The Influence of Antecedent Soil Moisture Conditions on Inter-rill Soil Erosion

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The soil’s inherent ability to resist erosion varies temporally due to differences in
- Temperature
- Time since ploughing
- Microbial activity
- Soil organic matter content
- Soil moisture
- Etc.

However,
- Few studies have looked at the effects of antecedent soil moisture conditions on inter-rill soil erosion
- In many soil erosion models soil erodability parameters are considered constant
The EPFL erosion flume
The EPFL erosion flume
Flume experiments

- 11 high intensity experiments
- Loam soil
- Pore pressure (3 locations, 4 depths)
- Overland flow, vertical and lateral drainage
  - 200 l buckets with water level recorders
Flume experiments

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- Sediment concentration in overland flow
Flume experiments

- 11 high intensity experiments
- Loam soil
- Pore pressure (3 locations, 4 depths)
- Overland flow, vertical and lateral drainage
  - 200 l buckets with water level recorders
- Sediment concentration in overland flow
- Concentration of individual size classes
  - 7 size classes
  - Pipette method and wet sieving
Results: Influence of antecedent conditions

Sediment concentration (g/l)

Overland flow (mm/hr)

Time since start of experiment (min)

Pore pressure (m)

at 0.05 m below the soil surface

E1: dry
E2: wet
E8: nearly saturated
Results: Sediment concentrations

- Peak sediment concentration (g/l)
- Steady state sediment concentration (g/l)

Slope (%)

- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14

Graphs showing the relationship between slope (%) and sediment concentration (g/l) for peak and steady state conditions.
Results: Peak sediment concentrations

- Pore pressure at start of the experiment (m):
  - -2.0
  - -1.5
  - -1.0
  - -0.5
  - 0.0

- Peak sediment concentration (g/l):
  - 0
  - 20
  - 40
  - 60
  - 80

- Steady state infiltration rate (mm/hr):
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10

- Slopes:
  - 2%
  - 7%
  - 12%
Influence of antecedent soil moisture on size distribution of eroded sediment
Influence of soil moisture and slope on size distribution at peak concentration

Percentage of total sediment <50 µm during peak sediment concentrations (%)

Pore pressure at the start of the experiment (m)

-2.0  -1.5  -1.0  -0.5  0.0

2% slope
7% slope
12% slope
Simulating these results: Parlange et al., 1999 JoH

- Decoupling of the short and long time behavior.
- Very short time solution for the processes associated with the rainfall impact.
- Longer time solution for the behavior controlled by convection.

Addendum to unsteady soil erosion model


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Abstract

A simple analytical approximation is obtained for erosion on a hillslope involving sediment transport when rainfall is the only source of water. The solution arises in earlier study requiring some numerical evaluation. Owing to its simplicity, the solution gives a clear understanding of the influence of the physical processes involved. Fundamentally, there is a very short time behavior associated with rainfall impact and a longer time behavior controlled by convection. It is this time decoupling which permits the solutions to be expressed in simple terms. The short time analytical results can be used to simplify greatly numerical procedures.

Keywords: Erosion; Sedimentation; Runoff; Analytical solution

1. Introduction

Recently, Hairiine and Rose (1991) and Rose et al. (1994) developed a physical model of soil erosion on a hillslope, which can be further justified by a microscopic/stochastic approach (Lisle et al., 1998). Hairiine and Rose (1991) and Rose et al. (1994) considered erosion by running water only in the presence of overland flow generated by rainfall excess.

Hogarth et al. (1998) gave a complete numerical solution of the problem, which takes into account both spatial and temporal dependence. However it requires solving 20 coupled partial differential equations (number chosen to represent adequately the particle size distribution) which precludes both its use for management purposes or to describe the physical processes simply. Its usefulness, rather, is to show that the physical model does indeed apply to describe the experimental observations such as those of Proffitt et al. (1991). It also suggests, that when the only source of water is rainfall, i.e. there is no incoming water at the top of the hillslope, the spatial dependence of the solution is minimal at the end of the flume. Then, neglecting the spatial dependence altogether, Sander et al. (1996) obtained a simplified analytical-numerical solution, which agrees quite well with the complete numerical solution and the experimental observations. However, even without spatial dependence, the solution is too intricate to recognize individual processes, i.e. understand the early time behavior and the interactions between different grain size classes. The present solution is simple enough to do so readily, as well as providing some justification for neglecting spatial dependence in the first instance.
Hairsine-Rose model

Figure from: Heilig et al., 2001, JoH

- Water conservation:
  \[
  \frac{\partial D}{\partial t} + \frac{\partial q}{\partial x} = R
  \]

- Sediment conservation:
  \[
  \frac{\partial D C_i}{\partial t} + \frac{\partial q C_i}{\partial x} = e_i + e_{di} - d_i - RC_i
  \]
  \[
  \frac{\partial M_{di}}{\partial t} = d_i - e_{di}
  \]

- Rainfall detachment:
  \[
  e_i = \frac{aP}{I} \left[ 1 - H(t, x) \right]
  \]

- Rainfall re-detachment:
  \[
  e_{di} = a_d P \frac{M_{di}}{M_{dt}} H(t, x)
  \]

- Deposition:
  \[
  d_i = V_i C_i
  \]
Optimization of the unknown variables

- Four unknown variables:
  - $a_d$
  - $\alpha = a_d DP/RM_{dt^*}$
  - $K = a_d/a$
  - $D$

- Affects the peak and steady state concentrations
- Affects the peak sediment concentration
- Affects the rise of sediment concentrations
- Affects the sharpness of the recession (fine sediment)
Model results

Exp. 4

Total concentration

- Observed
- Fitted

Sediment concentration (g/l)

- < 2 µm
- 2-20 µm
- 20-50 µm
- 50-100 µm
- 100-315 µm
- 315-1000 µm
- > 1000 µm

Time since start of the experiment (min)
Effect of antecedent moisture conditions on model parameters

\[ \alpha = \frac{a_d PD}{RM_{dt^*}} \]

- **2% slope**
- **7% slope**
- **12% slope**

Pore pressure at the start of the experiment (m)
Effect of antecedent moisture conditions on model parameters

\[ \alpha = \frac{a_d PD}{RM_{dt^*}} \]

Pore pressure at the start of the experiment (m)

-2.0 -1.5 -1.0 -0.5 0.0

2% slope
7% slope
12% slope

E1
E9

\( * \)
Effect of antecedent moisture conditions on model parameters

$$\alpha = \frac{a_d PD}{RM_{dt^*}}$$

- Pore pressure at the start of the experiment (m)
- 2% slope
- 7% slope
- 12% slope

$E_1$, $E_9$
Effect of antecedent moisture conditions on model parameters

$$\alpha = \frac{a_d PD}{RM_{dt^*}}$$

Pore pressure at the start of the experiment (m)

-2.0  -1.5  -1.0  -0.5  0.0

2% slope
7% slope
12% slope

α (-)

0  100  200  300  400  500

E9  E1
Incorporating the effects of antecedent moisture conditions (and slope) into the model

First step – simple parameter regression

\[ a_d = 2.14S + 0.69 \quad r^2=0.93 \]

\[ \alpha = 281.6\psi_{0.05} + 113.9 \quad r^2=0.73 \]

S = slope [%]

\( \psi_{0.05} \) = pore pressure at 0.05 m at start of the experiment [m]
Model results: Total concentration

![Graph showing model results for total concentration. The x-axis represents time since the start of the experiment in minutes (0 to 120), and the y-axis represents sediment concentration in g/l (0 to 40). The graph includes observed data points and fitted lines. The fitted lines are indicated as 'Exp. 4' and 'α and a_d from regression.' ]
Model results: application of the regression

Sediment concentration (g/l)

Exp. 4

Total concentration

Observed

Fitted

α and a_d from regression

Time since start of the experiment (min)
Conclusion: Experimental results

- Antecedent moisture conditions have a large effect on peak sediment concentrations, especially near saturation.
- Wetter conditions lead to a disproportionate large increase in transport of fine particles.
  - Important implications for simulating the transport of sorbed particles (phosphorus, pathogens, etc).
- Effect of antecedent moisture conditions on inter-rill erosion is possibly different for dry soils.
Conclusion: Model results

- Experimental observations do agree with the Hairsine-Rose theory
  - Initial transport of fine particles and coarsening with increasing time
  - Steady state composition reflects the original soil composition

- The $\alpha$ parameter in the model appears to be influenced by the antecedent moisture conditions

- Using a simple relation between initial pore pressures and the $\alpha$ parameter yields good results regarding the influence of antecedent moisture conditions on sediment concentrations and composition
Thank you

From: http://www.public.asu.edu/%7Emschmeec/rainsplash.html