

FLOOD MANAGEMENT AND RISK ASSESSMENT IN FLOOD-PRONE AREAS: MEASURES AND SOLUTIONS[†]

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ABSTRACT

Water-related disasters have increased considerably worldwide in recent years. While certain trends are global (like climate change), some actions to cope with these problems have to be taken locally. In any case, the land characteristics need to be known and analysed in order to cope with the hazards and avoid their transformation into damage or disasters when exceptional events occur.

This paper firstly presents preliminary definitions about the concepts of hazard, vulnerability, risk and damage/disaster, because there is a certain lack of uniformity in the use of terms, which sometimes causes confusion; thus definitions are offered, with special attention paid to flood problems. Then, risk analysis procedures are described, which consist of systematic actions in a cycle of preparedness, response and recovery, and would have to form part of integrated flood risk management. Moreover, flooding problem characteristics and the policy and related measures adopted by different European countries to protect themselves against floods, are considered and the lessons learnt from flood defence analysed, with the aim of featuring a new integrated flood management and mitigation approach that allocates more room for rivers and keeps a balance between present and foreseeable future spatial requirements of both water and people. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: flooding; risk management; flood protection measures; integrated flood risk management

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RÉSUMÉ

Les catastrophes liées à l'eau ont augmenté de façon considérable dans le monde entier au cours des dernières années. Bien que certaines tendances soient mondiales (comme le changement climatique), des actions pour faire face à ces problèmes doivent être prises au niveau local. En tout cas, les caractéristiques des terres doivent être connues et analysées afin de contrer les risques et éviter leur transformation en dommages ou catastrophes lorsque des événements exceptionnels se produisent. Cet article présente d'abord les définitions préliminaires sur les notions de danger, de vulnérabilité, de risque et de dommages/catastrophes naturelles, car un certain manque d'uniformité dans l'utilisation des termes induit parfois des confusions; des définitions sont donc proposées, avec une attention spéciale aux problèmes d'inondation. Ensuite, les procédures d'analyse des risques sont décrites, qui consistent en des actions systématiques dans un cycle de préparation, d'intervention et de rétablissement, et qui devraient faire partie de la gestion intégrée des risques d'inondation. En outre sont examinées les caractéristiques des problèmes d'inondations, les politiques et les mesures adoptées par les différents pays européens pour se protéger contre les inondations; les enseignements tirés de la défense contre les inondations sont analysés dans le but de bâtir un nouveau système de gestion intégrée des inondations et de méthode d'atténuation qui laisse plus d'espace aux rivières et maintienne un équilibre entre les besoins présents et futurs prévisibles de l'eau et des personnes. Copyright © 2010 John Wiley & Sons, Ltd.

MOTS CLÉS: inondations; gestion des risques; mesures de protection contre les inondations; gestion intégrée des risques d'inondation

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[†]Gestion des inondations et évaluation des risques en zones inondables: mesures et solutions.

INTRODUCTION

Floods are among the most damaging of natural hazards, and are likely to become more frequent, more prevalent and

more damaging in the future due to the effects of increase in population, urbanization, land subsidence and to a certain extent the impacts of climate change.

The nature and occurrence of floods are governed by diverse factors, including rainfall characteristics, properties of the drainage basin and land and water use and management in the river basin.

The terms “flood” and “flooding” are often used in different ways. According to Munich-Re (1997) flood is “a temporary condition of surface water (river, lake, sea) in which the water level and/or discharge exceed a certain value, thereby escaping their normal confines”. Flooding is defined “as the overflowing or failing of the normal confines of a river, stream, lake, canal, sea or accumulation of water as a result of heavy precipitation where drains are lacking or their discharge capacity is exceeded” (Douben and Radnayake, 2006).

Problems with floods and flooding are strongly related to population, population density and the improvement of the standard of living, especially in the emerging countries. An interesting feature in relation to population growth is the migration from rural to urban areas. The expectation is that due to this the population in the rural areas in the emerging and least developed countries will more or less stabilize and that the growth will be concentrated in the urban areas in these regions. In addition to this trend there is the expectation that within 50 years 80% of the world’s population will live in flood-prone areas, by far the majority of them in urban areas. This will require adequate drainage, flood management and flood protection provisions (Schultz, 2006b).

Although flooding is a serious hazard in humid regions, it can also be devastating in semi-arid regions, where high rates of runoff following storms may produce widespread flood damage down valley. Recurring floods are also typical in coastal and estuarine zones (Varnes, 1984).

To cope with these hazards, it is imperative that human society adopts an effective flood risk management approach, which has to be in harmonious coexistence with floods. In practical terms, the chance of flooding can never be eliminated entirely. However, the consequences of flooding can be mitigated by appropriate behaviour and actions. To be effective, the hazard approach must be embodied in the broader context of integrated river basin planning and management, and flood must be regarded as one of the many issues involved in the appropriate management of a river basin (Meadcroft *et al.*, 1996).

In the paper, after a preliminary definition of the key words used in the literature dealing with flood risk assessment, the main features of the risk analysis and flood and river basin management processes will be outlined, along with the lessons learnt from experiences in flood management and mitigation in Europe.

PRELIMINARY DEFINITIONS

Before the description of a possible methodology to carry out a risk analysis and its application to a number of case studies, it is necessary to provide some preliminary definitions, because of a certain lack of uniformity in the use of terms.

In a publication of the International Commission on Irrigation and Drainage (ICID) (van Duivendijk, 2005) *hazard* is defined as the “probability of occurrence of a potentially dangerous event in a fixed time range and in a fixed area”. In this definition the concepts of time and space are explicitly stated, but the event magnitude concept is not mentioned. The Einstein (1988) approach is quite different. The hazard concept definition is based on the geometrical and mechanical characteristics of the natural phenomenon. In this way the concepts of magnitude and area of a potentially dangerous event are explicit and hazard is defined as the “probability of occurrence of a danger in a fixed time range”.

In practice, *hazard H* is described in different ways in relation with the topic/issue (earthquakes, landslides, debris flows, etc.) dealt with. The return period is often used in order to characterise the events with fixed magnitude in a specific area. In this regard, a relevant aspect, neglected in Varnes’s definition, is the spatial propagation of the phenomenon. If the propagation is neglected, the risk analysis result is incomplete, because it is limited to the beginning of the process. Equally important, instead, is the probability that the wave reaches a certain place at a certain time. In this case it seems more appropriate to define it as induced hazard.

Exposure E can be defined as the “probability that a certain element be exposed to the risk when an event of fixed magnitude, in a fixed time range and in a fixed area, occurs”. Different authors define *E* as the “probability that an element be affected by a fixed hazard”. Sometimes exposure is also defined as a “quantitative index to sum up the number of persons and goods potentially subject to the event”.

Vulnerability V can be defined as the inverse of the resilience, where resilience describes the capacity of ecosystems to react against the stress. Thus, vulnerability represents the territorial system tendency to suffer damage during an extreme event. With reference to people, vulnerability can be assessed as the characteristics and situation of a person or group that influence their capacity to cope with, resist and recover from the impact of a natural hazard.

Risk R is the total damage caused by a specific event, and it can be obtained as a function of hazard, exposure and vulnerability: $R = H \cdot V \cdot E$.

According to the Swiss Civil Protection Agency, a disaster is an event where damage exceeds the capacity of the

affected society to recover by its own means. This definition is based on the economic capacity of the affected society, which means that the same event has different impacts depending on where it happens.

RISK MANAGEMENT

Risk is an integral part of social and economic processes and is often increased by human interference with natural hydro-meteorological phenomena. The struggle against extreme events like floods and droughts is as old as mankind. But in recent decades, new challenges are likely to influence risk management measures and policies. These challenges can be summarized as follows:

- increasing world population and economic growth lead to a more intense use of water and land resources;
- there is a rising awareness of the need for integrated flood risk management, considering the river basin as the basic planning unit;
- due to the relentless urbanization process, at worldwide level, hazards are increasingly transforming into disasters, putting development at risk;
- in flood-prone areas there may be the problem of land subsidence. This problem makes such areas increasingly vulnerable;
- climate change is likely to impact on climate variability, making extreme events more severe and more frequent. Anyway, compared to the items listed above, impacts of climate change are of limited importance: climate change causes changes in the order of magnitude of 10–30% per century, while the other processes may cause changes of 100–1000% per century;
- there is a rising concern that damage resulting from water-related disasters is growing disproportionately worldwide.

To cope with these challenges involves taking decisions and actions about appropriate levels of risks. These decisions and actions may be divided into the following two processes:

- risk analysis procedures;
- risk management cycle.

Risk analysis procedures

In recent years risk analysis has emerged as one of the most appropriate methods available nowadays to assess natural hazards, like floods and other water-related disasters. This methodology proved to be comparatively reliable in determining the hazard potential and the related probability

of occurrence of defined extreme events, even if modelling approaches differ.

This process requires expert knowledge to identify the potential risks and then to estimate the likelihood and the impacts of these risks. Risk likelihood and risk impact comprise uncertainty. In this context, the last two decades have seen amazing progress in the use of probability theory to assess uncertainty. Ang and Tang (2006) assumed that total uncertainty is an outcome of randomness and error in prediction. El-Cheikh *et al.* (2004) stated that while previous researches have employed the quantitative risk analysis (QRA) approach, they have also demonstrated the effectiveness of the probability theory and of other procedures, like Monte Carlo simulations and the fuzzy sets technique, in order to assess risks and to design a new risk analysis approach. These studies, however, do not tackle the logic behind the uncertain occurrence of the nominated risks, whether there is randomness behind the uncertainty or vagueness behind it.

In practice, the object of risk analysis changes, depending on both the hazard to be considered and the means or systems adopted to mitigate the damage. In this regard, floods are natural hazards, which occur periodically and episodically and cannot be prevented.

Therefore, the responsible authorities in most European countries developed methods of integrated risk management, which follow, mainly, the system engineering approach to express risk as a product of hazard and values at risk (El-Cheikh *et al.*, 2004), according to Equation (1):

$$R_{i,j} = p_{Si} \cdot A_{Oj} \cdot p_{Oj, Si} \cdot v_{Oj, Si} \quad (1)$$

where R is risk, p_{Si} probability of scenario i , A_{Oj} value at risk of object j (property or life), $p_{Oj, Si}$ probability of exposure of object j to scenario i , and $v_{Oj, Si}$ vulnerability of object j , dependent on scenario i .

Following Equation (1), it becomes apparent that all parameters have a linear influence on the result of risk analysis. The procedure of hazard assessment is methodologically reliable in determining the hazard potential and the related probability of occurrence (p_{Si}) by studying, modelling and assessing individual processes and defined design events. To this end, it is worth noting that, whilst in the past the concept of risk was primarily intended as a measure of the probability of a system's failure, it has acquired, nowadays, in pursuance of Equation (1), a more complex meaning. The risk has to be considered as a combination of both the probability and the magnitude of the consequences of a system's failure, and so, as the mathematical expectation of the consequence, taking into account all significant hazards and all significant mechanisms of failure (Mambretti *et al.*, 2008).

Therefore, the risk analysis procedure to be applied to a particular system should consist of two different and consequential phases: a first phase aimed at clarifying the object of the analysis and at defining the variables on which the risk depends, and a second one aimed at specifying the conditions and the modes of the considered system failure.

So far, little attention has been given to the damage potential affected by hazard processes, particularly concerning spatial patterns and temporal shifts. Studies related to the probability of exposure of an object to a defined scenario and the appropriate vulnerability of the object have predominantly been carried out so far as proposals to determine the risk to property and human life with the focus on risk within a specific location and specific points in time (Barbolini *et al.*, 2004).

There are many methodologies for flood risk assessment, and among them it is necessary to mention the fault tree, the probabilistic approach especially based on the Monte Carlo method. A detailed picture of these approaches can be found in recent literature (Van Gelder *et al.*, 2009; Floodsite, 2009).

It is worth mentioning the difficult task of assessing the potential loss of life, taking into account that the safety of people plays a role of paramount importance in the design of flood control measures. The number of fatalities depends not only on the physical characteristics of the flood, but also on the people's behaviour which is very difficult to predict and, generally, varies among countries. This is the main reason why the model proposed by HR Wallingford (2003) for the United Kingdom had to be modified to be applied to the rest of Europe (Priest *et al.*, 2009).

Risk management cycle

According to the International Strategy for Disaster Reduction (ISDR) (2004), the risk management cycle comprises "the systematic process, administrative decisions, organisation, operational skills and abilities to implement policies, strategies and coping capacities of the society and communities to lessen the impact of natural hazards and related environmental and technological disasters". This covers all forms of activities, including structural and non-structural measures to avoid or limit the adverse effects of hazards. On the whole, the risk management approach consists of systematic actions set up in a cycle of preparedness, response and recovery that should form part of any integrated flood risk management.

Preparedness consists of preventive and precautionary measures to prepare for an event before it occurs. It aims at minimizing the effect of development activities on accentuating the magnitude of hazards, reducing the exposure to natural hazards and minimizing the socio-economic

vulnerability of people and material assets exposed to these hazards. Response consists of measures that limit the effects of exposure to a hazard and its duration. It mainly focuses on alerting potentially affected people, rescuing victims and providing assistance in case of need. The recovery phase aims at enabling economic and social activities to return to normal with a minimum of delay. It also involves analysis of the disaster in order to learn lessons and integrate corrective measures into prevention and preparedness plans. To this end, it is important to underline that the effectiveness of the risk management cycle in reducing risks and damage depends, also, on the political will to apply risk management principles in developing planning, the existence of well-defined institutional responsibilities and on a democratic process of consultation and social control with effective governance.

The above principles of risk management should be applied for all risks. Preparedness, response and recovery require a sound knowledge of hazards. The key factors for risk management are time, extent of the impact and coping capacity of the society concerned. The challenge facing the international community is to support these activities, particularly in the least developed countries, where resources are limited, by means of actions aiming at:

- informing policy makers and the public of the trends in water-related risks and policy options to mitigate those risks;
- introducing long-term land use planning, taking into account the concerned aspects of flood risk management (including risk assessments) and adaptive management to reduce vulnerability to risks, which may increase over time, due to the processes as described above;
- raising awareness of water-related hazards and improving the capacity of communities to respond effectively;
- developing conventional and state-of-the-art technologies and monitoring systems tailored to local conditions for water-hazard alerts;
- fostering specific capacity development programmes for water managers.

FLOOD AND RIVER BASIN MANAGEMENT

The worldwide damage caused by flooding has been extremely severe in recent decades. No other natural hazard has appeared so frequently, claimed more human lives, generated such economic losses and ruined more fertile land (Douben and Radnayake, 2006). In the decade from 1986 to 1995, flooding accounted for 31% of global economic losses from natural catastrophes and 5.5% of the casualties (Borrows *et al.*, 2006).

It is assumed that under warmer conditions, due to the effect of climate change, the hydrological cycle will become more intense, stimulating rainfall of greater intensity and

longer duration, causing longer periods of flooding and droughts (Schultz, 2006a). To cope with such challenges, river basin management policies and flood mitigation measures must be implemented, enabling societies to increase their resilience to flood hazard, while ensuring that development efforts do not increase vulnerability to these hazards (Samuels *et al.*, 2006). The need for protective measures arises from the frequency and character of flooding and the potential damage to man and the environment.

The systematic approach to flooding problems

The objective of the systematic approach to flooding problems is to develop a set of measures suitable to reduce damage to an acceptable level and to maximize the efficient use of flood-prone land. To do this, it is necessary to integrate river basin management and flood hazard mitigation strategies into the broader context of river basin management both in terms of land and water management. In choosing between the strategies it is necessary to compare the effectiveness of the options against all the possible flood events.

Notwithstanding all these efforts, at present there are not sufficient and effective measures globally available to limit the growing chance and consequence of flooding. The evidence is that flood risk is increasing and continuing vigilance is needed to ensure that existing systems are maintained and improvements introduced. To this end, it is imperative that human society adopts the risk management approach outlined here, in such a way that there is harmonious coexistence with floods. In practical terms, the chance of flooding can never be eliminated entirely. However, the consequences of flooding can be mitigated by appropriate measures and actions. As previously underlined, the effects of climate change cannot be brought under control. However, suitable actions are both possible and needed to begin to reduce the exposure and vulnerability to flood hazard of people and property and, thereby, enhance flood security.

New, long-term strategies that address flood mitigation and control issues must include measures that are noticeably effective within the fundamental unit of a water management system, i.e. the river basin. To be effective these measures have to be integrated with other aspects, such as socio-economics, culture, nature and the environment. This process has led to the development of the so-called "Room for River" concept, which has become recognized as attractive for authorities managing river basins, at least in Western Europe, during the last decade (de Bruin, 2006). This concept has led to a substantial impact on the setting up of suitable measures, with respect to river basin management and flood protection, which are generally categorized as structural and non-structural (Schultz, 2001).

Flood protection measures: structural and non-structural. Structural measures of flood management are measures which alter the physical characteristics of the floods (storage in reservoirs, upstream river basin management, channel modifications, levees/embankments). Non-structural measures are measures which alter the exposure of life and property to flooding (floodplain land use planning, flood forecasting and warning, flood proofing, evacuation, insurance, etc.) (Van Dam, 1999). The first measures aim at reducing the challenge, the second enhance the coping capacity.

Challenges and developments

The objective of the systematic approach to flood hazard management is to maximize the efficient use of flood-prone land. To this end, the best solution is to regard the different structural and non-structural measures as complements, rather than as alternatives.

The use of a portfolio of mixed measures is always preferable because of the risk of failure of any single strategy. A fundamental stage of the process of evaluating and choosing a possible portfolio of measures would have to be an assessment of what will happen when it fails. It is therefore necessary to consider the effect of the whole intervention strategy across the entire spectrum of flood events at the river basin level. As a matter of fact interventions are usually targeted at reducing the impact of frequent floods in a particular area, but the impacts of these interventions on more extreme events must also be considered. The failure of a levee can result in worse flooding than if there had been no levee constructions (Office of Science and Technology (OST), 2004). Equally, considered across the entire spectrum of possible flood events, those sets of measures which attenuate the effects of floods across the entire spectrum of events are preferable to those which are effectively designed to cope with events of a given return time. Thus, improvements to storage capacity or channel capacity will usually, in principle, be preferable to embankments or levees since, if the channel capacity is increased, then there will be less water out of bank for all possible flood events. Conversely, if an embankment fails or is overtopped, the resultant flooding can be more severe than if there were no embankment.

Cost/benefit analysis is a useful way of analysing and comparing the different impacts of flood management options and measures not only in terms of reducing flood losses and increasing productivity, but also in their effects on the environment. In this context, public participation, through river basin management committees, represents a part of paramount importance of the frame concerning not only the selection of management strategies to adopt but also the long-term process of river basin management.

LESSONS LEARNT FROM FLOOD DEFENCE IN EUROPE

Flood risk management strategies have developed in the past under the influence of both the natural hazards that communities had to cope with and the political behaviour of societies. Hence, they could be considered the result of a cultural process. The human perception of floods has changed over time and so has the view on how to react to them.

At present, we are witnessing an increasing urgency to pay attention to flood risk management policy options as worldwide the risk is expected to increase. To this regard, recently UNESCO recognized that “something was wrong” in the old approach to flood risk management, given the “increase in numbers of victims and economic damage by floods during the last decades” (Rijkswaterstaat, 2000). It was recognized that floods result in real disasters because of the secondary effects, e.g. diseases from poor sanitation. This increase can be only partly attributed to climate change. But more important seems to be the growing populations, especially of urban areas. It was estimated that only 20% of the increase of flood risk is caused by climate change, whereas demographic and economic developments are responsible for the other 80% of the increase (Newson, 1992). In fact the 20% is even a high estimate, while the man-induced changes in land use and subsidence generally by far outweigh the impacts of climate change (Schultz, 2006a). This recognition brought about a shift away from control of the flood hazard (structural defence measures) towards managing flood risks through influencing and reducing the vulnerability of the society (non-structural defence measures).

The “Room for River” concept

Until recently it was standard policy to raise the crest level of the dikes to maintain the required level of flood protection. This century-old policy was abandoned at the dawn of the new millennium, in favour of the “Room for River” approach (Rijkswaterstaat, 2000). This paradigm change was based on the understanding that absolute protection against floods is unachievable. Therefore, the approach to managing flood risks shifted away from just protection to a more holistic risk management process resorting, mainly, to non-structural measures like flood forecasting, early warning and spatial planning. In the new approach to flood management, river cross sections are widened by situating the main dikes further away from the river, or by lowering the river forelands.

This process will lead to lower flood levels and to a new balance between present and foreseeable future spatial requirements for different land uses. Both people and water

need the resource of floodplains, and the new challenge is to design ways of sharing riverine room between floods and people. In practice, this changing view is reflected by the wealth of plans which are being drafted or already implemented in different European states.

Examples of flood defence policies

In the United Kingdom over the twentieth century, three stages can be discerned with regard to flood management strategies. From the 1930s to about 1970, there was strong impulse on drainage works for agricultural purposes, with a policy for flood. From 1970 to the early 1990s economic reasons predominated, leading to a flood defence priority aimed at protecting people and property. From the mid 1990s onwards, there has been a gradual shift towards flood risk management, under the influence of an environmental movement. This new trend culminated in the Making Room for Water Project carried out in late 2004, to meet the requirements of the “Room for River and People” approach. This project investigated drivers, responses and scenarios for flood risk over a timescale of 100 years. The scenarios took into account different policy frameworks for the country and the project considered flooding from all causes: urban storms, river, estuarine and coastal flooding. The “Making Room for Water” Project set out an integrated portfolio of approaches which reflect both national and local priorities and highlights the importance of non-structural measures, in particular spatial planning, in the context of both the flood risk and water management approaches.

In Germany, because of the federal structure of the country, plans have been made at various levels. There is a Flood Protection Act at the federal level, and there are water management plans in most *Länder*, which address the issue of flood risk at the local (*Länder*) level. This means that there is no single managing framework responsible for the whole country, and that things may be arranged differently in different *Länder*, which is the logical consequence of the federal structure.

The Netherlands has a long tradition of flood risk management, which gradually developed towards a flood defence approach in the 1950s. It led to the installation of the so-called Delta Committee and came up with the Delta Plan endorsed by the government. The Delta Plan focused mainly on the coast, but in its wake the polders on the flood-prone areas along the large rivers were dealt with similarly. The Plan established varying flood protection levels for different areas of the country, that still represent the design standards for flood protection and prevention in coastal areas and along the major rivers (Van Boetzel and Schultz, 2005).

During the implementation of the Plan, changes were made in the design of flood defences in accordance with the

standards of the “Room for River and People” concept. Factors like the growing awareness of sedimentation processes and of the need to preserve ecological systems and permit commercial navigation led to the “A Different Approach to Water 2000” policy document that features the government’s position on water management policy in the twenty-first century. Important principles in this respect are: greater flexibility in flood and water resources management and a three-step strategy of absorption, storage and discharge. Moreover, the Dutch government decided to anticipate climate change and its expected impacts on the environment by 2050 by investing in advance in measures aimed at creating more room for the river and remedying potential weaknesses in the coastal defences. Allocation of more room for waters, enhancement of flood defence measures and agreements on terms of actions and responsibilities between the various authorities are essential tools for the success of this policy.

While it is not useful to underline any more the contrasts and similarities between the policies of these countries over the years, nevertheless it is worth mentioning that the history of a country can significantly change people’s perception of hazard and vulnerability, and therefore can strongly influence the strategies for risk reduction (the so-called “Cultural Theory”, Thompson, 2002).

Case studies and lessons learnt in Italy

In Italy, in the wake of the floods that plagued the northern part of the country in the 1950s (Polesine, Po valley) and the 1960s (Florence, Arno river basin), to provide a remedy for the deficiencies in policy and strategy dealing with water-related disasters, a process was set in motion aimed at developing a new integrated approach to water management – at the river basin level and based on the “Room for River and People” concept – suitable to serve as a framework designed to prevent, mitigate, prepare for, respond to and recover from the effects of floods and other water-related disasters. This framework, known as “River Authority”, is designed to cope with water management and flood hazard mitigation issues within each of the main Italian river basins (Mambretti *et al.*, 2008).

The Lambro River case study. In Milan the flood-prone area of the Lambro River was studied. A two-dimensional model, based on the De Saint Venant equations, was built and calibrated using records of a large flood that happened in 1951.

An area, of about 20 km², was divided in squared cells of 50 × 50 m, each characterized by the ground elevation and the Manning roughness coefficient. Simulations were carried out with three different discharge values: one for the

incipient flood, one for a flood of a 200-year return period, and the last with a 500-year return period discharge.

The model gives the depth and velocity for each cell, as a function of the time. Maximum values of depth and velocity were computed for each cell and to each cell a degree of hazard was assigned, ranging from 1 (less dangerous) to 4 (extremely dangerous).

On this basis, the Milan Municipality issued the following technical rules:

- in the areas with hazard in class 1, no particular reasons against further urbanization have been determined;
- in the area with hazard 2 (medium risk), new urbanization is still possible, but the Municipality may require specific studies about hydro-geological features, and it may also be required to build defensive structures;
- in the area with hazard 3 (high risk) applications for new buildings must be equipped with documents concerning the hydro-geological conditions; together with plans for hydraulic and structural safety;
- in the area with hazard 4 (very high risk) no new urbanization is allowed, and works are permitted only in order to reduce the vulnerability of existing buildings. Strictly forbidden are all chemical and petrochemical activities along with garbage dumps.

Figure 1 shows the different hazard classes within the area where floods are expected.

The San Benedetto Po case study. A 2D model based on De Saint Venant equations was applied for the San Benedetto Po Municipality, near Mantova, where a stretch of the Po River was studied.

In this area the Po River flows in a completely flat landscape (slopes being of about 1‰); the river is pensile and main embankments are present. In this stretch, the low zone is about 500 m wide and the distance between the main embankments is about 1 km.

Despite considerable re-embankment work along the main river and its tributaries, the environmental feature of the San Benedetto Po is still critical from a hydraulic point of view. For these reasons the use of the described methods requires some different hypotheses. First, the topographic method cannot be used owing to the landscape; in fact, for pensile rivers this method leads to unacceptable over-estimations of flooded areas. On the other hand, when embankments are present, it is necessary to analyse different scenarios, assuming breaching of the bank at different places and in different situations.

In the present case, the area to be investigated is about 90 km². Choice of the area was based on historical events and on the characteristics of the landscape, which has low

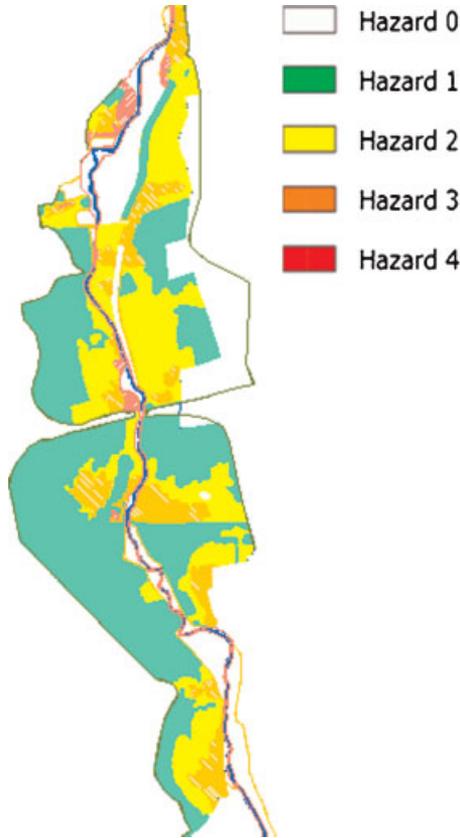


Figure 1. Hazard classes near the Lambro River in Milan. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

ground levels and narrows between the Po and the embankments of the Secchia River.

A regular 100 m square grid was superimposed on a topographic map of the potentially flooded area. The grid chosen is a compromise between the desired detail level and the computational effort (due to the extension of the area); moreover this choice is justified because of the landscape, which is very flat, with ground levels varying between 15 and 18 m+ MSL (mean sea level), so that greater detail would not bring more significant results.

The embankment breach was simulated as a breach of 100 m width and 4.5 m height, occurring when the water level in the river reaches 21 m+ MSL. The output from the river bed was simulated as the flow through a broad-crested weir.

In order to evaluate the output hydrograph from the breach, the wave in an upstream cross section of the river was computed. This hydrograph formed the basis for computation of water depths in the section concerned using Chézy's formula (steady flow hypothesis). It was found that lamination phenomena between the two sections (distance about 20 km) were negligible, due to the fact that the volume that could be stored in the floodplain areas was very small compared to the total wave volume.

The total volume of the wave with a 200-year return period was assessed at about $4.6 \times 10^9 \text{ m}^3$. The maximum discharge flowing from the breach was $979 \text{ m}^3 \text{ s}^{-1}$ while the ground level of the matching cell (equal to the bottom of the breach) was 19 m+ MSL. The area is reported in Figure 2.

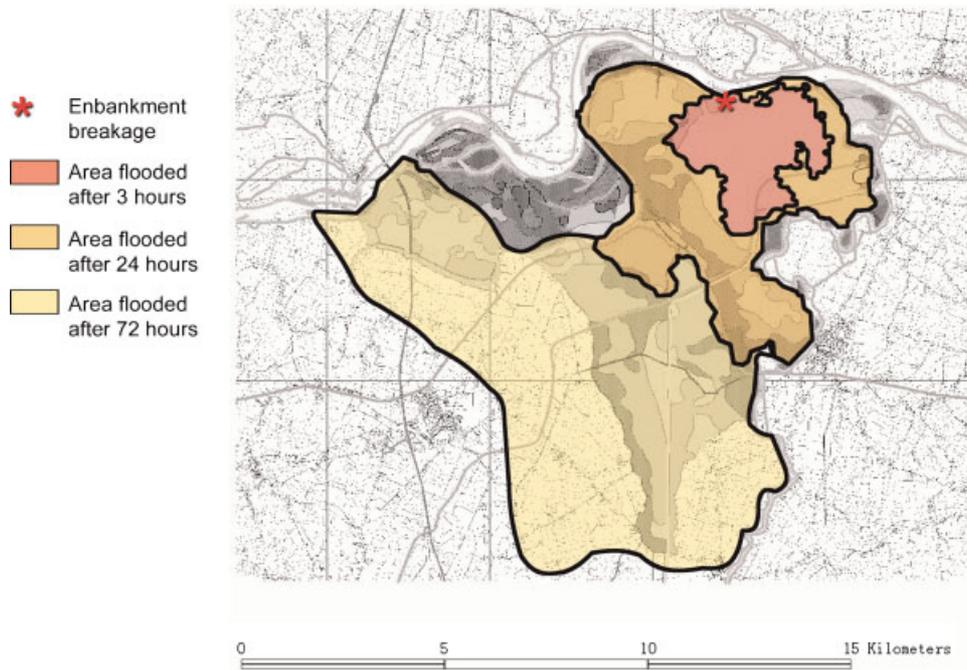


Figure 2. Simulated area and position of the embankment breach. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

The figure shows that the potentially flooded area lies between the embankments of the Po River (to the north-east) and those of the Secchia River (to the east). The north-east zone in this area is the lowest and, as a consequence, has the deepest water depths. A further restriction to the wave flow is the railway, which crosses the municipality landscape from north-west to south-east, following the southern boundary of the area where the greatest water depths are found. Other facilities, such as highways and pensile canals, seem not to influence in a significant way the wave propagation due to their limited heights.

The results show that the wave reaches the town 24 h after the embankment breach; this result plays a role of paramount importance in emergency planning. Flooded volumes and areas are respectively equal to $8.06 \cdot 10^8 \text{ m}^3$ and $6.6 \cdot 10^7 \text{ m}^2$. It can be observed that the wave, after overcoming structures of minor importance, is also able to flood the railway, which is situated 6 km from the breach and at a ground level of 19 m + MSL.

The Basento case study. The Basento case study is included in a larger investigation that comprises all rivers of the Basilicata region. The Basento River is 157 km long, with a river basin of 1535 km². The aim was to assess the flooding risk for the whole region, in order to comply with Italian land protection legislation, defined by the regional authority by means of the Hydro-Geologic Safety Plan (PAI). This plan aims to identify the different risk zones and to devise and work out flooding area maps for flow rates corresponding to different return periods.

Four codes were used for the simulation: Hec Ras, Mike 11 and Mike 21 (Danish Hydraulic Institute) and FLO-2D in order to compare the effectiveness of the different tools and to identify the most appropriate one.

The 1D simulations were carried out using field data of more than 650 river cross sections (including bridges, culverts, weirs and other hydraulic works) in order to assess both the geometric characteristics of streams and peak flows with 30-, 200- and 500-year return periods, respectively, and to be used as upstream boundary conditions for the 2D simulations.

It is worth underlining that integration between hydrodynamic models and detailed field data (as laser scanning data) is quite difficult and requires a great deal of pre-processing work. To this end, values of both water-surface elevation and top width in the river bed, obtained within the simulation process, were used in the GIS procedures to draw up maps of different flooded areas.

The differences between the simulations of the two 1D models reflect the differences between the solvers of the model's basic equations. Anyhow, these differences are meaningless, taking into account the scale of the maps (1: 5000 scale, 5 m contour line).

The area investigated covers a strip of about 3.5 km on both the left and right sides of the river. The set of topographic data, obtained by means of laser scanning, was used to generate the digital surface model (DSM), which allowed design of a key points model (KPM) – containing data of paramount importance for topographic maps – and depiction of the bathymetry of the investigated area.

With regard to the 2D models, Figure 3 shows the differences between two flooded areas (return period equal to 30 years) obtained by means of Mike 21 and FLO-2D models.

Main goals and lessons learnt from the Italian case studies. Generally speaking, the variables H , E , V and R are geographically defined and therefore they should be computed and displayed on a map. But in the real cases, as in those analysed in this paper, many difficulties arise and some changes to the general procedure have to be carried out, taking into account that the main goal is not necessarily the theoretical risk evaluation.

In the first case study, the Lambro River in Milan, the different hazard levels, which depend on a combination of water depth and velocity, were defined. In this case the result was achieved quite easily because the scenario was framed by Italian law, which prescribes that the consequences of a calamitous event have to be evaluated. Therefore with a 2D model an event with a 500-year return period was simulated.

The vulnerability could also have been geographically evaluated. Nevertheless, as the studied area is located in Milan and is quite large (approximately 20 km² divided in a grid of $50 \times 50 \text{ m}^2$), the exact definition of the vulnerability is quite a time-consuming task which, moreover, seems not to be very useful. In fact, in every cell there are one or more buildings which, theoretically, should be carefully evaluated. The result would probably be a scattered grid with vulnerability values changing greatly even for close cells, because new buildings have been built near old ones and therefore the resulting map of risk would be useless. Instead, it was preferred to give a prescription based on the hazard map, in order to define what can be done, and how, in the flood-prone areas. The prescribed rules are briefly highlighted in the appropriate section.

A completely different problem is the one presented in the second case study. Here the area is predominantly agricultural, and the position of a possible embankment breach (and its dimensions) is impossible to assess a priori. The dimensions were assumed similar to those of a breach that happened in a nearby area during the flood of 2000. Regarding the position, few hypotheses were considered and the one which seemed the most hazardous was chosen. Under this hypothesis, the simulations were performed in order to choose one (or more) positions where the breach may happen (or be induced) with little risk to people and

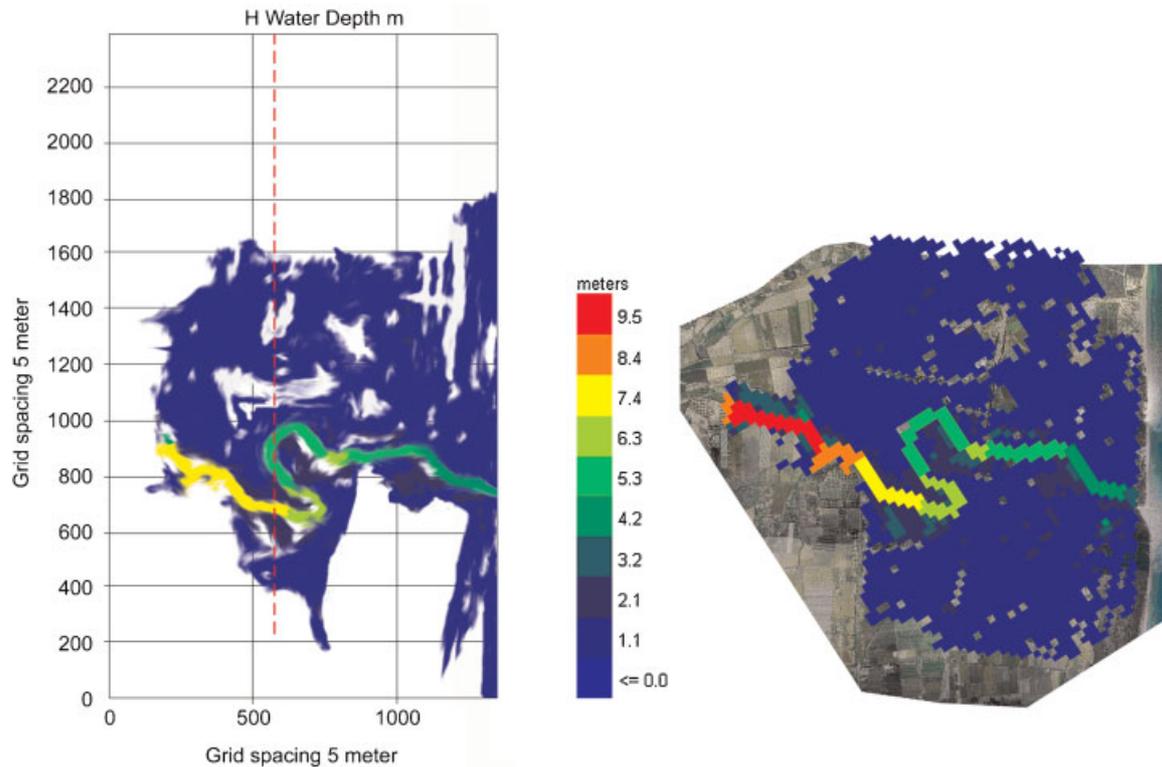


Figure 3. Basento River inundation maps for flood with 30-year return period: (left) Mike 21 and (right) FLO-2D results. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

property and to give an estimation of the time required by the water to flood the whole plain, to plan the activities of civil protection in order to avoid loss of life as much as possible, should the flood happen.

The third case study (Basento) was performed as if taking a “sample” from a much larger investigation in order to verify the influence of the model’s approximations and the uncertainties to be selected for further studies. It is well known, indeed, that while 1D models are very fast and easy to apply, but not accurate enough, 2D models are quite reliable, but too time-consuming to test a large number of scenarios. Moreover, there is a need to assess the “optimal” grid size, which affects the simulation time and the accuracy of the results.

On the whole, things are very difficult and the correct procedure for risk assessment is far from being well established.

The “Integrated Water Management” approach

In all European countries where the basic concepts of the “Room for Rivers and People” approach have been adopted, the pattern, whenever possible, was combined with other measures aimed at solving water management problems, such as diffuse source of pollution, contaminated water

bodies, water shortages and dropping (ground) water tables. The resulting portfolio of mixed measures is, generally, known as the “Integrated Water Management” approach (Penning-Rowsell *et al.*, 1992).

This framework allows good opportunities to combine water management with objectives of other policy sectors, including the reconstruction of rural areas, maintenance of ecological infrastructures, land use, residential construction and development of parks; moreover, it offers a crucial qualitative impulse to the spatial planning for the countries where it is adopted.

Notwithstanding all these advantages, problems may arise due to:

- lack of legislation, with respect to floodplain management. This includes lack of effective enforcement due to misunderstanding of responsibilities between the river manager authorities at various lower levels;
- the undervaluing of maintenance, resulting in budget shortages. This is a widespread problem that can be solved by envisaging medium-term water management plans at both national and river basin levels, with explicit criteria for prioritization;
- the need for innovative project design. Engineers and technicians tend to avoid change and must be reminded to try new methods and techniques;

- contaminated soils, causing public opposition, high costs and long-term mitigating procedures.

The gradual change from the “Flood Risk Management” to the “Room for River” and “Integrated Water Management” approaches that occurred and is ongoing in different European countries, was triggered by a sequence of increasing disasters. Such a change poses many challenges due to its impacts on the environment, the society and the economy. To properly cope with these challenges new knowledge is required on flood forecasting, risk computation and methods of spatial planning compatible with flood risk management. More effort must be put into damage mitigation and flood defence operations. Moreover, the intergenerational timescales for sustainability assessments pose additional questions of how to account for future changes in both environment and society and how to handle the uncertainty in the decision-making processes. These assessments need integrated and consistent scenarios for socio-economic developments, global emission and climate and for governance, institutions and values. The UK Flooding Futures projects indicate how this can be approached (Newson, 1992). Current research at national scale, as well as in the EC sixth framework Integrated Projects, is expected to provide concrete innovation on the assessment and management of flood risk within the multicultural context of Europe (Floodsite Consortium, 2005).

The European Directive on the assessment and management of flood risk

In 2000 the member countries of the European Commission accepted the European Water Framework Directive (EWFD). By so doing the member countries committed themselves to apply Integrated Water Resources Management (IWRM) in practice within the framework of a river basin approach (European Commission, 2000). In fact the focus of the EWFD is on the protection of water and not on the need for water use in riparian countries. In addition to this for quite a period the EWFD did not fully concern IWRM, while flood management was not yet covered under it. However, following the initiative taken under the Netherlands chairmanship in the second half of 2004, flood management also arrived on the European political agenda. This has resulted in the adoption of Directive 2007/60/EC of 23 October 2007 on the assessment and management of flood risks (Commission of the European Communities, 2006; European Parliament and the Council of the European Union, 2007; Schultz, 2009).

CONCLUDING REMARKS

One-third of annual natural disasters and economic losses, and more than half of the respective victims, are flood

related. A burgeoning global population and growing wealth, particularly in the last two or three decades, have increased the risk and the demand for protection from flooding. These features, together with climate change, development pressures and rising public expectations, are changing the way flood risk is managed. These influences are likely to become stronger and accentuate the need to adopt a new approach to living with an increasing threat of flooding.

Flood risk management is a pivotal element of integrated water management and must be based on a river basin approach. This requires international cooperation and an organization that is focused on this system level, with appropriate capabilities and instruments to manage different interests at different locations along rivers. So, effective flood risk management depends on adequate harmonization with spatial planning, capable of balancing standards and priorities on sustainability, safety and property. Moreover, the process requires cooperation among many partners at the national, regional and local level.

Knowledge and advanced scientific tools play a role of paramount importance in the effort of coping with flooding problems, along with capacity building in the context of political and administrative frameworks. All these means should be coordinated within an “Integrated Water Management” approach based on the “Room for River” concept.

Flood protection is a shared responsibility, according to the old adage “make frameworks to prepare a consistent strategy and avoid ad hoc flood defence initiatives”. Therefore, governments need to establish clear institutional, financial and social mechanisms and associated processes for flood risk management, in order to ensure the safety of people and property and, thereby, contribute to flood defence and sustainable development. In this way a harmonious coexistence with floods can be achieved.

REFERENCES

- Ang AH, Tang WH. 2006. *Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering*, 2nd edn. Wiley: Hamilton Printing Company, USA; 406 pp.
- Barbolini M, Cappabianca F, Sailes R. 2004. Empirical estimate of vulnerability relations for use in snow avalanche risk assessment. In *Risk Analysis IV*, Brebbia C (ed.). WITPress: Southampton, UK; 533–542.
- Boetzelaer ME van, Schultz B. 2005. Historical development of approaches and standards for flood protection along the Netherlands part of River Rhine. In *Proceedings of the Workshop on Integrated Land and Water Resources Management in History*, Frankfurt am Oder, 16 May 2005. Schriften der DWhG, Sonderband 2, Siegburg, Germany.
- Borrows P, Bruin D de. 2006. The management of riverine flood risk. *Irrigation and Drainage* **55**, suppl. 1: 151–157.
- Bruin D de. 2006. Guest editor’s editorial. *Irrigation and Drainage* **55**, suppl. 1: 1–2.
- Commission of the European Communities. 2006. *Proposal for a Directive of the European Parliament and of the Council on the Assessment and Management of Floods*. Brussels.

- Dam JC van editor. 1999. *Impacts of Climate Change and Climate Variability on Hydrological Regimes*. Cambridge University Press; 140 pp.
- Douben N, Ratnayake RMW. 2006. Characteristic data on river floods and flooding; facts and figures. In *Floods, from Defence to Management. Proceedings of the 3rd International Symposium on Flood Defence*, 25–27 May 2005, Nijmegen, the Netherlands, Alphen J van, van Beek E, Taal M (eds). Taylor & Francis/Balkema Publishers: Leiden, the Netherlands.
- Duivendijk J van. 2005. *Manual on Planning of Structural Approaches to Flood Management*. ICID Guideline, New Delhi, India.
- Einstein HH. 1988. Special lecture: Landslide risk assessment procedure. In *International Symposium on Landslides*, C. Bonnard (ed.), *Landslide*, vol. 2, July, Lausanne; 1075–1090.
- El-Cheikh M, Lamb J, Gorst N. 2004. Risk quantitative analysis using fuzzy sets theory. In *Proceedings of the International Conference of Computational Methods in Science and Engineering*, Leiden; 159–162.
- European Commission, 2000. EU Water Framework Directive, Directive 2000/60/EC, Brussels, Belgium.
- European Parliament and the Council of the European Union, 2007. Directive 2007/60/EC of 23 October 2007 on the assessment and management of flood risks, Brussels, Belgium.
- Floodsite Consortium. 2009. *Language of Risk Project: Definitions*. Report T32-04-01. The Hague, 2005.
- International Strategy for Disaster Reduction (ISDR). 2004. *Terminology: Basin Terms of Disaster Reduction*. Updated version, 2004; Final version (2004).
- HR Wallingford. 2003. *Flood Risks to People Phase 1. Final Report*. Prepared for Defra/Environment Agency Flood and Coastal Defence R&D Programme.
- Mambretti S, De Wrachien D, Sole A. 2008. Flood-risk assessment and hazard mitigation measures: Case studies and lessons learnt in Italy. In *International Conference on Flood Recovery Innovation and Response*, 2–3 July 2008, Institute of Civil Engineers, London, United Kingdom.
- Meadcroft IC, Reeve DE, Allop NWH, Diment RP, Cross J. 1996. *Development of New Risk Assessment Procedures for Coastal Structures. Advances in Coastal Structures and Breakwaters*, Thomas Telford and the Institution of Civil Engineers: London, UK; 6–25.
- Munich-Re, 1997. *Flooding and Insurance*. Münchner Rückversicherungs-Gesellschaft. Munich, Germany.
- Newson M. 1992. *Land Water and Development: River Basin Systems and their Management*. Routledge: London, United Kingdom.
- Office of Science and Technology (OST). 2004. *Future Flooding – Executive Summary*. London, United Kingdom.
- Penning-Rowsell EC, Green CH, Thompson PM. 1992. *The Economics of Coastal Management: a Manual of Assessment Techniques*. Belhaven Press: London, United Kingdom.
- Priest S (Lead Author). 2009. *Building Models to Estimate Loss of Life for Flood Events*. Executive Summary, Report N. T10-08-10. The Hague, the Netherlands. http://www.floodsite.net/html/partner_area/search_results3b.asp?docID=518
- Rijkswaterstaat. 2000. *A Different Approach to Water Policy in the 21st Century*. The Hague, the Netherlands.
- Samuels P, Klijn F, Dijkman J. 2006. An analysis of the current practice of policies on river flood risk management in different countries. *Irrigation and Drainage* **55**, suppl. 1: 141–150.
- Schultz B. 2001. Irrigation, drainage and flood protection in a rapidly changing world. *Irrigation and Drainage* **50**(4): 261–277.
- Schultz B. 2006a. Flood management under rapid urbanisation and industrialisation in flood-prone areas: a need for serious consideration. *Irrigation and Drainage* **55**, suppl. 1: 3–8.
- Schultz B. 2006b. Opportunities and threats for lowland development. Concepts for water management, flood protection and multifunctional land-use. In *Proceedings of the 9th Inter-Regional Conference on Environment-Water. EnviroWater 2006. Concepts for Watermanagement and Multifunctional Land-Uses in Lowlands*, Delft, the Netherlands, 17–19 May 2006.
- Schultz B. 2009. Development of trans-boundary cooperation in the Rhine River Basin. In *Proceedings of the 7th Annual Mekong Flood Forum on Integrated Flood Risk Management in the Mekong River Basin*, Mekong River Commission Secretariat, Vientiane, Lao PDR 13–14 May 2009, Bangkok.
- Thompson M. 2002. Understanding environmental values: a cultural theory approach. Event paper, Carnegie Council on Ethics and International Affairs (downloadable at: <http://www.carnegiecouncil.org/>).
- Van Gelder P (Lead Author). 2009. *Reliability Analysis of Flood Defence Systems*. Executive Summary, Report N. T07-09-20, The Hague, the Netherlands. http://www.floodsite.net/html/partner_area/search_results3b.asp?docID=758
- Varnes DJ, IAEG Commission on Landslides and Other Mass Movements and Landslide Hazard Zonation. 1984. *A Review of Principles and Practice*. UNESCO Press: Paris, France; 63 pp.