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Evaluation of Erosion-Sediment Transport Model for a Hillslope Using Laboratory Flume Data

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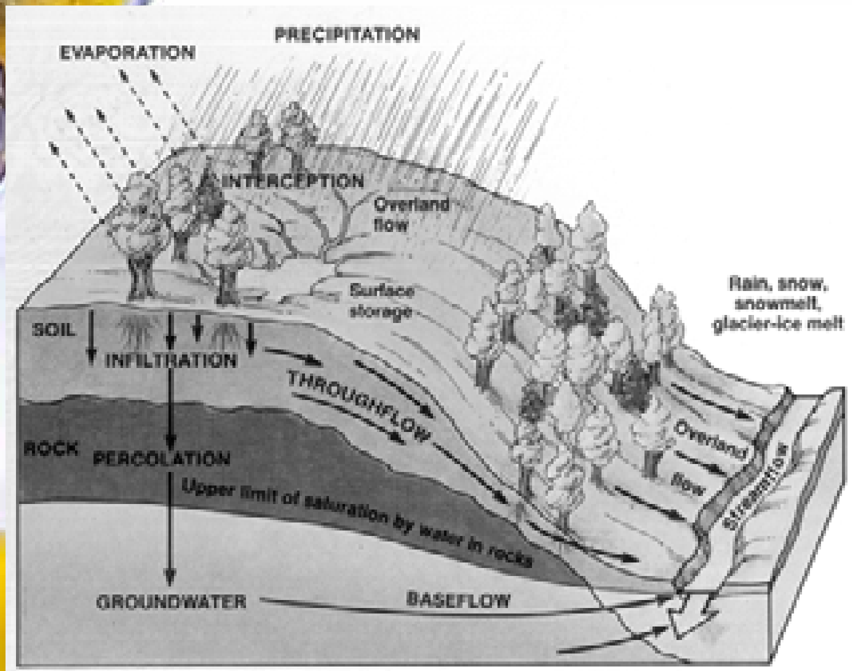
INTRODUCTION

BACKGROUND

- Climate change ⇨ increase in rainfall

BACKGROUND

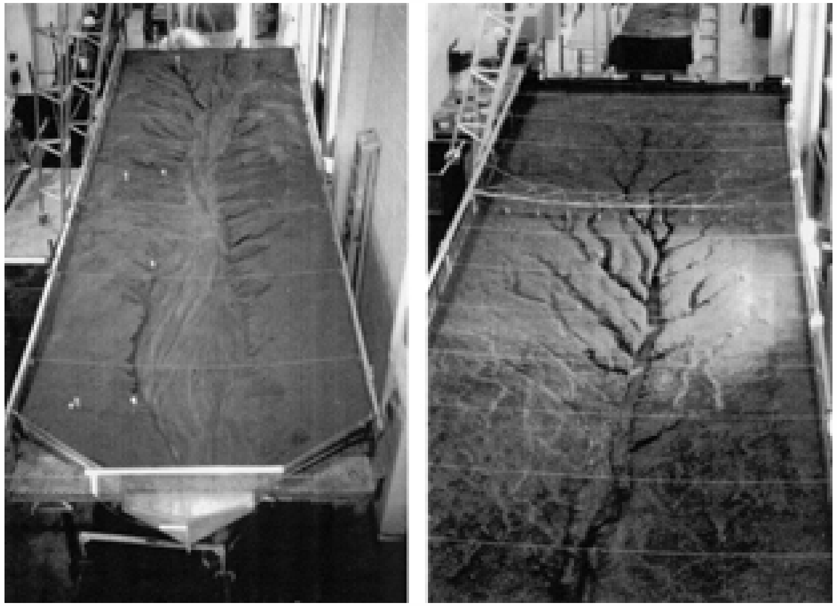
- More overland flow and non-point source pollution (e.g. sediments) ⇨ water quality degradation

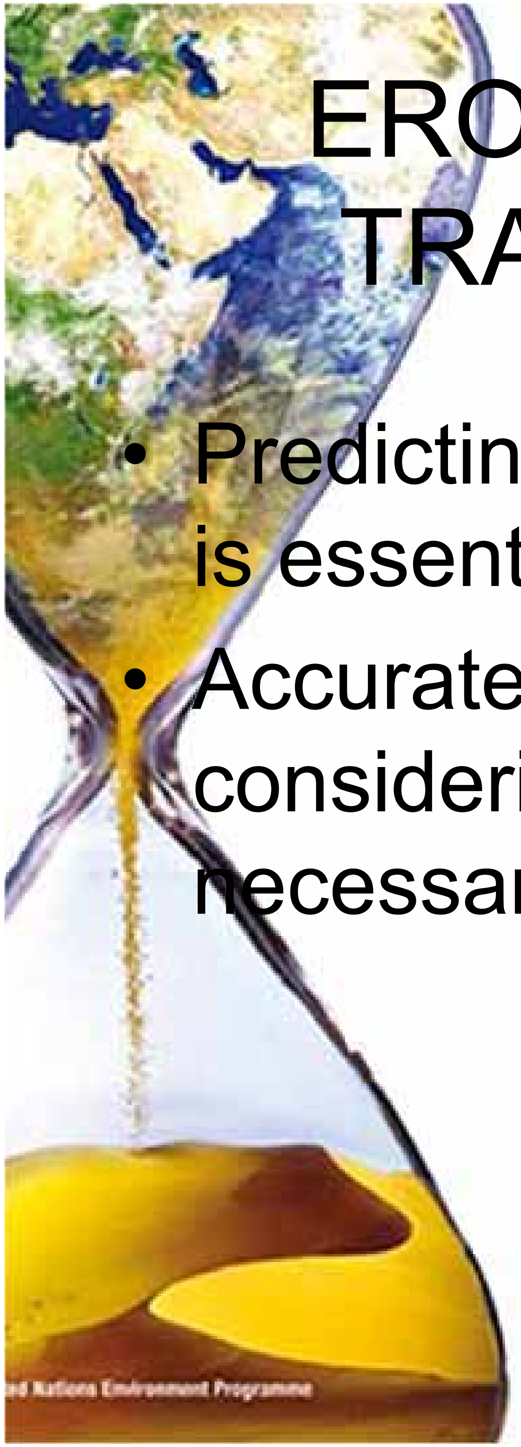


SOIL EROSION AND LANDSLIDE

EROSION AND SEDIMENT TRANSPORT ON HILLSLOPES

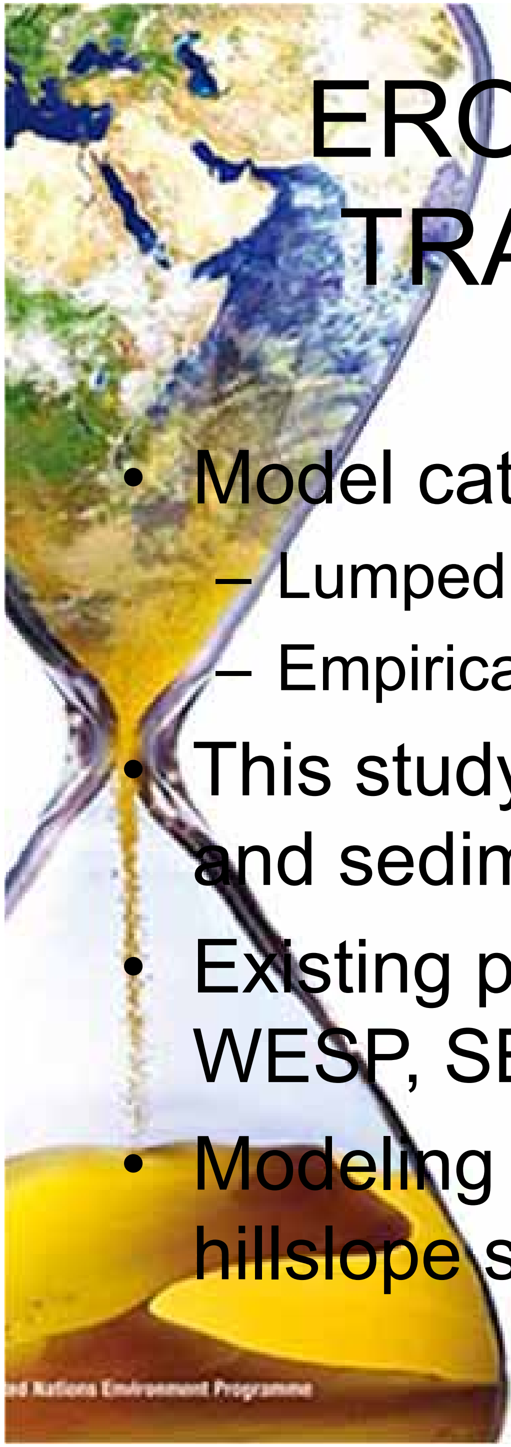
- Rills: small rivulets on hillslopes where runoff is concentrated
- Interrill areas: source areas between the rills
- Rills contain greater flow and sediment discharge than interrill area





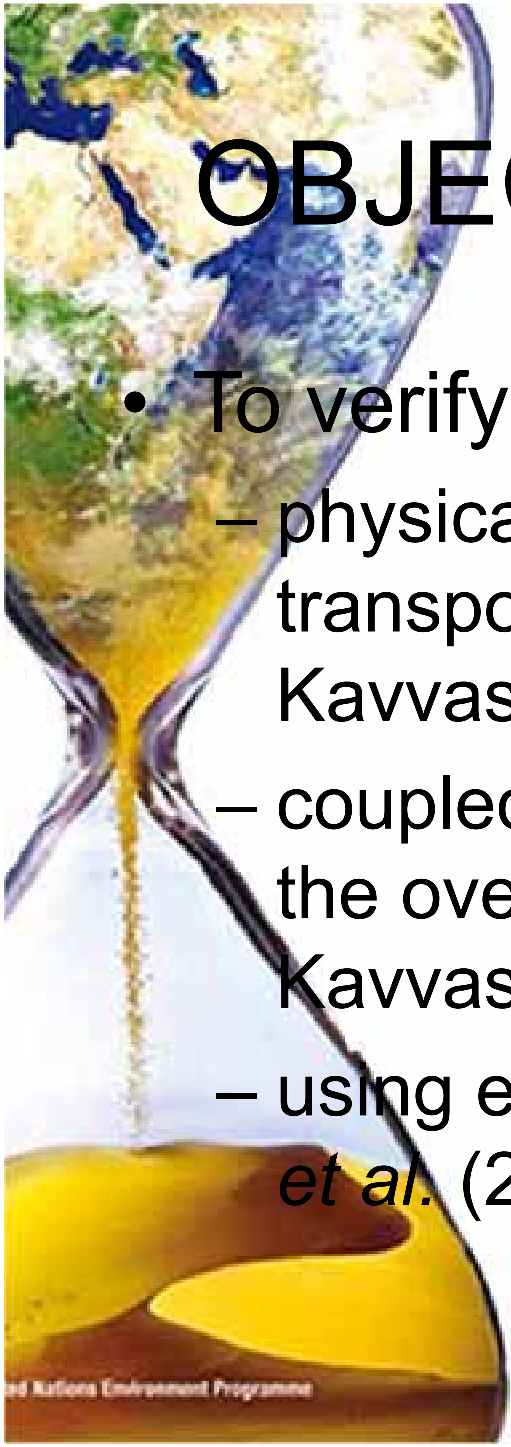
EROSION AND SEDIMENT TRANSPORT MODELING

- Predicting erosion and sediment transport is essential for water quality management
- Accurate modelling of overland flow considering microtopography of hillslope is necessary for sediment transport modeling



EROSION AND SEDIMENT TRANSPORT MODELING

- Model categories
  - Lumped or distributed
  - Empirical or Physically based
- This study presents a physically based erosion and sediment transport model
- Existing physically based models are KINEROS, WESP, SEM, SHESED, and EUROSEM
- Modeling of erosion and sediment transport at hillslope scale is rarely verified



OBJECTIVE OF THE STUDY

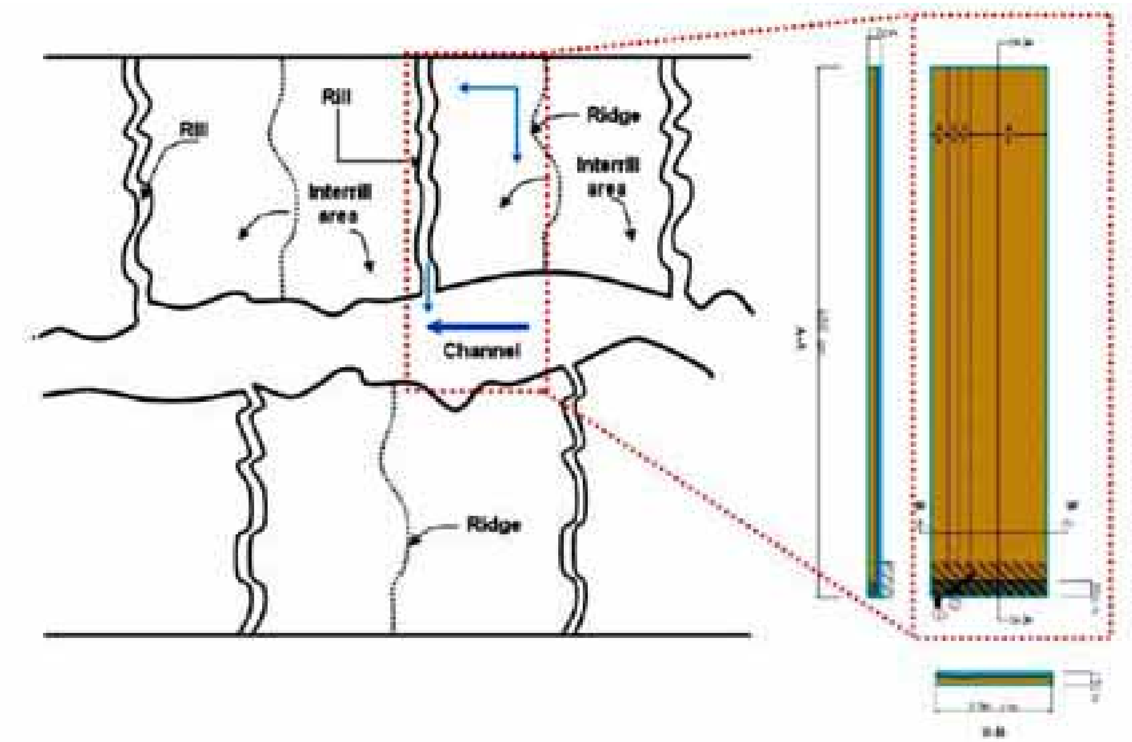
- To verify
  - physically based erosion and sediment transport model developed by Aksoy and Kavvas (2001)
  - coupled to a hillslope hydrological model from the overland flow equations by Yoon and Kavvas (2000)
  - using experimental data acquired from Aksoy *et al.* (2012).

METHODOLOGY

EXPERIMENTAL SETUP

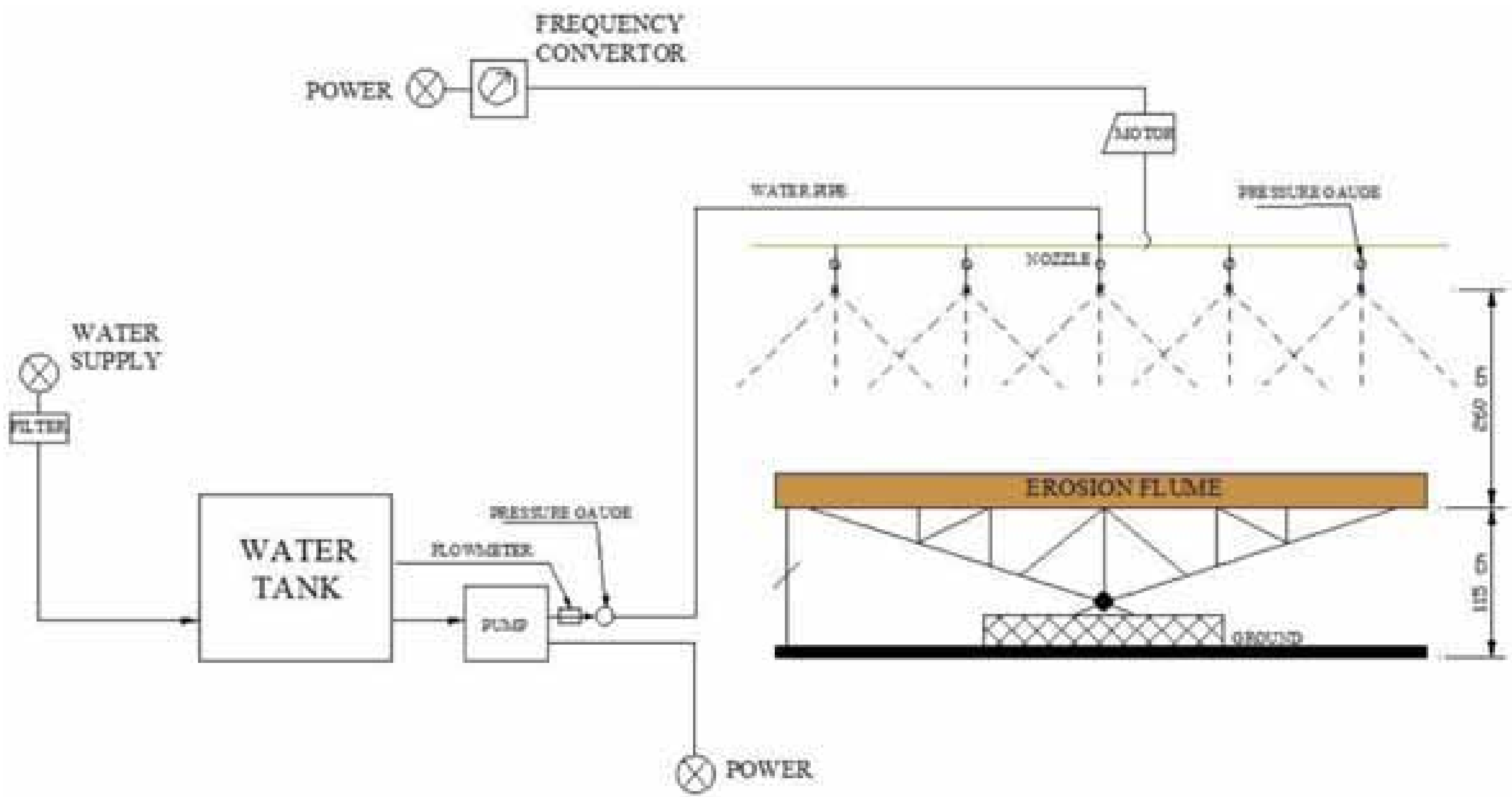
Schematic description of microtopography in a watershed and plan view of the erosion flume (Aksoy *et al.*, 2012)

- 136 cm wide x 650 cm long erosion flume with depth of 17 cm



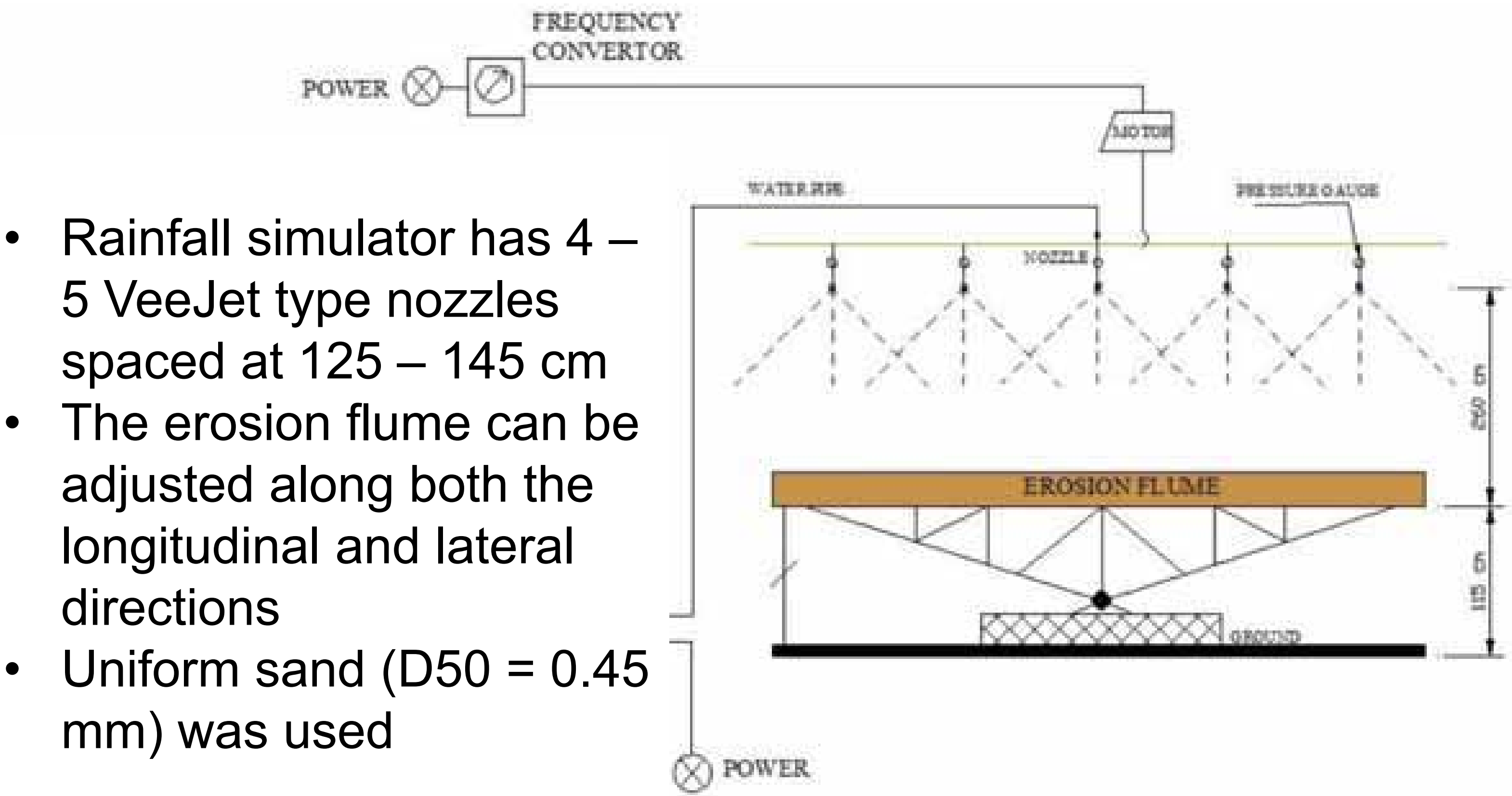
EXPERIMENTAL SETUP

Sketch of rainfall simulator and erosion flume (Aksoy *et al.*, 2012)



EXPERIMENTAL SETUP

Sketch of rainfall simulator and erosion flume (Aksoy *et al.*, 2012)



- Rainfall simulator has 4 – 5 VeeJet type nozzles spaced at 125 – 145 cm
- The erosion flume can be adjusted along both the longitudinal and lateral directions
- Uniform sand (D50 = 0.45 mm) was used

EXPERIMENTAL SETUP

- Rainfall intensities used were 105 mm/hr and 45 mm/hr and had a duration of 15 minutes for all tests
- The model was calibrated and validated using the experimental results from the setup of the flume having 10 per cent longitudinal and 5 per cent lateral slopes

MATHEMATICAL MODEL

- Erosion and Sediment Transport Equation for Interrill Area (Aksoy & Kavvas, 2001)

$$K_1 \frac{\partial}{\partial t}\left[h(x;t)C_s(x;t)\right] + K_2 \frac{\partial}{\partial x}\left[\left[h(x;t)\right]^{3/2} C_s(x;t)\right] = \frac{E(x;t)}{\rho_s} - K_3\left[\left[h(x;t)\right]^{3/2} C_s(x;t)\right]$$

$$K_1 = \frac{\pi^2}{8}$$

$$K_2 = 0.4577\left(\frac{\pi}{2}\right)^{5/2} C_x S_{o,x}^{1/2}$$

$$K_3 = \left(\frac{\pi}{2}\right)^{5/2} \frac{1}{l_y} C_y S_{o,y}^{1/2}$$

MATHEMATICAL MODEL

- The interrill area erosion term is the sum of the rainfall impact erosion and runoff erosion

$$E = \alpha R^{\beta} + \sigma\left(\eta\left(\gamma h S_o\right)^{\varepsilon} - \rho_s C_s q\right)$$

  - α and β are rainfall impact parameters with β set to 1 or 2
  - σ is the transfer rate coefficient
  - η and ε are dimensionless coefficient and exponent for transport capacity
  - γ is specific weight of water
  - h is flow depth
  - S_o is topographical slope
  - ρ_s is sediment density
  - C_s is volumetric sediment concentration
  - q is discharge

MATHEMATICAL MODEL

- Erosion and Sediment Transport Equation for Rill (Aksoy & Kavvas, 2001)

$$\frac{\partial}{\partial t}\left[A_R(h_R)C_{s,R}\right]+\frac{\partial}{\partial x}\left[Q_R(h_R)C_{s,R}\right]=\frac{1}{\rho_s}(E_R+q_{s,IR})$$

$$A_R(h_R)=b_R h_R$$

$$Q_R(h_R)=C_R\sqrt{S_R}\left[\frac{(b_R h_R)^3}{b_R+2h_R}\right]^{1/2}$$

MATHEMATICAL MODEL

- The rill erosion term is defined as

$$E_R(x,t) = \sigma\rho_s b\left[gS\frac{bh(x,t)}{b+2h(x,t)}\right]^{1/2} 0.635D\left[\delta(x,t) - 2.5\ln\left(1+0.4\delta(x,t)\right)\right]$$

$$-\sigma\rho_s 0.4577\left(\frac{\pi}{2}\right)^5 C_y\sqrt{S_{oy}}\,C_s(t)\left[h(t)\right]^{3/2}$$

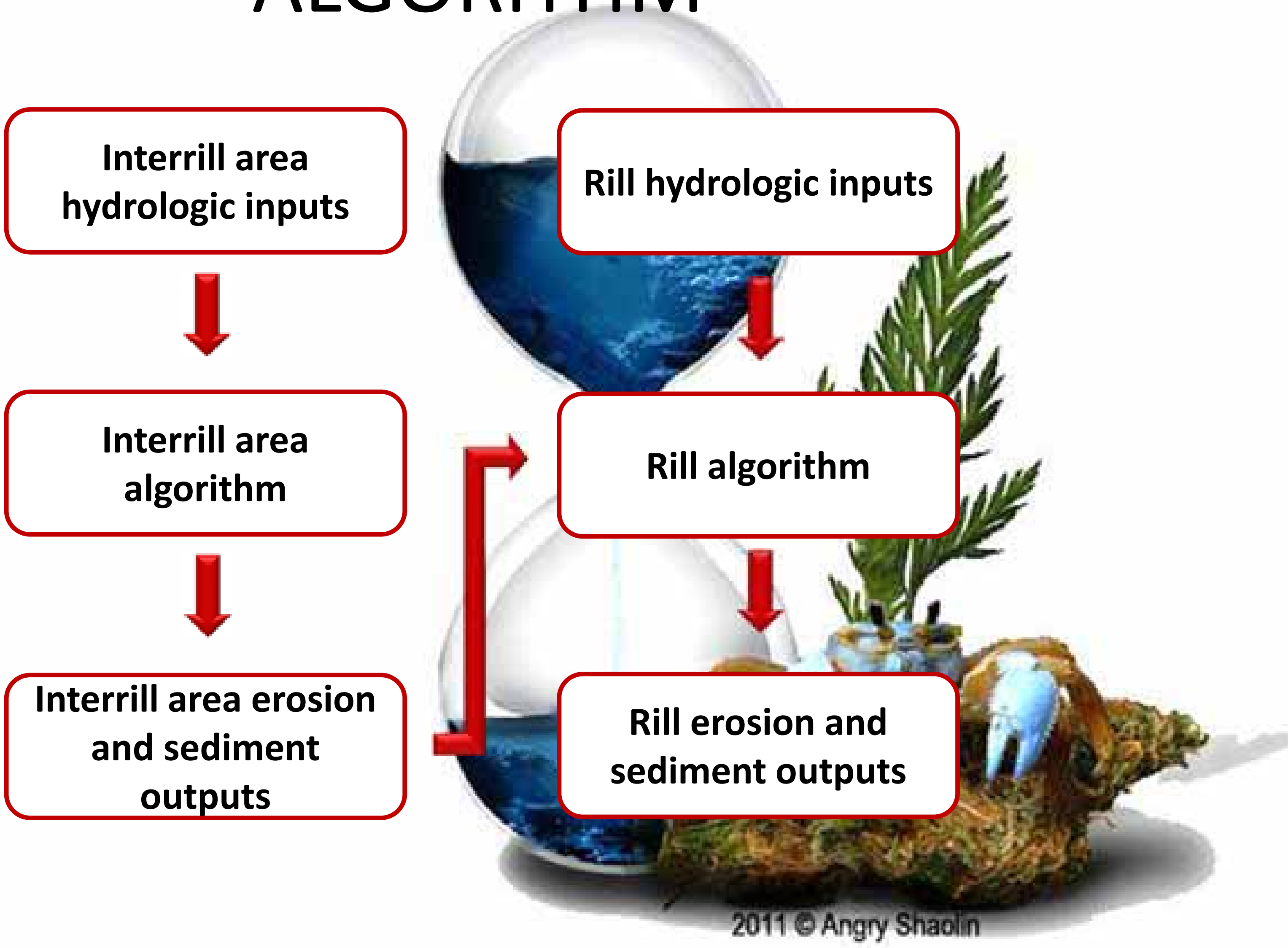
where

$$\delta(x,t) = \frac{\gamma}{\tau_c(\gamma-\gamma_s)}\frac{S}{D}\frac{bh(x,t)}{b+2h(x,t)} - 1$$

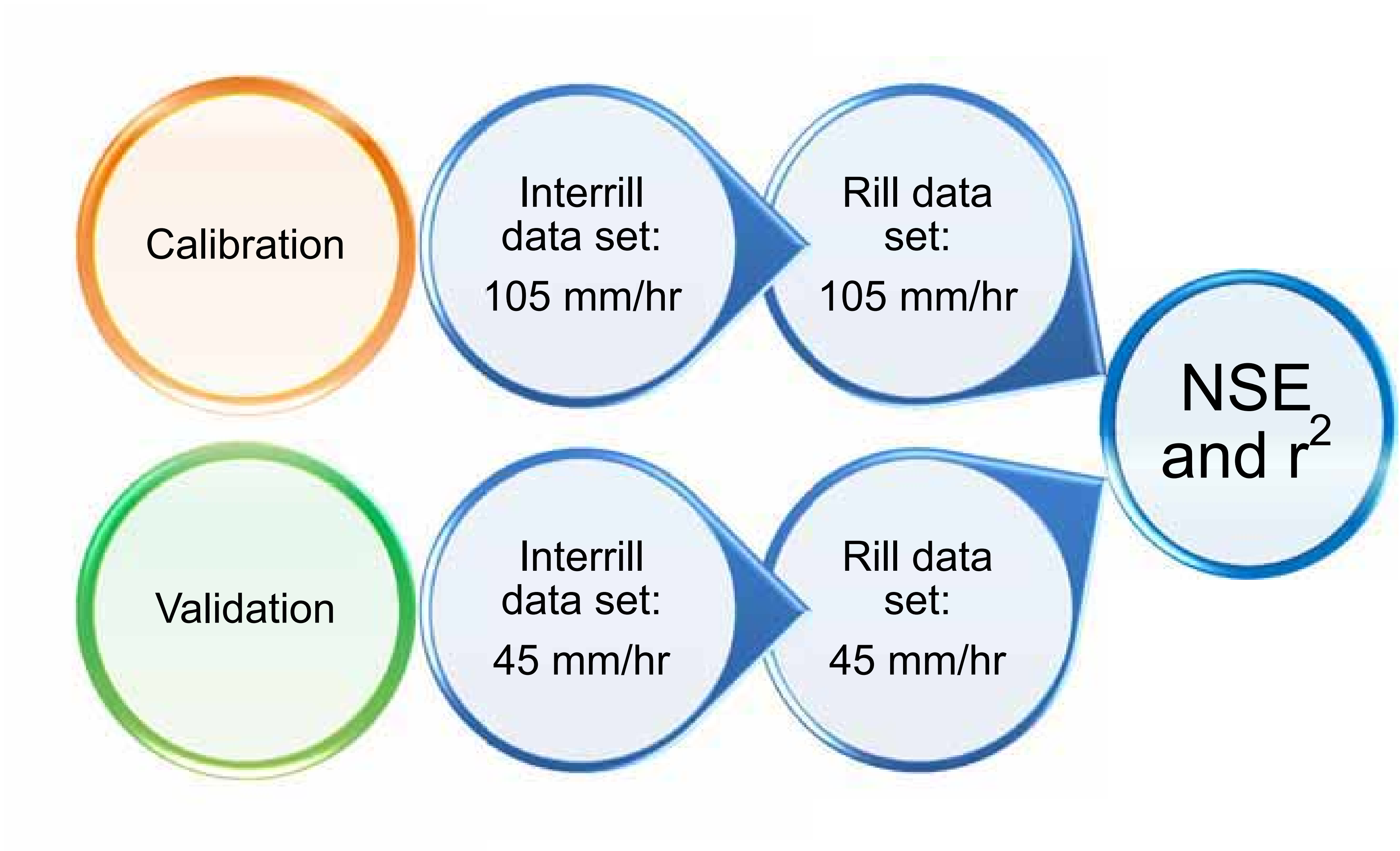
MATHEMATICAL MODEL

- σ is the rill transfer rate coefficient
- ρ_s is sediment density
- b is rill width
- S is slope along the rill
- D is sediment diameter
- C_s is volumetric sediment concentration
- Cy is Chezy coefficient
- τ_c is critical shear stress

STRUCTURE OF DEVELOPED ALGORITHM

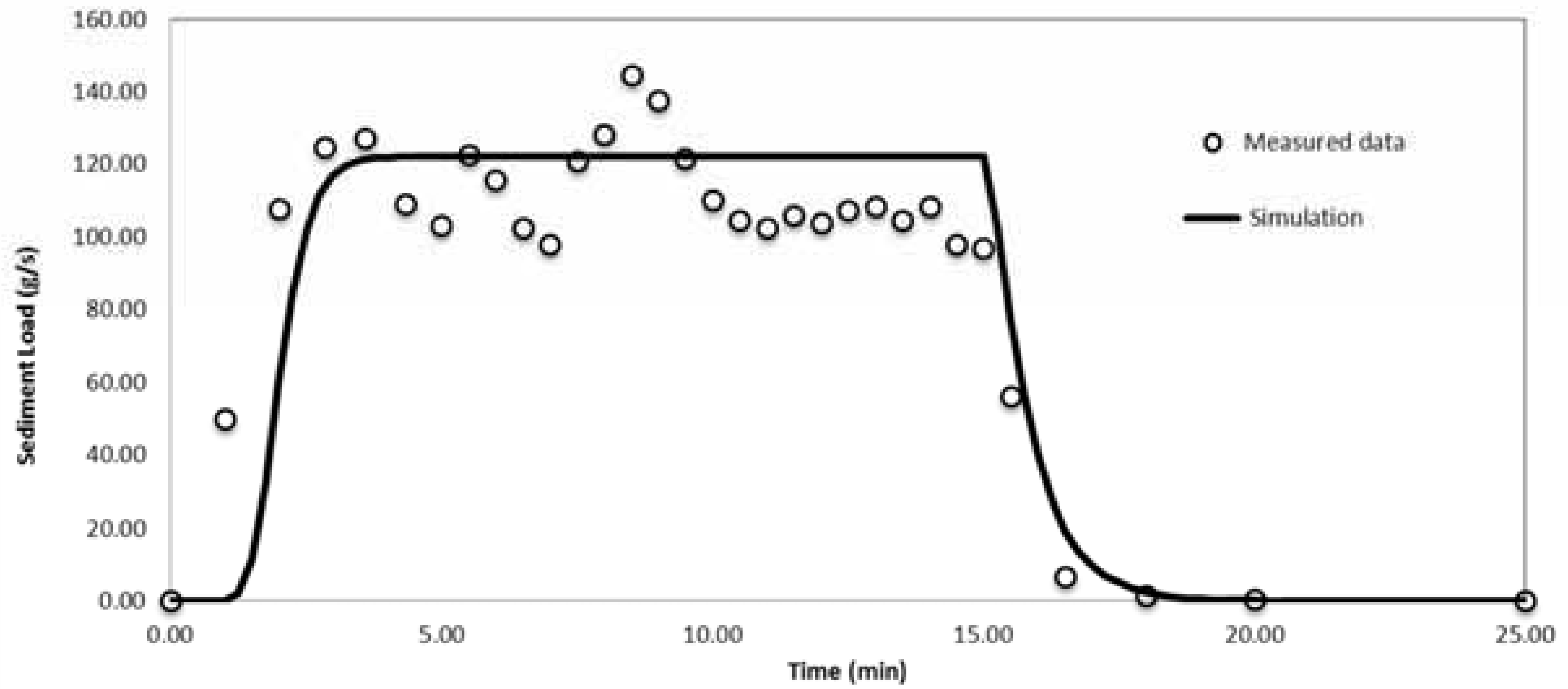


CALIBRATION & VALIDATION



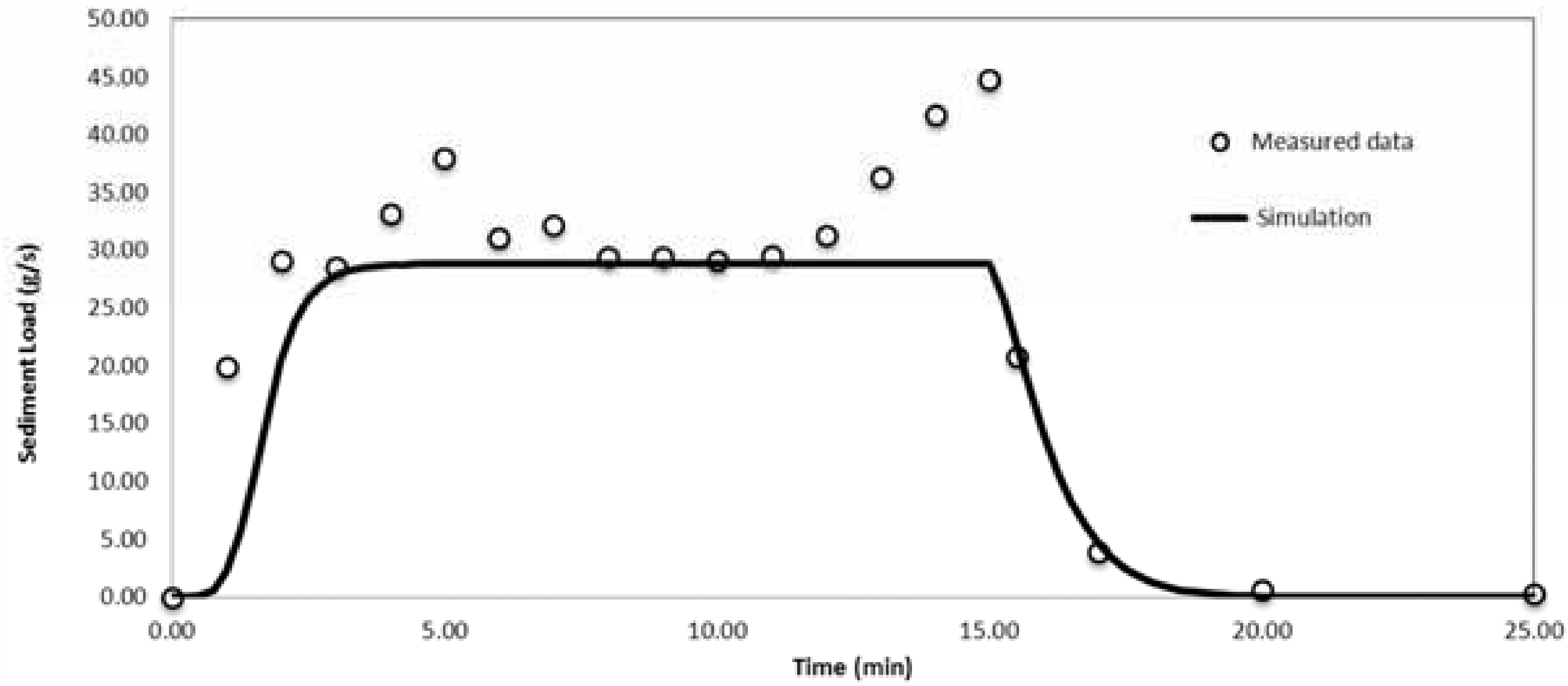
RESULTS

CALIBRATION (Interrill Area-Rill)



Intensity (mm/hr)	Interrill					Rill		r^2	NSE
	α (-)	β (-)	σ (m^{-1})	η (-)	ε (-)	$σ_r$ (m^{-1})	$τ_c$ (-)		
105	1.00	1.00	1.00	0.035	1.00	0.053	0.060	0.84	0.80

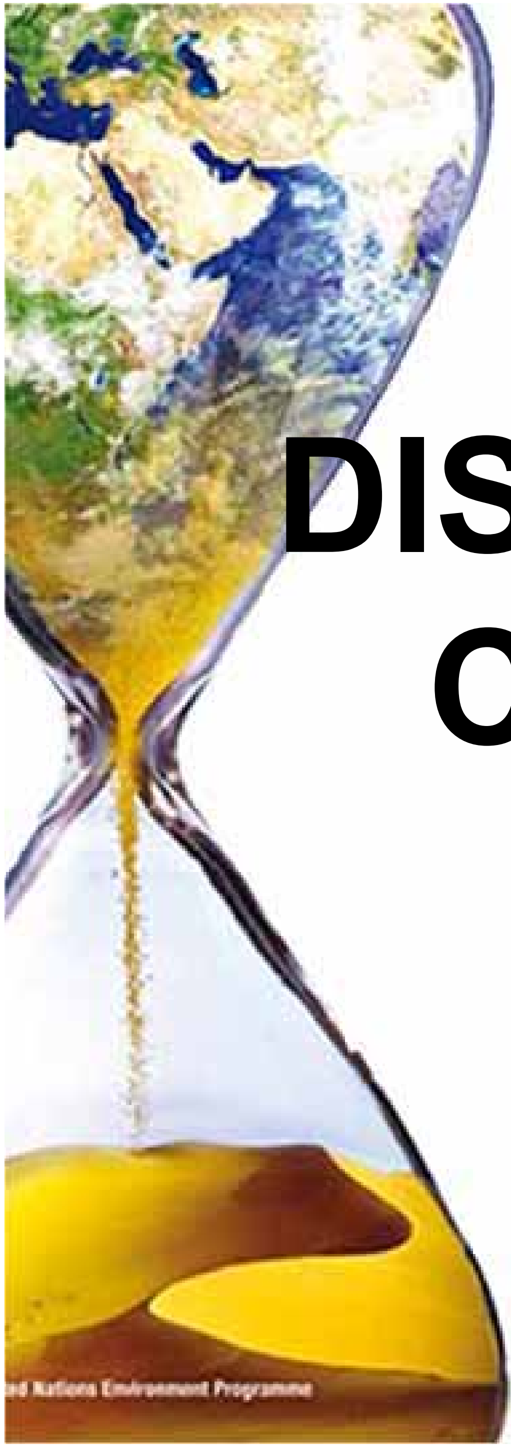
VALIDATION (Interrill Area-Rill)



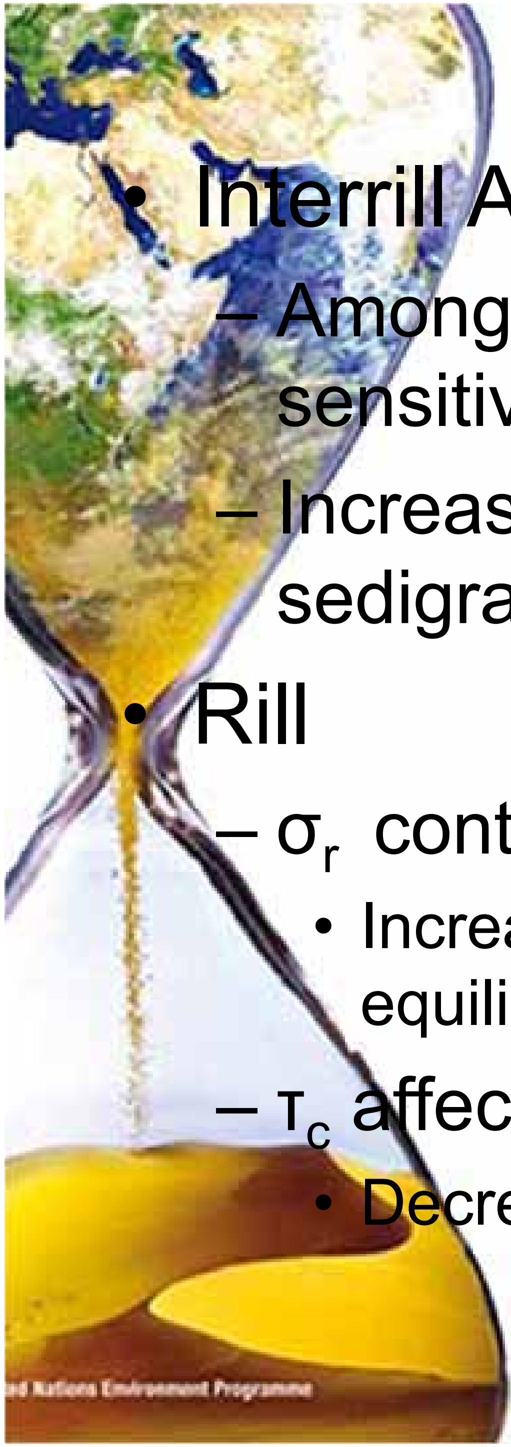
Intensity (mm/hr)	Interrill					Rill		r^2	NSE
	α (-)	β (-)	σ (m^{-1})	η (-)	ε (-)	σ_r (m^{-1})	τ_c (-)		
45	1.00	1.00	1.00	0.035	1.00	0.053	0.060	0.83	0.72

SUMMARY OF RESULTS

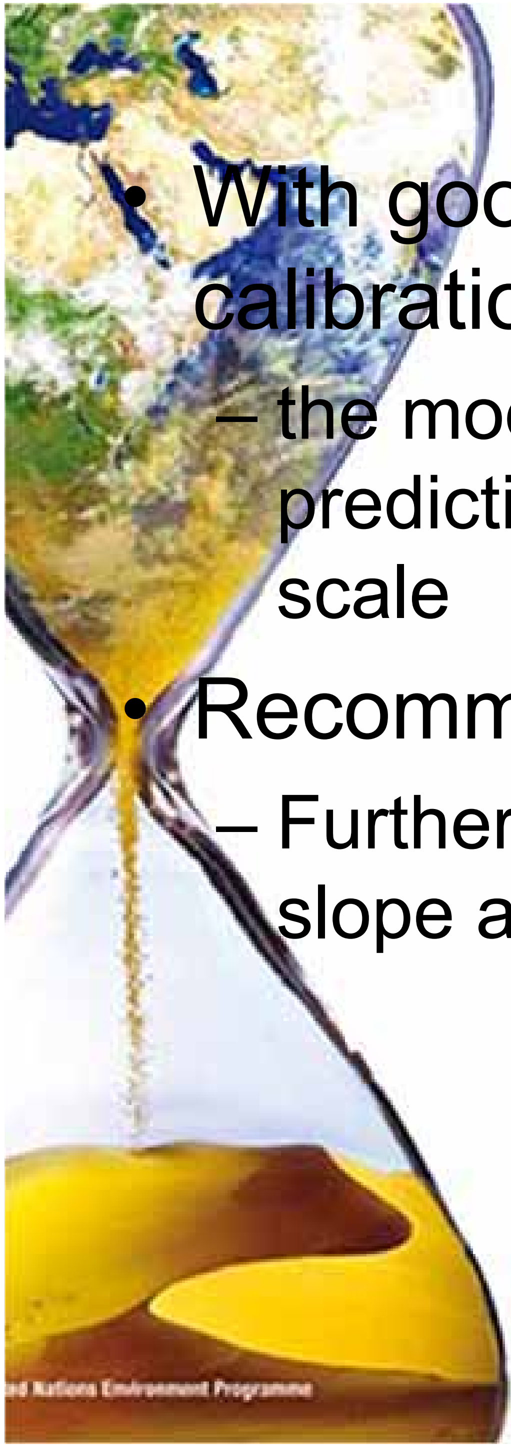
Intensity (mm/hr)	Interrill			Rill		r^2	NSE
	σ (m^{-1})	η (-)	ε (-)	σ_r (m^{-1})	τ_c (-)		
105	1.00	0.035	1.00	0.053	0.060	0.84	0.80
45	1.00	0.035	1.00	0.053	0.060	0.83	0.72



DISCUSSION AND CONCLUSION



- Interrill Area
  - Among the 5 calibration parameters, the most sensitive parameter was η
  - Increasing η also increased the peak of the sedigraph
- Rill
  - σ_r controlled the magnitude
    - Increasing its value makes sedigraph reach equilibrium faster
  - τ_c affected the peak of the sedigraph
    - Decreasing its value increased the peak



- With good statistical performance for both calibration and validation
  - the model is thought to be a promising tool for predicting sediment discharge at hillslope scale
- Recommendation for future studies
  - Further validation of the model with more slope and rainfall combinations

ACKNOWLEDGEMENT

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TÜBİTAK

한국학술진흥재단

국토해양부

Thank you!