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DETERMINATION OF EXTREME FLOODS USING A DISTRIBUTED HYDROLOGICAL MODEL

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Abstract - Hydrological models developed for extreme precipitation of PMP type are difficult to calibrate because of the scarcity of available data for these events. This article presents the process and results of calibration for a distributed hydrological model at fine scale developed for the estimation of probable maximal floods in the case of a PMP. This calibration is done on two Swiss catchments for two events of summer storms. The calculation done is concentrated on the estimation of the parameters of the model, divided in two parts. The first is necessary for the computation of flow speeds while the second is required for the determination of the initial and final infiltration capacities for each terrain type. The results, validated with the Nash equation show a good correlation between the simulated and observed flows. We also apply this model on two Romanian catchments, showing the river network and estimated flow.

Key Words: Probable Maximum Flood (PMF), Probable Maximum Precipitation (PMP), alpine catchment, distributed hydrological model, outlet.

1. INTRODUCTION

Studies conducted in recent years have shown that global warming could be accompanied by an increase in the frequency of heavy precipitation and flooding in Switzerland and in many parts of the globe [3], proving the importance of current research on modeling of rainfall and floods on a fine scale. The old methods of flow calculation are simple and use empirical equations and a uniform rain. These calculation methods have shown their limits in the case of natural disasters caused by extreme precipitation. For this, a new approach was proposed to achieve a reasonable estimate of probable maximum flood in a watershed, the PMP-PMF method (Probable Maximum Precipitation - Probable Maximum Flood), which gives the maximum precipitation and flood with a return period of 10000 years. Switzerland is represented on the PMP form of maps with a resolution of 2 km [1].

We developed a distributed hydrological model that includes a simulation of moving clouds and of the precipitation data from these clouds, as well as the surface and underground flows on a watershed, with a very fine granularity. The purpose of this model is to achieve a better estimate of the effects attributed to the phenomenon of PMP-PMF, since conventional methods could lead to an overestimation of flood flows, especially for large basins and mountainous areas, leading to significant additional costs. For the calibration of the developed model, it is necessary to calibrate the parameters using measured data. As the PMP is difficult to measure, since it has a return period of 10000 years, we must realize the calibration with episodes of extreme flooding seen on the same river where the simulation is done. The aim of this paper is to present the results of the calibration process for two Swiss basins and the application of our model for two Romanian basins. In the following sections we present our hydrological model and the results obtained in Switzerland and Romania.

2. THE HYDROLOGICAL MODEL

The hydrological model developed includes three parts: the spatiotemporal rain distribution, water flow modeling and modeling of snowmelt [4]. The first part of our model corresponds to the fine-scale spatiotemporal modeling of PMP. The calculation was performed using the advection-diffusion equation that models the temporal behavior of several clouds in space and time. Our model provides a different structure for each pixel of the area, contrary to most other models of precipitation. The second part involves the modeling of water flow using a digital terrain model (DEM). Surface water follows the slope of the terrain to the basin outlet. Each terrain cell receives and gives a certain volume of water to neighboring cells, according to Manning's equation and the terrain slope. This part also includes the infiltration of water into the ground. The flow velocity in the underground is calculated by Darcy's law (1856), assuming a uniform soil thickness. Like for the surface, each cell in the underground receives a volume of water from upstream neighbors. The local infiltration is also added to the received flow, and has the same role for groundwater flow as the precipitation for surface flow. When the ground becomes saturated, the water exits to the surface by the phenomenon of exfiltration.

The third part of our model includes modeling of snowmelt. We will limit ourselves to the worst case

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scenario that can happen in reality, the snowmelt caused by the arrival of a rain extreme PMP. This part is important because rain can increase the snowmelt and with it the extent of the flood.

automatic network (ANETZ). The flow data is used from the Federal Office of Environment (BAFU). With this data, the hydrologic model developed is able to calculate flows on all points of the watershed.

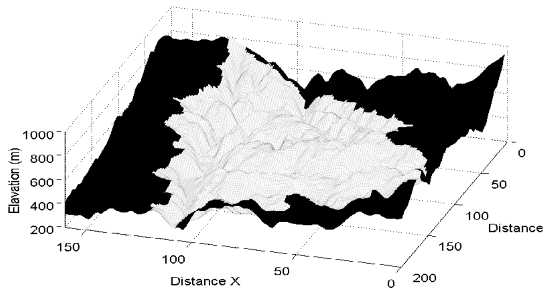

Figure 1. Delimitation of the basin studied (Surduc- Romania)

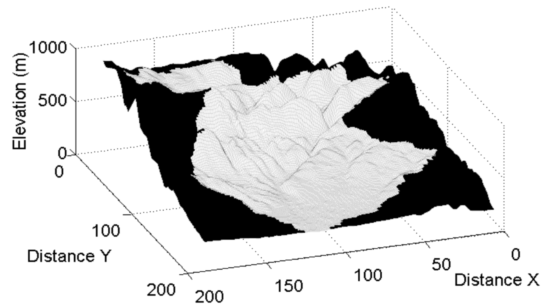

Figure 2. Delimitation of the basin studied (N of Oravita- Romania)

3. CALIBRATION AND RESULTS

3.1. Swiss catchments

Two Swiss watersheds were selected based on their sizes and the absence of glaciers. The first is that of the Allenbach in Adelboden, located in the Bernese Alps and has an area of 28.8 km2. According to the Hydrological Atlas of Switzerland this basin does not contain ice and is one of the most typical in Switzerland for torrential floods caused by violent thunderstorms in summer. The second basin is that of the Sitter, located in eastern Switzerland, with an area of 90.3 km2. This basin was chosen because of its large size. A glacier covers only 0.08% of the catchment area, its effects on flows may be neglected in our calculation. Figure 2 and Figure 3 show the watersheds delineated by our model.

3.2. Romanian catchments

In Romania two catchments areas were chosen to test our model outside Switzerland.

The first basin tested is around Lake Surduc (Figure 1), located in the west of Romania. It was chosen to highlight the behavior of our model when the basin contains a lake. The area of the basin is 42 km^2, of which 3.57 km^2 represent the lake. Lake Surduc is the largest lake in the Timis area. It is used for drinking and industrial water in Timisoara city and for micro-hydropower. The second basin (Figure 2) is positioned in Nord of Oravita and was selected to test the capability of our model to determinate the flood plains in this area.

3.3. Data available

For the basins in Switzerland, we have data for several weather parameters, water flows, the 25m DEM and simplified geotechnical map of 30 terrain types. They are determined as follows. Altimetry data were obtained from the DEM (Digital Elevation Model) based on contour lines, made available to us by Swisstopo. Weather data were provided by the Federal Office of Meteorology and Climatology. The granularity of this data is ten minutes, measured by an

For the Romanian basins this data was unavailable so a theoretical rain was used.

3.4. Results

The results obtained in this article focus firstly on the calibration of our developed hydrological model and secondly on its application in Romania.

The calibration was done for two flood events: the first on August 7, 2004 on Allenbach (storm of 2 hours) recording a peak flow of about 60 m3 / s and that of 7 June 2007 on the Sitter reaching a peak rate of about 76 m3 / s.

The temporal granularity of available rain data is ten minutes, but our model requires a finer granularity of three minutes. To get it, we recalculated the structure of the rain through linear interpolation. The rain used in our calculation is distributed uniformly in space and varying in time. This distribution reflects the fact that rainfall measurements are only available for one point of the terrain.

The calibration focuses on estimating the parameters introduced in the developed model [4]. To determine these parameters, we have established an order of priority. The first parameter to determine is the volume of water that can infiltrate into the ground. The second parameter is the hydraulic conductivity, which influences the velocity of groundwater flow. The third and fourth parameters influence the velocities of surface runoff. They are the roughness coefficient and the river width for each type of flow used in the Manning equation. The last parameters to be determined are the initial and final infiltration capacity for each soil type. These parameters were established based on literature and a simplified map of 30 soil types.

The influence of parameters on the flow at the outlet is as follows. The roughness coefficient and width of rivers act primarily on the concentration time of the basin and the value of peak flow. The volume of water infiltrated influence the initial part of the hydrograph, ie the increase rate of the flow. Finally, the hydraulic conductivity has a double influence. At the beginning of the episode, it can increase throughput by causing more exfiltration, but at the end of the episode, the effect is reversed because there is less water remaining in the underground. This dual effect may also be observed for infiltration capacity. If it increases, the flow is reduced at the beginning of the episode, but also increased towards the end.

Flow modeling produced from a DEM gives a discrete representation of a surface assumed continuous. The DEM has a mesh size of 25x25 m. This modeling is done through an iterative procedure by calculating the volume of water that spreads from one cell to its neighbors across the field. In the end, the outlet is determined as the point of maximum flow.

Figure 5 and Figure 6 show in white the streams formed automatically based on the topography of the land without any manual processing of water pathways. Figure 7 and Figure 8 show the results obtained after setting the model parameters. The observed flow is represented with a continuous line while the flow simulated by our model is represented with a dashed line. The parameters used are specific for each type of flow and for each watershed.

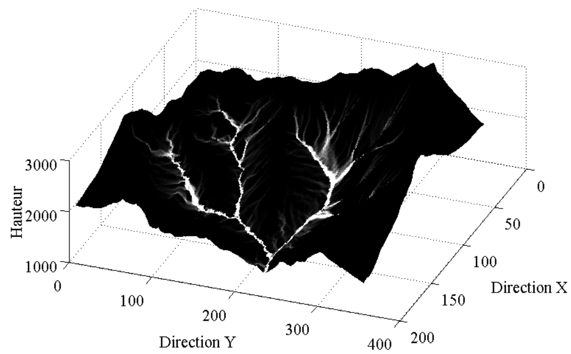

Figure 3. River network (Allenbach)

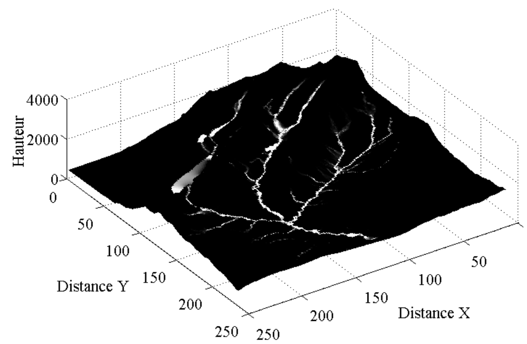

Figure 4. River network (Sitter)

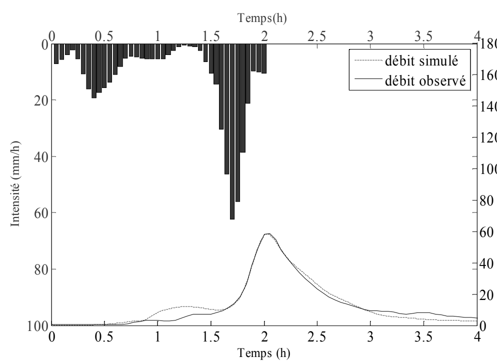

Figure 5. Histogram of rain and flood hydrograph (Basin - Allenbach)

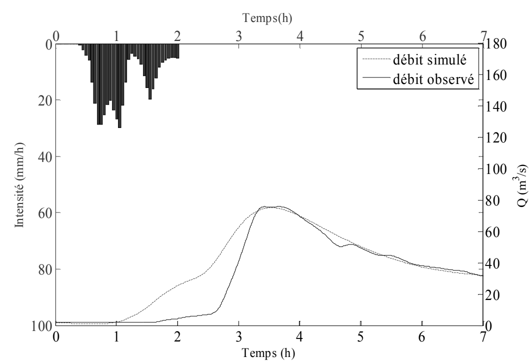

Figure 6. Histogram of rain and flood hydrograph (Basin-Sitter)

The measured and simulated flows were compared using the Nash equation (1), the water volume ratio (2) and the peak flow ratio (3), as follows:

$$Nash = 1 - \frac{\sum_{t=0}^{n} (Q_{obs}(t) - Q_{sim}(t))^2}{\sum_{t=0}^{n} (Q_{obs}(t) - \overline{Q_{obs}(t)})^2} \quad (1)$$

$$r_{vol} = \frac{V_{sim}}{V_{obs}} = \frac{\sum_{t=0}^{n} Q_{sim}(t)}{\sum_{t=0}^{n} Q_{obs}(t)} \quad (2)$$

$$r_{pic} = \frac{Q_{sim\max}}{Q_{obs\max}} \quad (3)$$

where Qobs(t) = the observed flow, Qsim(t) = the simulated flow, $\overline{Q_{obs}}$ = the average of observed flow, Vsim = the average of simulated flow; Vobs = volume simulated, Qsimmax = peak of the observed flow, Qobsmax = peak of simulated flow.

Table 1: Evaluation of model calibration

	Calibration basin Allenbach	Calibration basin Sitter
Nash Coefficient	0.96	0.80
rvol	1.03	1.20
rpic	0.99	0.97

The Nash coefficient can vary between - ∞ and 1. A coefficient of 1 indicates a perfect match between the simulated and the measured flows. According to this analysis using the equation Nash, our model follows very well the evolution of the flow in the two basins for the rain events taken into account. A coefficient of 1 indicates a perfect match between the simulated and the measured flows According to this analysis using the equation Nash, our model follows very well the evolution of the flow in the two basins for the rain events taken into account. After calibration, our model manages to estimate very well the concentration time and, at the same time, the value of peak flow in the two basins and for the two flood events studied. The temporal evolution of the simulated flow also shows a good correlation with the observed flow, as shown by the Nash coefficient.

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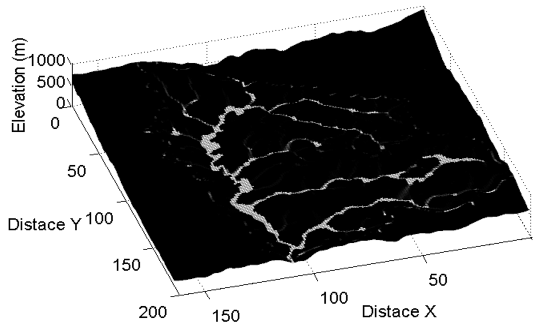

Figure 7. River network (Surduc- Romania)

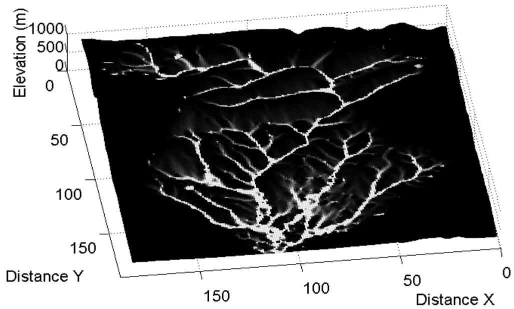

Figure 8. River network (N Oravita- Romania)

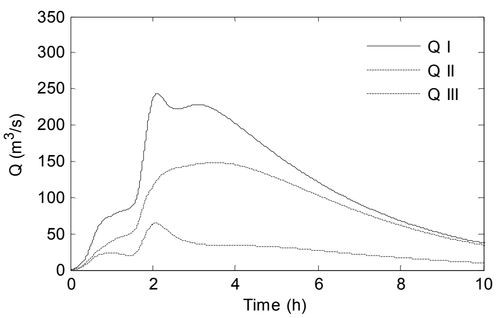

Figure 9. Histogram of rain and flood hydrograph (Basin - Surduc- Romania)

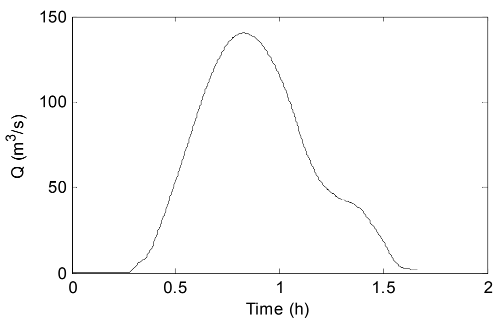

Figure 10. Histogram of rain and flood hydrograph (Basin - N Oravita- Romania)

On the other hand there are some differences, such as for the Sitter watershed for which the simulated flow begins to rise earlier than the observed, which starts later but rises much faster to finally reach the same value. This kind of difference could be justified by the fact that the real rain is not uniform, and it is possible that the real rainfall is higher near the outlet, resulting in a more abrupt increase in flow. Despite these differences, the correspondence between the two rates is very good.

The calculation for estimating water flow in Romania used our model for the two catchments in a theoretical case, since rainfall data was unavailable.

The rain has a spatial and temporal distribution obtained using the first module developed in our model, that is, we use several moving clouds to distribute the precipitation. For these examples we admitted one soil type for these basins and identical parameters to the case of the Allenbach catchment.

On the Surduc basin we show the three points of maximum flow on the border of the lake. Q I represents the flow at the lake entrance, while Q II and Q III the two largest tributaries. On the Oravita basin, the flow is presented at the outlet.

The figures show that our model can easily reproduce the river network from a DEM and give estimates of water flow which could further be used to determine the floodable areas in these basins.

4. CONCLUSION

The aim of this paper is to present our distributed hydrological model for estimating extreme flood with a goal of reducing risk. We have shown how to perform the calibration of such a model even with very little data on the ground. We described the main parameters of our model by detailing the influence of each on the flow at the outlet. This description of the calibration process is an important contribution brought in this article. The results showed a very good correlation between simulated and observed flows, and for two alpine catchments of different sizes and two episodes of summer storm. This good correlation shows that the model is valid and gives us confidence that these results can be extrapolated to the phenomena of extreme rainfall of PMP.

We also presented results on two Romanian basins showing how the model can reconstruct the river network and estimate flows for a precipitation episode. As future work, we need to obtain flow measurements for these basins which will be used for calibration.

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