Numeriek modelleren van effecten van sedimentconcentratie op stroming

Terug naar overzicht

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WLH Colloquium

"Numerieke oppervlaktewatermodellering, mogelijkheden en beperkingen"

(23-24 oktober 2003, Antwerpen)

Numerical modelling of sediment concentration effects on flow

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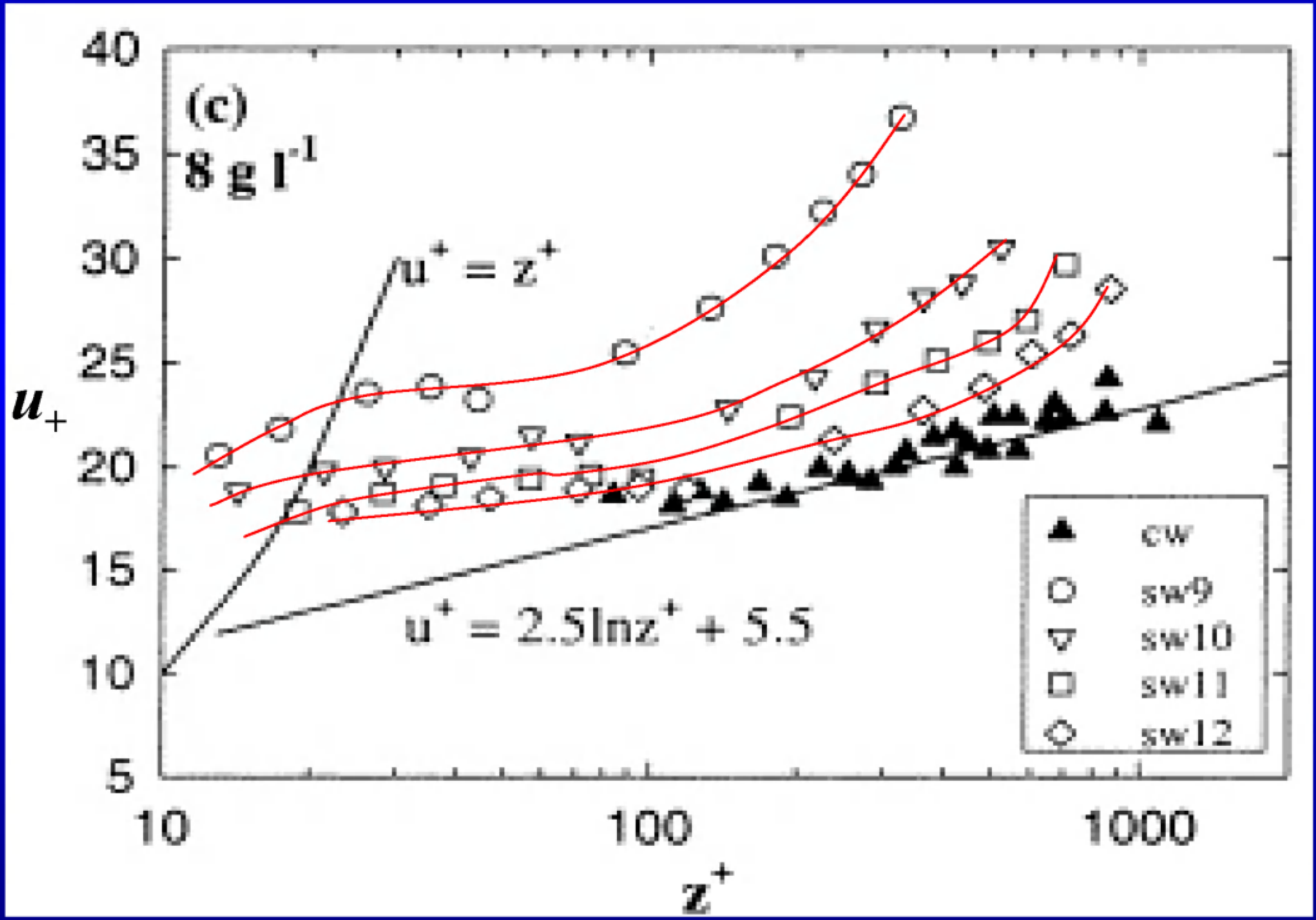
Experimental observations

- Mostly steady state flume experiments, i.e., fully-developed turbulent open-channel flow (e.g. *Vanoni* (1944), *Einstein & Chen* (1955), ...)
- Interpretation of results confusing for a long time (*until 80s*): ***some*** velocity profiles show significant deviations from standard logarithmic law
  - Increase/decrease of velocity: drag (bottom roughness) reduction/increase
  - Slope changed: decrease of von Karman "constant"

Example: drag reduction

Experiments *Li & Gust* (2000)



Insights from physics

- Fluid and particles do not move at same speed (*from experiments*).
- Small particles damp turbulence, larger ones increase turbulence production (*Gore & Crow*).
- Interactions between coherent structures in turbulence and particles can explain drag modification (*from experiments*).

Modelling in physics

- 2-phase approach
- Turbulence closure: DNS or LES

But ...

- Applications restricted to:
  - Very small scales
  - Low Reynolds number flow
  - Idealized particles (e.g. identical, spherical)
  - Low concentrations
- Many simplifications to reduce equation complexity (i.e., terms neglected), far from realistic engineering conditions

Modelling in engineering

- Large scale problems → historical development linked to computing capacity: *increasing capacity allows more complex models.*

- However, sediment transport models have evolved from single-phase hydrodynamic models, with little or no (empirical) corrections for sediment effects, assuming they are unimportant (low C) → **<u>incomplete models</u>**.

Justification of a better approach

- Important sediment-turbulence interactions for dense near-bottom layers observed in lab and field:
  - Drag reduction (e.g. Yellow River: $n < 0.010$)
  - Gravity currents (fluid mud flow, …)
  - Sheet flow
- Discrepancies between measured and modelled flow fields can be explained by flow-sediment interaction effects.

Engineering
Sedimen Transport Models
General lay-out

- Continuous-phase approach (validity: $\phi < 1\%$)
- Equations:
  - Suspension hydrodynamics
  - Moving boundaries (free surface)
  - Turbulence closure (vertical: k-ε, horizontal: simple LES)
  - Conservation/transport (advection-diffusion) of sediments, solutes, ...

Turbulence modulation (1)

- Assuming the mixing length modulation to be expressed as: $\ell = F_m \ell_0$
- The following can be proven theoretically:
  - Eddy viscosity in open-channel flow:

$$\nu_t = F_m \kappa_0 u_* z (1 - z/h) = F_m \nu_0$$

  - Velocity profile: $U = \frac{u_*}{\kappa_0} \ln\left(\frac{z}{\alpha z_0}\right)$

$\alpha\ (F_m)$ = friction correction factor

Turbulence modulation (2)

- Mixing (eddy diffusivity) modulation function:

$$K_s = F_s K_0 = F_s \frac{\nu_0}{\sigma_0} = \frac{\nu_t}{\sigma_t}$$

- Turbulent Schmidt number:

$$\sigma_t = \frac{\nu_t}{K_s} = \sigma_0 \frac{F_m}{F_s}$$

Consistent model

Where do sediment concentration effects appear in the model ?

- Turbulent Schmidt number appears in diffusion term of sediment transport eq. and buoyancy term of k-ε eqs.
- Corrected near-bottom boundary conditions for k-ε turbulence model and near-bottom velocity, in accordance with consistent PML model for the wall layer.

Required closures

- Turbulent Schmidt number (or modulation functions F_m and F_s):
  - Usually expressed as an empirical function of a Richardson number (*ratio of buoyancy to inertia effect*) → turns out to be insufficient
- Bottom roughness modification factor α:
  - A preliminary closure was found based on numerical experiments (*Toorman*, 2002)

- Hence, better closures still to be found

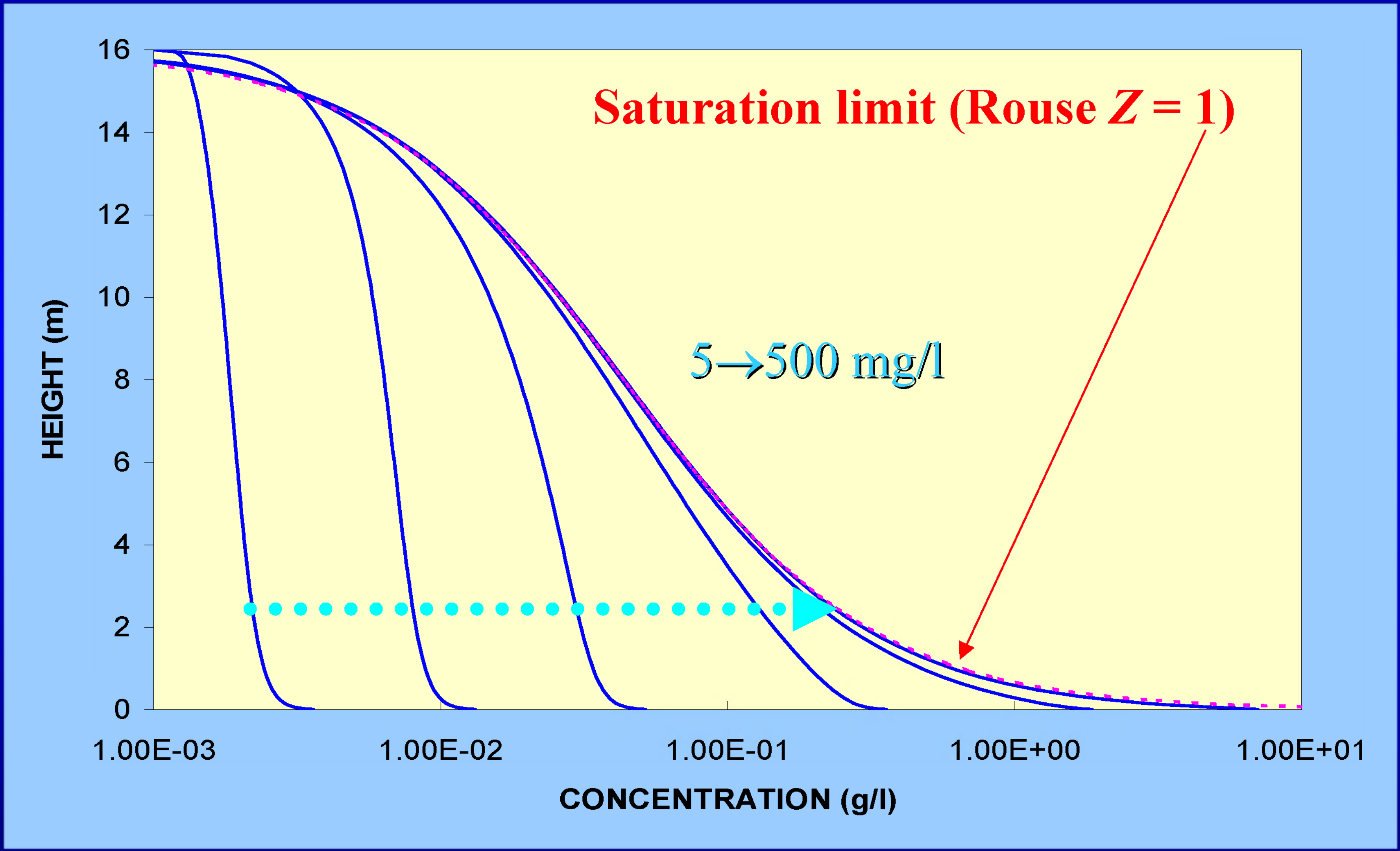
Numerical experiments

- Fully-developed turbulent open-channel flow driven by a constant pressure gradient, i.e., a fixed energy input:

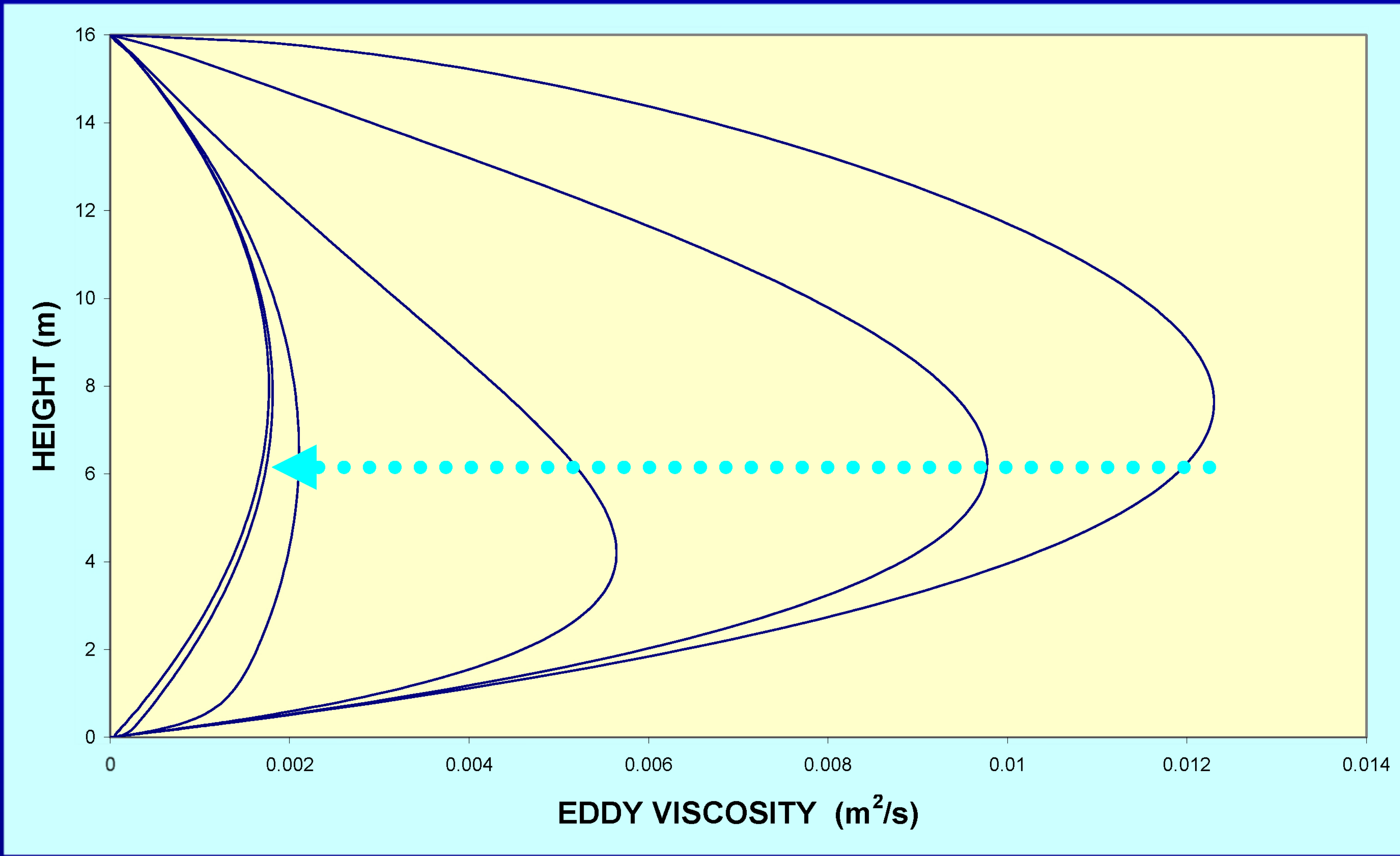
$$u_* = \sqrt{\frac{h}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x}}$$

- variation of u_*, w_s or *sediment load*
- Turbulence modulation: *Munk-Anderson* damping functions

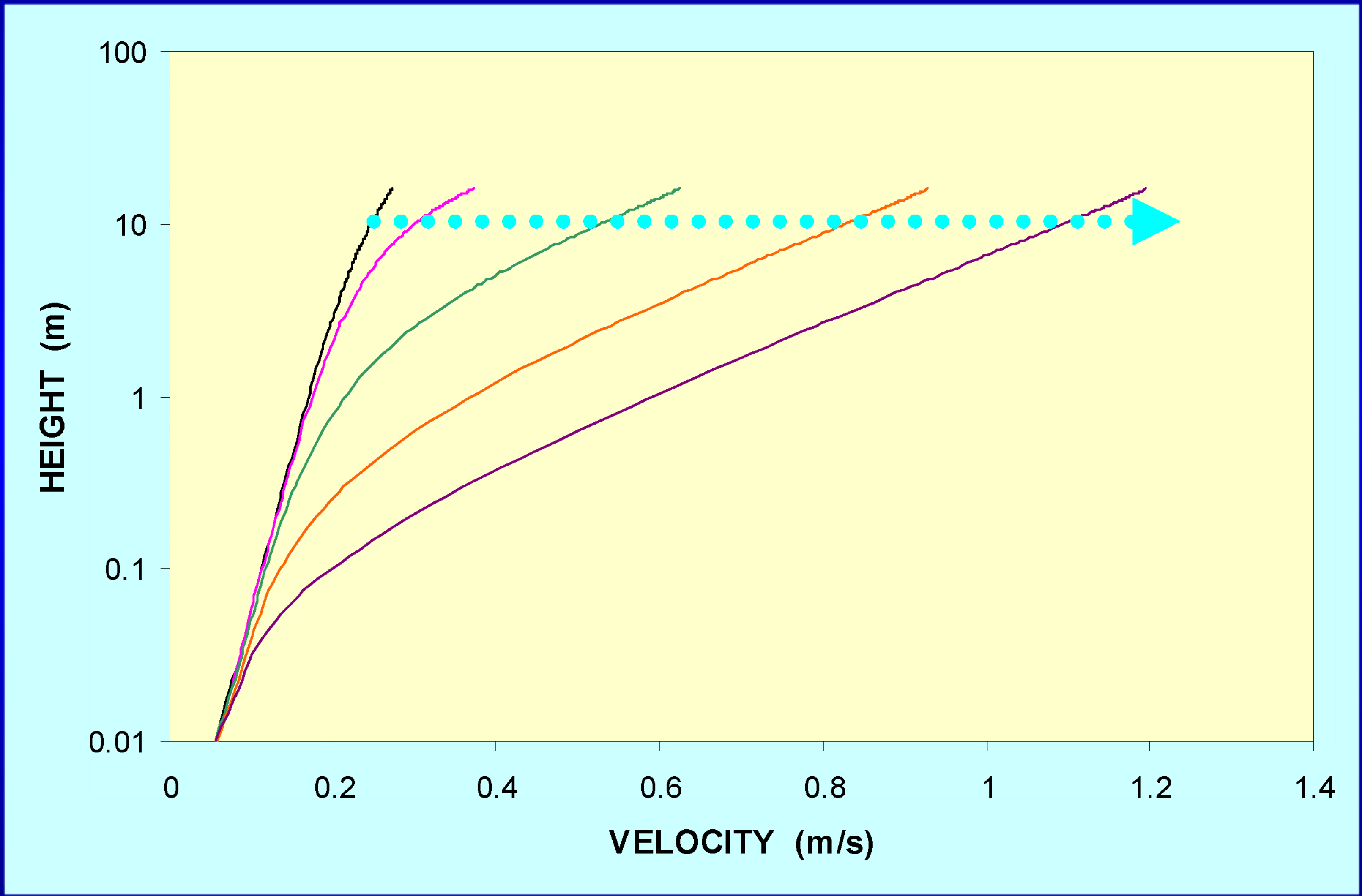
Sediment-laden open-channel flow



Sediment-laden open-channel flow



Sedimentladen open-channel flow

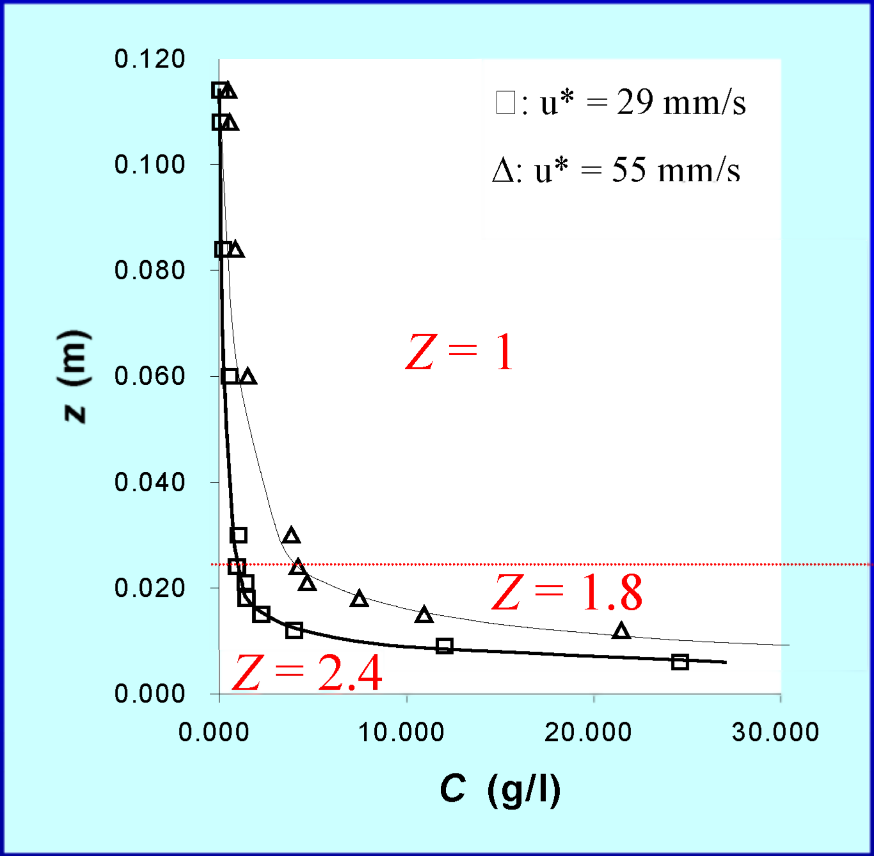


The saturation problem

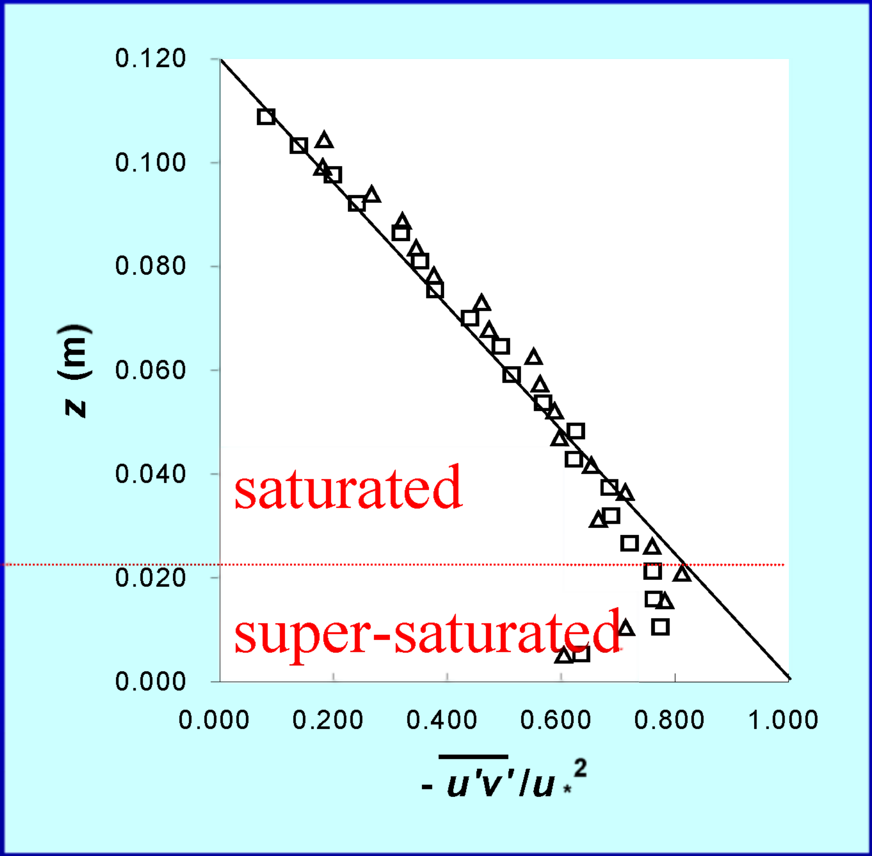
- Very high concentrations above the bottom destroy turbulence and increase the thickness of the laminar sublayer
- Particle-particle interactions ("4-way coupling") generate additional stress (turbulent grain shear stress)
- The model should account for this in the bottom boundary condition, or for low speed flow conditions (e.g. tidal reversal) where the laminar layer may become thick.

Experimental data

Concentration



Reynolds Stress



Flume data EPFL (*Cellino*, 1998) fine sand (d_{50} = 135 μm)

The spatial scale problem

- The various levels of scales (*grain size, viscous sublayer and super-saturated layer thickness, topographic scales, water depth*) cannot be captured at the same time by one type of model.
- For 3D engineering models this implies the need for a new, more detailed description of an equivalent roughness to account for sub-grid scale effects, including sediment induced drag modulation and topographic roughness.

Conclusions

- Sediment concentration effects on the turbulent water column can be modelled, provided that proper closures are found for the modulation functions.
- The super-saturated bottom-layer still requires further research.

Current/future research

- Study of the super-saturated layer
- Bottom roughness characterisation as a function of turbulence intensity and sediment concentration over flat and uneven bottoms
- LES data (VUB) as calibration data for KUL engineering model (FWO project)