Geophysical Research Abstracts, Vol. 7, 04672, 2005
SRef-ID: 1607-7962/gra/EGU05-A-04672

A preliminary review of rainfall thresholds for the initiation of landslides

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In 1980, Nel Caine published a well know report in which he proposed the first rainfall intensity-duration threshold for the initiation of mass movements. The work of Caine was based on the analysis of 73 rainfall events word wide that resulted in shallow landslides, i.e., natural slope failures with a depth of less than 3 meters. Since 1980, many different investigators have used, tested and criticize the intensity-duration curve of Caine, and have proposed new local, regional and national thresholds. In the framework of the RISKAWARE (Advanced Weather forecast system to Advise on Risk Events and management) Interreg III C - CADSES European Project, we report on a preliminary attempt to revise the world-wide intensity-duration threshold proposed by Caine, and to critically review the literature on rainfall thresholds for the initiation of mass movements. Given the scope of the EU project, care was taken to examine the advantages and the limitations of the available rainfall thresholds in the framework of early warning systems for civil defence against meteorological hazards. To accomplish this work we have systematically searched the literature, examining more than 120 published papers and technical reports discussing the rainfall conditions and the meteorological and climatic settings that resulted in slope failures. From more than 30 reports we have obtained quantitative information on the rainfall conditions that resulted in mass movements, and from 20 reports we have obtained published rainfall thresholds. We obtained quantitative information on rainfall induced landslide events in 20 countries, in 5 continents, which we show on a word map. We use this information to prepare an intensity-duration plot that shows 557 points representing rainfall conditions that resulted in individual or multiple rainfall induced landslides, and 269 points showing rainfall conditions that did not result in mass movements. In the plot,

we rank the events based on the type of the triggered landslides (e.g., shallow slide, soil slips, debris flows, slide, or landslide of unknown type). In the same plot we show 10 intensity/duration thresholds proposed in the literature for the initiation of slope failures in different parts of the world. Most of the curves are empirical, obtained by drawing lines that best separate rainfall conditions that resulted in slope failures from those that did not resulted in mass movements. Surprisingly, we find little information on quantitative, probabilistic or statistically based thresholds. We further attempt to classify the many different thresholds proposed in the literature for the occurrence of landslides, including: intensity/duration thresholds, various normalized intensity/duration thresholds, and thresholds that consider in several different ways the antecedent rainfall, climatic and soil conditions. We list the information required to obtain each threshold, we examine the field of applicability of the thresholds, including the physiographic region, the climatic setting and the landslide type for which they were proposed, and we critically analyse their potential use in early warning systems for civil defence against meteorological hazards.