T	2-D
Vegetation height	Land use	S/T	2-D
Leaf area index	Land use	S/T	2-D
Width of roads	Land use	S	1-D
Width of grass strips	Land use	S	2-D
Aggregate stability	Erosion	S/T	2-D
D50	Erosion	S	2-D
Cohesion	Erosion	S/T	2-D
Random roughness	Soil surface	S/T	2-D
Manning's n	Soil surface	S/T	2-D
Coverage stones	Soil surface	S	2-D
Coverage crusts	Soil surface	S/T	2-D
Coverage compacted areas	Soil surface	S/T	2-D
Soil profile composition	Infiltration (SWATRE)	S	3-D
Initial soil water potential	Infiltration (SWATRE)	S/T	3-D
K-h-theta relationships	Infiltration (SWATRE)	S	3-D
Saturated hydraulic conductivity	Infiltration (Green & Ampt)	S/T	3-D
Saturated soil moisture content	Infiltration (Green & Ampt)	S/T	3-D
Initial soil moisture content	Infiltration (Green & Ampt)	S/T	3-D
Soil depth	Infiltration (Green & Ampt)	S	3-D
Saturated hydr. cond. of grass strips	Infiltration (Green & Ampt)	S	2-D
Saturated hydr. cond. of crusts	Infiltration (Green & Ampt)	S	2-D
Saturated hydr. cond.of compacted	Infiltration (Green & Ampt)	S	2-D
Channel width	Channels	S	1-D
Cohesion channel bed	Channels	S	1-D
Side slope channels	Channels	S	1-D
Width of wheel tracks	Wheeltracks	S	2-D
Number of wheel tracks	Wheeltracks	S	2-D
Depth of wheel tracks	Wheeltracks	S/T	2-D
Manning's n of wheeltracks	Wheeltracks	S/T	2-D
Cohesion of wheel tracks	Wheeltracks	S/T	2-D
Slope gradient of wheel tracks	Wheeltracks	S/T	2-D
Saturated hydr. cond. of wheel tracks	Wheeltracks	S	2-D
Soil texture fractions (6)	Multiclass	S	2-D
Calibration measurements	**Category**	**Sampling in space/time**	**Spatial sampling**
Outflow at the outlet of the catchment	Calibration	T	1-D
Sediment concentration of outflow	Calibration	T	1-D

4. Equipment needed for measuring LISEM required parameters.

This chapter describes the measuring equipment that can be used for acquiring the parameters that are needed for running the LISEM model.

Table 4 Possible equipment solutions for measuring the parameters needed for running the LISEM model.

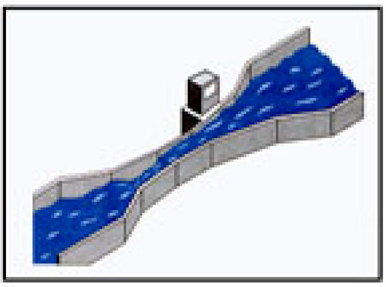
Nr.	Description	Type of equipment needed	Measuring frequency*
1	Rain amount / rain intensity	Rain Gauge	Continuous
2	Vegetation cover	Digital camera / software	Monthly
3	Vegetation height	Tape measure	Monthly
4	Leaf area index	Digital scanner / software	Monthly
5	Width of roads	Tape measure	Once
6	Width of grass strips	Tape measure	Once
7	Aggregate stability	Aggregate stability	Once
8	D50	Granular analysis	Once
9	Cohesion	Torr vane device	Once
10	Random roughness	Random roughness measuring device / digital camera / software	Monthly
11	Manning's n	Hillslope setup	Once
12	Coverage stones	Estimation	Once
13	Coverage crusts	Estimation	Once
14	Coverage compacted areas	Estimation	Once
15	Soil profile composition	Survey	Once
16	Initial soil water potential	Manual TDR / pF-curve	Monthly
17	K-h-theta relationships	Laboratory determination	Once
18	Saturated hydraulic conductivity	Laboratory determination	Once
19	Saturated soil moisture content	Laboratory determination	Once
20	Initial soil moisture content	Manual TDR	Monthly / Continuous
21	Soil depth	Tape measure	Once
22	Saturated hydr. cond. of grass strips	Laboratory determination	Once
23	Saturated hydr. cond. of crusts	Laboratory determination	Once
24	Saturated hydr. cond.of compacted areas	Laboratory determination	Once
25	Channel width	Tape measure	Once
26	Cohesion channel bed	Torr vane device	Once
27	Side slope channels	Tape measure / calculator	Once
28	Width of wheel tracks	Tape measure	Once
29	Number of wheel tracks	-	Once
30	Depth of wheel tracks	Tape measure	Once
31	Manning's n of wheeltracks	Field setup	Once
32	Cohesion of wheel tracks	Torr vane device	Once
33	Slope gradient of wheel tracks	Slope meter	Once
34	Saturated hydr. cond. of wheel tracks	Laboratory determination	Once
35	Soil texture fractions (6)	Laboratory determination	Once
36	Outflow at the outlet of the catchment	Flume / Flow meter	Continuous
37	Sediment concentration of outflow	Sampler (automatic / manual)	Continuous

In the table above a distinction is made between parameters that have to be measured once (for characterising the these parameters for a specific catchment), parameters that have to be measured monthly (these parameters are important parameters that change in time), and parameters that have to be monitored continuously (because they can change very rapidly). Below an overview is given of the equipment needed for the parameters mentioned in table 3.

4.1. *Automatic equipment for the continuous measurements*

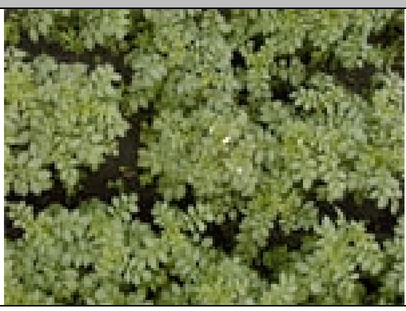
Table 5 Possible equipment solutions for the various parameters listed in Table 3: automatic equipment.

Nr	Equipment	Specifications
1		**Rain gauge**; tipping bucket, 0.2mm/tip. Automatic logging data logger, records date and time of every tip.
20		**Initial water content (monthly)**; manual TDR, volumetric water content

20		**Initial water content(continuous)**; automatic TDR logger, volumetric water content
36		**Outflow at the catchment outlet**; flume and water level sensor with data logger.
37		**Sediment content of the outflow water;** automatic water sampler, or manual water sampling, oven, electronic balance.

4.2. *Manual equipment for monthly measurements*

Table 6 Possible equipment solutions for the various parameters listed in Table 3: manual equipment for frequent use.

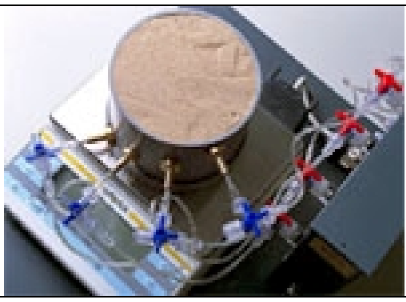
Nr	Equipment	Specifications
2		**Vegetation cover**; ratio leaf / bare soil, determined by digital camera.
3		**Vegetation height**; determined by tape measure.

4		**Leaf Area Index**; determined by measuring area of a number of representative leaves using a digital scanner.
10		**Random soil roughness**; measured by a pin board and a digital camera.
16		**Initial soil water potential**; measured by a TDR device and the water retention characteristic.

4.3. *Manual equipment for single measurements*

Table 7 Possible equipment solutions for the various parameters listed in Table 3: manual equipment for single use.

Nr	Equipment	Specifications
5, 6, 21, 25, 27, 28, 30		**Various widths, depths and heights**

7		**Aggregate stability**; laboratory setup.
8	-	**Granular analysis**; laboratory setup.
9, 26, 32		**Cohesion**; Torr Vane device.
11, 31		**Manning's –n**; field setup.
12, 13	-	**Coverage of stones and crusts**: estimation.
15	-	**Soil profile composition**; soil survey
17		**K-h-Theta relationships of soil samples**; laboratory setup.

18, 22, 23, 24, 34		**Saturated conductivity**; laboratory setup.
19		**Saturated soil moisture content**; electronic balance.
29,	-	**Number of wheel tracks**; counting.
33	-	**Slope gradient**: slope meter.
35	-	**Soil texture fractions**: laboratory determination.

5. Data management for multidiscipline projects

An important aspect in large projects having to deal with large amounts of data coming from different sources is data management. First of all, a definition of data management will be given:

' Data management is the handling (collection, storage, processing and distribution) of all parameters acquired within a project, following standard procedures'

There are a number of reasons why data management is important;

- Often, projects are highly dependent on the data that is gathered
- A large amount of different parameters are stored
- Often, more than one sources of data are present
- Different partners within the project need available the data
- Data check / processing is needed for some data
- Different versions of data may exist due to processing / shipping of data

This is why certain rules have to be agreed upon and procedures have to be followed, in order to guarantee the integrity of the obtained data.

A possible data flow within the project is shown in Figure 4, where three data sources are drawn, 'field measurements'. After being acquired, the data is being stored and processed on a local PC. A backup is made from this PC, and a copy of this backup is sent to central data storage, e.g. a disc at the office of the project co-ordinator.

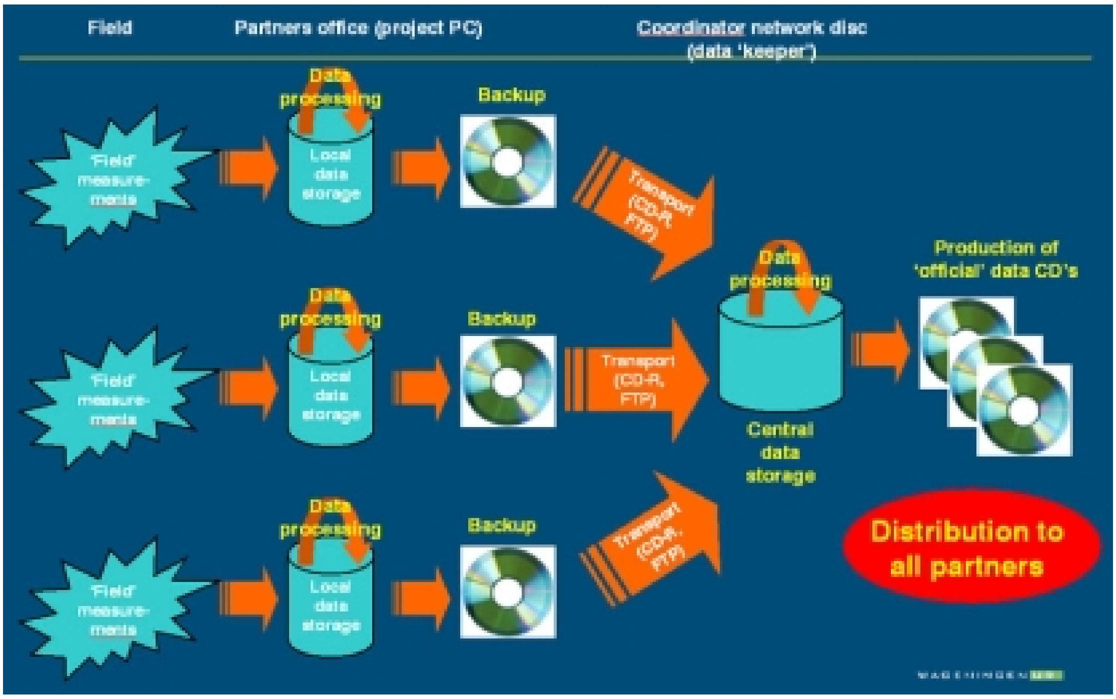


Figure 4 a possible data management strategy

After possible additional processing, 'official' data –CD's are produced and distributed among the project partners. This procedure guarantees that all people involved in the project have access to the same data set. A good method for facilitating this process is setting up a template data structure for the whole project. This data structure can then be copied to the PC's of the project partners that are involved in data acquisition and processing. This guarantees an identical storage of data in appropriate folders, and makes storage of the data on the central data storage easier. A sample data structure is shown in Figure 5.

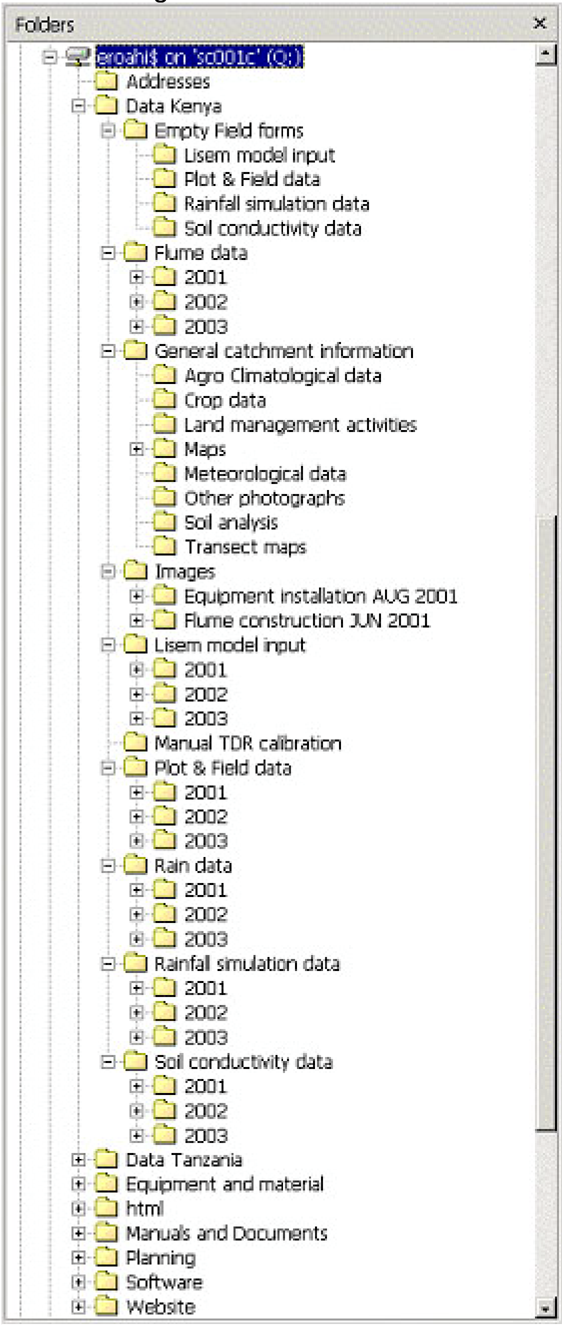


Figure 5 Sample data structure

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