Flood management in highly developed areas: problems and proposed 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, 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. In this study, risk analysis procedures are described, which consist of the systematic actions in a cycle of preparedness, response and recovery where an integrated flood risk management is required. Then, flooding problem characteristics, policies and related measures adopted by different Countries to decrease the risk of floods are considered. Lessons learnt from flood defence are analysed, highlighting that more room for rivers is required, and the balance between present and foreseeable future spatial requirements of both water and people is pointed out. In addition, definitions about the concepts of hazard, vulnerability, risk and damage/disaster are presented, with special attention paid to flood problems, because there is a certain lack of uniformity in the use of terms, which sometimes causes confusion. In this study, structural and non-structural actions that should be performed are analyzed and their significant differences are commented. Furthermore, with regards to the city of Jeddah, the rainfalls which caused the floods in 2009 and 2011 are analyzed and their return period is estimated. It is therefore demonstrated that while under certain conditions it is possible to design structural defences, in other conditions this is not possible and non-structural defences should be designed. Examples for some application of both structural and non structural defence measures in different Countries are shown.
[Huda A. Qari, Ibrahim Jomoah, Stefano Mambretti. **Flood management in highly developed areas: problems and proposed solutions.** *J Am Sci* 2014;10(3):6-15]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 2

Key Words: risk assessment, floods, structural and non-structural defences.

1. Introduction

Floods are among the most damaging of natural hazards, and are likely to become more frequent, more relevant 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 catchment and land and water use and management in the catchment.

The terms "flood" and "flooding" are often used in different ways. According to ICID (Schultz, 2006) 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".

Although flooding is a serious hazard in humid regions, it can be devastating also in semiarid regions, where high rates of runoff following storms produce widespread flood damage down valley. Recasting floods are also typical in coastal and estuarine zones (Ward, 1978).

To cope with these hazards, it is imperative that human society adopts an effective flood hazard 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 catchment planning, and flood must be regarded as one of the many issues involved in the appropriate management of a catchment (Newson, 1992).

Within this context, mathematical models are used for the following purposes (Van Duivendijk, 2006):

- simulation of flood waves in rivers and their floodplains;
- assessment of the effectiveness of certain flood protection measures on extent of flooding and damages;
- evaluation of flood damages;
- design and construction of flood risk maps for zoning purposes;

- analysis of the effects of infrastructure and urban developments, as well as changes in land use, on flood;
- flood forecasting and warning;
- education, to increase communication and public awareness.

In the paper, after a preliminary definition of the key – words used in the literature dealing with flood hazard assessment, the main features of the risk analysis and flood and river basin management processes will be outlined; then, the characteristics of the rainfall events that produced floods in Jeddah are briefly evaluated; finally, lessons learnt from experiences in flood mitigation and control are presented.

2. Preliminary definitions

Before the description of a possible methodology to carry out 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 the UNESCO report (Varnes and IAEG. 1984) *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 approach is quite different (Einstein ,1988). 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 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. To this regard, a relevant aspect ,neglected in Varnas' definition , is the spatial propagation of the phenomenon. If the propagation is neglected, the risk analysis results uncompleted, because it is limited to the beginning of the process. It is equally important, instead, the probability that the wave reaches at a certain time, a certain place. In this case it seems more appropriate to define it as induced hazard.

Exposition 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 subject to a fixed hazard " Sometimes exposition 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 damages during an extreme event.

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

According to the Swiss Civil Protection Agency, *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 impact depending on where it happens.

3. Event in Jeddah (2009 and 2011)

Unfortunately, not many data are available for analyzing the two major events that hit the city of Jeddah in 2009 and 2011. However, some evaluations can be performed.

In order to decide whether the mentioned events were "exceptional" or not, the rainfall DDF or IDF curves have to be studied. Al-Khalaf (1997) reports rainfall data with different return periods for the cities of Taiz, Jermuz, Hema Saysid, Wadi Dahiyah and Ain Aziziayh.

Obviously, when a major event is recorded, the spatial distribution is an important parameter, because the simplified hypothesis that the rainfall is equally distributed on the whole area brings to an overestimation of the actual rainfall depth and therefore to the discharge. Unfortunately, this information related to the mentioned flooding events is not available.

However, it is reported that in the area 70 mm have fallen in 2009, and 111 mm in 2011, in 3 hours. As Elfeki *et al.* (2011) reported, the time of concentration of the area might be expected around that duration.

It is now interesting to determinate the return periods of the two events. To do that, first the IDF curves have been determined for the different sites; then the rainfall depths for three hours duration are computed; finally, inverting the Gumbel distribution the return periods of the events are estimated.

With regards to the IDF curves, in figure 2 they are shown for the Jermuz site; the computed curves are in the three-parameter form, i.e.:

$$i(\vartheta, T) = \frac{A(T)}{\left(\vartheta + B(T)\right)^{C(T)}}$$

where i is the expected rainfall intensity [mm/hr] function of the duration □ [hr] and of the return period T [years] and A, B and C are the coefficients of the curve, function of the return period.

Actually, the carried out curves show significant differences; moreover, the curve computed for Taif seems to be problematic, as the rainfall depth related to the duration of 120 seems to be equal to (or even lower than) the rainfall depth related to 90 minutes. These data are therefore neglected.

In figure 1, on the IDF curves (transformed in DDF multiplying the intensity by the duration), the recorded points have been also plotted in order to show the very good agreement; moreover, the curves are plotted until the duration equal to 180 minutes, which is the time for which the depths during the flooding events have been recorded. In table 1 the estimated coefficients A, B and C of the IDF curves are shown.

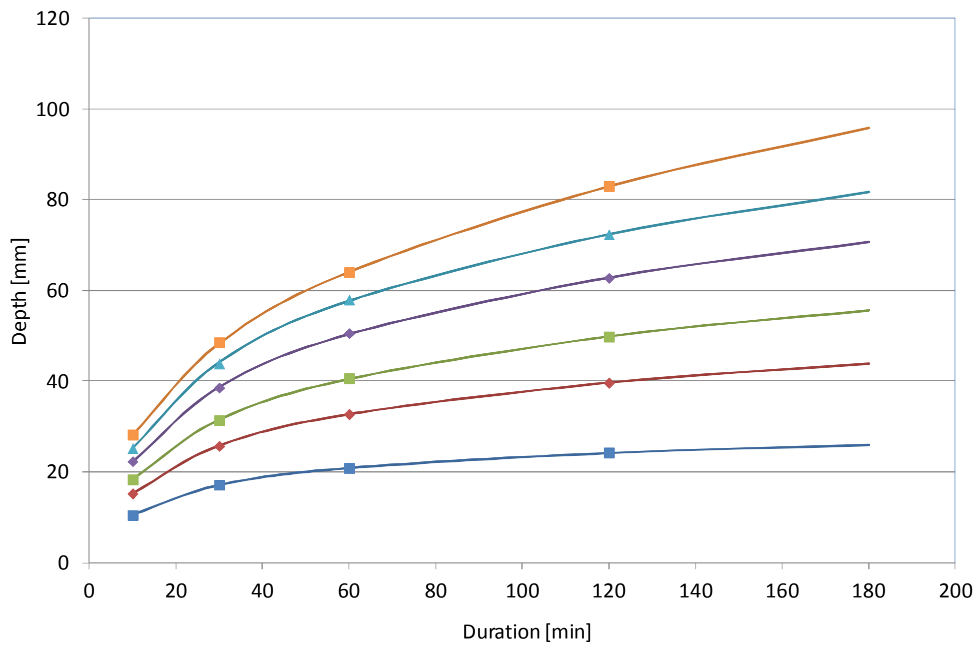

Figure 1: Depth data for Jermuz; return period equal to 2, 5, 10, 25, 50 and 100 years.

Table 1: Coefficients of the IDF curve for the Jermuz site.

	T = 2 yrs	T = 5 yrs	T = 10 yrs	T = 25 yrs	T = 50 yrs	T = 100 yrs
A	23.83	36.59	45.12	55.95	63.99	67.85
B	0.163	0.152	0.150	0.150	0.149	0.088
C	0.878	0.799	0.775	0.755	0.745	0.668

With these curves, expected depths for 180 minutes are computed for all sites (with the mentioned exception of Taif) and the carried out data are reported in table 2.

Table 2: Expected rainfall depth [mm] for the different sites and three hours duration.

		T = 2 yrs	T = 5 yrs	T = 10 yrs	T = 25 yrs	T = 50 yrs	T = 100 yrs
Jermuz	Depth [mm]	26.01	43.84	55.65	70.60	81.68	95.80
Hema Saysid		23.41	36.72	45.48	56.33	64.40	75.82
Wadi Dahiyah		30.59	43.36	51.77	62.39	70.28	75.96
Ain Aziziayh		15.60	35.79	49.08	65.45	77.47	87.36

Because these are extreme events data, they are expected to follow the Gumbel distribution , i.e.: and

$$P(h) = e^{-e^{-\alpha\cdot(h-u)}}$$

where P is the non-exceeding probability, tied to the return period T with:

$$T = \frac{1}{1-P}$$

and $\alpha = \frac{1.283}{\sigma}$ and $u = \mu - 0.45 \cdot \sigma$ where μ and (2) σ are the mean and the standard deviation of the sample.

Inverting the usual procedure, from data the values of α and u are estimated for each site; the carried out values are reported in table 3.

Table 3: Estimated Gumbel distribution parameters.

	α	u
Jermuz	0.06349	20.23
Hema Saysid	0.08536	19.12
Wadi Dahiyah	0.08898	26.47
Ain Aziziayh	0.05644	9.13

Finally, inserting the recorded depth in the Gumbel distribution with the estimated parameters, the return period of the two flooding events can be estimated; they are very different among sites, and are reported in table 4.

Table 4: Estimated return period for the two flooding events.

	Estimated Return Period [years]	
	Flood 2009 [70 mm]	*Flood 2011* [111 mm]
Jermuz	24	319
Hema Saysid	78	2550
Wadi Dahiyah	49	1850
Ain Aziziayh	32	315

Results show very large differences and are very interesting; this variability can be attributed to the rainfall regime, which is notoriously characterized by long dry periods, and therefore rainfalls have probably to be analyzed with more complex methods than those used in Western Countries.

However, results are very clear in showing the flood occurred in 2009 should have been controlled with structural methods, which should be able to manage events up to 100 – 200 years return period. On the other hand, the event occurred in 2011 seems to be exceptional, and structural methods should not manage these kind of events as they would become too expensive; therefore, non structural events have to be designed.

4. 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 old as mankind. But in the last decades, new challenges are likely to influence risk management measures and policies. These challenges can be summarized as follows:

- climate change is likely to impact climate variability, making extreme events more severe and more frequent;
- 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 of integrated water resources management, considering the river basin as the basic planning unit;
- due to the relentless urbanisation process, at world wide level, hazards are increasingly transforming into disasters putting development at risk;
- there is a rising concern that damages resulting from water related disasters are growing disproportionately world wide.

To cope with these challenges involves taking decisions and actions about appropriate levels of risks. These decisions and actions may be divided into the two processes of Risk Analysis Procedures and Risk Management Cycle.

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 phase 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 carried out so far as proposal to determine the risk of property and human life with the focus on risk within specific location and specific points in time (Barbolini *et al.,* 2004).

According to the 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 to limit adverse effects of hazards. On the whole, the risk management approach consists of systemic actions set up in a cycle of preparedness, response and recovery that should form part of any integrated water resource management.

These principles 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 before the international community is to support these activities, particularly in developing 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 water sector planning through integrated water resources management (including risk assessments) and adaptive management to reduce vulnerability to risks;
- 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.

5. Flood and river basin management

The worldwide damage caused by flooding has been extremely severe in recent decades. Moreover, 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(van Dam, 1999). 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 (Schultz, 2001). The need for protective measures arises from the frequency and character of flooding and the potential damage to man and the environment.

Protection can be either structural and non-structural.

Structural measures of flood management are measures which alter the physical characteristics of the floods (storage in reservoirs, upstream catchment management, channel modifications, levees/embankments). Non – structural measures are measures which alter the exposure of life and properties to flooding (floodplain land use planning, flood forecasting and warning flood proofing, evacuation, insurance, etc.) (van Duivendijk, 2005).

The first measures aim at reducing the challenge, the second ones enhance the coping capacity.

The principal structural tools used in flood management are storage of floodwater and increase in discharge capacity of a river system. Storage of floodwaters can be achieved by either storing (part of) the flood wave in upstream reservoirs or by storing water in riverine areas set aside for that purpose in the lower reaches of the river.

For the increase in discharge capacity of the river system, several methods are used, such as:

- deepening and widening the existing river channels;
- introduction of additional flood ways parallel to the river or conveying part of the flood to another river or to another outlet to se sea;
- flood embankments along the river allowing for higher (flood) water levels.

All these tools are, generally, used on their own or in combination.

Flood storage reservoirs range in scale from large – scale structures to local ones. Large – scale reservoirs, because of their cost, often need to be managed for multiple purposes including hydroelectric generation and storage for irrigation. Such multi – purpose management involves compromises, since the flow storage requirements for the different purposes rarely coincide.

Channel improvements, generally, consist of structures which minimize the resistance to flow. Levees, embankments and walls are solutions which are often necessary when space preclude any other solution.

Non – structural approaches to flood management naturally fall into two categories:

a. planning measures which can be assessed, defined and implemented in the flood plains to reduce the risk to property from identifiable future floods;

b. emergency response measures which are applied when a damaging flood is forecast, imminent or under way, to help mitigate its damaging effects.

According to ICID (van Duivendijk, 2005) planning measures are:

- flood forecasting
- control of floodplain development and catchment management
- flood insurance
- flood proofing.

Response measures are:

- flood emergency response planning
- flood fighting
- flood warning
- evacuation;
- emergency assistance and relief.

In general terms, planning measures are taken well in advance of a flood whose magnitude is as yet unknown and are in principle long term, while response measures comprise short – term actions taking account of the imminent or passing flood.

6 The "Room for River and People" concept

Until recently 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 and People" approach (Samuels *et al.,* 2006). 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 only protection to a more holistic risk management process resorting, mainly, to non – structural measures like flood forecasting early morning 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.

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 aiming at solving water management problems, such as diffuse source of pollution, contaminated water bodies, water shortages and dropping water – tables. The resulting portfolio of mixed measures is, generally, known as the "Integrated Water Management" approach (Rijkswaterstaat, 2000).

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 widespread problem, that can be solved by envisaging medium – term water management plans at both national and catchment 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 People" and "Integrated Water Management" approaches, that occurred in different European countries, was triggered by a sequel 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 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 of both the environment and the 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 ad climate and for governance, institutions and values. The UK Flooding Futures projects indicate how this can be approached (OST, 2004). Current research in the EC sixth framework Integrated Project is expected to provide concrete innovation on the assessment and management of flood risk within the multi – cultural context of Europe (Floodsite, 2005)

7. Flood – risk Management: a case study

In Italy, in the wake of the floods that plagued the northern part of the Country in the fifties (Polesine, Po valley) and in the sixties (Florence, Arno river catchment), to provide a remedy for the deficiencies in policy and strategy dealing with water – related disasters, a process was set in motion aiming at developing a new integrated approach to water management – at the catchment 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 catchments. In order to show how the same problem has to be dealt with different methods, the same case study is presented with different perspectives.

7.1 The general plan for Milano

In Milan the flood prone area of the Lambro river has been studied. A two – dimensional model, based on the De Saint Venant equations, has been built and calibrated using recording of a large flood happened in 1951.

An area, of about 20 km^2, has been divided in squared cells of 50 *m* x 50 *m*, each characterised by the ground elevation and the Manning roughness coefficient. Simulations have been carried out with three different discharge values: one for the incipient flood, one for a flood of 200 years return period, and the last with a 500 years return period discharge.

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

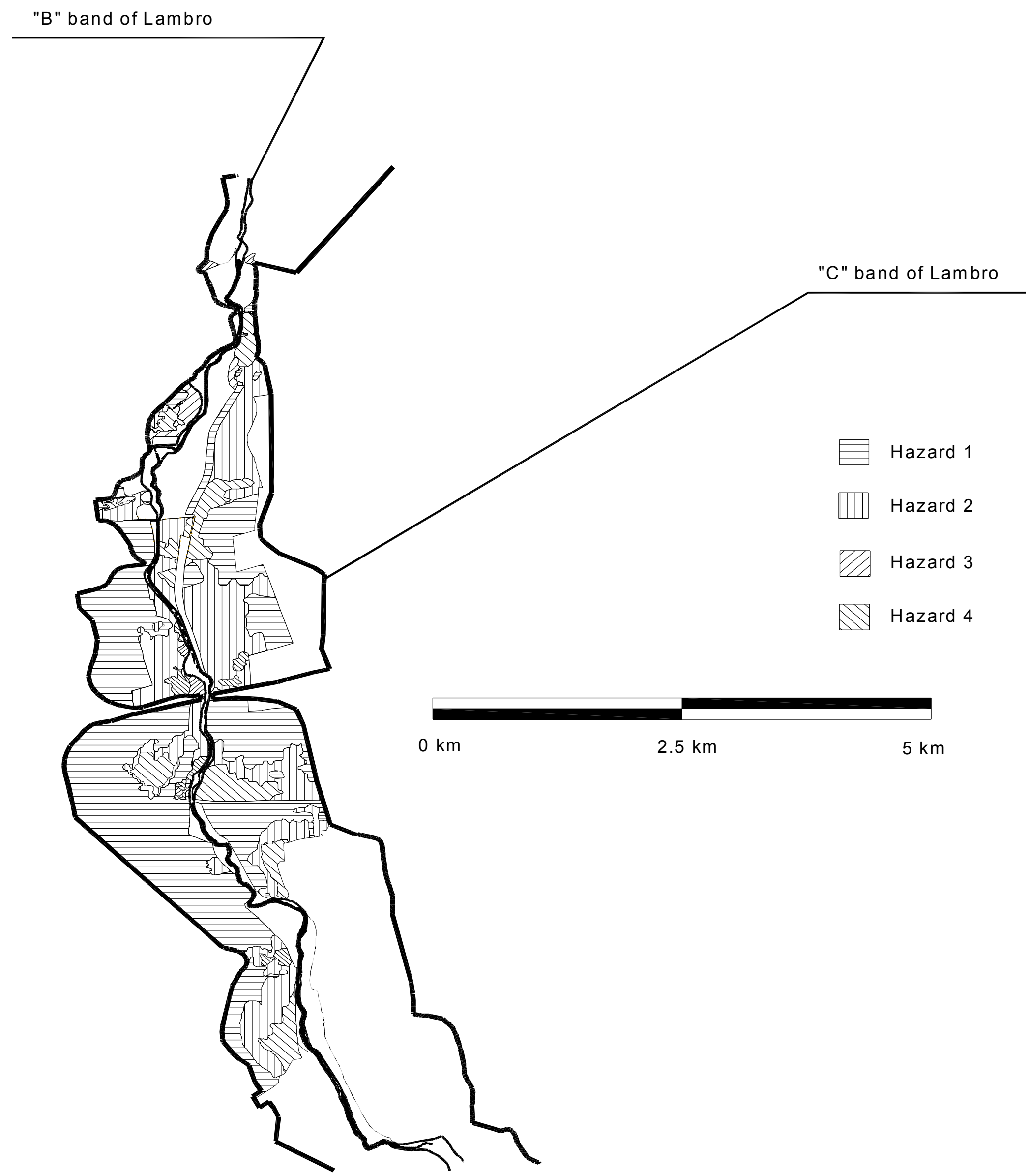

Figure 2: Hazard classes near the Lambro river in Milano.

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

- in the areas with hazard in class 1, no particular reasons against further urbanisations have been determined;
- in the area with hazard 2 (medium risk), new urbanisation 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 urbanisations are allowed, and works are permitted only in order to reduce the vulnerability of existing buildings. Strictly forbidden are all the chemical and petrol-chemical activities along with garbage dumps .

Figure 2 shows the different hazard classes within the area where flood are expected.

7.2 A particular case

The above reported plan is valid for the whole town. However, there are cases to be analyzed with more detail, because of the risk to people already living in the most hazardous areas. The group of houses shown in figure 3 is surrounded by the Lambro river and an irrigation canal, from which the distances are negligible.

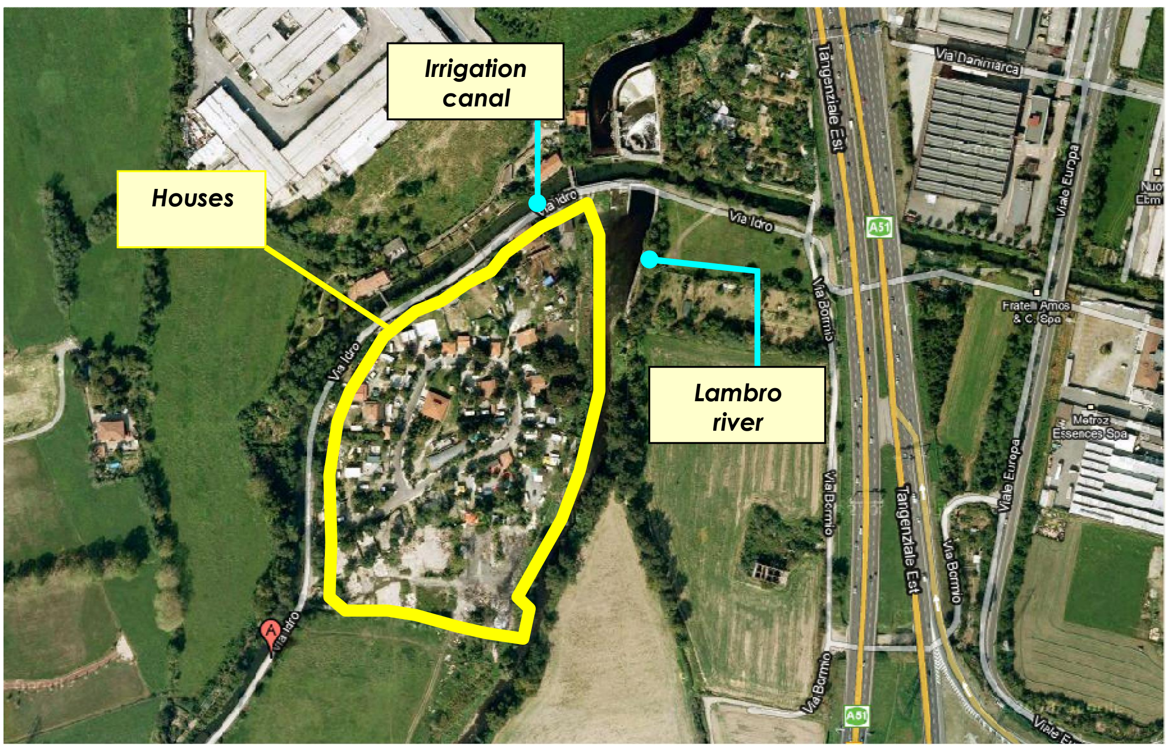

Figure 3: Houses in the most an hazardous area in Milano, surrounded by the Lambro river and an irrigation canal.

The return period for which the site is safe is around three years. Fortunately, this value is underestimated because of the uncertainties related to the modelling of the downstream bridges and to the solid transport in that part of the river. However, because of the risk some defence measures have to be taken, and because of the configuration of the area, these have to be non-structural, as structural defences would be both expensive and ineffective.

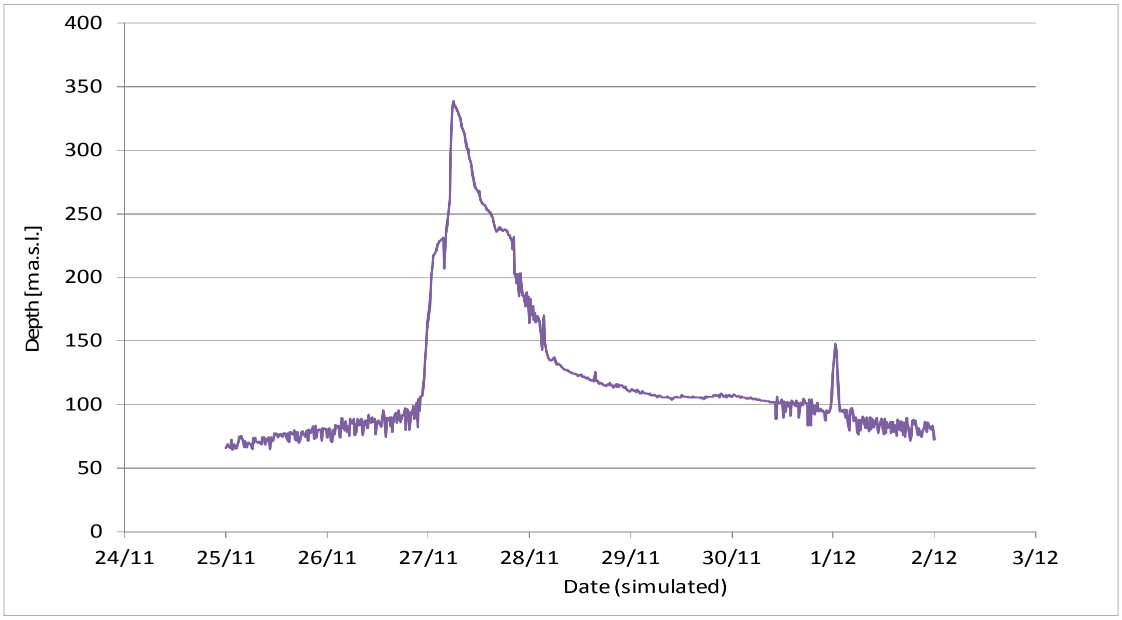

Figure 4: simulated hydrograph for an event 200 years return period.

Simulations of the flow waves with different return periods allows the determination of the related hydrographs. In case of evacuation, the examination of the hydrograph allows the estimation of the time available to alert the civil protection and to start the related operations. For an effective early warning system, it is necessary to install an appropriate number of raingauges and at least a water level device in order to be aware of the expected danger.

8. Concluding remarks

One – third of the 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.

In the last years, the city of Jeddah has been hit twice by floods. From the recorded data seems the flood occurred in 2009 could have been managed with structural defences, as its return period was less than 100 years; on the other hand, the event occurred in 2011 was with a very high return period, and therefore different defences should be designed. In the paper some examples have been shown.

In Jeddah some defensive interventions are required. Future developments should be related to rainfall analysis first. More detailed data are required, both spatially and timely. The usual rainfall analysis performed in Western Countries could not be sufficient to explain the Arabic climate, and therefore more attention has to be paid to this aspect and to the adopted procedures. Second, an accurate description of the flooded areas and their upstream catchment has to be performed; hydraulics simulations can be carried out and developing different scenarios the best structural design can be performed. Moreover, with the help of hydraulic simulations the most hazardous areas can be identified and specific plans (non structural defences) can be designed in case of major events occurrence. To this end, and because of the climate characteristics of Saudi Arabia, Early Warning systems could be most effective to reduce the expected damages.

This is the basis to design an appropriate flood risk management, which is a pivotal element of integrated water management. This requires cooperation and an organization that is focused on this system level, with appropriate capabilities and instruments to manage different interest in different locations along the river. So, effective flood risk management depends on adequate harmonization with spatial planning, capable to balance standards and priorities on sustainability, safety and property. Moreover, the process requires cooperation among many partners at the national, regional and local level. The difficulties in operating in urbanized areas are shown by means of a case study.

However, it is shown as knowledge and advanced scientific tools play a role of paramount importance in the strain of coping with flooding problems, along with the 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 and People" 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.

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3/1/2014