PhD Thesis

DEVELOPMENT OF MATHEMATICAL MODEL FOR CALCULATING CONTINUOUS HYDROGRAPHS AND SEDIMENT GRAPHS IN A BASIN DUE TO RAINFALL

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Workshop: Sediment management in channel networks: from measurements to best practices

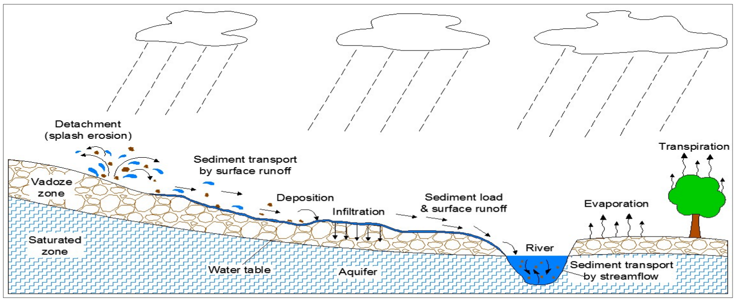
Summary

Continuous hydrologic simulations, as well as continuous simulations of soil and streambed erosion processes are performed in two neighboring basins in north–eastern Greece. Three different models aiming at continuous simulations of hydromorphological processes at the basin scale, are presented.

The first models are two **Composite Mathematical Models (CMMs)**, which were developed by combining several known physically–based and empirical methods together. The CMMs consist of three submodels:

- a rainfall–runoff submodel
- a soil erosion submodel
- a sediment transport submodel for streams

The third model is the GIS version of Soil and Water Assessment Tool, SWAT (**ArcSWAT**).



Under study natural basin processes

Aim of the thesis

- Contribute to the integrated hydromorphological study at the basin scale
- Provide valuable information for the future trend of the hydromorphological processes
- Contribute to the proper design and maintenance of the hydraulic structures (dams, hydroelectric structures, etc.)
- Positively add in decision making towards management and conservation planning against erosion
- On the grounds that the majority of rivers in Greece is ungauged, this thesis provides models and methods that accurately calculate stream discharges, soil erosion, and sediment discharges (at the basin scale) across the country, as well as in other parts of the Mediterranean, with similar morphological and climatic conditions

Novelty of the thesis

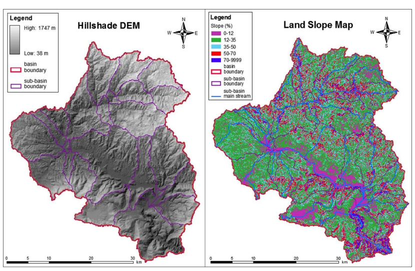
Sediment discharge is a highly non–linear physical procedure and high levels of disaggregation (sub–daily to hourly time steps) incorporate a very high degree of non–linearity, especially in flooding periods.

Therefore, the novelty of this thesis lies in the following facts:

- Provides several different ways – depending on the availability of data – for producing continuous sediment graphs, at any stream segment throughout the basin
- The application of all models is performed at hourly time step, for long periods of time. Given the complexity of the under study physical quantities, this imparts a very high precision and detail to the hydromorphological study of a basin at the temporal scale
- Continuous quantitative assessment of sediment discharge

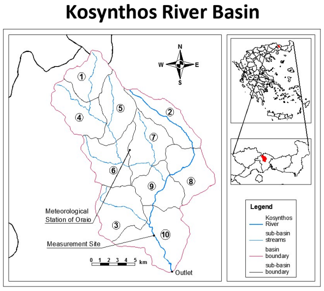
Study areas

Nestos River Basin



Area: 838.63 km^2 | Altitude: 38 m – 1747 m
Avg Slope: 37% | Main stream len: 63 km
Avg Temp: 14.5 ^{o}C | Annual Avg Pcp: 880 mm

Kosynthos River Basin



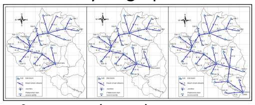
Area: 237 km^2 | Altitude: 72 m – 1700 m
Avg Slope: 37.3% | Main stream len: 35 km
Avg Temp: 14 ^{o}C | Annual Avg Pcp: 750 mm

Materials and methods

Composite Mathematical Models (CMMs)

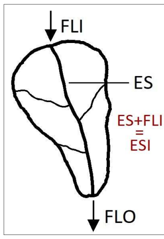
Rainfall–runoff submodel was built and simulated by the deterministic, semi–distributed hydrologic model **HEC–HMS 4.2**, and it consists of a combination of known methods:

- Hydrologic losses into the ground and rainfall excess – SCS–CN method
- Evapotranspiration – FAO–56 Penman–Monteith method
- Transformation of rainfall excess to runoff hydrograph – SCS unit hydrograph
- Concentration time – Pasini's and Giandotti's formulas
- Baseflow – Exponential recession model
- Routing of total discharge – Muskingum–Cunge model



Soil erosion submodel 1

Relationships of **Poesen** (1985), **Nielsen** (1986), **Engelund and Hansen** (1967)



$$ES = q_t \quad if \quad q_r + q_f > q_t$$
$$ES = q_r + q_f \quad if \quad q_r + q_f \le q_t$$
$$ESI = ES + FLI$$

The sediment supply due to soil erosion, **ES**, to the main stream of a sub–basin is estimated by means of a comparison between the available sediment, **q_r+q_f**, in the sub–basin area and the sediment transport capacity by runoff, **q_t**. The sediment from the preceding sub–basin, **FLI**, must also be taken into account, in order to estimate the total sediment, **ESI**, transported to the main channel of the sub–basin considered.

Soil erosion submodel 2

Modified Universal Soil Loss Equation (**MUSLE**) (Williams, 1975)

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{sub}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

Stream sediment transport submodel

Relationships of **Yang and Stall** (1976)

$$\log c_{ts} = 5.435 - 0.286 \log \frac{wD_{50}}{v} - 0.457 \log \frac{u_*}{w} + \left(1.799 - 0.409 \log \frac{wD_{50}}{v} - 0.314 \log \frac{u_*}{w}\right) \log\left(\frac{us}{w} - \frac{u_{cr} s}{w}\right)$$

$$FLO = q_{ts} \quad if \quad ESI > q_{ts}$$
$$FLO = ESI \quad if \quad ESI \le q_{ts}$$

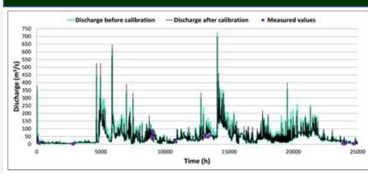
The sediment yield, **FLO**, at the outlet of the main stream of a sub–basin is estimated by means of a comparison between the available sediment, **ESI**, in the stream and the sediment transport capacity by streamflow, **q_{ts}**.

ArcSWAT

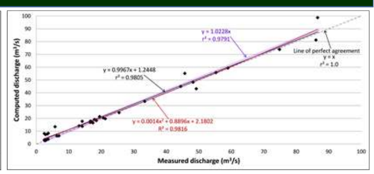
SWAT elaborates a great variety of different methods to model the hydromorphological processes. Amongst these, the principal methods for the rainfall–runoff, soil erosion, and streambed erosion are mentioned:

- Hydrologic losses into the ground and rainfall excess – Green–Ampt
- Soil erosion method – MUSLE
- Streambed erosion – Yang sand and gravel model (1996)

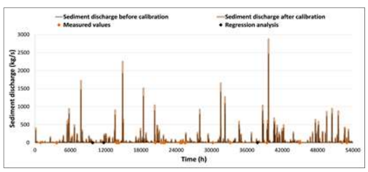
Results



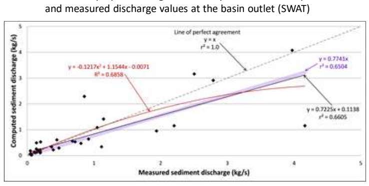
Basin outlet discharge hydrograph - SWAT (July 5th, 2008-May 12th, 2011)



Linear and polynomial regression analysis between computed and measured discharge values at the basin outlet (SWAT)



Basin outlet sediment graph - CMM (June 1st, 2008-July 29th, 2014)



Linear and polynomial regression analysis between computed and measured sediment discharge values at the basin outlet (CMM)

Conclusions

- The continuous nature of the runoff and total discharge hydrographs enables the development of a continuous sediment graph
- A par excellence event-based erosion model, such as MUSLE, was proven to be very successful for continuous soil erosion modeling
- CN should not be directly linked with the total stream discharge, as it has a direct influence only on the surface runoff
- The combination of a hydrologic model with a soil erosion model and a stream sediment transport model enables the transition of the hydrograph, due to a rainfall event, at a basin outlet to the corresponding sediment graph. In other words, the variation with time of the sediment discharge at the basin outlet is computed on the basis of the variation with time of the stream discharge due to the rainfall event
- The results of the efficiency criteria conclude that the continuous hydromorphologic modeling can be successfully applied to both Kosynthos and Nestos River basin