ABSTRACT

Micro scale simulation of extreme precipitation and floods. Application to small alpine catchments without glaciers

Floods and dam overtopping risks, especially for earth fill dikes, during strong rainfall, preoccupy the authorities and the population since long time. Studies accomplished during the last years showed that the global warming of climate was accompanied by an increase in strong rainfall frequency and consequently in flood events in Switzerland and in numerous regions of the globe during the 20th century. The global and regional climatic models envisage that the frequency of the strong rainfall should continue growing during the 21st century in Switzerland and in the world. This makes the current research on rainfall-runoff modeling more important.

In Switzerland, in order to assure a good protection on both the human and the economic plan, maps of probable maximum precipitation (PMP) were developed. The PMP was confronted to the extreme rainfall measured in the different regions of country. This PMP is then used by the hydrological models to calculate the probable maximum flood (PMF).

Even though the PMP-PMF method exists, it requires a certain number of precautions. If it is applied incorrectly or on the basis of insufficient data, it can lead to an overestimation of flood events, particularly for large basins and mountainous regions leading to significant additional costs.

These problems result in particular from the fact that most of the hydrologic models distribute the extreme rainfall (PMP) uniformly in time throughout the watershed. To address this problem, this thesis has as main goal to develop a distributed hydrological model, called MPF (Modeling Precipitation Flood) capable of estimating the PMF in a realistic way from a spatio-temporal distribution of PMP using clouds.

The developed MPF model consists of three major parts. In the first part, the extreme rainfall calculated by a meteorological model at the mesoscale with a horizontal resolution of 2 km is distributed at a local scale (25 or 50 m) in a non-uniform way in space and in time. The second part concerns the modeling of the runoff and the subsurface flow including infiltration and exfiltration. And the third part includes snowmelt modeling based on the heat transfer calculation. The MPF model was calibrated on alpine watersheds where rainfall and flow data is available for a considerably long period, which includes several episodes of heavy rainfall and flow rates. From these events, the model input parameters such as soil roughness and the average width of the river in the case of surface runoff were estimated. Following the same procedure, the parameters used in the simulation of subsurface flows are also estimated indirectly, since direct measurements of subsurface flow and exfiltration are difficult to obtain.

The model of spatiotemporal rainfall distribution has also been validated by using radar images containing the structure of the rain caused by a supercell cloud. The hyetographs obtained on several points of the terrain are very close to those recorded with radar images.

The results of the model validation on strong floods episodes show a good accordance between the simulated and observed flow. This correlation was measured with three efficiency criteria, all of which have given satisfactory values. This shows that the developed model is valid and can be used for extreme events such as the PMP.

Simulations have been made on several watersheds having the PMP rainfall as input data. Various conditions such as the situation of saturated or non-saturated soil, or the presence of a snow layer on the ground at the time of the PMP were considered, which leads to an estimate of PMF for catastrophic scenarios.

Finally, the obtained results show how to better estimate the value of the dam safety flood from a 10’000 years return period extreme precipitation.

Keywords: Probable Maximum Flood (PMF), Probable Maximum Precipitation (PMP), distributed hydrological model, outlet, alpine catchment, MPF (Modeling Precipitation Flood).