MODELLING SURFACE RUNOFF TO MITIGATE HARMFUL IMPACT OF SOIL EROSION

Pavel KOVAR, Darina VASSOVA
Faculty of Environmental Sciences
Czech University of Life Sciences Prague

HydroPredict Conference 2010
Prague, September 20 to 23, 2010

INTRODUCTION

Problems Caused by Water Erosion

- Loss of soil is an important issue worldwide, due to:
  - Increased frequency of hydrological extremes
  - Inexistent or insufficient erosion control measures
  - Improper land use
  - Improper agricultural/forest management
- First steps for solving problems related to water erosion :
  - Empirical models:
    - **USLE/MUSLE** (Modified/Universal Soil Loss Equation, Delivery Ratio)
  - Simulation models:
    - CN-based models (**EPIC**, **CREAMS**, **AGNPS**, ...)
    - Surface Runoff and Erosion Processes (**SMODERP**, **EROSION 2D**, ...)
  - Advanced simulation models:
    - **EUROSEM** (European Erosion Model, http://www.cranfield.ac.uk/eurosem/Eurosem.htm)
    - **WEPP** (Water Erosion Prediction Project, http://milford.nserl.purdue.edu/weppdocs/)

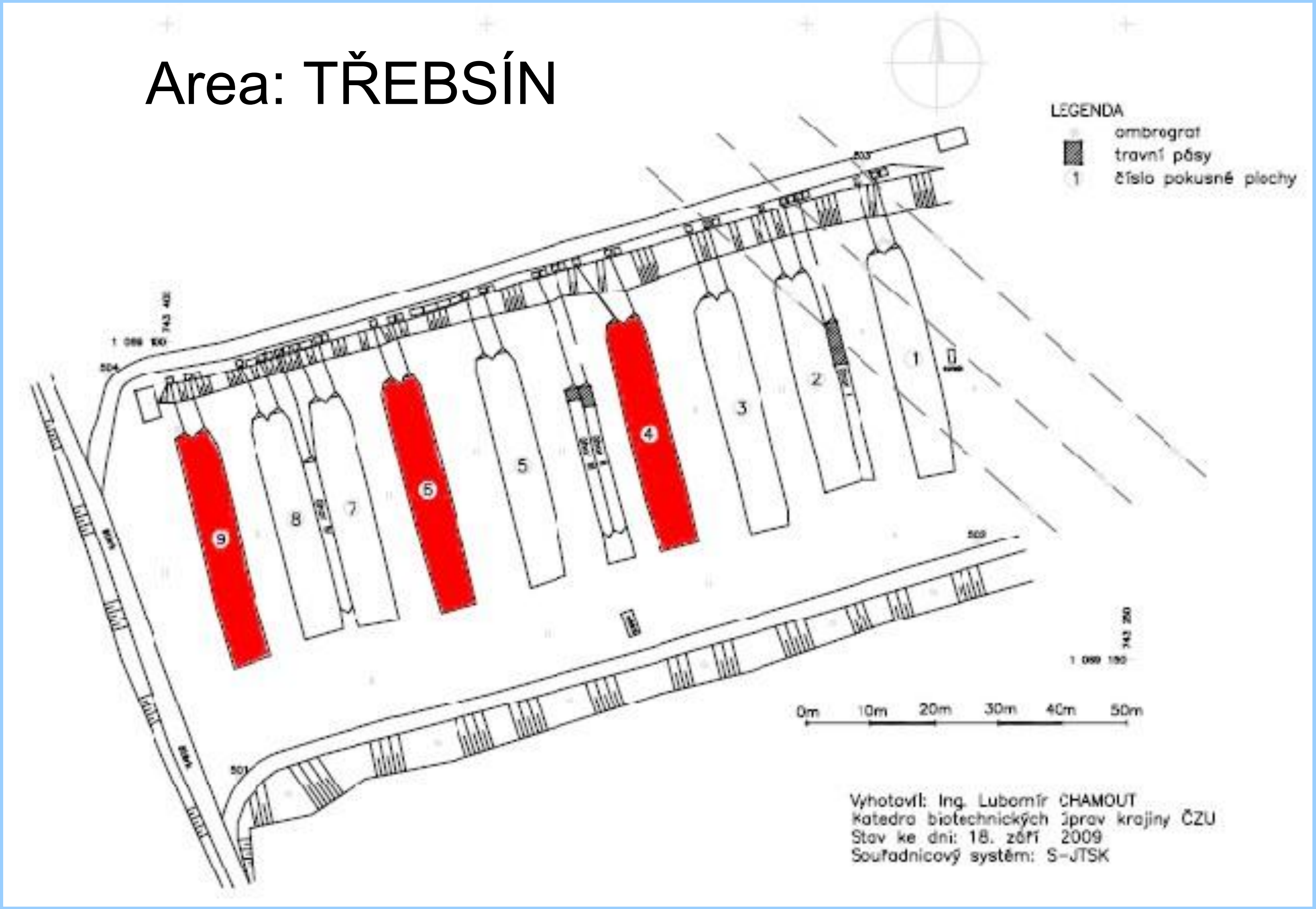
INTRODUCTION

CAN WATER EROSION BE PREDICTED USING A MODIFIED HYDROLOGIC MODEL?

In this presentation we will try to determine the common principles of surface runoff and soil erosion analyses:

- Physically-based models
- Natural rainfall-runoff events data
- Simulated rainfall-runoff data (using rain simulator)
- Design rainfall data
- Observed and computed rain erosivity data assessment
- Soil loss analysis based on soil erodibility (rill and interrill erosion assessment)

EXPERIMENTAL RUNOFF PLOTS



EXPERIMENTAL SITES DESCRIPTION

Soil characteristics:

- Brown soil “Eutric Cambisol” on weathered eluvials and deluvials
- Field capacity (average): 33.5%
- Porosity (average): 48.3%

Plot parameters and crops

Plot No.	Length (m)	Wide (m)	Slope (%)	Area (m^2)	Crop 2007	Crop 2008	Crop 2009	Crop 2010
9	37.7	6.6	11.2	248.8	sunflower	maize	maize	maize
6	37.8	6.7	12.8	253.3	sunflower	maize	maize	maize
4	37.4	6.8	14.3	254.3	sunflower	maize	maize	maize
Average	37.6	6.7	12.8	250.0				

Soil hydraulic parameters

$$SF = \frac{(So)^2}{2K_s}$$

Plot No.	Satur. hydraulic conductivity K_s ($mm \cdot min^{-1}$)	Sorptivity at FC So ($mm \cdot min^{-0.5}$)	Storage suction factor SF (mm)
9	0.214	1.06	2.63
6	0.177	1.20	4.07
4	4.360	4.64	2.47

RAIN SIMULATOR

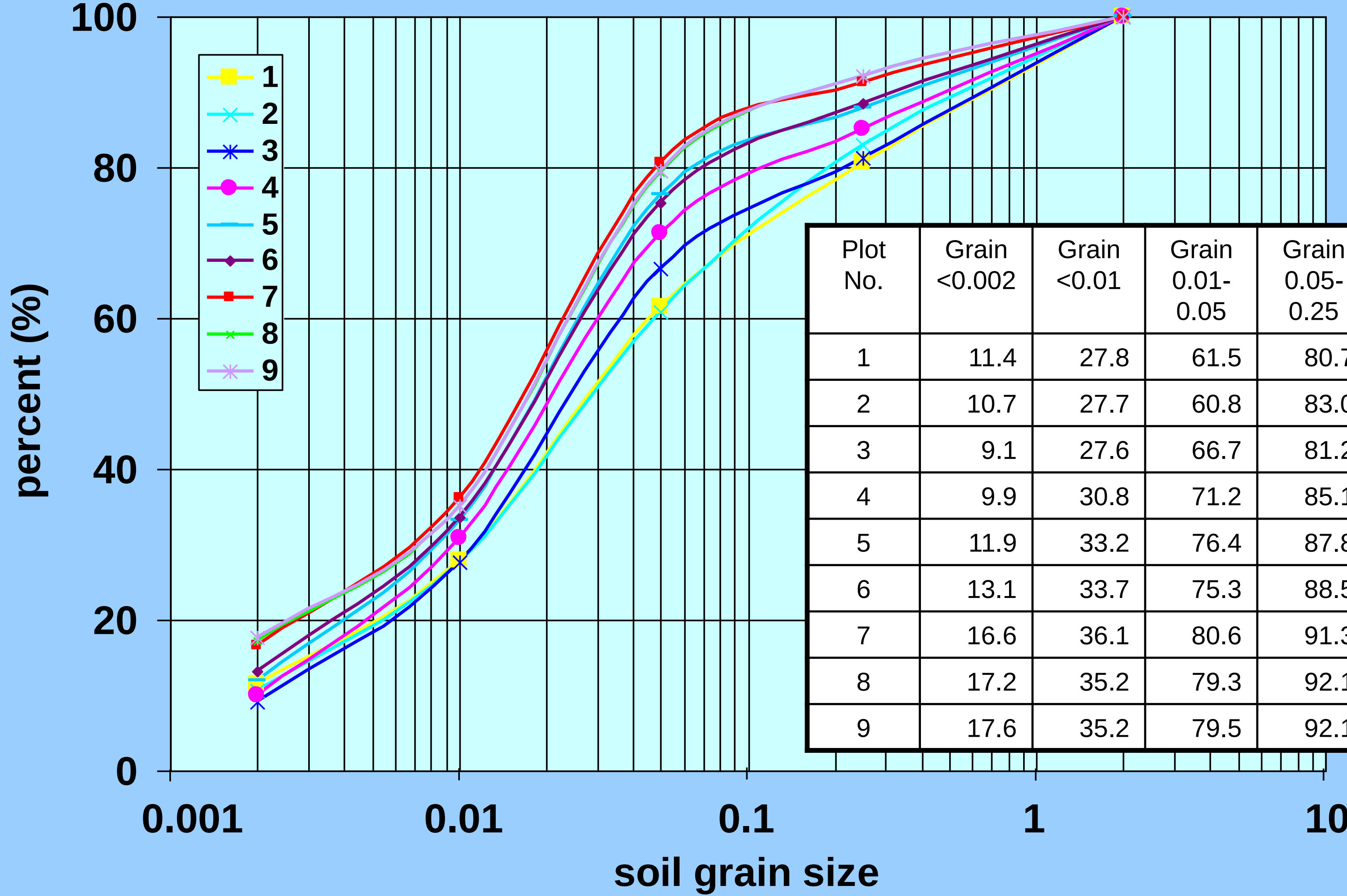
RAIN SIMULATOR

SHEET FLOW

DISCHARGE/LOAD MEASUREMENT DEVICE

GRANULARITY CURVE

FOR EXPERIMENTAL RUNOFF AREAS AT TŘEBSÍN



Plot No.	Grain <0.002	Grain <0.01	Grain 0.01-0.05	Grain 0.05-0.25	Grain 0.25-2.0
1	11.4	27.8	61.5	80.7	100.0
2	10.7	27.7	60.8	83.0	100.0
3	9.1	27.6	66.7	81.2	100.0
4	9.9	30.8	71.2	85.1	100.0
5	11.9	33.2	76.4	87.8	100.0
6	13.1	33.7	75.3	88.5	100.0
7	16.6	36.1	80.6	91.3	100.0
8	17.2	35.2	79.3	92.1	100.0
9	17.6	35.2	79.5	92.1	100.0

MODEL KINFIL – PRINCIPLES

EINFIL Part

- Infiltration computation:
  - Green Ampt (and Morel-Seytoux)

$$i = K_s\left(1 + \frac{(\theta_s - \theta_i)\cdot H_f}{i \cdot t_p}\right)$$

- Storage suction factor:

$$S_f = (\theta_s - \theta_i)\cdot H_f = \frac{(So)^2}{2K_s}$$

- Ponding time:

$$t_p = \frac{S_f}{i \cdot \left(\frac{i}{K_s} - 1\right)}$$

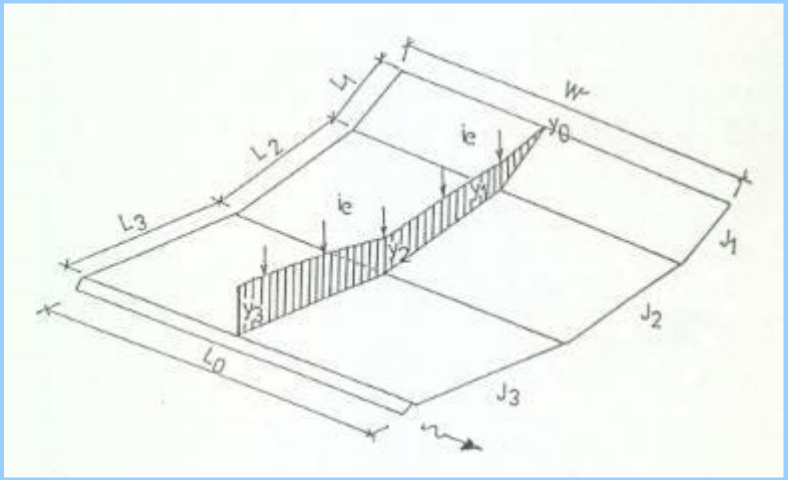
KINFIL Part

- Computation of flow on slopes using kinematic wave computation:
  - (Lax-Wendroff numerical scheme)

$$\frac{\partial y}{\partial t} + \alpha m y^{m-1}\frac{\partial y}{\partial x} = i_e(t)$$

THE KINFIL PARAMETERS

ROOT	depth of root zone (m)
KS	saturated hydraulic conductivity ($m \cdot s^{-1}$)
SO	sorptivity at field capacity ($m \cdot s^{-0.5}$)
POR	porosity (–)
FC	field capacity (–)
SMC	(or API) soil moisture content (mm)
JJ	number of planes in cascade (–)
SLO	slope of plane (–)
LEN	length of plane (m)
WID	width of plane (m)
NM	Manning roughness
DS	mean soil particle diameter (mm)
D(i)	soil particle category diameters (mm)
RO	soil particle density ($kg \cdot m^{-3}$)

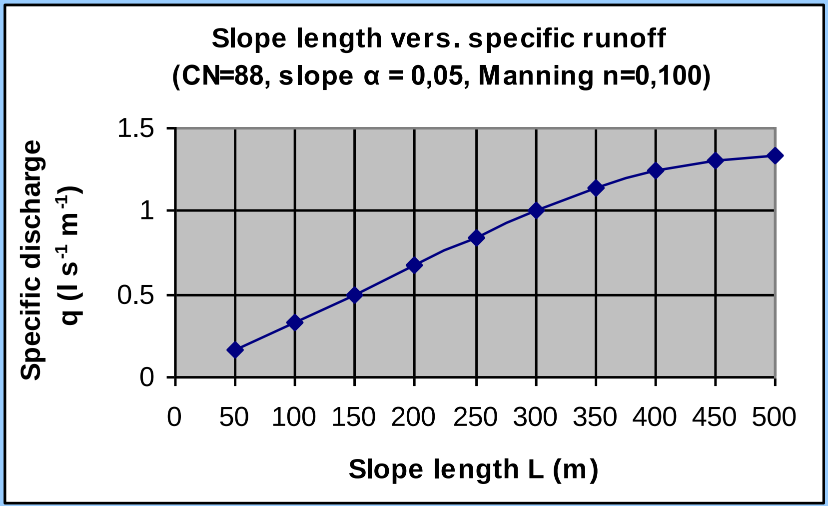


$$\frac{\Delta t}{\Delta x} \leq \frac{1}{\alpha m y^{m-1}}$$

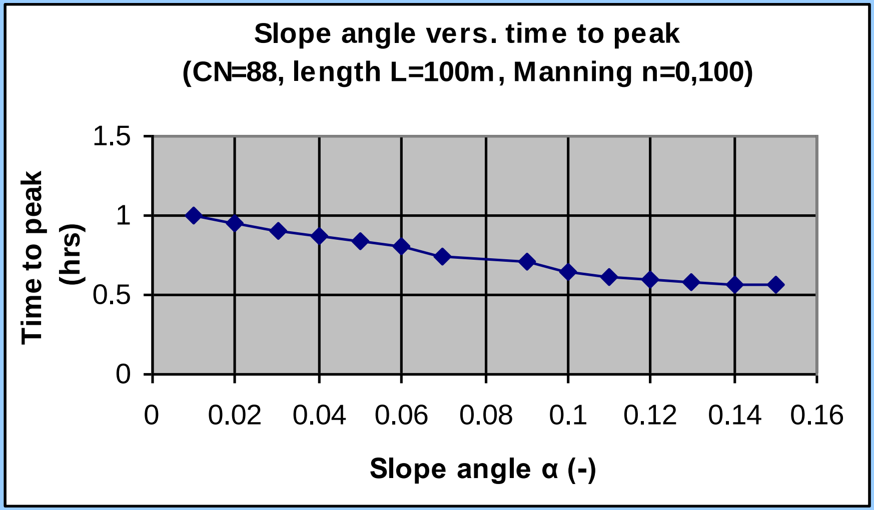
– cascade of planes
– cascade of segments

IMPACT OF PHYSIOGRAPHIC CHARACTERISTICS ON SURFACE RUNOFF

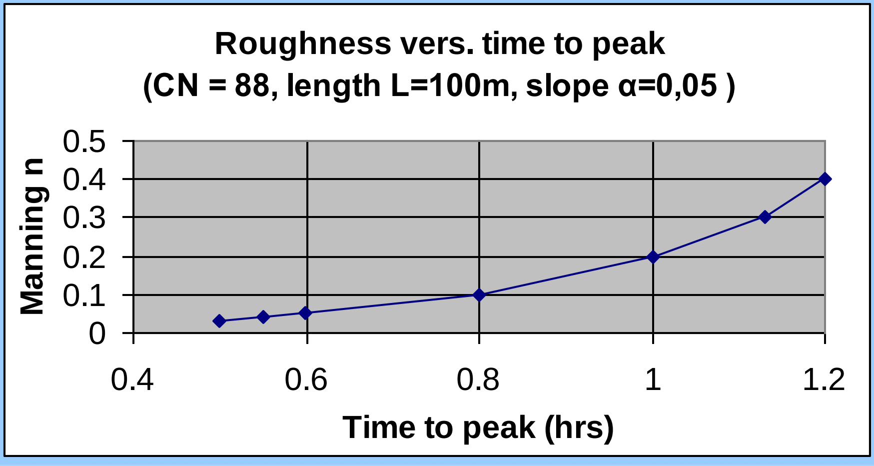
Length of slope



Angle of slope



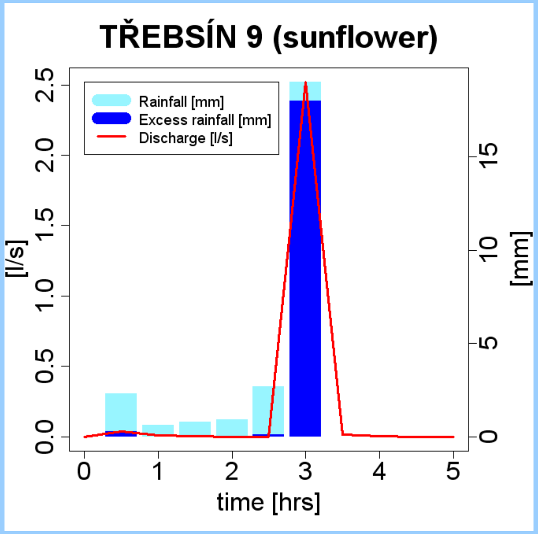
Hydraulic roughness

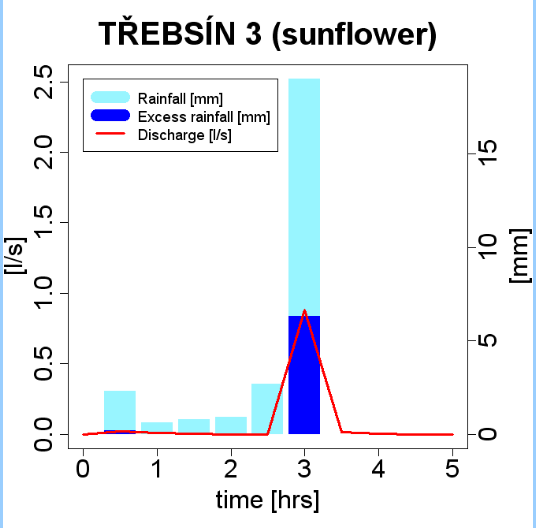


NATURAL RAINFALL-RUNOFF OBSERVATION

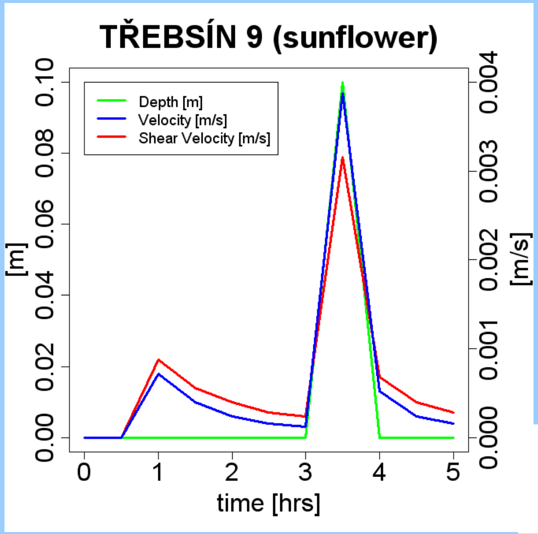
DT = 30 min, area 250 m^2 (36.0 × 7.0 m), 10 August 2007

Rainfall-runoff events

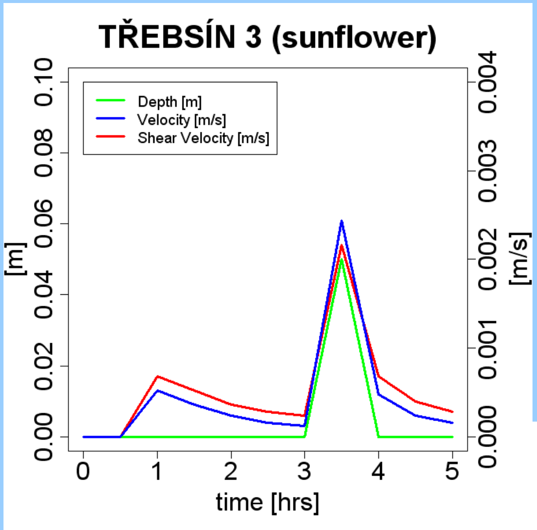




Depths, velocity and shear velocity



Soil loss:
5330 kg · ha^{-1}

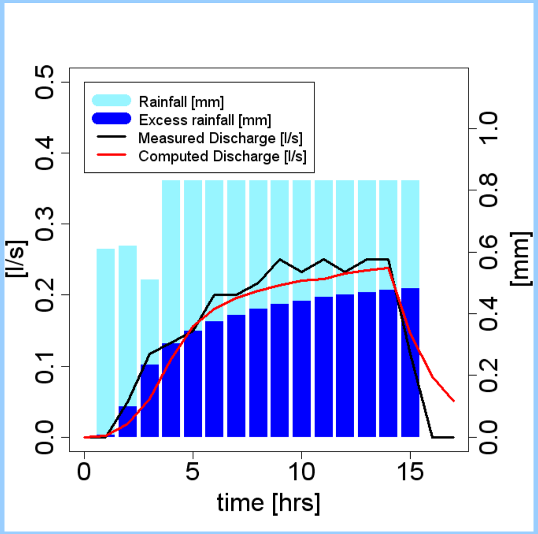


Soil loss:
281 kg · ha^{-1}

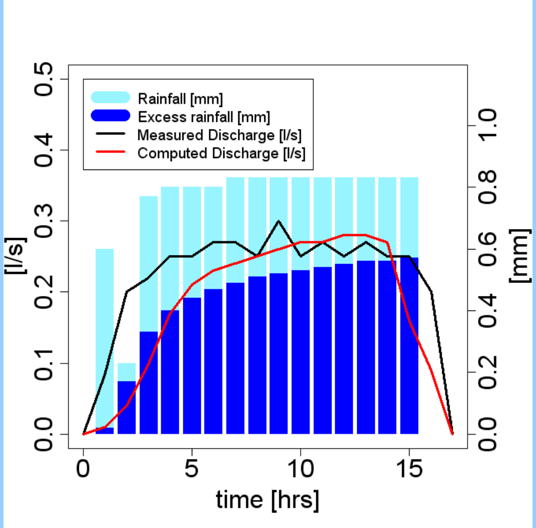
SIMULATED RAINFALL-RUNOFF EVENTS

TŘEBSÍN 9, DT = 1 min, area 30 m^2 (3.0 × 10.0 m)

26 Aug. 2009 (DRY, SMC_o=23.4%, Maize)

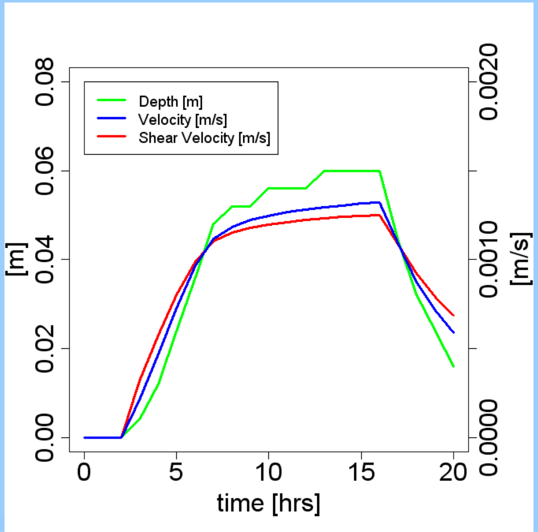


26 Aug. 2009 (WET, SMC_o=39.3%, Maize)

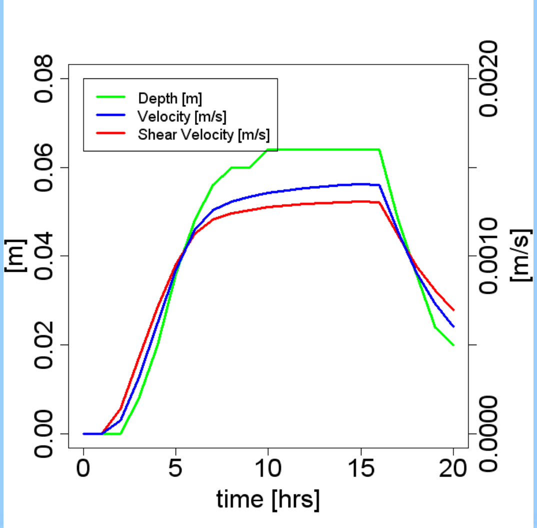


Depths and Velocities

26 Aug. 2009 (DRY)



26 Aug. 2009 (WET)

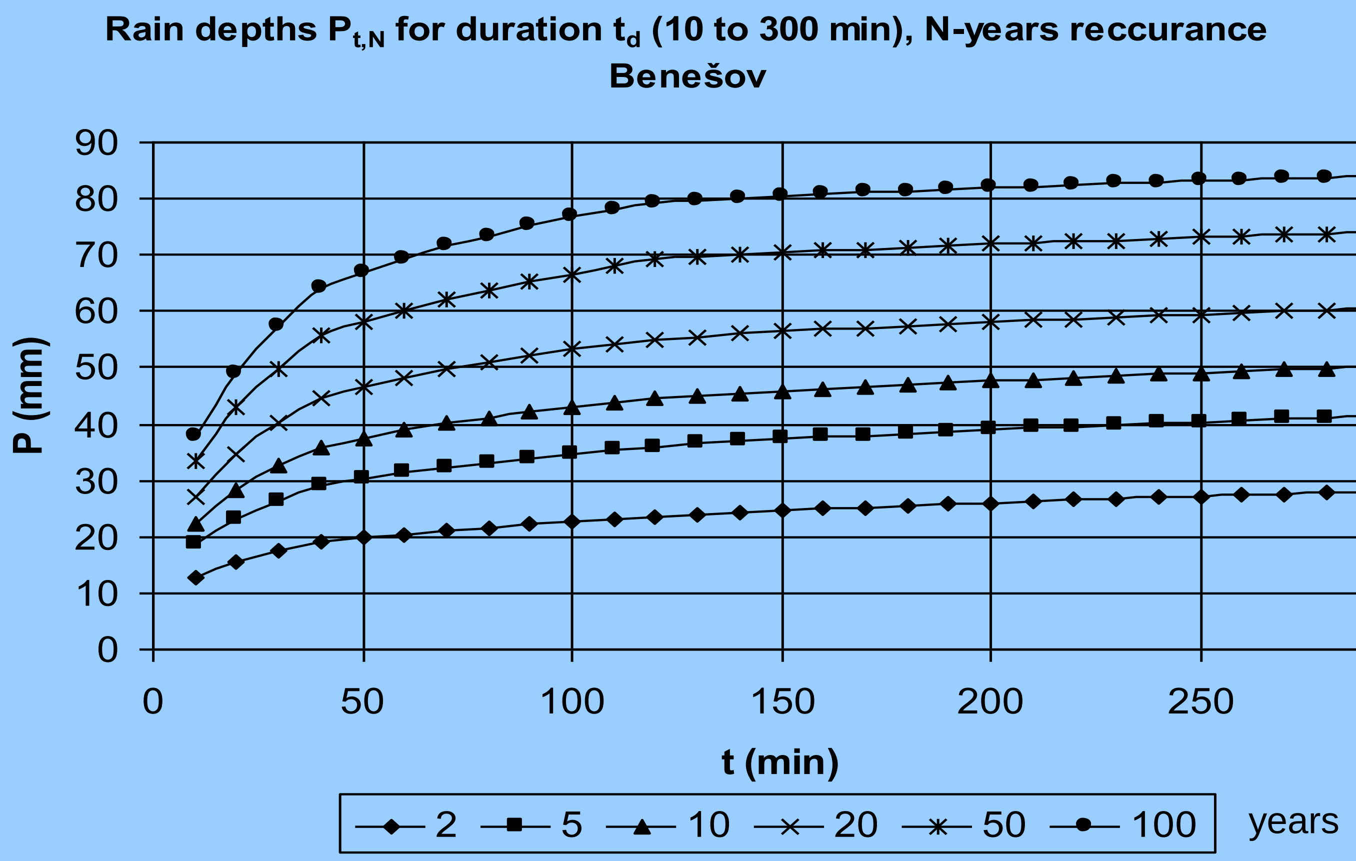


DESIGN RAINFALLS

Rain gauge Benešov: $P_{t,N}=P_{1d,N} \cdot a \cdot t^{1-c}$

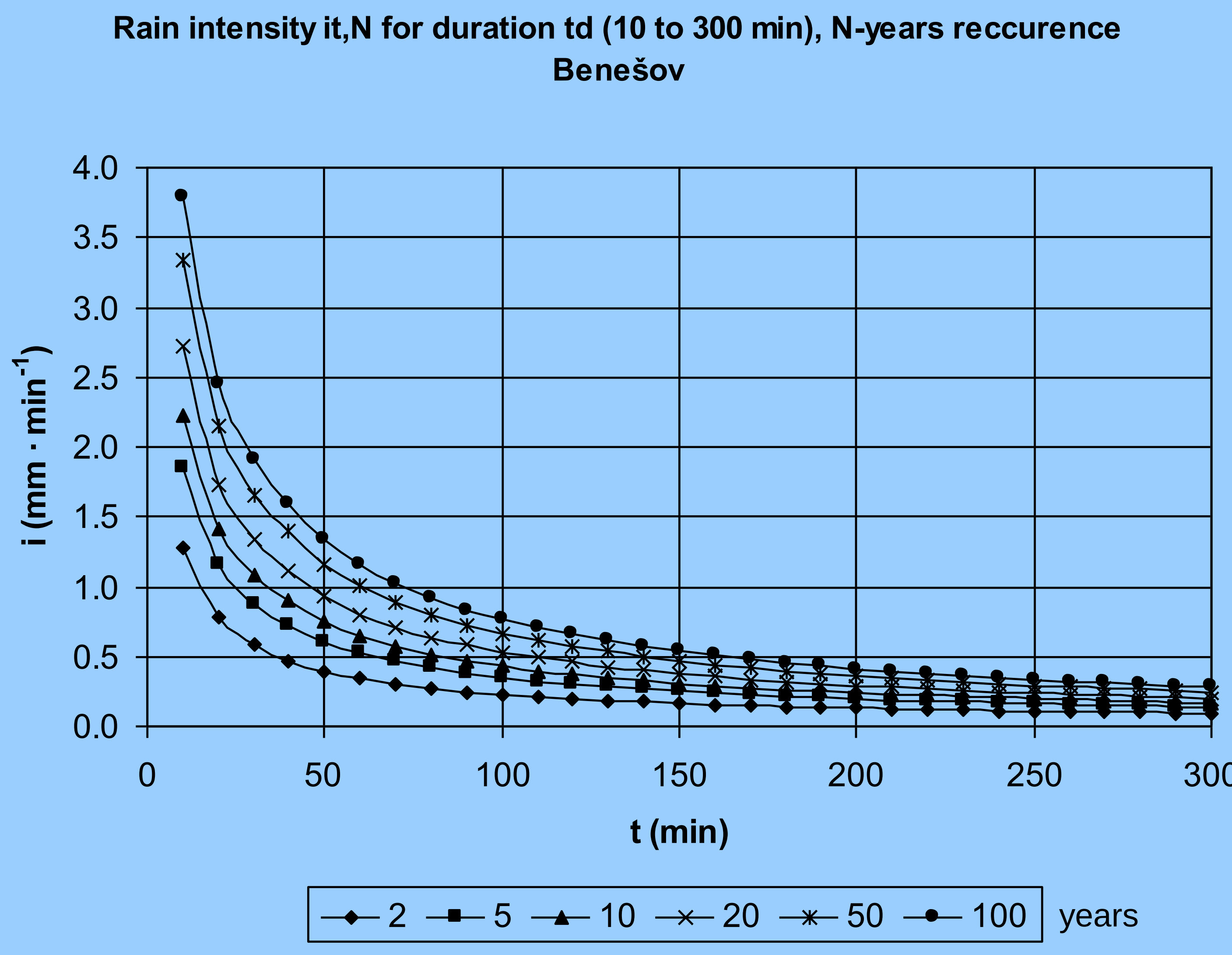
$$i_{t,N}=P_{1d,N} \cdot a \cdot t^{-c}$$

Design rainfall depths $P_{t,N}$ (mm):



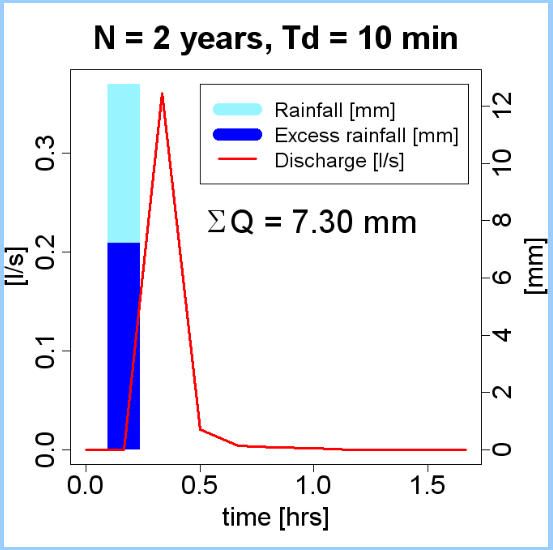
DESIGN RAIN INTENSITIES

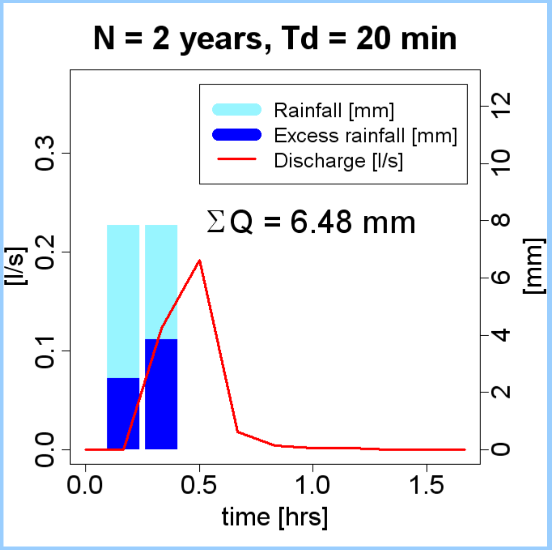
Design rain intensities $i_{t,N}$ (mm · min^{-1}):

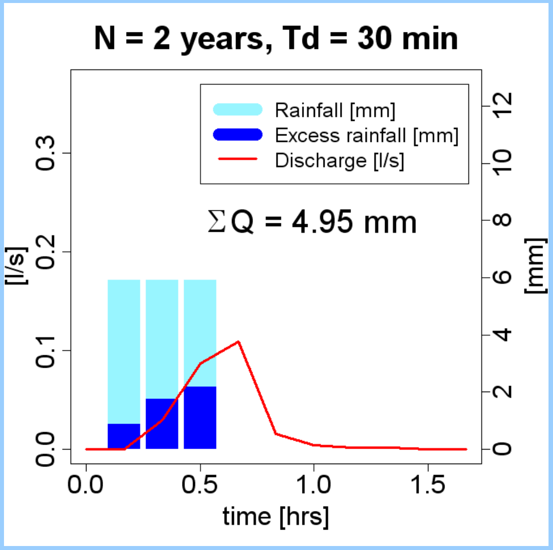


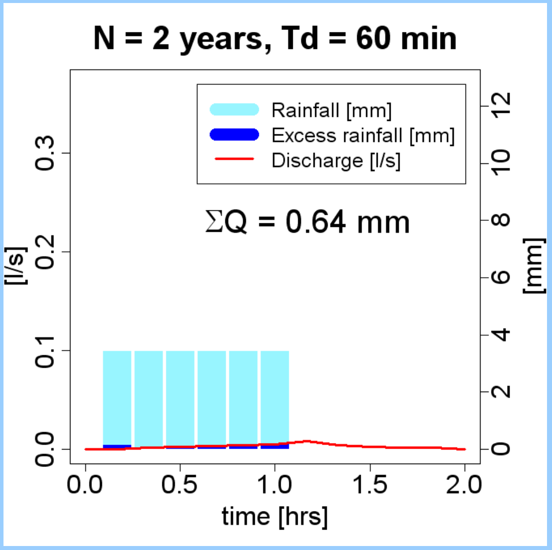
SURFACE RUNOFF FROM DESIGN RAINFALL

Locality: TŘEBSÍN 9, area 30 m^2, Maize



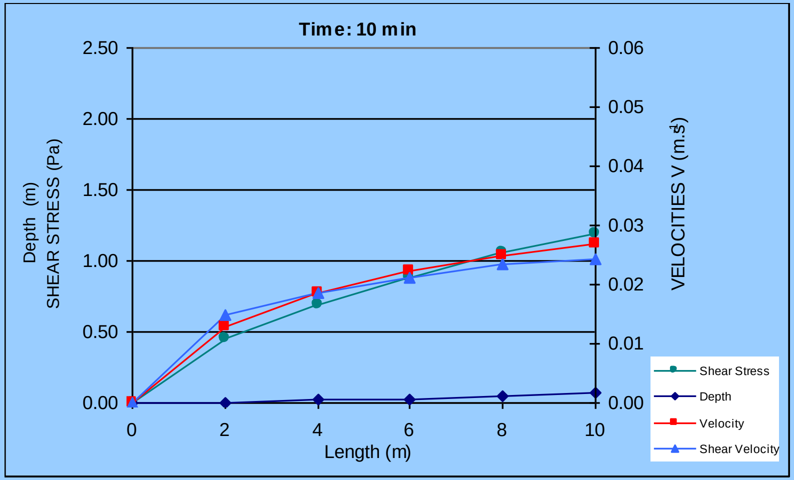


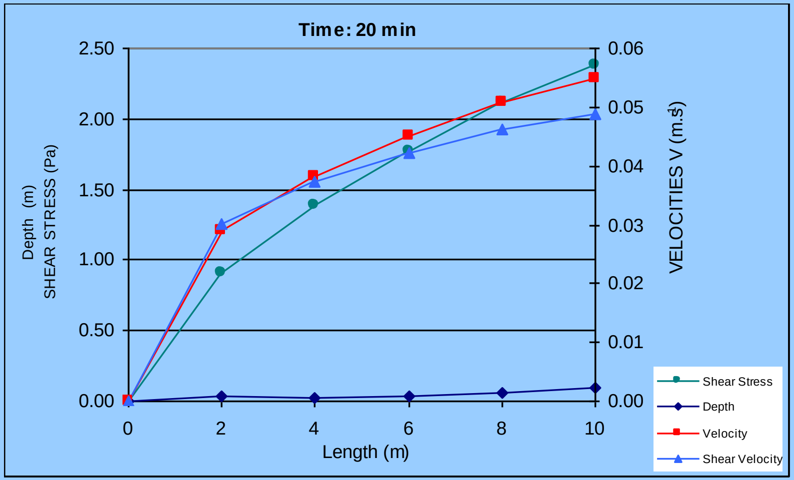


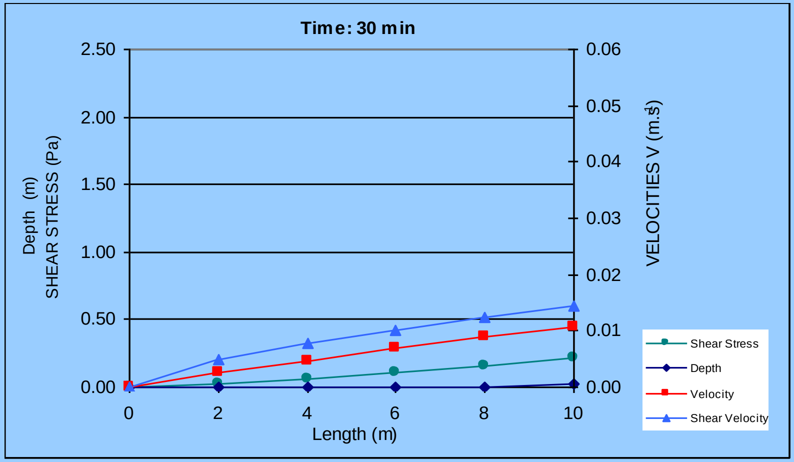


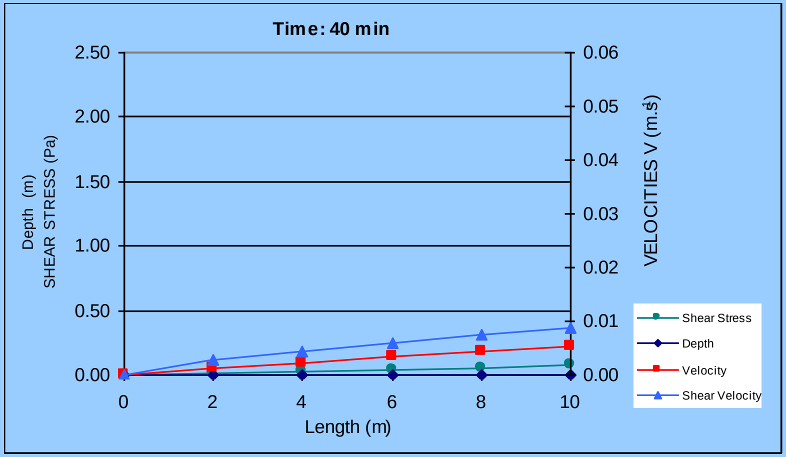
DESIGN RUNOFF: DEPTH, VELOCITIES AND SHEAR STRESS VALUES AT DIFFERENT TIME

Locality: TŘEBSÍN 9, area 30m², N = 2 years, TD = 10 min









DESIGN RUNOFF: POTENTIAL SOIL LOSS

Locality: TŘEBSÍN 9, N = 2 years, TD = 10 min

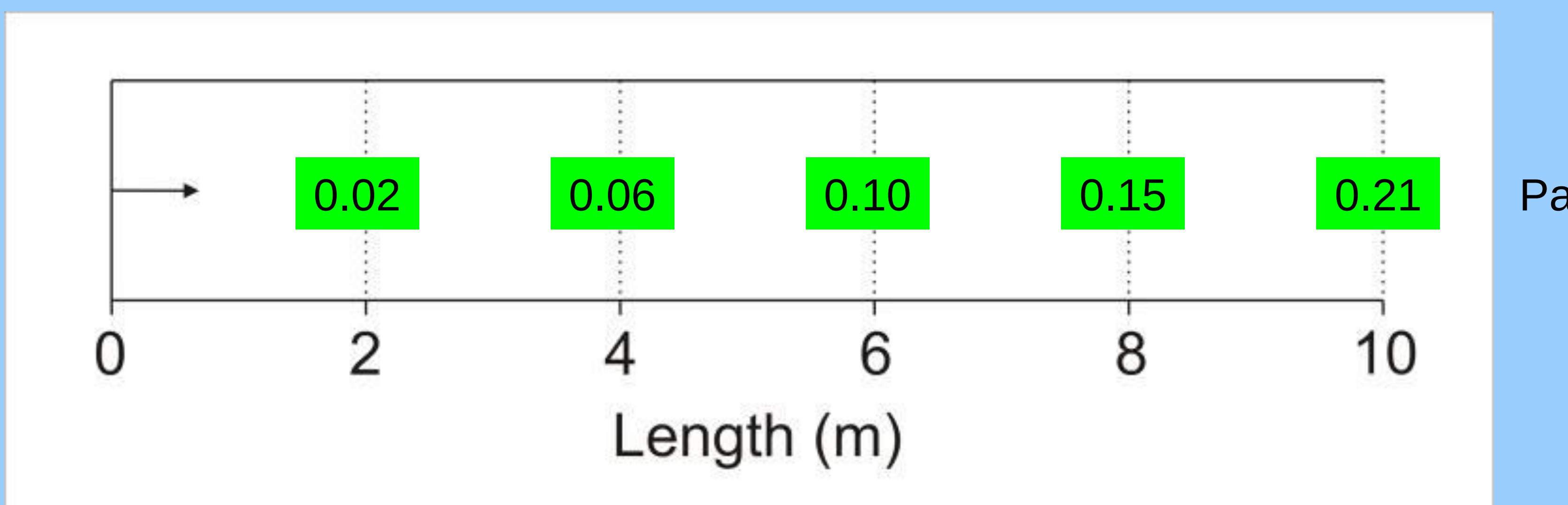
Grain size categories and their critical shear stress:

Category (mm)	< 0.01	0.01–0.05	0.05–0.25	0.25–2.00
τ_c (Pa)	0.0076	0.0380	0.1900	1.6700

Effective medium grain size D_s = 0.030 mm, τ_c = 0.5 Pa

Experimental runoff area:

Potential soil loss (for D_s) at 20’



CONCLUSIONS

ADVANTAGES OF THE KINFIL MODEL

- provides results from the physically-based scheme.
- provides possibilities to calibrate model parameters for natural rainfall-runoff event reconstructions.
- simulates surface runoff discharges, depths, velocities and shear stress accurately enough to be compared with measured discharges and soil losses measured by rain simulator equipment.
- simulates also the change of land use and farming management.

MODELLERS AIM

- to extend research in soil losses caused by rill erosion (τ_0 vers. τ_K for various granulometric spectra).
- to compare the KINFIL and WEPP models results.

Thank you for your attention