City University of New York (CUNY)
CUNY Academic Works

International Conference on Hydroinformatics

2014

# Calibration Strategies Designed For Long Term Sediment Transport Modelling

Robert Klar

Stefan Achleitner

Stefan Jocham

Markus Aufleger

How does access to this work benefit you? Let us know!

More information about this work at: https://academicworks.cuny.edu/cc_conf_hic/272
Discover additional works at: https://academicworks.cuny.edu

This work is made publicly available by the City University of New York (CUNY).
Contact: AcademicWorks@cuny.edu

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

# CALIBRATION STRATEGIES DESIGNED FOR LONG TERM SEDIMENT TRANSPORT MODELLING

R. KLAR (1), S. ACHLEITNER (1), S. JOCHAM (1), M. AUFLEGER (1)
*(1): Unit of Hydraulic Engineering, Institute for Infrastructure Engineering, Department of Civil Engineering Sciences, University of Innsbruck, Technikerstraße 13a, A-6020 Innsbruck, Austria*

The presented work deals with the calibration of a 2D numerical model for the simulation of long term bed load transport. A settled basin along an alpine stream was used as a case study. The focus is to parameterize the used multi-fraction three-layer sediment transport model such that a dynamically balanced behavior regarding erosion and deposition is reached. Due to high computational demands, the type of calibration strategy is not only crucial for the result, but as well for the time required for calibration. Brute force methods such as Monte Carlo type methods may require a too large number of model runs.
All here tested calibration strategies are based on multiple model runs using the parameterization and/or results from previous runs. One concept was to reset to initial bed elevations after each run, allowing the resorting process to convert to stable conditions. As an alternative or in combination, the roughness was adapted, based on resulting nodal grading curves from previous runs. Additionally, a systematic variation was done, considering results from previous runs and the interaction between river sections. This approach can be considered as similar to evolutionary type calibration approaches, but using analytical links instead of random parameter changes.

## INTRODUCTION

The work presented is part of a project, aiming to realize long term simulation of bed load transport in an alpine basin. Therefore a 2D hydro-morpho-dynamic numerical model is used to cover the main reach, the Ötztaler Ache, within the 890 km$^2$ catchment. Due to large simulation times, the calibration strategy is important and requires to be structured and target oriented. Besides the reliable assessment of hydraulic and bed load inputs from upstream and the lateral tributaries, the setting of initial conditions of the bed load material is found crucial. Field investigations, especially carried out in the upstream parts, addressed the upper and the sub surface layer in the mainstream. Results from line-by-number analysis at different locations along the stream together with two local excavations and subsequent sieve analysis allow an estimate of the grainsize distribution at site. Although the field investigations made in the catchment are above the average, starting conditions of in-stream grain size distributions cannot be established fully. Considering that the river is in a dynamic equilibrium, the current state of the bed material (roughness, grainsize distribution, etc.) is the result of past bed forming events. Still this is hardly assessable in a sufficient spatial resolution. Postulating that, the used model enables the simulation of the dynamics of bed elevations sufficiently, the model itself can be used with any starting conditions and should finally converge to stable conditions. Limiting factor in practice are again the very long simulation periods when dealing with several years of simulation horizon. Thus, to limit warm up periods for the model and to avoid unrealistic calibration efforts (in terms of simulation times), the starting conditions used should be already realistic and resilient.

In the following, different strategies to “calibrate“ the models´ initial conditions are tested regarding their practicability, robustness and ability to converge to a stable parameter setup.

## METHODS

### Numerical model

Hydro_GS-2D (Nujic [1]) was applied for all numerical simulations. The software is a two dimensional Finite Volume code to solve the shallow water equations. A three layer multi fraction approach is used to describe morphological changes and bed-load transport. Mass balance is calculated between a top mixing layer, an intermediate subsurface layer and a bottom layer. The grain size distributions in the mixing and subsurface layers are determined according to Hirano [2]. Bed load transport is calculated with a multi fraction application of the Meyer-Peter & Müller equation [3] coupled with a hiding function as introduced by Hunziker [4] and Hunziker et al. [5].

### Stable initial conditions - Concept of Calibration

The strategies described in the following are not to be seen as a classical calibration procedure where simulation results are tested against measured conditions. The goal is namely to obtain initial conditions of the model that represent conditions of a dynamic equilibrium. Since a river stretch faces varying conditions for inflows (water and sediment) and varying bed conditions (geometry and grain size distribution), there cannot be a single setup be named representing the only setup for initial conditions. Still, for starting long term simulations, it was found that having conditions out of the typical bounds can lead to a destabilization of the model. Exorbitant depositions or erosions can be the case which cannot be handled by adapting model parameters during the simulation.

The goal is to obtain a set of mean parameters which can be found in a period of dynamic equilibrium as observed in past years. The basic concept is to run short term simulations (one or more weeks) with hydro- and sedigraphs covering a typical discharge level.

No or little changes in bed elevation are expected in case the initial conditions are well set. In all other cases, the elevation and grain size distribution is altered by the model towards equilibrium conditions. Assuming that especially the grain size distribution in the considered section has improved, the geometry is set back to the original, the roughness may be adapted based on resulting nodal grading curves and the simulation period is re-run. In case the strategy works, the bed conditions improve after each time re-running the model. Figure 1 shows the principle sketch for the re-running process. The re-running of the Hydro_GS-2D calculations, the analysis of the results and the parameter adaptions are done in an automatic way by using software tools developed to speedup calculation time (Klar et al [6]) and to perform roughness adaption (Klar et al. [7]).

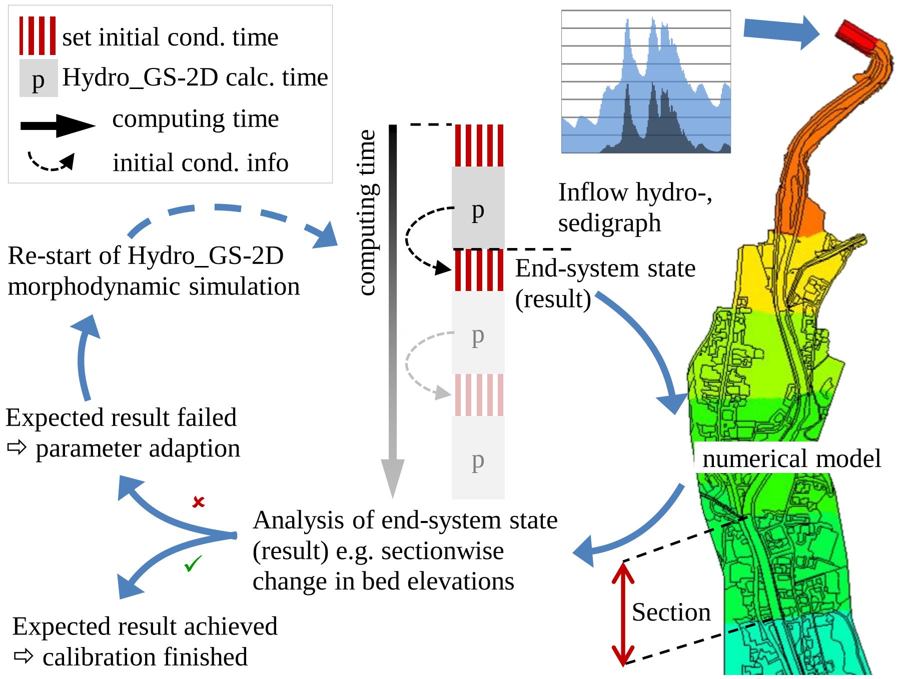

Figure 1. Principle sketch for re-running the model

Following this basic concept, three different types (variations) of the calibration concept are tested. Altered bed material influences not only its own mobility but changes as well the associated roughness and resulting drag forces. Consequently this allows different options in the procedure, which can be categorized as followed:

*Method 01 - base method*

The baseline method adapts the bed elevation after each simulation cycle and enforces the original bed elevations after each run. The resorting processes are enabled since the grain size distributions are preserved from the previous simulation. Spatial transfer is made nodewise.

*Method 02 - grain based roughness adaption*

Essentially, the method follows the base method (01). To smoothen the changes, mean grain size distributions are calculated after each simulation cycle for bed sections. A section is defined as being homogeneous regarding bed width, average slope, initial grain size distribution and bed roughness conditions. Thereby the sections' resulting characteristic grain size of the top mixing layer $d_{i,m}$ is calculated by averaging their varying nodal characteristic grain sizes $d_i$ (e.g. $d_{90}$). On that basis the new sections' skin friction coefficients $k_{St,skin}$ are calculated for the re-runs. These new sections' skin roughness coefficients are then assigned as Hydro_GS-2D model material parameters as initial conditions for the next re-run. In this work, the adaption of the sections' roughness is done explicitly by using an equation of Wong and Parker [8]. Wong and Parker reanalyzed the Meyer-Peter and Mueller [3] data and suggested to express the roughness coefficient associated with skin friction $k_{St,skin}$ as:

$$k_{St,skin}=23,2 \cdot d_{90,m}^{-1/6} \tag{1}$$

Finally grain size distributions for the whole river bed are generated and used as initial system state for the re-runs. To eliminate local adverse effects (e.g. fast developing erosion, etc.) adaptations are made again section wise.

*Method 03 - Roughness adaption based on aggradation trends*

Again the concept of re-running simulations followed by the reset of elevations is used. Other than in method 02, the roughness is adapted in user defined (fixed) steps of $\Delta\mu$ within a section. The previous run is evaluated for its changes of elevation (volume changes). In case of dominant aggradation, the skin friction coefficient $k_{St,skin}$ is to be lowered as a consequence. Therefore $\mu$ is increased by $\Delta\mu$ to obtain an increased transport in the next simulation run. $\mu$ is the Ripple factor considering the influence of the skin friction on the total roughness and defined as follows:

$$\mu = \left(\frac{k_{St,total}}{k_{St,skin}}\right)^{1.5} \qquad (2)$$

The Ripple factor $\mu$ directly influences the transport capacity by multiplying the dimensionless effective shear stress $\theta$ as shown in the following equation:

$$\Phi_b = SCF \cdot \sum F_i \cdot 8 \cdot \left(\varphi_i \cdot \left(\mu \cdot \theta - \theta_{cms}\right)\right)^{1.5} \qquad (3)$$

where $\Phi_b$ is the calculated transport capacity, SCF is a prefactor amplifying or mitigating transport capacity (ranging between 0.625 and 1), $\varphi_i$ is a compensation factor handling selective transport of different grain sizes, $\theta_{cms}$ is the dimensionless critical shear stress for entrainment. Finally, $k_{St,skin}$ can be regarded as a function of $\mu$ considering the earlier model run (n-1):

$$k_{St,skin} = f(\mu_{n-1} + \Delta\mu) \qquad (4)$$

In this work, $\mu$ is kept in the range between 0.4 and 1. If equilibrium state cannot be reached in the defined range of $\mu$ while $k_{St,total}$ is kept constant and $k_{St,skin}$ is adjusted, both roughness coefficients are changed and $\mu$ is kept constant. $k_{St,total}$ changes influences hydraulic conditions whereas $k_{St,skin}$ exclusively determines the sediment transport.

## STUDY CASE

### Model description

In order to test the calibration strategies, a detailed 2D-numerical model of an about 2000 m long stretch of the Gurgler Ache is used (see Figure 1). The mesh consists of approximately 7900 elements and 7700 nodes and is part of a large research project dealing with the long term morphodynamic evolution of the Ötztaler Ache, the main river of an alpine catchment in Tyrol (Austria) and its tributaries.

The study area provides gradients varying from 1.2 to 3.5 % with an average slope of 2.5 %. At that location the mean discharge MQ is determined to 5.6 $m^3/s$. Five bed load relevant tributaries discharge into the model area. The river bed is structured into 16 sections with similar bed slope, channel width, bed grading curves and initial roughness coefficients (total roughness values $k_{St,total}$ ranging from 10 to 28 $m^{1/3}/s$). As test scenario a representative time period of one week in the year 2008 was selected and simulated. Figure 2 shows the hydrographs and sedigraphs for the total input from upstream and the tributaries and the average inflow mean grain size diameter $d_m$.

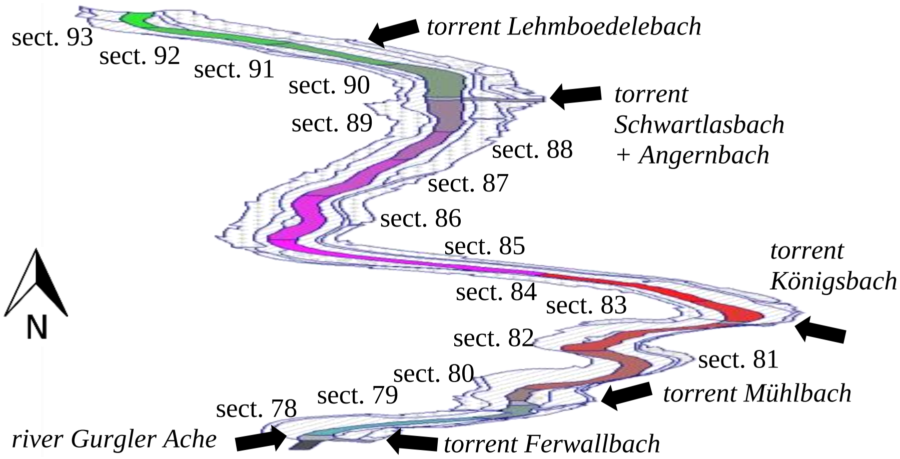


Figure 1. Model area with sections and tributary torrents (perspective view)

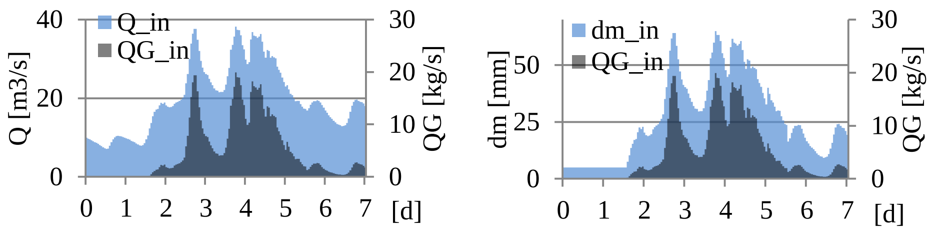


Figure 2. Hydrograph, sedigraph, inflow mean grain size diameter $d_m$ over time

**RESULTS**

Figure 3 shows accumulated volume changes along the longitudinal section. The first Hydro_GS-2D run (no calibration) results in aggradation of the inflowing sediment load in the upper sections. In the middle sections erosion takes place while the lower sections stay relatively stable. Method 01 and 02 result nearly continuously in aggradation along the longitudinal section after 20 re-runs. Method 03 ensures dynamic equilibrium without aggradation in the upper sections. In the middle part erosion is observed which is settled in the lower sections.

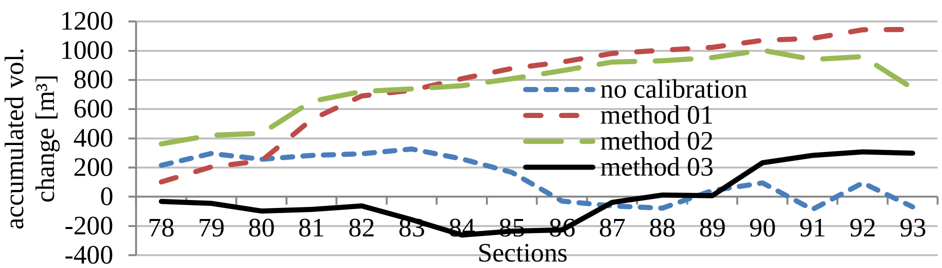


Figure 3. Accumulated volume change (longitudinal section) for the calibration strategies

In Figure 4 the absolute volume change rates for each section are shown.

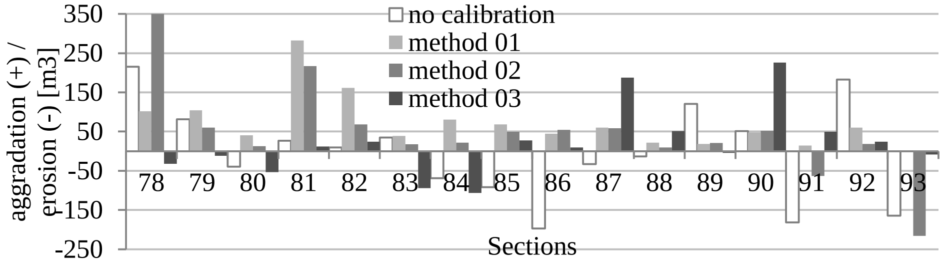


Figure 4. Sectionwise volume change (longitudinal section) for the calibration strategies

Figure 5 compares the evolution of accumulated volume changes for two calibration strategies. In Method 01 the numerical model evolves sectionwise to coarse grain sizes in the top mixing layers and therefore nearly non erosive conditions and low sediment transport patterns for the one week test scenario. The grain based roughness adaption (method 02) shows similar results due to the great influence of resorting processes compared to the low effect of the applied roughness adaption.

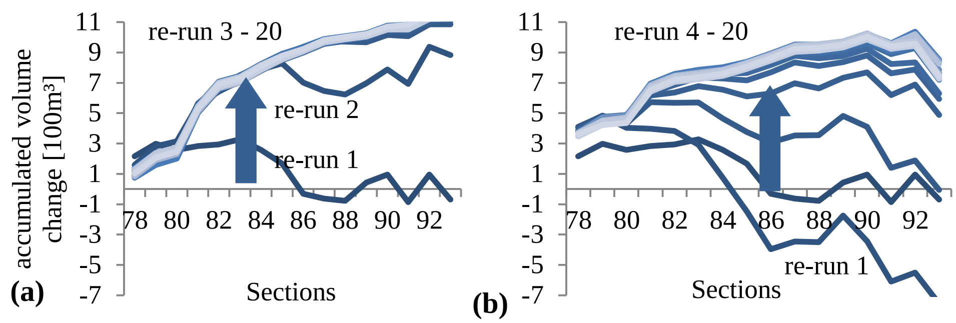


Figure 5. Evolution of accumulated volume changes (longitudinal section) for 20 re-runs, (a) method 01 – base method, (b) method 02 - grain based roughness adaption

The following figures show the evolution for selected parameters from re-run 1 to 20. Figure 6 illustrates the coarsening of the nodal grading curves exemplary for section 81 and method 02. At the same time the skin friction coefficient $k_{St,skin}$ decreases due to the applied roughness adaption. The inflowing sediment load from tributaries and upper boundary is rather aggradated than transported.

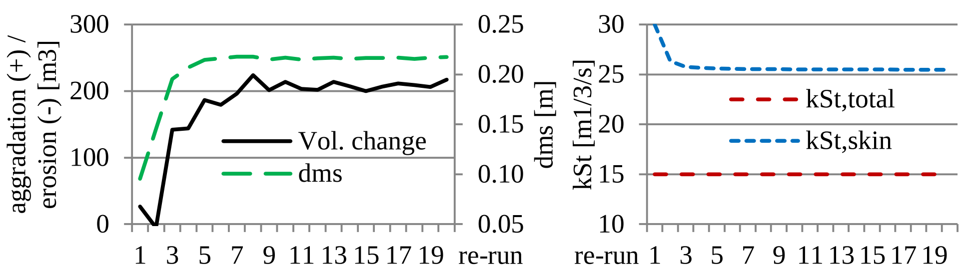


Figure 6. Evolution of total volume change, mean grain size diameter of the mixing layer $d_{ms}$, total roughness coeff. $k_{St,total}$ and skin friction coeff. $k_{St,skin}$ for method 02 and section 81

Figure 7 shows the systematic variation of the parameters $k_{St,skin}$, $k_{St,total}$ and the associated Ripple factor μ of calibration method 03 based on aggradation trends. The left diagram illustrates the evolution towards equilibrium state with resulting low volume change for the test scenario in section 81. The Ripple factor μ is adapted considering the results from the previous run. This is done sectionwise by changing the skin friction coefficient $k_{St,skin}$ according to Eq. (2). If the adaption of μ is not sufficient to reach equilibrium it is kept constant and both roughness coefficients are adjusted as described above and shown in the right diagram.

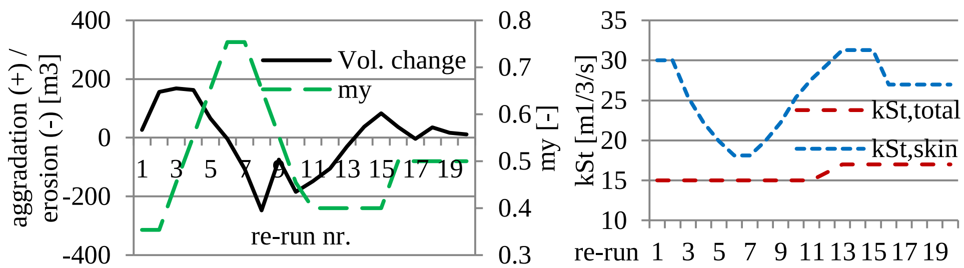


Figure 7. Evolution of total volume change, Ripple factor μ, total roughness coefficient $k_{St,total}$ and skin friction coefficient $k_{St,skin}$ for method 03 and section 81

Table 2. Sediment inflow/outflow sums and transported mean and max. grain size diameters

| Calibration strategy | ΣQG [m3] | $d_{m,mean}$ [mm] | $d_{m,max}$ [mm] |
|---|---|---|---|
| Sediment inflow | 1142.5 | 26.8 | 64.9 |
| No calibration, first run | 1046.6 | 57.8 | 182.7 |
| 01 - base method | 28.3 | 26.9 | 191.3 |
| 02 - grain based roughness adaption | 296.2 | 143.9 | 500.0 |
| 03 - roughness adaption based on aggradation trends | 790.7 | 67.1 | 213.9 |

Table 2 gives an overview regarding the outflow sums and transported grain sizes for all applied calibration methods. The outflow sedigraph (QG_out) and transported mean grain size diameters (dm_out) compared to the input (QG_in, dm_in) for the first Hydro_GS-2D run are shown in Figure 8. Those with applied calibration strategies after 20 re-runs are presented in Figure 9 (a) to (c). Method 01 (a) results in nearly no sediment output. With method 02 (b) higher output rates are achieved. The same can be observed for method 03 (c) but there the first peaks appear much earlier in time compared to all other results. For all simulation runs the transported grain sizes at the model outlet are coarser compared to the average of all inflows.

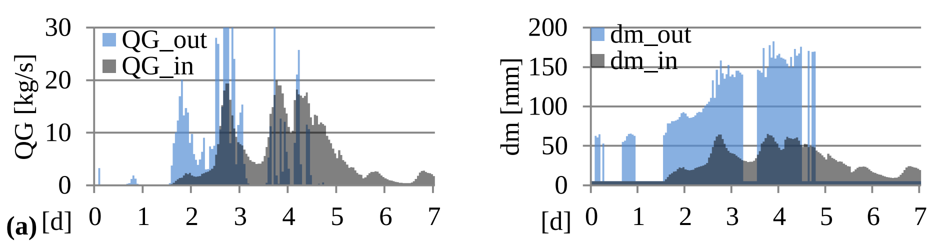


Figure 8. No applied calibration strategy, first Hydro_GS-2D run

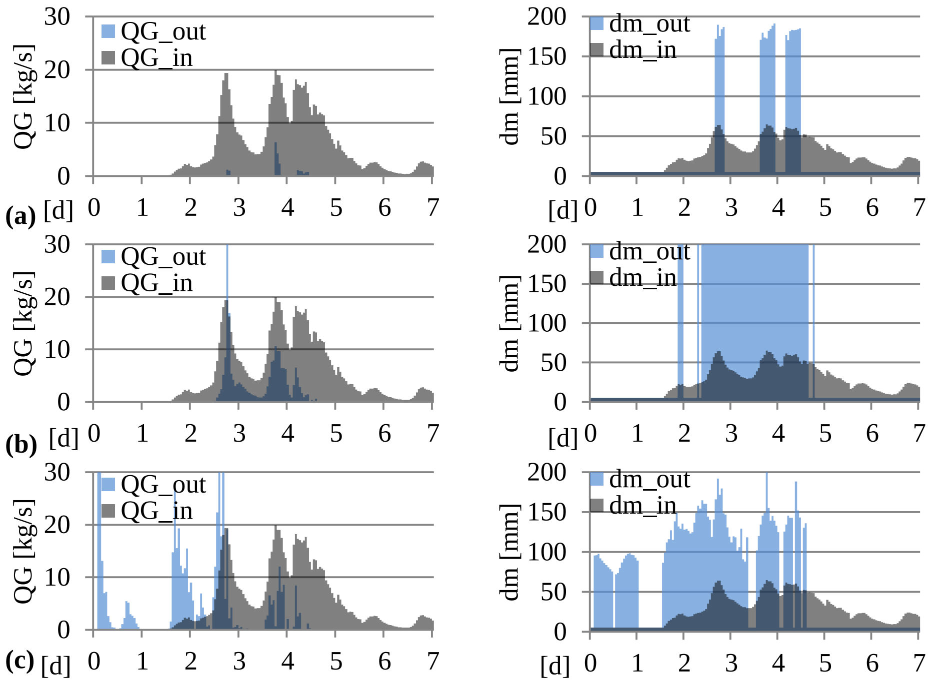


Figure 9. (a) method 01, (b) method 02 and (c) method 03

**CONCLUSIONS**

Method 03 (roughness adaption) is found to converge to a stable parameter setup. Due to the dynamics of the inflow, it oscillates around a state rather that it converges to a single setup. This dynamic equilibrium is observed for the upstream sections, but requires more re-runs prior being visible downstream. Thus, altering global model parameters is found suitable in the given case, although it is characterized by complex turbulent flows, steep sections and a wide range of grain size distributions. Still, the sensitivity of the method to the selected inflow conditions needs to be addressed.

**REFERENCES**


[1] Nujic M., “Hydro_AS-2D - Ein zweidimensionales Strömungsmodell für die wasserwirtschaftliche Praxis”, Hydro_AS-2D User Manual, (2009).

[2] Hirano M., “River bed degradation with armouring”, Proceedings of the Japan Society of Civil Engineers, Vol. 195, (1971), pp 55-65.

[3] Meyer-Peter E. & Müller R., “Eine Formel zur Berechnung des Geschiebetriebs”, Schweizerische Bauzeitung, Vol. 67 (3), (1949), pp 29-32.

[4] Hunziker R. P., “Fraktionsweiser Geschiebetransport”, In Vischer D. (ed), Reports of the Laboratory of Hydraulics, Hydrology and Glaciology of the Swiss Federal Institute of Technology 138, Zürich: self-published, (1995).

[5] Hunziker R. P., Fardel A. & Garbani Nerini P., “Hydro_GS-2D Mehrkorn – Modell und Versuchsbeschreibung”, Hydro_GS-2D Reference Manual, (2009).

[6] Klar, R., Achleitner, S., Umach, L. & Aufleger, M., “Long-term simulation of 2D fractional bed load transport – benefits and limitations of a distributed computing approach“, 10th International Conference on Hydroinformatics, HIC 2012, Hamburg, Germany, (2012).

[7] Klar, R., Umach, L., Achleitner, S., Aufleger, M., “Adaptive Roughness Approach for 2D Long-Term Morphodynamic Simulation“, Proc. International Conference on Fluvial Hydraulics, San José, Costa Rica, (2012), pp 443 - 450.

[8] Wong, M. and G. Parker, “Re-analysis and correction of bedload relation of Meyer-Peter and Müller using their own database”, Journal of Hydraulic Engineering, (2006), 31p.