Modelling daily sediment yield from a meso-scale catchment, a case study in SW Poland.

S.D. Keesstra[(1)], J. Schoorl[(2)] A.J.A.M. Temme[(2)],

(1) Land Degradation and Development Group, Wageningen University, Droevendaalse steeg 4, 6708PB, Wageningen, The Netherlands. E-mail: saskia.keesstra@wur.nl
(2) Land Dynamics group, Wageningen University, Droevendaalsesteeg 3, 6708 PB Wageningen, Netherlands E-mail: arnaud.temme@wur.nl, jeroen.schoorl@wur.nl

ABSTRACT

For management purposes it is important to be able to assess the sediment yield of a catchment. However, at this moment models designed for estimating sediment yield are only capable to give either very detailed storm-based information or yearly averages.
The storm-based models require input data that are not available for most catchments. However, models that estimate yearly averages, ignore a lot of other detailed information, like daily discharge and precipitation data. There are currently no models available that model sediment yield on the temporal scale of one day and the spatial scale of a meso-scale catchment, without making use of very detailed input data.
To fill this scientific and management gap, landscape evolution model LAPSUS has been adapted to model sediment yield on a daily basis. This model has the water balance as a base. To allow calibration with the discharge at the outlet, a subsurface flow module has been added to the model. Our version of the model only requires a DEM (10 to 30 m pixel size), a soil map, a land use map, daily discharge and precipitation data and a general idea of the soil depths in the catchment. With this information the model can be calibrated for the water flow part which will give a good indication of the possibilities for sediment transport. This new version of LAPSUS was tested on a catchment in SW Poland, the Nysa Szalona.

Keywords: Sediment yield modeling, meso-scale catchments, landscape evolution model LAPSUS.

INTRODUCTION

For management purposes it is important to be able to assess the sediment yield of a catchment. However, at this moment models designed for estimating sediment yield are only capable to give either very detailed temporal or spatial information or yearly averages.
There are temporal small scaled models like the storm-based models LISEM (de Roo and Jetten, 1999) and WEPP (Laflen et al., 1991), or spatially small-scaled models like TOPOG (Gutteridge Haskins and Davey, 1991). These models require input data that are not available for most catchments. However, models that estimate yearly averages, like the RUSLE (Renard et al., 1994) and related models, ignore a lot of other detailed information which is available for most catchments, like daily discharge and precipitation data. Currently, no models are available that model sediment yield on the temporal scale of one day and the spatial scale of a meso-scale catchment (50-300 km^2), without making use of very detailed input data.

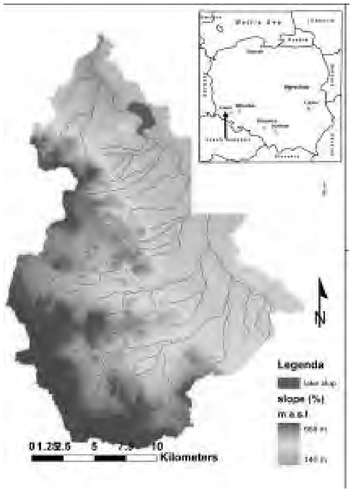

Figure 1: Study area: Lake Slup, in the Nysa Szalona catchment in SW Poland, 51° 05’ N, 16° 07’E.

The spatial and temporal meso-scale is scientifically interesting as it is the most common scale for catchment managers and the scale on which most hydrological data is recorded. Furthermore, most sediment and water provided to large-scale rivers originates from meso-scale headwater catchments (up to 90%, Lajczak, 2003; Wainwright et al, 2003). To understand the processes of water and sediment generation in the headwaters of the major waterways it is important to look at these processes on a resolution that is large enough to be representative of the processes involved and small enough to be homogeneous and thus allow unambiguous results.

In south-eastern Poland a meso-scale catchment of the Nysa Szalona (350km^2; Fig. 1) was selected to conduct an investigation involving the interaction between land use and sediment and water delivery. The determining factors influencing the sediment and water delivery from this meso-scale headwater catchment will be assessed. The selected catchment is an ideal research area as it has both multiple land uses and a reservoir, where all sediment discharged form the catchment has been stored since its construction in 1978.

The aim of this study was to construct a sediment delivery model that can be used for a meso-scale catchment (50-350km2) using a daily time-step. To calculate this we only use a soil map, a land-use map, a 6 year hydrological record (precipitation and discharge) and the available sediment database in the downstream reservoir (Keesstra et al, submitted).

METHODS AND RESULTS

Existing LAPSUS Model

The model under construction is based on the landscape evolution model LAPUS (www.lapsusmodel.nl). LAPSUS is a multi-process model, but here we focus on the erosion and sedimentation module. This module is based on the potential energy content of water flowing over a landscape surface and the continuity equation for sediment movement, operating at landscape extent and annual resolution. It can be used at different grid sizes (Schoorl, 2002) and has shown good results for simulating erosion/accumulation rates at slope, sub-catchment and catchment scale, introducing the effect of different lithologies, land uses and climates (Buis, 2008, Temme, 2009).

An interesting feature of the model is that run-off routing can be simulated both with steepest descent and multiple flow directions. The steepest descent flow routing directs the run-off towards one single cell with the steepest gradient. In the multiple flow direction routing, all down-slope neighbors receive a fraction of the run-off following Holmgren (1994).

LAPSUS uses a relatively limited amount of input parameters: an erodability map, which is a derivative of the soil map, a DEM, a map with the soil depth, a land use map and precipitation. From these inputs it calculates erosion and deposition due to overland flow and hence generates a changed DEM for the next time-step.

CHANGES TO THE MODEL TO PRODUCE LAPSUS-DAILY

Because the flow of water and sediment are at the core of LAPSUS, only a limited number of changes were required to change from annual to daily resolution.

The most important addition in new model is the possibility to calibrate model outputs with the measured daily discharges. However, in the original model no groundwater flow was incorporated. Therefore, we have included two hydrological flow paths in the model. We included a simple reservoir cascade to simulate the groundwater.

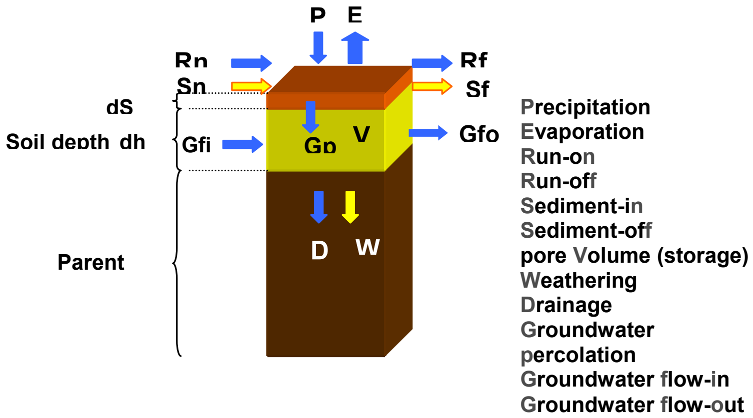

Figure 2: Incoming and outgoing fluxes

At daily resolution, the basic assumption that all water is run through the system within one time step is no longer true. Therefore we split the system in two levels: overland flow and groundwater flow (Fig. 2). Groundwater flow passes one cell per day; the other system, the surface flow, reaches the outlet in one day. Groundwater flow has can also flow in multiple directions, and can also re-enter the surface flow system, simulating saturation excess overland flow and return flow. A maximum infiltration rate, derived from the soil map, allows the simulation of infiltration excess overland flow. Deep percolation was not taken into account and the model assumes that all precipitation that does not evaporate is discharged at the outlet.

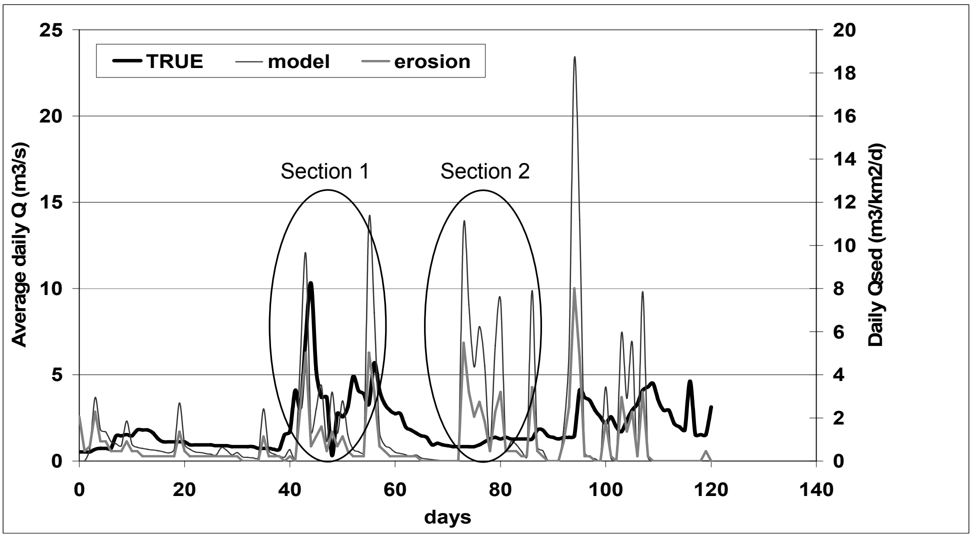

Figure 3: Model results compared with measured discharges.

The evapotranspiration term in the model is derived for each year in a similar manner. On the basis of the latitude and for calibration purposes included temperature record, the ETo was calculated following the equation of Hargreaves (Allen et al., 1998).

DISCUSSION AND CONCLUSIONS

The preliminary results presented below are the first results of test runs made with the model (Fig. 3). In section 1 (Fig. 3) the model seems to predict the discharge quit well. However, in section 2 (Fig. 3) the model output is different from the measured data. This deviation is likely due to both our current lack of calibration and to choices made in the process representation. As calibration is currently ongoing, the importance of the second problem will likely become clear soon. We need to reveal what kind of hydrological mechanisms work in the catchment which are now not incorporated in the model.
In a second phase, we need to look into the erosion-deposition process. Up till now, the model was used for yearly averages. Now that we use daily time-steps, a threshold for erosion must be built in. In reality, during small rainstorms, no sediment transported to the outlet. Therefore, a threshold is needed to model this feature. In the near future we hope to answer most of these questions and develop a model that can be used for estimating sediment yield in meso-scale catchment by using the daily discharge as calibration tool.

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