TELEMAC as a hydrodynamic rainfall-runoff model: New extension using the Green-Ampt-infiltration

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Abstract – **Within the cooperation project HiOS (2017-2021) TELEMAC-2D had been intensively used as a Hydrodynamic Rainfall-Runoff Model (HDRRM) using the SCS-CN-method for the calculation of the effective rainfall. This TELEMAC-2D model proved to be an efficient and versatile tool for the simulation of flash floods. Nevertheless, the accumulated run-off was frequently overestimated. The reason for this could be the inability of the SCS-CN-method to represent re-infiltration. Therefore, a new extension considering the physically based Green-Ampt-infiltration was implemented. The methodology and the results of the testing are given. The plausibility of the new extension was validated using a case study area nearby Bayreuth in Bavaria (Studio-project, 2021 ongoing).**

Keywords: rainfall-runoff, infiltration, re-infiltration, ponding time, non-uniform rainfall.

I. Introduction

Rainfall-Runoff modelling is an essential part of flood hazard analysis. Most of the time, the analysis is carried out combining separately hydrological and hydrodynamic models. For catchment sizes <100km² small scale models hydrodynamic rainfall-runoff models are a promising alternative melting two models into one.

During the cooperation project HiOS more than 40 Bavarian catchments and municipalities were analysed using HDRRM. Simulated results were compared to measured data for each catchment. Even without calibration, the simulation met peak of discharge and evolution with time comparatively well.

Frequently the total volume in terms of accumulated runoff was overestimated. A typical result for the simulated accumulated discharges at the catchment outlet compared to the measured accumulated discharge and the accumulated precipitation is given in **Erreur ! Source du renvoi introuvable.**.

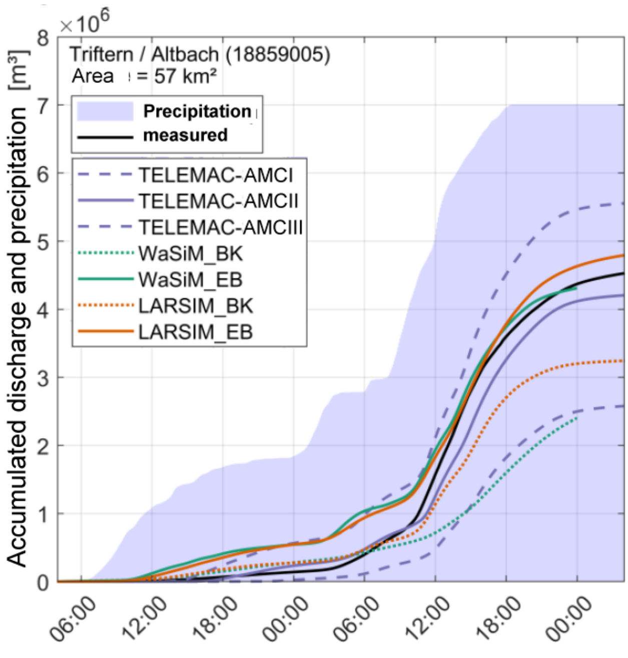

Figure 1. Accumulated discharges and precipitation [m³] for case study Triftern (HiOS-project) for TELEMAC-2D and other hydrological models

For this case, the antecedent moisture content class III is valid (AMCIII = wet conditions). The dynamic of the graph is represented sufficiently, but too much water is kept in the simulation model. It is assumed that the conceptual approach of the SCS-CN-method does not represent the infiltration process adequately. This method defines infiltration as a portion of the precipitation. Therefore, using SCS-CN-method implies zero infiltration, if there is zero rainfall. This is obviously not realistic, because re-infiltration can continue after the rain provided surface water is present.

The Green-Ampt-infiltration is physically based and has non-zero infiltration in wetted regions even if there is no rainfall. The influence of the Green-Ampt-approach applied to HDRRM is analysed hereafter.

II. IMPLEMENTATION

The Green-Ampt-Infiltration is implemented in parallel to the existing SCS-CN-method. Thus, either Green-Ampt-infiltration or SCS-CN-method can be chosen.

A. SCS-CN-method

The Ligier-implementation [3] enhanced by the possibility to accomplish for spatial variable rainfall also called non-uniform rainfall has been already described [5]. The subroutines *prosou* and *run_scs_cn* were modified and the subroutines *radarmap* (reading of rainfall radar data) and *rfasp* (NNB-mapping of rainfall radar data) added.

B. Green-Ampt-method

The Green-Ampt method is similar to Darcy's law. It calculates the infiltration rate f [$L^3/(s\ L)$] using the following relation:

$$f(t) = K_{sat}\left[1 + \frac{|\psi_f|\,(\theta s - \theta i)}{F}\right] \quad t > tp \qquad (1)$$

$$f(t) = P \quad t \leq tp$$

where K_{sat} [L/T] is the saturated hydraulic conductivity, ψ_f [L] the suction head at the wetting front, θ_s [-] is the volumetric moisture content near saturation, θ_i [-] the initial volumetric moisture content and F [L] the cumulative infiltrated water.

According to equation (1), the model yields an implicit equation for the estimation of the infiltration rate. However, the infiltration rate at a certain time can only be obtained by using iterative computation techniques. Over time, several authors developed explicit approximations to overcome this problem. Here, the explicit formulation of Serrano [2] is used and implemented in subroutine *infiltration_ga*.

III. TESTING

The testing of the implementation consists of two parts. During the first part (A) of the implementation the Serrano-approximation is checked against the exact solution of the Green-Ampt-equation (1). For this test, the Serrano-approach is extracted and executed separately. In the second part (B), the plausibility of the enhanced TELEMAC-2D is checked using the Ligier-testcase and a test-case area near Bayreuth/Bavaria (STUDIO-project).

The Serrano-approach uses the following decomposition of the cumulative infiltration F.

$$F(t) \approx F_0(t) + a\ln(m_1(t))\left[1 + \frac{m_2(t)}{[1-m_1(t)][1+m_2(t)\ln(m_1(t))]}\right] \quad (2)$$

for $t > t_p$

using the following relations:

$$F_0(t) = K_{sat}(t - t_p) + F_p$$

$$a = |\psi_f|\,(\theta_s - \theta_i)$$

$$m_1(t) = (F_0(t) + a)/(F_p + a)$$

$$m_2(t) = a/(F_0(t) + a)$$

The comparison of the approximation of Serrano [2] and the exact solution for equation (1) is given in using the Studio-case-study (see next chapter III.B). The resulting ponding time is 76 min. For the simulation time, the differences between the exact solution and the Serrano-approximation are negligibly small.

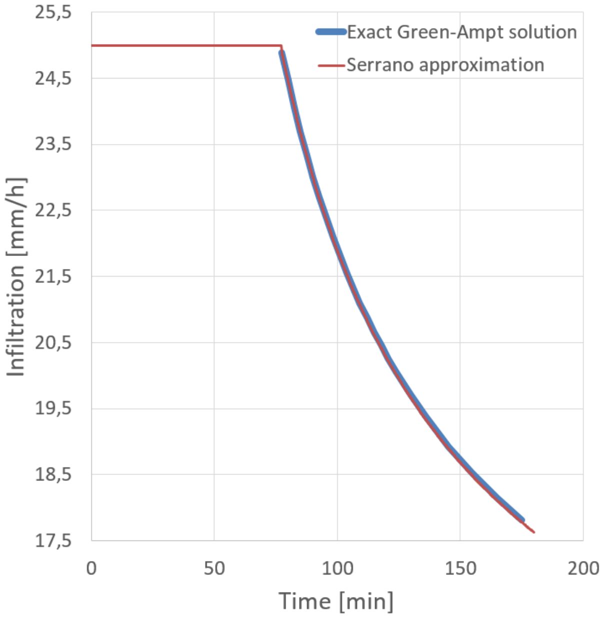

Figure 2. Comparison of exact GA-solution and approximated according to Serrano [2]

A. Testing the implemented GA-method

Global test 1: The simple reservoir-setup by Ligier [3] was used to test the basic requirement: inside a flooded area the infiltration should continue after the rainfall stops. A rainfall intensity p= 100mm/h lasting for one hour was defined. After one hour the rainfall is zero. The water level inside the reservoir decreased after one hour when Green-Ampt was applied. For SCS.CN-method the water level stayed constant.

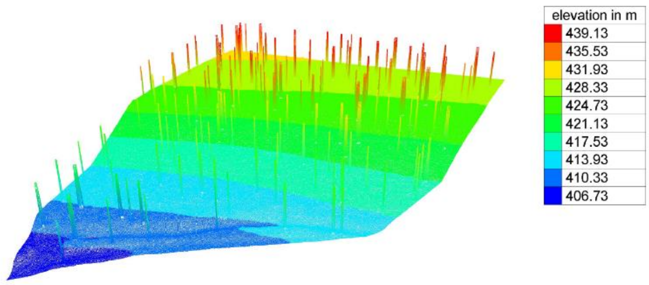

Figure 3. Case study area for Green-Ampt-infiltration, 3d-view (STUDIO-project).

Global test 2: For the domain given in Figure 3 a uniform unstationary rainfall is defined. For this case, the basic requirement is that the infiltration rate is uniform and equal to the rainfall intensity as long as $t<t_p$. For $t>> t_p$ the infiltration rate f [L/T] should converge to the saturated hydraulic conductivity K_{sat} [L/T]. The rainfall is constant for 2 hours with P=25mm/h and then zero. When the rainfall stops, the infiltration is limited to the water availability and becomes water depth dependent. The saturated hydraulic conductivity is K_{sat}.= 3.03 10^{-6} m/s = 10.905 mm/h. The pressure head at the wetting front is ψ_f.= 0.1524m. The volumetric moisture content θ_s near saturation is practically equal to the soil porosity n = θ_s = 0,5050. The initial water content is θ_i = 0,2335. The total simulation time is 3 hours. The simulation result for these assumptions is given in Figure 4.

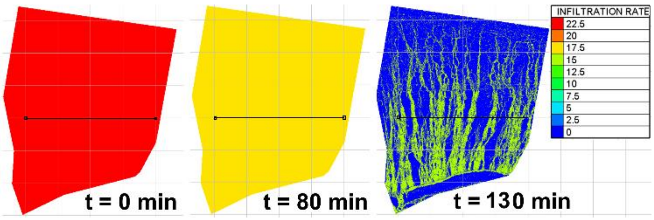

Figure 4. Infiltration rates [mm/h} at different time levels (STUDIO-project) for TELEMAC-2D with Green-Ampt-infiltration.

After the ponding time t > t_p=76min. the infiltration rate decreases. When the rainfall stops after 2 hours, infiltration is limited to areas with flow concentration.

IV. Conclusion

The first results demonstrate the general suitability of the Green-Ampt approach and proofs the correctness of the implementation. Next step is the calibration and validation of the approach. Further enhancements with un-ponded, infiltration and unsteady rainfall might improve the quality of the results.

Acknowledgement

The cooperation project “Hinweiskarte Oberflächenabfluss und Sturzflut” (Indicator Map for Surface Runoff and Flash Floods) abbreviated HiOS, analyses surface runoff and flash floods in various aspects. HiOS started in 2017 and lasted until 2021. It consisted of three teams working on GIS, hydrologic and hydrodynamic modelling. Technical University of Munich TUM, Ludwig-Maximilians-Universität LMU and the Leibniz-Supercomputing Centre LRZ are partners in this project. HiOS was funded by the Bavarian State Ministry of the Environment and Consumer Protection (StMUV) and supervised by the Bavarian Environment Agency.

The project STUDIO investigates nature-based solution against consequences of droughts in a forest area nearby Bayreuth/Bavaria. STUDIO is funded and supervised by the Bavarian Environment Agency.

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