Overland flow and erosion in agricultural lands

Process, model, assessment
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FORM-OSE
Post-Graduate Training School
“Living with hydro-geomorphological risks:
From theory to practice”

Structure

a. Introduction, processes and factors
b. Impacts
c. Models and applications

Soil erosion is an “old problem”
- on steep slopes
- in semi-arid regions
Recognised more recently
- in loess regions in the European temperate climate zone with moderate relief
Focus of today’s course

The french example, inventory based on reports

Source:
In Le grand atlas de la France rurale.
Background of erosion problems in temperate climate

Change from forest/pasture towards arable land use

- Temp (exposure of the soil surface)
- Aeration (tillage)
- Exposure of the soil surface to raindrop impact during part of the year
- Decomposition of mat. org. by mineralisation and oxidation
- Organic bound of soil in the soil
- Aggregate stability
- Crust formation
- Infiltration
- Overland flow
- Splash erosion
- Erosion

Why in areas with loess-derived soils (1)?

Source: Kihlbom 1970

Why in areas with loess-derived soils (2)?

Low structural stability

Scodro (2001)

Timing aspects: climat and agriculture
(ex: Bretagne © C. Gascuel, 2001)

Spring: a quick soil desagregation

- Rainfall characteristics
- Vegetation cover
- Soil conditions: roughness and infiltrability
- Sowing
- Weeding
- Harvesting

Winter: hydrologic conditions

- Two key-periods

Soil surface conditions, crusting

croûte structurelle
(certain fragments remain well distinct)
croûte sédimentaire
(erosion of the surface)

- phase 0
  - etat initial fragmentaire
  - poreux et meuble après un travail du sol
  - infiltration possible: 30 à 40 mm/h

- phase 1
  - fermeture de la surface par effet "splash"
  - infiltration possible: 6 à 2 mm/h

- phase 2
  - sédimentation dans les fissures
  - infiltration possible: 1 mm/h

The processes

- Splash erosion
- Overland flow generation
  - Hortonien (rainfall intensity > infiltration cap)
    - Rainfall intensity, soil surface state
    - Saturation (soil pore space is filled with water, additional rainfall cannot infiltrate)
    - Rainfall quantity, soil moisture storage capacity, impeding layer
  - Exfiltration
  - Snowmelt (on frozen soil)
- Soil detachment by overland flow
- Transport
- Deposition
Spatial aspects, scales

Erosion  Transport

Degradation delivery

Upstream overland flow formation and diffuse erosion

Photos: A.V. Auzat

Photos: A.V. Auzat

Photos: P.M. van Dijk
Structure

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Impacts

• On site
  ➞ Soil loss, reduced soil depth
  ➞ Loss of nutrients
  ➞ Modified physical and chemical properties, AWC
  ➞ Destruction of crop
  ➞ In case of gullies: problematique access with agr. machines

• Off site
  ➞ Sediment and pollutants transfers
  ➞ Surface water quality and ecosystem degradation
  ➞ Damage to infrastructure and built-up areas (muddy flows)

• Direct and indirect economical costs for communities and individuals

Damage depends on the land occupation

Damage in fields
Blotzheim, juin 2003
© R. Armand

Damage to infrastructure
© P. van Dijk
Damage in built-up areas
Landser, 25 mai 2001

© Lemmel M., Scodro E.

Blotzheim, juin 2003 © R. Armand

Water quality impacts and effects on aquatic ecosystems
La Dijle (Belgique)
Mai 1986

Structure
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b. Impacts
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Models, in order to:
• Identify problem areas (target areas for measures)
• Increase our knowledge
• Evaluate and predict (effects of measures, catchment management, climate/land use change)

✓ At different spatial scales (field, catchment, region...)
✓ At different time scales (minutes to years)
Model types

- empirical
  - USLE, RUSLE, MUSLE
- deterministic
  - CREAMS, AGNPS, SWAT, SWIM
- physically-based
  - WEPP, KINEROS, EUROSEM, LISEM, SHE
- stochastic
  - RillGrow...

Models, objectifs, scales

- LISEL, 4 km²
- Rillgrow, 3 m²

Two models, two spatio-temporal scales

- LISEM: the Limburg Soil Erosion Model
  - Event (time step: seconds)
  - Physically-based
  - Distributed
  - Catchment-scale (raster cell size 5 to 50 m)

- RECODES: climate and land use change impacts on sediment delivery to streams in the Rhine basin
  - Time step: 1 month
  - Distributed, (raster cell size: 1 km²)
  - To reply to water management questions for the Netherlands in the period until 2100

Model 1: LISEM

- LISEM: GIS embedded catchment model

Flowchart of LISEM

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM</td>
<td>Erosion</td>
</tr>
<tr>
<td>Land use</td>
<td>Overland flow</td>
</tr>
<tr>
<td>Soil</td>
<td>Hydrogramme</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Deposition</td>
</tr>
</tbody>
</table>

Flowchart of LISEM
LDD (Local Drainage Direction)

The LDD defines flow direction in all cells and thus spatial structures.

Basic data

DEM

Soil

Land use

Model parameters derived from soil type

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>STH (mm)</td>
<td>25.50</td>
<td>25.50</td>
<td>25.50</td>
<td>25.50</td>
<td>25.50</td>
<td>25.50</td>
</tr>
<tr>
<td>KSAT (m/s)</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>KSAT (m/s)</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>KSAT (m/s)</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
</tr>
<tr>
<td>STH (mm)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>SOILDEP (mm)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
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<tr>
<td>THETAI (%)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
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<tr>
<td>THETAS (%)</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
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</tbody>
</table>

Model parameters derived from land use

<table>
<thead>
<tr>
<th>OCCUPATION DU SOL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH (%)</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>COH F(0) (kPa)</td>
<td>0.69</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>COH F(1) (kPa)</td>
<td>0.89</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>COH F(2) (kPa)</td>
<td>0.89</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>COHADD (kPa)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LAI (m²/m²)</td>
<td>0</td>
<td>0</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>RR F(0) (mm)</td>
<td>0.89</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>RR F(1) (mm)</td>
<td>0.89</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>RR F(2) (mm)</td>
<td>0.89</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Application of LISEM, no. 1

Effects of soil surface conditions

(Mickaël Lemmel, 2001)
Erosion

- Initial soil surface state
- Moderate degradation
- Strong degradation

Application of LISEM, no. 2
LISEM + TCRP (tillage controlled runoff pattern)
Accounting for tillage structures effects on runoff patterns and erosion

Effects of tillage direction

Structures de drainage de la partie amont du BV GUTZ
Runoff distribution over the catchment

LDD modifié avec TCRP
LDD topographique
Lame d'eau ruisselée (mm)

- Different spatial structure
- Overland flow concentration often occurs at field boundaries

Takken et al., 1999

topography
tillage

Application of LISEM, no. 3
Scenarion studies at the catchment scale
(Marc Pichaud, 2001)
Scenarios with different combinations of:
- grass strips
- reduced tillage
- retention structures (dikes)

**reduction of eroded surface**

(\(<0.5\text{tonne/ha}\))

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**Model 2: RECODES**

(GAMES + USLE)

Climate and land use change: impacts on sediment delivery in the Rhine basin

(Van Dijk, 2001)

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**Approach**
- fully distributed model with a time step of one month
- a sediment production module to quantify mobilisation of sediment by soil erosion at the hillslope scale
- a module accounting for sediment storage through a delivery ratio expression
- sediment supply: between or within cells
- written in PCRaster dynamic modelling language

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**The basic modules**
- **Sediment production**: USLE, RUSLE, ABAG
- **Delivery ratio**: GAMES, the fraction of mobilised sediment that actually reaches the stream depends on:
  - proximity of source to stream
  - the probability of overland flow occurrence
  - the character of the terrain along the route towards the channel (roughness, slope angle)
Snowmelt effects are taken into account.

Hydrological coefficient described the availability of overland land to transport sediment towards streams.

Sediment source to stream distances are estimated using a detailed drainage network map.

Local annual erosion and sediment delivery to streams.

Source: Van Dijk (2001)
Attention! Errors and uncertainty!

- Errors in input data
- Model errors
  - Never consider model output as the truth
  - Uncertainty analyses! (such as Monte Carlo analyses)
Why do erosion models perform poorly?

Deterministic, spatio-temporal models require many input parameters which all contain some degree of errors. Model output can be very sensitive to some of them (non-linearity).

Error propagation

In case rainfall or infiltration has an error of 5, 10, 15, et 20%...

...the error in modelled catchment discharge can be > 300%!

Example: sensitivity to Ksat

Incertainty / model complexity
Thanks!