Strengthening Local Authorities in Flood Risk Management: A case study from Naga, the Philippines

D. Alkema, K. Tennakoon, J. Otieno and N. Kingma

ITC / Department of Earth Systems Analysis
PO Box 6
7500 AA Enschede,
The Netherlands
Phone: +31-(0)53 4874 286
Fax: +31-(0)53 4874 336
E-mail: alkema@itc.nl

Abstract

The city of Naga is a medium sized city on the isle of Luzon in the Philippines. It is located in an area that is frequently hit by typhoons that cause severe inundations of the city and the surrounding agricultural lands. Several types of floods affect the area, sometimes in combination: a) riverine floods from the Bicol, the main river in the area, b) flash-floods from the torrent Naga, and c) storm surges from the sea. In close collaboration with the municipality of Naga, a research program was initiated to investigate to what extend hydrodynamic modelling can be used as an instrument to: a) assess the flood hazard situation in terms of inundation probability and b) to make a risk assessment based on the flood hazard and the elements at risk. This paper presents the first results of flood inundation modelling. In the future the city intends to use these models as simulation tools to support decision-making in designing mitigation measures and to assess the suitability of potential urban expansion sites.

1   Introduction

Urban risk is rapidly increasing, particularly in developing countries, where urbanisation is often occurring in areas susceptible to disasters. Almost half of the world population lives in cities, where all kinds of human activities are concentrated. Thus, cities are more and more vulnerable to disasters, particularly to earthquakes, and flooding. Whereas large cities often are able to attract the resources and capacity to set-up disaster management information system, medium-size cities most often lack these possibilities. In order to improve the safety of these communities, and consequently make them more sustainable and prosperous, a GIS based risk assessment and decision support systems for disaster management should be developed and implemented. This study aims at developing a methodology for flood risk assessment and decision support that can be beneficial for local authorities in planning and for managing disasters. This paper presents the first results of a collaboration with the city of Naga, the Philippines. During the first stage, emphasis was put on the application of deterministic flood models and Geographic Information Systems flood hazard assessment and how these can be used in the decision process.

2   Flood hazard and risk assessment

Floods are natural phenomena, that are part of a river's discharge fluctuations and extreme events can inundate large areas along the river's main coarse. This causes many problems when these areas are used for urban settlement, industrial zones, infrastructure, etc. which is not unlikely given the fact that alluvial plains are attractive for settlement for many reasons. They usually are fertile and their relative flatness offers many advantages for construction of buildings and roads. With increasing population and expanding cities more and more people move into areas that are not suitable for permanent settlement. The result is that floodplains are among the most densely populated areas in the world now and that a lot of valuable property is concentrated here. The consequences of floods are far reaching and will have enormous impact on the local – and sometimes national – economies. Today, flooding is the leading cause of losses from natural hazards and is responsible for a greater number of damaging events than any other type of natural event, worldwide. Especially developing countries are hit hard by flooding disasters for several reasons: 1) Many developing countries lie within areas that are subject to (extreme) variable climatologic conditions; 2) Rapid population growth and migration towards cities accelerate the uncontrolled expansion towards less suitable areas; 3) Limited (or absent) resources inhibit the construction of protection measures and hinder disaster preparedness investments; 4) Low resilience reduces the capacity to recover from the consequences of the flood. This not conclusive short-list illustrates the enormous challenges that city authorities in developing countries face in their efforts to reduce flood risk and to formulate a sustainable floodplain management plan. Assistance in their effort could be given by the application of

mathematical models to simulate flood events in order to get a better understanding of flood-behaviour and its consequences.

Flood management is a broad spectrum of water resource activities aimed at reducing potential harmful impact of floods on people, environment and economy of the region (Simonovic, 1999). This implies that floods are a problem when they interfere with things that we care about, like human life and well-fare, economic consideration and environmental concerns. According to Varnes (1984) the expected number of lives lost, injured persons, damage to properties, or disruption of economic activities can be expressed by the formula:

$$RISK = HAZARD \times VULNERABILITY \times VALUE$$

The HAZARD represents the probability of occurrence of a flood of a certain magnitude. The VULNERABILITY is defined as the inability of an element or system to maintain its structure and pattern of behaviour due to the flood. The VALUE indicates the worth of the element or system, which can sometimes be expressed in monetary terms, but which can also be identified as intrinsic-, scientific-, sentimental- or ecological value. A proper risk assessment therefore requires knowledge of the hydrological processes that form the source of the flood-hazard and of the valuation of the socio-economic consequences. This can be done in a three-step approach:

1) *Catchment modelling*; how does the river respond to extreme climatologic events and what is the potential maximum discharge at various locations along its coarse.
2) *Flood propagation modelling*; what happens when a certain discharge passes through a certain section of the river; will the dikes be overtopped or not, or what will happen if the dikes breach at certain locations.
3) *Risk valuation*; If the dikes are overtopped or breached, what are the consequences for the people living and working in the inundated area. Is there time for evacuation, are critical buildings in danger (schools, hospitals,...) and what is the possible total economic and non-economic damage?

This sequence of analysis is a very useful approach for flood managers, because it allows the application of models to simulate "what-if"-scenarios to evaluate the risk situation. This can be done for the present situation, but also for the evaluation of the consequences of new developments in flood prone areas. This information about a future situation is very relevant during the planning design phase of new developments. If the overall risk increases, additional measures are needed to mitigate the negative side-effects of the new development or may even lead to a complete new plan or in the termination of the project. Another possible application is to evaluate the potential benefits of new flood defence systems by checking if the present "real" costs can be balanced against the future "virtual" benefits of avoided flood loss.

The first two steps are typical hydrological studies: The aim of the first step is to transform catchment characteristics like topography, relief and land cover, complemented with precipitation data, run-off, groundwater flow, snow-melt, etc. into estimates of the discharge at various location along the river downstream. The second step is usually carried out at a local to regional scale, at a selected stretch of the river. The aim of this step is to obtain the characteristics of a flood as it enters and propagates through the area that is being inundated and gives information on how fast the water will flow, how long it takes for the water to arrive at a certain location, how fast the water level rises, etc. It will show the effects of the surface topography, like embanked roads and different land cover types. The third step requires knowledge of the vulnerability and value of the elements exposed to the floodwater. Agricultural activities suffer damage in a different way than for instance an urban area. Furthermore it should be noted that not all damage can be quantified in monetary terms, like health and psychological consequences. Therefore an analysis is required that transforms the results of the flood propagation characteristics into a valuation of the risk. Experience from past floods, economic analyses, agricultural expertise, emergency practice and knowledge from many other disciplines need to be combined to arrive at an integrated risk assessment.

3   Flood modelling

The application of predictive models for flood hazard assessment is already widespread for many years. The approach can be very simple, like intersecting a plane that represents the water surface with a digital elevation model, to very sophisticated like the full three dimensional solutions of the Navier-Stokes equations. But two main approaches in predictive modelling seem the most popular, though their application depends strongly on the problem at hand. The one-dimensional solution of the St. Venant equations (see e.g. Fread, 1992) is often applied for discharge modelling on catchment scale, for instance with the models MIKE11 or HEC-RAS (see e.g. Brunner, 2002). These models require a characterization of the terrain through a series of cross-sections perpendicular to the direction of flow. For each cross-section the average water depth and flow velocity are calculated, but for the areas between the cross-sections these values need to be estimated by interpolation. The assumption is that all flow is parallel to the main direction of the river channel. Flow perpendicular to this direction is not considered. Therefore for inundation of more complex topography a two-dimensional approach is more useful. These two dimensional models, like Delft-FLS (Stelling et al. 1998 and Hesseling et al. 2003), LISFLOOD (Bates and De Roo, 2000), Telemac 2D (Hervouet and Van Haren, 1996) and MIKE_21 (Abbott and Price, 1994) are finite difference or finite elements models, based on the conservation of mass and energy (or momentum). They require a continuous representation of the terrain topography.

Whatever approach seems the most appropriate for a given problem, the application of such kind of deterministic modelling poses high demands on the data, the modelling skills, computation power and interpretation capabilities of the hazard assessment team.

4   Flood risk assessment

To assess the consequences for the socio-economic environment, the flood hazard indicators need to be transformed to flood risk. Some attempts have been made to make this transformation, e.g. the stage-damage curves of the US Army Corps of Engineers (USACE 1996) and the ANUFLOOD package in Australia (Smith, 1994) but these consider only the inundation depth. Gendreau (1998) combines inundation depth, duration and maximum acceptable return period into a risk assessment. Abt et al. (1989), Temez (1992) and Penning-Rowsell and Tunstall (1996), propose combinations of flow velocity and inundation depth to distinguish between hazardous and non-hazardous floods. The RIPARIUS project proposes a hazard and risk matrix in which hazard categories are defined by flow velocity, inundation depth, flood warning time and annual probability of flooding. In general, two types of risk assessment can be distinguished: Those that try to express the flood risk in monetary units (damage) and those that aim to evaluate the flood risks in terms of human life, well-being and degree of disturbance. The wide variety of methods and approaches to flood risk assessment, shows that transforming flood hazard indicators into a risk assessment is still awkward.

5   The Naga case study; preliminary results

The city of Naga is a medium sized city on the isle of Luzon in the Philippines. It is located at the confluence of the Bicol river and the river Naga. The main parts of the city are located at low elevation in flat terrain just above the average water level in the rivers. Since the area is frequently hit by typhoons, the city and the surrounding agricultural lands often suffer from floods. Several types of floods affect the area, sometimes in combination: a) riverine floods from the Bicol, the main river in the area, b) flash-floods from the torrent Naga that originates on the slopes of the nearby volcano and c) storm surges coming from the Bay of San Miguel (Pacific Ocean). When the rivers overflow their banks, domestic, commercial, industrial and institutional areas are inundated which causes a lot of human suffering, direct damage and disruption of the daily routine. In the last decades several studies were carried out for the city to analyse potential mitigation measures and some of these were implemented, like some embankments along the Bicol-river, but it seems that these have not reduced the flood risk significantly. There are two explanations for this. On the one hand there is an enormous increase in the vulnerability due to the almost uncontrolled growth of the city. More and more people are forced to live in marginal areas

along the river. On the other hand it also appears that the flood hazard itself has increased, for instance due to sedimentation within the embanked riverbed (Adolfo 2003). This study is part of a joint research with the municipality of Naga to introduce new technologies in flood hazard assessment in order to build risk reducing capacity.

5.1 2-D flood modelling on the Bicol flood plain

To assess the characteristics of the flood water as it propagates through the terrain, a 2 dimensional flood model is required. Initially the flood model Delft-FLS was used for this case study, but Delft-FLS was later integrated in the combined 1D-2D flood modelling package SOBEK of WL|Delft Hydraulics. The 2-D component is specially designed to simulate overland flow over initially dry land and through complex topography. The computation scheme is based upon the following characteristics:

- The approximation of the continuity equation is such that a) mass is conserved, not only globally but also locally and b) the total water depth is guaranteed to be always positive which excludes the necessity of "flooding and drying" procedures;
- The momentum equation is approximated such that a proper momentum balance is fulfilled near large gradients.

The combination of positive water depths and mass-conservation assures a stable numerical solution. A proper momentum balance provides that this stable solution converges. The robust numerical scheme allows for the correct simulation of sub-critical and super-critical flow. Further information regarding the model properties can be found in Stelling et al. (1998) and Hesselink et al. (2003).

1.5.1 Data requirements
Delft-FLS requires the following information:

- An accurate digital terrain model (DTM) that includes all topographical features with their correct heights and depths, like dikes, embankments, channels, sluices, tunnels, etc.
- Land surface cover information in terms of hydraulic roughness coefficients both for the "dry" (polder) and the "wet" (channels) surfaces.
- Discharge or water level time-series at the inflow boundary and a rating curve or water level time-series at the downstream boundary.

All spatial data has be available in raster format (ArcInfo ASCI-files).

1.5.2 Data output
The model produces three types of output: 1) It produces raster maps at predefined time-steps that show the spatial distribution of the water depth and flow-velocity; 2) it creates time-series at regular intervals of the water level and

flow-velocity at predefined locations and discharges though predefined cross-sections; and 3) it makes an animation file that shows the dynamic behaviour of the flood as it propagates through the polder.

1.5.3 Model sensitivity

Alkema and De Roo (in press) have tested the model on the real inundation of the Ziltendorfer polder during the 1997 Oder flood in Germany. Even though the inundation occurred here in a polder environment, the study areas are comparable in size and gradient. The results of this study showed that the hydraulic surface roughness coefficients affect the speed at which the area inundates, but that they do not influence the maximum water depth. Furthermore the model was found to be very sensitive to the presence and dimensions of obstructing elements. The predicted water level was affected by the quality of the downstream rating curve. It was concluded that in respect to water depth and arrival time of the flood water Delft FLS performed rather well. For other parameters, like flow velocity, validation was not possible.

5.2 Data

The flood simulations were done at two different scales: One set of simulations were carried out for the lower part of the Bicol flood plain, and another set for the immediate area surrounding the city of Naga. The lower Bicol flood plain comprises approximately the last 25 kilometres of the Bicol river and the estuary into the Golf of San Miguel. The border of the area considered is defined by the 5 m (a.s.l.) contour line, but most of the terrain varies in altitude between 0 and 2 meters (see fig. 1). The natural higher ground is formed by the alluvial fan of the Naga river that enters the plain from the East and by the natural levees along the meandering channel of the Bicol. Back swamps form the lowest and poorly drained parts of the area. Most of it used for wet rice production. To facilitate drainage, canals were dug in the 1970s as part of Bicol River Basin Development Project and dikes were constructed to offer protection against floods. Most of the data that was used in this study was produced by this development plan, including 1 meter contour maps, elevation measurements of infrastructure and hydrological information, like discharges, water levels and rating-curves. Additional measurements and observations were carried out during a field survey, carried out in September 2003. The land cover information was derived from satellite images like Aster and Landsat 7, complemented with ground truth observations.
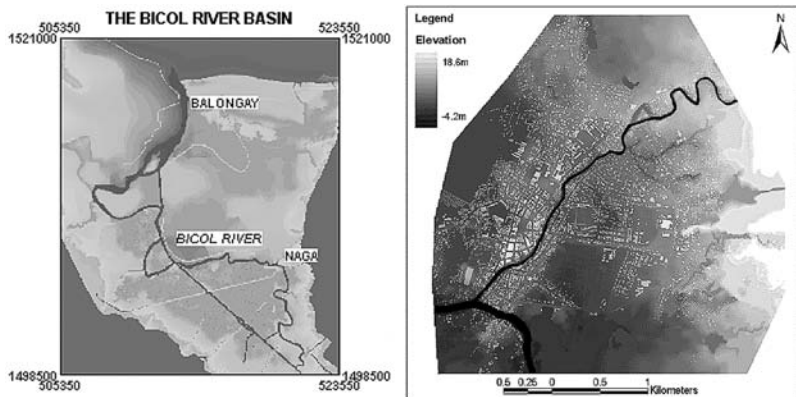
Figure 1:   Digital Elevation Models of the Bicol floodplain (left) and of Naga city (right).

5.3 Model results

The basis of this flood hazard assessment was the reconstruction of a flood event that occurred in 1988 caused by the typhoon "Yonning". First, several simulations were carried for the Bicol floodplain, where the hydrological conditions were set by a measured discharge from the Bicol at the upstream boundary and the sea level at the downstream end. These simulations yielded the boundary conditions for the detailed flood hazard assessment for Naga city. The output of the model calculations are transformed into several parameter maps that characterize different aspects of the flood event. Figure 2 shows four parameter maps: The maximum water depth, the maximum momentum of the water flow (inundation depth times flow velocity), the maximum speed at which the water level rose and the warning time. Other parameters that can be calculated based on simulations are e.g. duration of the inundation, flow velocity and potential sedimentation rates. Similar maps are derived for the detailed flood analysis within the urban centre of Naga. Figure 3 shows the water depth and the flow velocity at a certain time step as the flood water propagates through the streets.
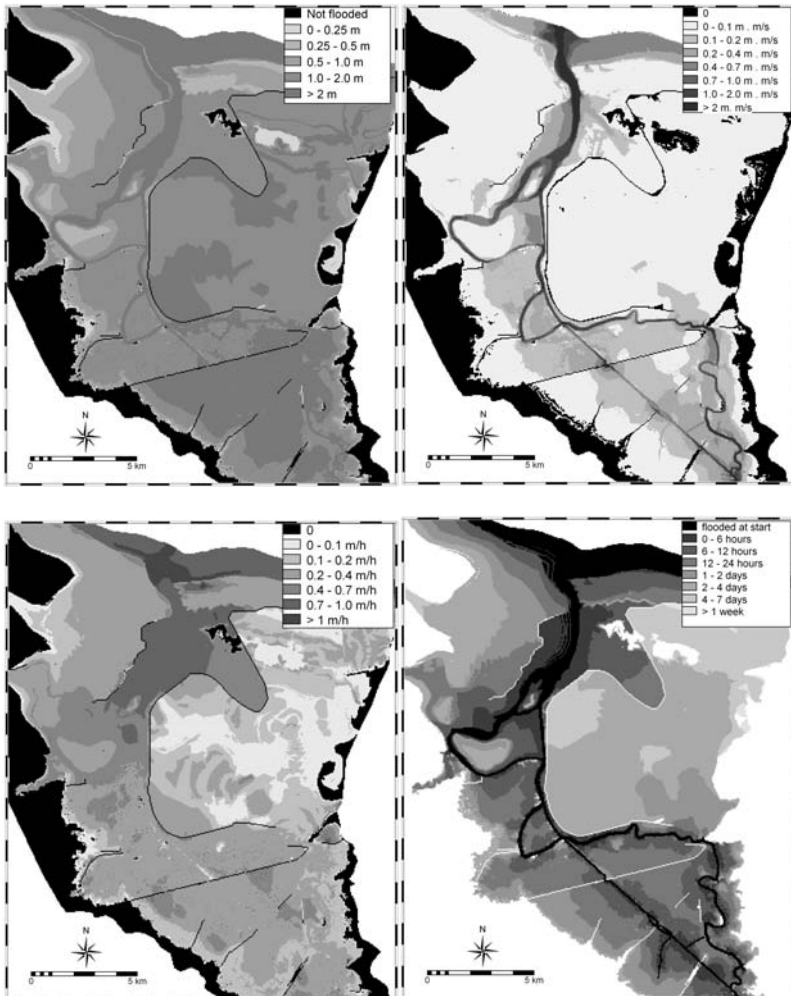
Figure 2: Simulated water depths (top left), momentum of the water flow (top right), speed of rising of the water level (bottom left) and the warning time (bottom right) for the 1988 Yonning flood event.
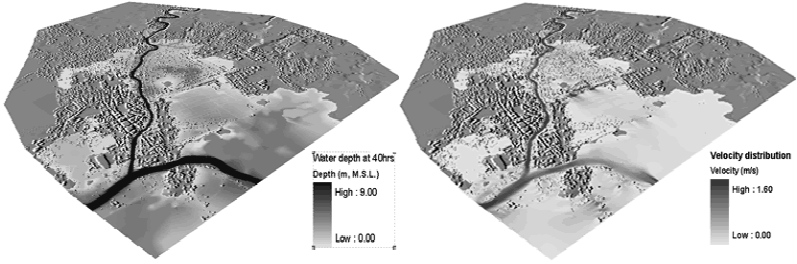
Figure 3:   Detailed flood
              simulations for Naga
              city Waterdepth (left)
              and flow velocity
              (right).

5.4 Model calibration

Model calibration was based on two sets of observation. The first was on maps
that indicated the average water depth per administrative unit for the Yonning
flood event. A second dataset was collected in the field by interviewing people
and requesting them to indicate the maximum inundation depth as they recalled.
The results of the comparison between simulated water depths and the depths as
it was remembered by the people are plotted in figure 4. The comparison
between district average depths and simulated depths showed similar results.
Even though there is a clear positive relation, the result deviate significantly
from the expected line x=y and it therefore concluded that these datasets have
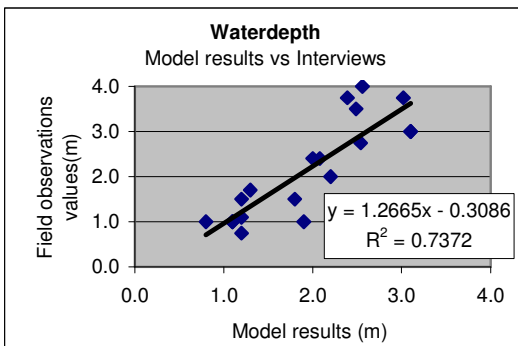little significance for model calibration and validation.

Figure 4:   Comparison between
              simulated water depths
              and inundation depths
              according to people's
              recollection.

6 Discussion

This paper presents the first results of a collaboration between a local government (the municipality of Naga, the Philippines) and a training & research institute (the ITC, the Netherlands). Through a joint research project, this collaboration aims at: a) Getting a better understanding of the dynamics of flood events on the Bicol floodplain and in the city of Naga itself, b) To transform this understanding in workable concepts of flood risk to create flood risk zonation maps and c) To train staff at the municipality so that in the future they'll be able to continue this kind of studies independently. Through a case study, a base dataset is constructed that allows the application of advanced hydraulic models. Since the model outcome depends to a large extent on the quality of the input data, much emphasis is put on a critical review of the accuracy of the available data. The results presented in this study are therefore not to be considered as predictions, but rather as a first step towards a continuous flood risk assessment methodology. It will take many more years of surveying and monitoring before a sufficiently accurate base dataset is constructed and calibration and validation data has been collected before a flood hazard forecast can be made. However, without such a start it is our believe that no funds will allocated to collect these data. The results of such a preliminary joint study, in tandem with capacity building at the local level, will help convincing authorities to invest in such a long term risk reducing endeavour.

The application of mathematical models allows the simulation of "what-if" scenarios so that the effect of all kinds of new developments on the flood characteristics can be assessed. 2D flood modelling can provide useful information for decision makers and can help in reducing flood risk.

7 Acknowledgement

References

[1] Abbott, M. B. and Price, W.A. (1994): Coastal, estuarial and harbour engineer's reference book. E and FN Spon, London. UK.

[2] Abt, R.S., Wittler, RJ. and Taylor, M. (1989): Predicting human instability in flood flows.Hydraulic engineering; Proc. Of the ASCE Hyraulic Division Conference

[3] Adolfo, J. and Calara, P.M. (2003): Erosion and development at the Bicol River Basin. Internet document Kaiba news and features.
www.geocities.com/kaibanews/permanent/previousissues/080702erosion.htm

[4] Alkema, D. and A. De Roo (in press): Testing of a 2D flood propagation model by reconstructing the inundation of the Ziltendorfer Niederung (Germany) during the 1997 Oder flood.

[5] Bates, P.D. and De Roo, A.P.J. (2000): A simple raster based model for flood inundation simulation. Journal of Hydrology 236 (p 54-77). Elsevier.

[6] Brunner, G.W. (2002): HEC-RAS River Analysis System; Hydraulic Reference Manual. US Army Corps of Engineers, Davis, USA.

[7] Fread, D.L. (1992): Flow Routing. In: Maidment, D.R. (Ed): Handbook of Hydrology. Pp 10.1 – 10.36 McGraw – Hill, Inc. New York, USA.

[8] Gendreau, N. (1998): Protection objectives in flood risk prevention. Proceedings of the Brittish Hydrological Society International Conference, Exeter, UK 6-10 July 1998, p. 145-154.

[9] Hesselink, A.W., G.S. Stelling, J.C.J. Kwadijk, and H. Middelkoop (2003): Inundation of a Dutch river polder, sensitivity analysis of a physically based inundation model using historic data. Water Resources Research Vol 39, No 9.

[10] Hervouet, J.M. and Van Haren, L. (1996): Recent advances in numerical methods for fluid flows. In: Anderson, M.G., Walling, D.E. and Bates, P.D. (eds): Floodplain Processes. Pp 183 – 214. John Wiley & Sons Ltd. England.

[11] Penning-Rowsell, E.C. & Tunstall, S.M. (1996): Risks and resources: Defining and managing the floodplain. In: Andersen, M.G., Walling, D.E. and Bates, P.D. (Eds) Floodplain resources. John Wiley and Sons, Ltd. London, UK

[12] Simonovic, S.P. (1999): Social criteria for evaluation of flood control measures: Winipeg case study, Urban Water, 1, 167-175.

[13] Smith, D.I. (1994) ; Flood damage assessment - a review of urban stage damage curves and loss-functions. Water South Africa, vol 20, no 3, July pp 231-238.

[14] Stelling, G.S., H.W.J. Kernkamp, & M.M. Laguzzi (1998), Delft Flooding System: A powerful tool for inundation assessment based upon a positive flow simulation. In: Babovic & Larsen (eds) Hydroinformatics '98. Balkema Rotterdam, the Netherlands.

[15] Temez, J.R. (1991): Planificación hidrológica-ordenación de zones inundables, CEDEX, Madrid, Spain.

[16] USACE - U.S. Army Corps of Engineers (1996): Risk-based analysis for evaluation hydrologic/hydraulics, geotechnical stability, and economics in flood damage reduction studies. Engineering regulation 1105-2-1-1 dated March 1,1996

[17] Varnes, D.J. (1984), Landslides hazard zonation: A review of principles and practice. UNESCO, Paris, Natural Hazards, v3.