Discussion of sensitivity analysis of non-equilibrium adaptation parameters for modeling mining-pit migration

Authors: Dong Chen, Acharya Kumud, Stone Mark

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Discussers: Ludovic Gouverneur, Benjamin Dewals, Pierre Archambeau, Sébastien Erpicum, Michel Pirotton

Affiliation of the discussers: research unit : Hydrology, Applied Hydrodynamics and Hydraulic Constructions, ArGEnCo department of the University of Liege, Belgium.

The authors examined the nonequilibrium adaptation length and adaptation coefficient for suspended load in a depth-averaged two-dimensional hydrodynamic and sediment transport model. This model was used in one-dimensional flow configurations. In particular, the DHL experiment was chosen as representative of suspended load dominated case. A sensitivity analysis was then conducted to estimate the influence of α, the adaptation coefficient for suspended load.

In the discussed paper, the adaptation coefficient values in Fig.3 were chosen arbitrarily, except α= 4.5 which results from Armanini and Di Silvio (1981) predictive formula. Furthermore, the parameter a was evaluated using $a=2d_{50}$, although, Armanini and Di Silvio (1981) originally assumed that a is equal to the Nikuradse’s roughness of the bed :

$$a = \frac{33h}{\exp\left[1+\left(\kappa C_{chézy}\right)/\sqrt{g}\right]} \tag{8}$$

with $C_{chézy}$ the Chézy roughness coefficient of the channel and κ the von Karman constant. This formulation is used in the discussers’ model.

In this discussion, the more recent Zhou and Lin (1995) as well as Guo and Jin (1999) formulae for the adaptation coefficient were tested in addition to the formula by Armanini and Di Silvio (1981). These three formulae are compared for two experiments. In addition, the necessity of using time and space dependent values of α is analyzed.

Numerical model

A 1D numerical model has been used to compute the flow and sediment transport as well as bed evolution. The model is based on the cross-sectional- and Reynolds-averaged Navier-Stokes equations for flow modeling, on an advection-diffusion equation for suspended sediments, and on the Exner equation for bedload transport and bed evolution.

Discretization of the equations relies on a 2nd order accurate finite volume scheme over a uniform one-dimensional grid. Time integration is performed using a two-step Rung-Kutta scheme, providing also 2nd order accuracy in time. The hydrodynamic computation is implemented using a pseudo-time stepping method which constitutes a particular case of the general method developed by Kerger et al. (2009).

The mathematical model, its discretization and implementation into a computational code were validated by comparison with experimental, numerical and analytical data.

Trench experiment

Due to some missing data in the original article concerning the trench experiment, a very similar experiment is studied here, for which complete modeling data are available. The considered experiment was carried out at Delft Hydraulics Laboratory (1980). The value of the parameters were the same as in the discussed article, except the settling velocity ω_S = 0.013 m/s and the trench depth h_{trench}= 0.15 m. The roughness height k_S and the inlet concentration C_0 were 0.025 m and 150 g/l, respectively.

The water depth h= 0.39 m was measured at the inlet of the channel. To satisfy this condition, the water depth at the outlet, which is the downstream boundary condition of the hydrodynamic model, was set to 0.372 m.

In Eq. (1), the sediment carrying capacity C_* plays a fundamental role. However, the authors do not mention how they calculate it. We use Wuhan (1959)'s formula which expresses C_* (kg/m^3) as:

$$C_* = k\left(\frac{U^3}{h\omega_s}\right)^m \tag{9}$$

where U is the mean flow velocity; ω_s is the particle settling velocity; $h$is the flow depth; k and m are coefficients. Guo & Jin (2001) established a relation for k using Bagnold (1966)'s formula as:

$$k = \frac{(\gamma\gamma_s)}{(\gamma_s - \gamma)} \frac{\left[(1-e_b)e_s\right]}{C^2_{ch\acute{e}zy}} \tag{10}$$

where γ and γ_s are the specific weight of clear water and sediment; e_b and e_s are the bed-load and suspended sediment transport efficiencies. Based on laboratory data, Bagnold (1966) suggested that $(1-e_b)e_s$= 0.01 for straight channel. The parameter m may be estimated from Eq. (9) if the equilibrium concentration is known somewhere in the channel. This formulation is incorporated in our model. The inlet concentration C_0 is considered to be at equilibrium. Thus, the equilibrium concentration formula can be calibrated. This results in k = 0.0098 and m = 0.835. Guo and Jin (2001) found the values k = 0.0097 and m = 0.84, which agree with the values calculated here. In Guo and Jin's formulation, the bottom layer relative height was set to 0.01.

The values of α have been predicted based on the three aforementionated formulae, using the flow characteristics in the middle of the trench.

As shown in Fig. 4, the morphological evolution of the trench computed based on Guo and Jin's formula reasonably matches measured data. The value obtained for α as well as the agreement with experimental results are consistent with Guo & Jin (2001) and Dewals (2006). In contrast, the values predicted by the formulae of Zhou and Lin (1995) as well as Armanini and Di Silvio (1981) fail to reproduce the morphological evolution of the trench.

In Guo and Jin's case, the discussers also compared predictions obtained assuming α constant and uniform with those considering α as time and space dependant. The three statistical parameters presented in the original article were calculated to evaluate their relative behavior : **Bias** = 5.28 10^{-4} cm, **RMS** = 1.39 10^{-6} cm and **AGD** = 1.00008036. Hence, the time and space variation of α are found not to lead to significant changes on the final results for the configuration considered here.

Net entrainment experiment

In Van Rijn (1981), a 30 m long and 0.5 m wide flume was used with initially clear water flowing over a sand bed. No sediments were supplied at the upstream end of the flume section. The sediments were entrained into suspension, tending towards the full transport capacity. The sediment concentrations were measured in steady uniform flow conditions.

The flow depth was 0.25 m, while the average flow velocity was 0.67 m/s. The bed material was characterized by d_{50}= 230 µm. The sediment fall velocity and the roughness height were evaluated at 0.022 m/s and 0.01 m, respectively.

Water samples were collected simultaneously at four locations to determine the spatial distribution of the sediment concentrations. At each location four water samples were taken over the depth. We have integrated these measured concentrations to obtain the depth-averaged concentrations.

In the simulation, a zero-concentration profile was specified at the inlet boundary to simulate the clear-water inflow. C_* was set to the value measured at the downstream end of the channel which results in C_*= 310 mg/L.

The influence of the adaptation parameter α on the adapatation rate is shown in Fig. 5: the larger the value of α, the shorter the adaptation length. It can also be observed that Armanini & Di-Silivio's and Zhou & Lin's formulations lead to most satisfactory results and are once more very close to each other.

Since the bed level and the hydrodynamic conditions remain almost uniform and constant, α is neither time nor space dependant in this particular case.

Summary and conclusion

Three predictive formulae for α were compared in two configurations. Armanini & Di Silvio and Zhou & Lin's formulations have shown a similar behavior. They were accurate to simulate the net entrainment experiment. Their predictive power (no calibration) makes them very powerful for such situations. Guo & Jin's formula has proved to perform well in the moving trench experiment.

Using a constant value for α is a current practice in sediment transport modeling. This assumption is valid for the net entrainment experiment. Indeed, in these particular cases the flow conditions are constant, spatially and temporally. This assumption is theoretically non valid in the moving trench experiment. The sensitivity of the sediment transport process to these spatial and temporal variations was examined. Nonetheless, no significant changes were observed with respect to the final bed elevation. It is concluded that the assumption of a constant value for α is justified when flow perturbations remain moderate.

References

Armanini, A., & Di Silvio, G. (1981). A one-dimensional model for the transport of a sediment mixture in non-equilibrium conditions. *Journal of Hydraulic Res. , 26* (3), 275-292.

Bagnold, R. (1966). An Approach to the Sediment Transport Problem From General Physics. *U.S. General Survey* .

Delft Hydraulics Laboratory. (1980). *Computation of Siltation in Dredged Trench.*

Dewals, B. (2006). *Une approche unifiée pour la modélisation d'écoulement à surface libre, de leur effet érosif sur une structure et de leur interaction avec divers constituants. PhD Thesis, University of Liège.*

Di Sivio, G., & Armanini, A. (1981). Influence of the upstream boundary conditions of the erosion-deposition processes in open channel. *XIX IAHR Congress*. New Delhi, India.

Engineering, W. U. (1959). Investigation on sediment-carrying capacity in the middle stream of Yangtz River. *Journal of Sediment Research , 4* (2), pp. 54-73.

Guo, Q.-C., & Jin, Y. (1999). Estimanting the adjustement coefficient used in nonequilibrium sediment transport modelling. *Proc. Annual Conf. Canadian Society for Civil Engineering, II*, pp. 217-226.

Guo, Q.-C., & Jin, Y.-C. (2001). Estimating Coefficients in one-dimensional depth-average sediment transport model. *Canadian Journal of Civil Engineering* (28), pp. 536-540.

Kerger, F., Archambeau, P., Erpicum, S., Dewals, B. J., & Pirotton, M. (2009). A fast universal solver for 1D continuous and discontinuous steady flows in rivers and pipes. *International journal for numerical methods in fluids* .

van Rijn, L. (1981). The development of concentration profiles in a steady, uniform flow without initial sediment sediment load. *IAHR Workshop on particle motion and sediment transport.* Rapperswil,Switzerland.

Zhou, J., & Lin, B. (1995). 2-D Mathematical model for suspended sediment-Part I: Model theory and validations. *Journal of Basic Science and Engineering* , pp. 78-79.

Figure

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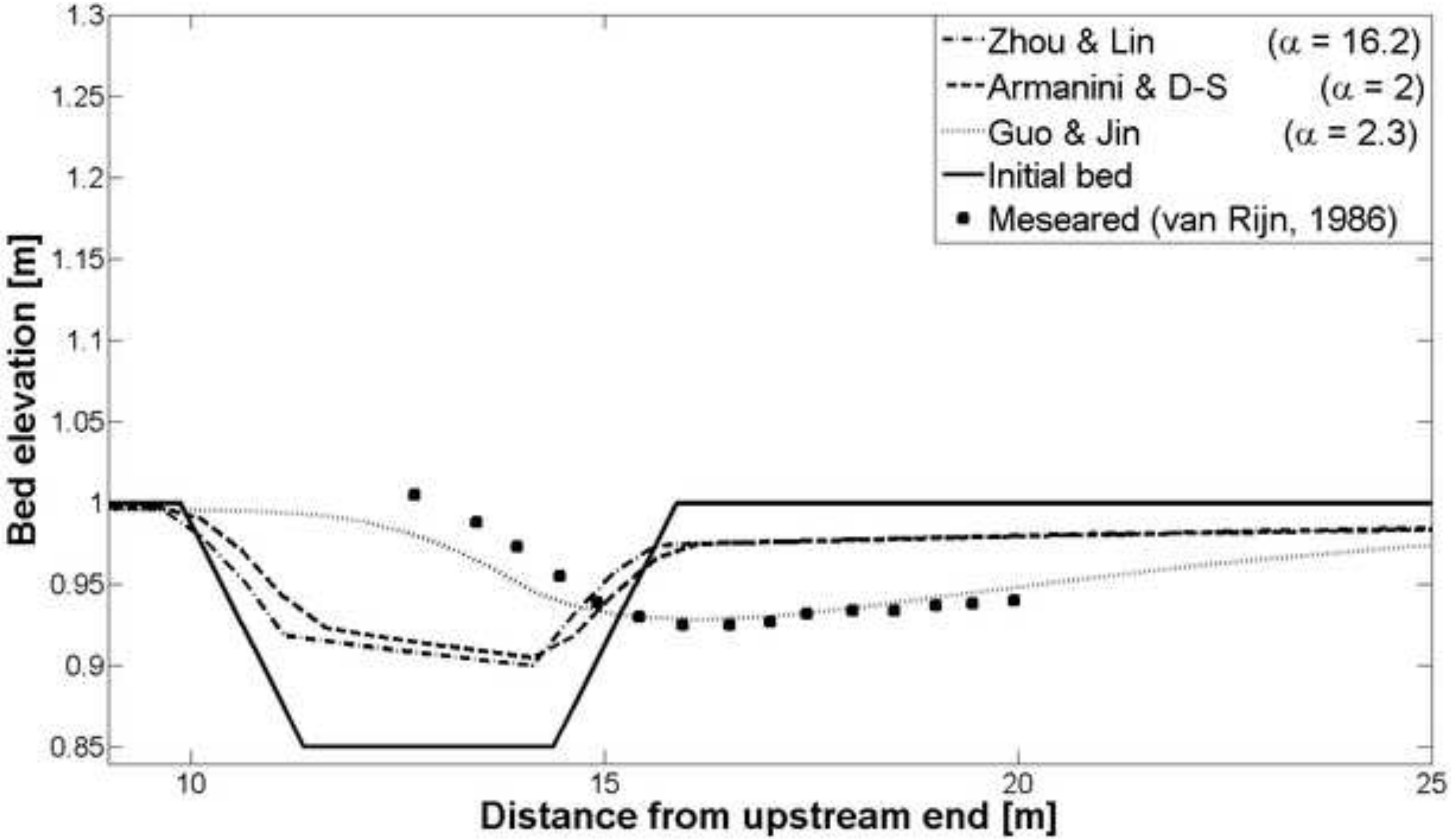

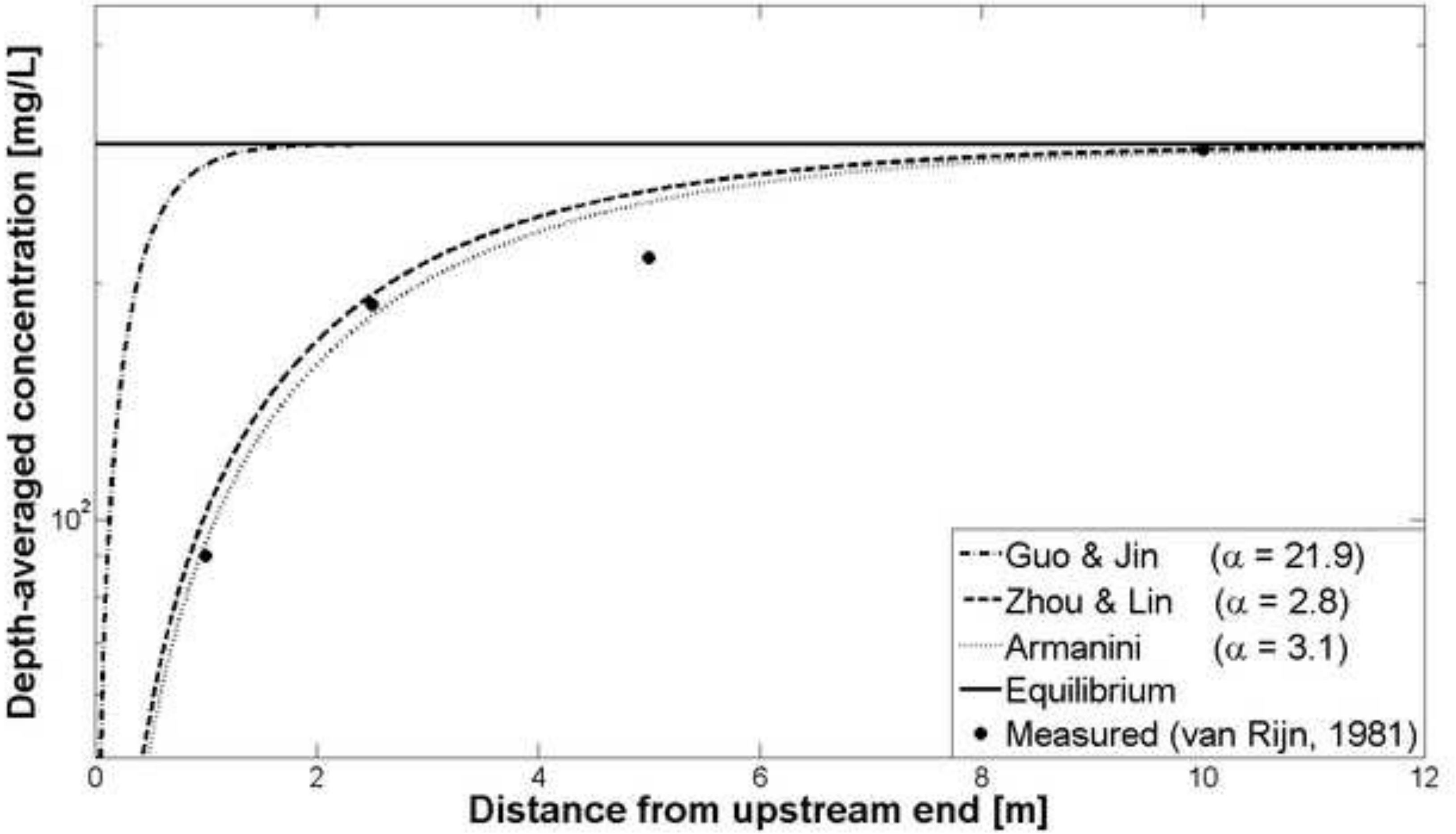
Depth-averaged concentration [mg/L]
10^2
0
2
4
6
8
10
12
Distance from upstream end [m]
Guo & Jin (α = 21.9)
Zhou & Lin (α = 2.8)
Armanini (α = 3.1)
Equilibrium
● Measured (van Rijn, 1981)

Figure Caption List

Fig. 4: Comparison of computed and measured bed elevations computed in DHL (1980) experiment

Fig. 5: Comparison of computed and measured concentrations in Van Rijn (1981) experiment