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# Distributed sediment yield modelling: Importance of initial sediment conditions

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The importance of initial sediment conditions on model calibration and validation is analysed. A sediment model was calibrated and validated under three different initial sediment conditions: (0) no sediment availability, (1) calibration of the initial sediment condition and (2) using a warm-up simulation. The model results were assessed in terms of the graphic of fine sediment transport, or sedigraphs, and the visual fit of the hysteresis on the sediment rating.

All strategies provided adequate results. However, the loop rating curve analysis demonstrated that the choice of initial sediment conditions affected the simulation results. Without any initial sediment condition, the model results were typically inferior to the simulation results with calibration or warm-up. The calibration of initial conditions proved to be the most reliable technique to generate clockwise hysteresis loops, but failed in reproducing other loop types. Overall, the warm-up simulations showed encouraging results, providing satisfactory fine sedigraph simulation results.



## 1. Introduction

The integrated management of soil erosion and sediment redistribution at the catchment scale has acquired a great importance during the last decade (Owens and Collins, 2006). A common way to assess sediment production and transport is through a mathematical modelling approach (Harmon and Doe, 2001). Mathematical models are useful land management decision support tools. For example, sediment yield models are used to determine soil redistribution due to environmental changes (Van Rompaey et al., 2005).

There are many theoretical approaches to sediment modelling. A literature review can be found in Merritt et al. (2003), Aksoy and Kavvas (2005) and Karydas et al. (2012). All these studies point out that, during last decades, development of new models tended to produce conceptual and physically based distributed models. Some examples include EUROSEM (physically based mode, Morgan et al., 1998), LISEM (physically based model, de Roo et al., 1996), LASCAM (conceptual model, Viney and Sivapalan, 1999) or CatchMODS (conceptual model, Newham et al., 2004). This is because the sediment cycle is characterised by high complexity and non-linearity. These are features that simple empirical lumped models cannot describe easily. Moreover, the spatial variability of erosion and deposition processes is fundamental for catchment management decision support.

The last 60 years brought significant advances in sediment transport modelling but models are not without limitations (Favis-Mortlock et al., 2001). A strong limitation to the application of many existing sediment models is the need for a reliable calibration and validation (Jetten et al., 1999), which is required in order to prove the model robustness and reliability. In the past, modelling research studies highlighted the importance of calibration and validation for hydrological (Klemeš, 1986; Beven, 1989) and sediment models (de Roo and Jetten, 1999; Folly et al., 1999; Van Oost et al., 2005; Verstraeten, 2006; Polyakov et al., 2007). While hydrological model calibration is an issue that has been very often discussed in literature, very few papers describe clear and scientifically acceptable calibration and validation procedures for sediment models. Moreover, the use of automatic calibration algorithms in erosion and sediment yield modelling has been considered by Freedman et al. (1998) and Santos et al. (2003, 2010) for WESP model, Viney and Sivapalan (1999) for the LASCAM model and Ogden and Heilig (2001) for the CASC2D-SED model.

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Relevant questions regarding sediment model calibration and validation include: (1) how to select the calibration and validation periods; (2) which objective function(s) is(are) to be used; and (3) which calibration technique is the most appropriate. One of the main problems is the estimation of the initial condition (defined as the initial value of model state variables). Typically, the most influent variables to be estimated at the beginning of a simulation are the antecedent soil moisture condition, the groundwater level, initial river flow stage and discharge and the initial in-channel sediment supply.

The initial sediment availability, i.e. the amount of sediment available for sediment transport at the beginning of the simulation. While the relevance of in-channel sediment deposits has already been highlighted by many authors, only a few papers analysed the influence of initial sediment availability on the sediment modelling process (e.g. Wicks and Bathurst, 1996). The mobilisation of sediment deposited by previous floods may cause a time gap between sediment concentration peak and water discharge peak, resulting in a clockwise hysteresis loop in the relationship between suspended sediment concentration and water discharge (or between sediment discharge and water discharge, i.e. the sediment rating curve). Several types of hysteresis loops are shown for example in Nistor and Church (2005). Hysteresis loop patterns can provide information about sediment erosion and transport interaction, rainfall intensity and duration, runoff production, sediment availability (e.g. Smith and Dragovich, 2009), etc. Different hysteresis loops depend on runoff and sediment transport processes and on the sediment source location(s) (e.g. Williams, 1989; Seeger et al., 2004; Eder et al., 2010). Particularly, clockwise hysteresis usually demonstrates that the catchment sediment dynamic is dominated by gully and river channel erosion rather than hillslope erosion (Piest et al., 1975; Nistor and Church, 2005). This situation is quite frequent: as many papers show, the relative contribution to total sediment yield of gully and river channel erosion and deposition might be very relevant compared to hillslope (or sheet and rill) erosion (Osterkamp and Toy, 1997; Merritt et al., 2003; de Vente et al., 2008; Smith and Dragovich, 2009; Vanmaercke et al., 2012).

Continuous simulation models also need an initial condition. In this case, while initial soil moisture and initial groundwater level can be estimated by simulating a relatively short warm-up period (Senarath et al., 2000; Brath et al., 2004), the available sediment strongly depends on the previous extreme events and a warm-up period length cannot be established *a priori*. Automatic calibration requires a high number of simulations and the processes involved in sediment yield modelling require a fine time discretisation. Therefore, due to computational time limitations, the calibration period must be as short as possible – although sufficiently long for an adequate calibration (Klemeš, 1986; Brath et al., 2004). Very often calibration is done using one or a few individual rainstorm events, thus increasing the influence of initial condition on model results.

In this study, different estimation techniques were investigated. Three sediment sub-models were calibrated and validated, employing different sediment initial condition estimation strategies: (0) no sediment availability, (1) manual calibration of the initial condition and (2) using warm-up simulation. Manual calibration and warm-up simulation are two common techniques for estimating initial sediment condition. The possibility of setting the initial sediment condition to zero (i.e. no available sediment in the drainage network) was also investigated in order to provide a reference to compare with the other two options.

In this study, the importance of initial sediment conditions on model calibration and validation was analysed using the model TETIS (Francés et al., 2002, 2007; Bussi et al., 2013). The TETIS model was modified, including some new features (automatic calibration algorithm, manual sediment initial condition setting tool and new calibration coefficients), in order to achieve the objectives of this study. It is a parsimonious model which takes advantage of all available spatial information. The TETIS model was selected especially for its flexible structure, which makes it suitable for a wide range of climatic and geological situations, and because it allows the automatic calibration of the hydrological and sediment parameters. In order to attain the objective of this study, the distributed hydrological and sediment model was applied and tested on the Goodwin Creek catchment (USA). The model results were assessed in terms of fine sedigraph (particle diameter less than 0.062 mm), hysteresis loop visual fit and several model metrics including the Nash and Sutcliffe Efficiency (NSE), the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE).

## 2. Model description

The TETIS model is based on two sub-models for the hydrology and sediment transport. Both sub-models are described as follows.

### 2.1. Hydrological sub-model

The TETIS hydrological sub-model is a distributed conceptual hydrological model developed for continuous simulation of the hydrological cycle. The model has been satisfactorily applied to different catchment areas (from less than 1 km$^2$ up to 60,000 km$^2$) at different spatial resolutions (square cells from 30 $\times$ 30 m to 500 $\times$ 500 m) under a wide range of climates (from semi-arid to humid). Some recent examples of these applications can be found in Francés et al. (2007, 2011), Vélez et al. (2009), Andrés-Doménech et al. (2010) and Salazar et al. (2013).

In TETIS each cell of the spatial grid describes the water cycle by means of five connected tanks. The relationships between tanks, representing the different hydrological processes, are described by simple linear reservoirs and flow threshold schemes. The processes described in the TETIS hydrological sub-model include snowmelt, canopy interception, soil capillary storage and evapotranspiration, overland runoff, soil gravitational storage and interflow, aquifer storage and base flow, and groundwater recharge. Overland runoff, interflow and base flow are connected to the stream network following the scheme represented in Fig. 1.The stream network is divided into gullies and river channels. Grid cells are classified, depending on their drainage area, into gully and river channel cells, by defining two drainage area thresholds. Every cell receives inflows from upstream and drains downstream following a 3D scheme generated from a Digital Elevation Model. Fig. 1 shows a 2D simplification of this scheme. Following the original classification from Francés et al. (2007), T2 refers to the superficial water storage

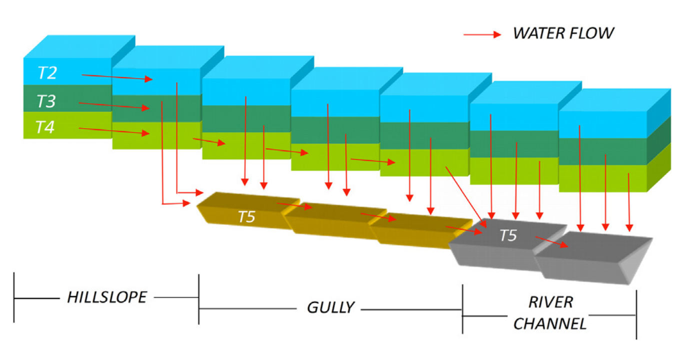


**Fig. 1.** Horizontal conceptual scheme of TETIS model for runoff propagation. T2 to T5 indicate the TETIS model tanks. In this figure, gullies and river channel threshold areas are equal to 2 and 5 cells, respectively.