Geophysical Research Abstracts,
Vol. 11, EGU2009-5156-1, 2009
EGU General Assembly 2009

Analysis of flood hazard under consideration of dike breaches

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The study focuses on the development and application of a new modelling system which allows a comprehensive flood hazard assessment along diked river reaches under consideration of dike failures. The proposed Inundation Hazard Assessment Model (IHAM) represents a hybrid probabilistic-deterministic model. It comprises three models interactively coupled at runtime. These are: (1) 1D unsteady hydrodynamic model of river channel and floodplain flow between dikes, (2) probabilistic dike breach model which determines possible dike breach locations, breach widths and breach outflow discharges, and (3) 2D raster-based diffusion wave storage cell model of the hinterland areas behind the dikes. Due to the unsteady nature of the 1D and 2D coupled models, the dependence between hydraulic load at various locations along the reach is explicitly considered. The probabilistic dike breach model describes dike failures due to three failure mechanisms: overtopping, piping and slope instability caused by the seepage flow through the dike core (micro-instability). Dike failures for each mechanism are simulated based on fragility functions. The probability of breach is conditioned by the uncertainty in geometrical and geotechnical dike parameters. The 2D storage cell model driven by the breach outflow boundary conditions computes an extended spectrum of flood intensity indicators such as water depth, flow velocity, impulse, inundation duration and rate of water rise. IHAM is embedded in a Monte Carlo simulation in order to account for the natural variability of the flood generation processes reflected in the form of input hydrographs and for the randomness of dike failures given by breach locations, times and widths.

The scenario calculations for the developed synthetic input hydrographs for the main river and tributary were carried out for floods with return periods of T = 100; 200; 500; 1000 a. Based on the modelling results, probabilistic dike hazard maps could be generated that indicate the failure probability of each discretised dike section for every scenario magnitude. Besides the binary inundation patterns that indicate the probability of raster cells being inundated, IHAM generates probabilistic flood hazard maps. These maps display spatial patterns of the considered flood intensity indicators and their associated return periods. The probabilistic nature of IHAM allows for the generation of percentile flood hazard maps that indicate the median and uncertainty bounds of the flood intensity indicators. The uncertainty results from the natural variability of the flow hydrographs and randomness of dike breach processes. The same uncertainty sources determine the uncertainty in the flow hydrographs along the study reach. The simulations showed that the dike breach stochasticity has an increasing impact on hydrograph uncertainty in downstream direction. Whereas in the upstream part of the reach the hydrograph uncertainty is mainly stipulated by the variability of the flood wave form, the dike failures strongly shape the uncertainty boundaries in the downstream part of the reach.

Finally, scenarios of polder deployment for the extreme floods with T = 200; 500; 1000 a were simulated with IHAM. The results indicate a rather weak reduction of the mean and median flow hydrographs in the river channel. However, the capping of the flow peaks resulted in a considerable reduction of the overtopping failures downstream of the polder with a simultaneous slight increase of the piping and slope micro-instability frequencies explained by a more durable average impoundment.

The developed IHAM simulation system represents a new scientific tool for studying fluvial inundation dynamics under extreme conditions incorporating effects of technical flood protection measures. With its major outputs in form of novel probabilistic inundation and dike hazard maps, the IHAM system has a high practical value for decision support in flood management.