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DEFENCE MEASURES IN FLOOD RISK ASSESSMENT: A CASE STUDY

D. DE WRACHIEN[1] & S. MAMBRETTI[2]
[1]Department of Agricultural Engineering, State University of Milano, Italy.
[2]DIIAR, Politecnico di Milano, Italy.

ABSTRACT

Flood defense is a problem of vital importance, for which knowledge and advanced scientific tools play a paramount important role in the strain of coping with flooding problems. In this context, flood modeling represents the basis for effective flood mitigation measures. By using models, an attempt is made to replace trial-and-error-based strategies, as practiced in the past, with more physically based measures of flood management and control. Mathematical models are the best tools, nowadays available, for the design of efficient flood protection strategies and excellent supporters of decision-makers. With reference to these issues, the paper provides a complete application of the procedures, nowadays available, for risk assessment, from catchment to a very local scale, on the Lambro River in Milano, Italy. It is shown that social and political constraints may force risk managers to find different solutions to solve the problems they have to face, which may be related to non-hydraulic issues.

Keywords: case studies, early warning, flood hazard, mathematical models.

1 INTRODUCTION

In the design of a plan for flood risk management the objective is to maximize the efficient use of flood-prone land. The expectation is that within 50 years 80% of the world 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 [1].

To this end, the best solution is normally carried out by selecting structural and non-structural measures. Structural measures of flood management are those which alter the physical characteristics of the floods (storage in reservoirs, channel modifications, and levees/embankments). Non-structural measures, instead, are those which alter the exposure of life and property to flooding (floodplain land use planning, flood forecasting and warning, upstream river basin management, flood proofing, evacuation, insurance, etc.) [2]. The first measures aim at reducing the challenge (i.e.: the hazard), the second enhance the coping capacity (i.e.: the vulnerability).

These structural and non-structural measures are normally seen as complements, rather than alternatives [3]. However, in many cases, their application is to be decided depending on circumstances and on the area to protect. Moreover, there are differences related to the costs and to the time that the different measures require to be implemented.

In practical terms, the chance of flooding can never be eliminated entirely. However, the consequences of flooding can be mitigated by appropriate behavior 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 [4].

In this paper, the case of the river Lambro is examined. This river crosses the city of Milano, in the North of Italy, which is one of the largest and most important towns in Italy, and whose defense is of paramount importance. Milano has considerably grown during the last decades (Fig. 1), together with its upstream catchment. The consequence of such a growth

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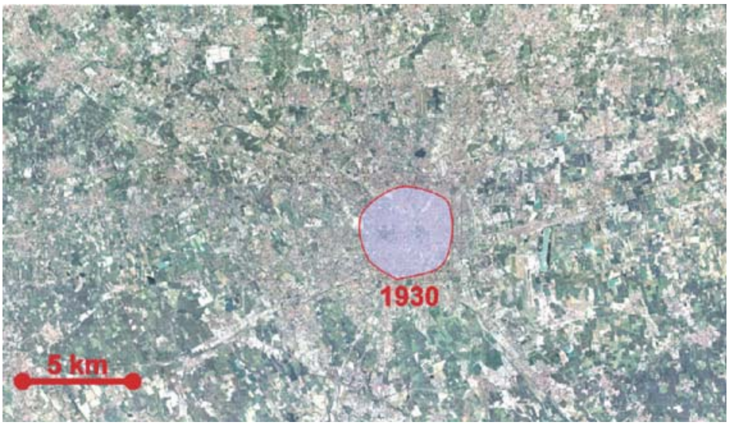

Figure 1: Milano: extension of the city in 1930, shown by the circle, compared with the current, in 2011.

is the increased imperviousness of the catchment, which implies a larger water volume to be conveyed to the river, and an increase in the velocity of wave formation (due to the reduction of the concentration time); both of them are feasible to increase the peak of discharge in the river, and therefore the frequency of floods [5].

To cope with this problem, authorities designed pertinent structural measures. In Milano, in this context, a plan has been designed for the river [6,7], which rules the new urbanization in the different areas close to its banks. Linked with this problem, there are particular cases which have to be studied considering the social and political constraints. It is worth mentioning the difficult task of assessing the potential loss of life, taking into account that the safety of people plays a paramount important role 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 behavior which is very difficult to predict and, generally, varies among countries. This is the main reason why the model proposed by Wallingford [8] for the United Kingdom had been modified to be applied to different European countries [9].

The aim of the paper is to present an application of the procedures for hazard evaluation to a case study and to assess the hazard feasible to affect the studied area, along with the social and political constraints. Because of the latter, non-technical issues, the risk manager was asked to provide suboptimal solutions. Things are complicated by the common underestimation of risks, which appear distant or global [10,11].

2 OVERVIEW OF THE CATCHMENT

The catchment upstream of Milano is characterized by a high number of water courses, in a very large area delimited in the north by the PreAlps, in the south by the Po River, in the west by the Ticino River, and in the east by the Adda River. The entire hydrographical network can be led back to the Lambro Settentrionale River, affluent of the Po River, which collects the contributions of the entire subcatchment called Lambro-Seveso-Olona. In the catchment, there are eight major natural watercourses and eight main artificial canals, which are connected to the natural streams. The city of Milano lies in the center of this drainage network (Fig. 2).

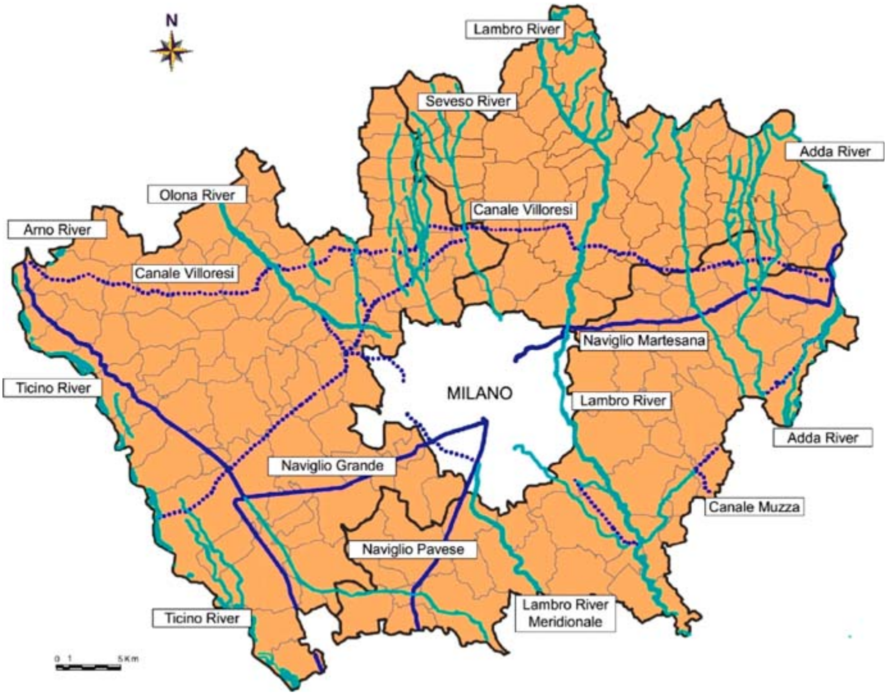

Figure 2: Catchment of Milano, with its complex systems of rivers and canals.

With regard to the Lambro catchment, which is the main object of this study, the area can be divided in four parts. The first part, upstream, can be considered quite disconnected from the downstream parts because of a lake which can act as a storage basin (Pusiano Lake). The second part is not much urbanized; the third, instead, is very urbanized and includes the city of Milano. The fourth part is downstream Milano and, therefore, not very important for this study. In the second part of the catchment, the discharges depend on the geologic and hydrologic land characteristics, while in the third part they depend especially on the sewer overflows [12].

The area of the catchment, considering as its outlet the city of Milano, is equal to 553 km^2 of which 284 km^2 are not urbanized (111 km^2 are upstream the Pusiano Lake) and 269 km^2 are urbanized. At the outlet, the so-called ‘hydrologic discharge’, for return period equal to 200 years, is equal to 370 m^3 s^{-1}. With the expression ‘hydrologic discharge’ the authorities mean the discharge that would reach the outlet if no floods or other constraints or modification of the wave would occur upstream. On the other hand, the ‘acceptable hydraulic discharge for the river’ in Milano is equal to 215 m^3 s^{-1}; this is the maximum discharge that could flow through Milano. Unfortunately, in few points, and especially in correspondence to the oldest bridges, the compatible discharge drops down to 100 m^3 s^{-1}.

In particular, events with a return period of more than 20 years are already highly critical for the following situations:

- high risk of flooding for the cities of Monza and Cologno Monzese (upstream Milano) and Milano itself;
- high risk of interference, with potential serious structural and functional damages, with the highway road and railway bridges and infrastructures.

3 THE HYDRAULIC DEFENCE OF THE CITY OF MILANO

During the 1970s, a series of risk mitigation works were carried out in the city of Milano. The aim of these works was the reduction of the exceeding discharges flowing through the urban areas because the drainage network was unable to convey them. In fact, by the first half of the 20th century, the complex Navigli waterway (artificial canals, the construction of which started in the 12th century) had been either covered or filled in and, as mentioned, many rivers were connected to this system and, therefore, the network became hydraulically limited [13].

The main works consisted in the construction of a bypass, which collects the excess of discharge from the upstream rivers, preventing their entry into the city and thereby avoiding (or reducing) floods. Actually, some works are still needed because the discharge capacity of the bypass has to be increased. However, this bypass does not collect the discharge from Lambro River, as the latter is at the extreme east of the city and, in any case, the resulting discharge would be too high both for the bypass and the final recipient. Therefore, the structural defense measures, which have been studied to reduce the discharge of the river Lambro upstream the city of Milano, can be summarized as follows:

- increase in the storage capacity within the catchment to appropriately reduce the peaks of flood flows;
- maintenance of natural areas of flooding in the riversides;
- rebuilding and adaptation of the bridges with insufficient cross section;
- reduction of the combined sewer overflows; and
- increasing of the cross section of the river.

Because of the importance of the river and the cities through which the river flows, the return period for the designed structures has been assumed equal to 200 years.

4 GENERAL PLAN FOR RIVER LAMBRO IN THE CITY OF MILANO

In Italy, the river authorities, who are in charge for the management of the river works and for planning the activities in the areas related to rivers, divide the flood prone areas in three subareas, [14], which are as follows:

- ‘A’ the area flooded by a discharge equal to 80% of a flood of 200-year return period;
- ‘B’ the area flooded by a discharge of a flood of 200-year return period;
- ‘C’ the area flooded by a discharge of a flood of 500-year return period, or a ‘catastrophic’ event if available.

The definition of these areas is assumed by the authorities for the most important rivers. Due to the frequency of flooding events, ‘A’ and ‘B’ areas are parts of the river itself and no activities are allowed; in other terms, in these areas no new structures can be built and when rehabilitation works are scheduled for the existing, they have to be performed in order to reduce the vulnerability. Moreover, no industries can be set in these areas and the existing ones are allowed only if no dangerous activities are performed. On the other hand, ‘C’ areas can be very large, and, so, it is not possible to forbid any activities there. To this end, the authorities define other subareas with different degree of potential hazard where some activities are possible. For instance, the Lombardy region defines four subareas within ‘C’ areas, which are as follows:

- ‘R1’ area, where slight risk is expected, and therefore where no specific constrains are determined for the urbanization;

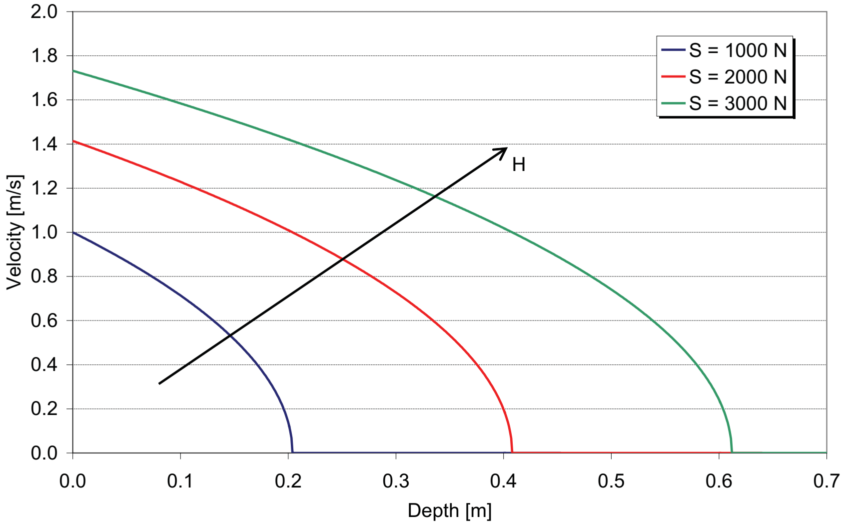

Figure 3: Determination of hazard level.

- ‘R2’ area, where medium risk has been assessed and where, for the development of further urbanization appropriate countermeasures have to be taken, and where the Municipality may require specific studies regarding hydro-geological features;
- ‘R3’ area, where high risk has been assessed and therefore no further urbanization should be permitted, but for public use, while restoration is allowed and the application of countermeasures against flood are recommended; moreover, documents concerning the hydrogeological conditions are required;
- ‘R4’ area, of a very high risk, where no urbanization is allowed and restorations is permitted only if vulnerability reduction is achieved; strictly forbidden are all the chemical and petro-chemical activities along with garbage dumps.

To this end [15,16] a 2D model has been built, based on the SV equations and calibrated using recordings of a large flood that happened in 1951. The model used for the simulations is an earlier version of the FLO-2D [16-18], with rectangular grid. The area, of about 20 km^2, has been divided in squared cells of 50 m × 50 m, each characterized 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-year return period, and the last with a 500-year return period discharge.

The model provides 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), according to the Lombardy region requirements and using the chart shown in Fig. 3. Figure 4 gives the different hazard classes within the expected flooded area.

5 LOCAL WARNING

The above-reported plan is valid for the whole town, along with the Lambro River, is shown in Fig. 5. However, there are cases to be analyzed with more detail, because of the

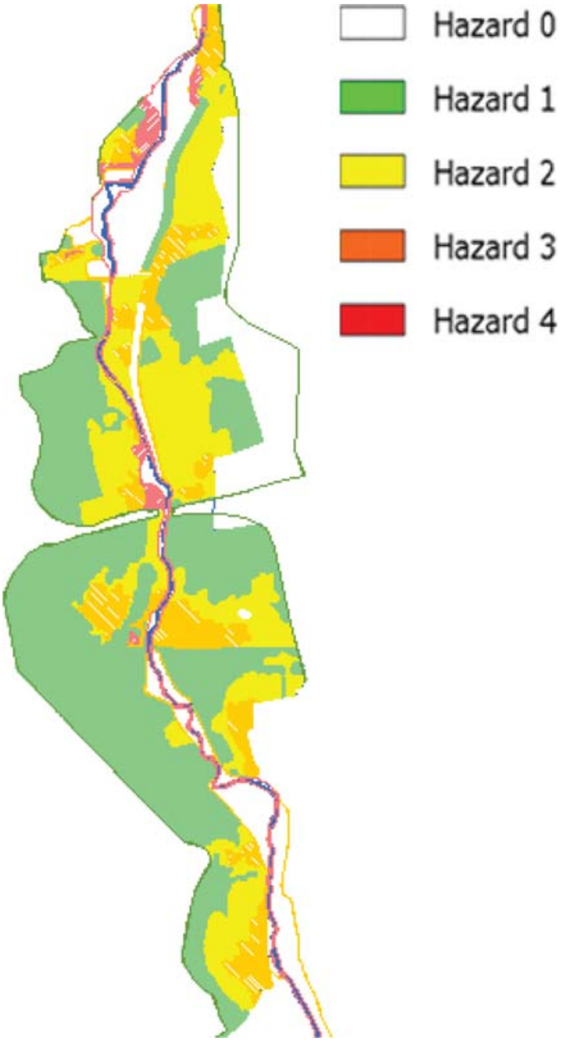

Figure 4: Hazard classes near the Lambro River in Milano.

risk to people living in hazardous areas. The group of houses shown in Fig. 6 is surrounded by the Lambro River and an irrigation canal, from which the distances are very short (few meters). This is an authorized gipsy camp, installed in the early 1980s when no preliminary studies had been carried out. It resulted that the camp is inside the ‘B’ area of the Lambro River, and therefore the only allowed activities to be performed are related to the vulnerability reduction. Figure 7 shows the area with the location of the camp. In the figure, different areas have been colored: zones which can be flooded with return period lower than 10 years are colored in red; lands expected to be flooded with 200-year return period are colored in green; and areas feasible to be flooded with 500-year return period are colored in yellow.

To obtain a permanent and safe camp, some simulations have been carried out and countermeasures have been studied on the basis of the characteristics of the river and the location

Figure 5: Overview of Milano and position of the gipsy camp.

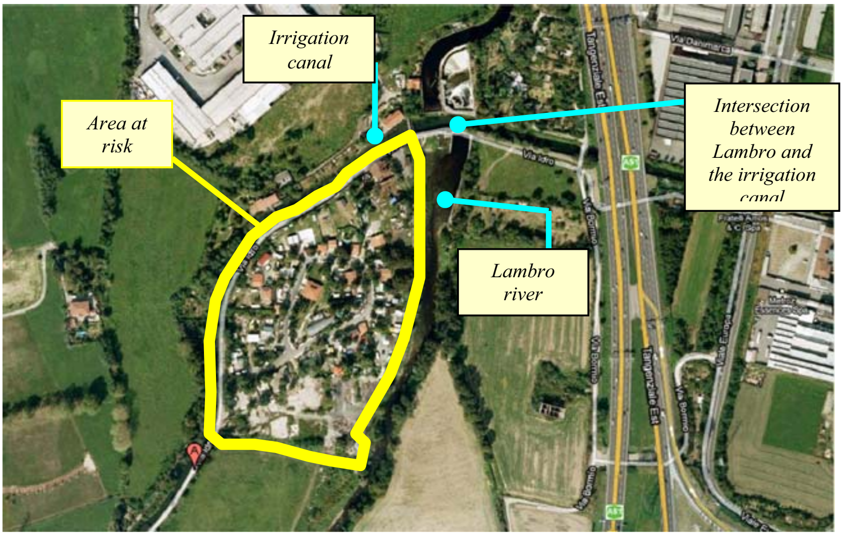

Figure 6: Area at risk: aerial photograph.

of the camp. To this end the well-known HEC-RAS [19] has been used to assess the maximum value of the discharge and to design the most suitable measures to evacuate the camp when a given threshold is exceeded. Different boundary conditions have been tested, starting from the downstream bridges; however, as can be seen in Fig. 8, their influence is negligible at the distance where the area at risk is positioned.

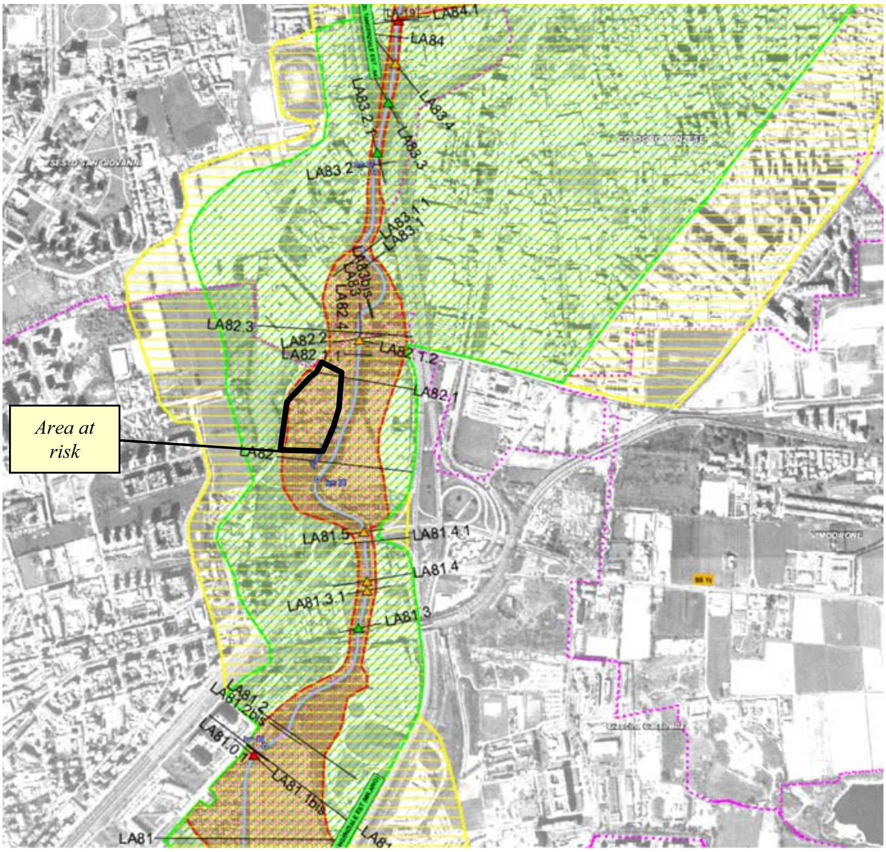

Figure 7: Lambro River: area at risk in the context of hazard evaluation.

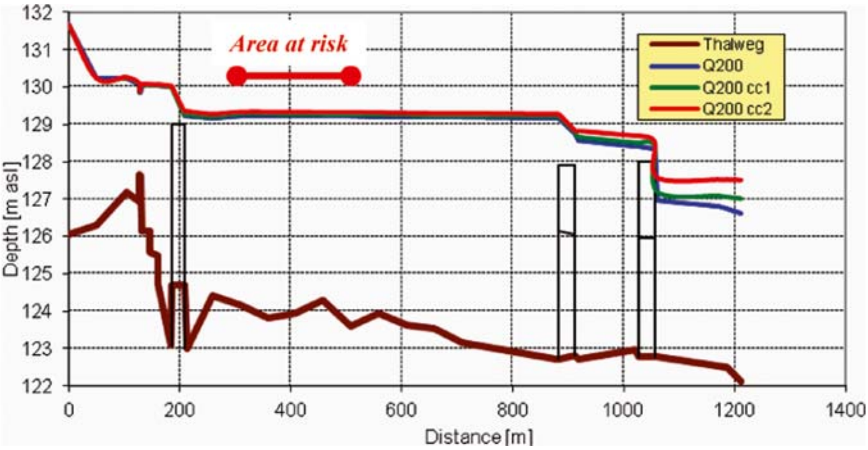

Figure 8: River depth during an event which return period is 200 years, as carried out from simulations.

The return period for which the site is safe is around three years. Probably, this value is underestimated because of the uncertainties related to the modeling of the downstream bridges and to the solid transport in that part of the river. In fact, no serious floods have been actually recorded in the area. However, because of the risk, some defense measures have to be taken, and due to the configuration of the area, these have to be non-structural, as structural defenses would be both expensive and ineffective.

In fact, the problem regarding this area concerns not only the floods that can arise because of the bank overtopping but also the structure positioned just upstream the camp, shown in the aerial photograph in Fig. 6 and, in more detail, in Fig. 9. As can be seen in the latter figure, the intersection between the river and the canal is peculiar, and probably needs to be rectified, because it is the river (larger and with more irregular discharge values) that underpasses the irrigation canal. During the major events, the structure becomes not sufficient for the discharge, and therefore the river may overtop the whole structure, flooding the upstream and downstream areas. The complete rebuilding of the structure, which (in the authors' opinion) is the only way to solve this problem, is unjustifiably expensive considering that the only advantage obtained is the protection of the gipsy camp.

To select different options, simulations of the flow waves with different return periods have been carried out. As can be seen (Fig. 10) the rising limb of the hydrograph, computed at the section of the area at risk, is quite steep, and this means that, if evacuation is the selected option, the time allowed for moving people is short. Therefore, the positioning of only a device to record the levels seems to be not sufficient, and rain gauges have to be installed as well. Obviously, when the decisions are taken on the basis of the rainfalls, these have a higher degree of uncertainties.

Finally, it is to be observed that, from a purely technical point of view, the best solution is simply moving the gipsy camp out. As mentioned, this 'optimal' technical solution is not

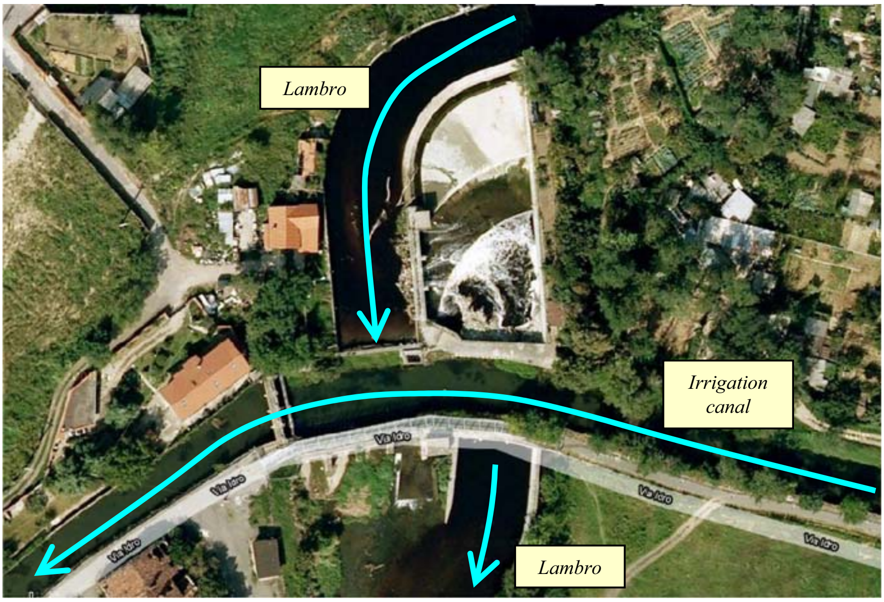

Figure 9: Intersection between the Lambro River and the irrigation canal: as can be seen; it is the river that underpass the irrigation canal.

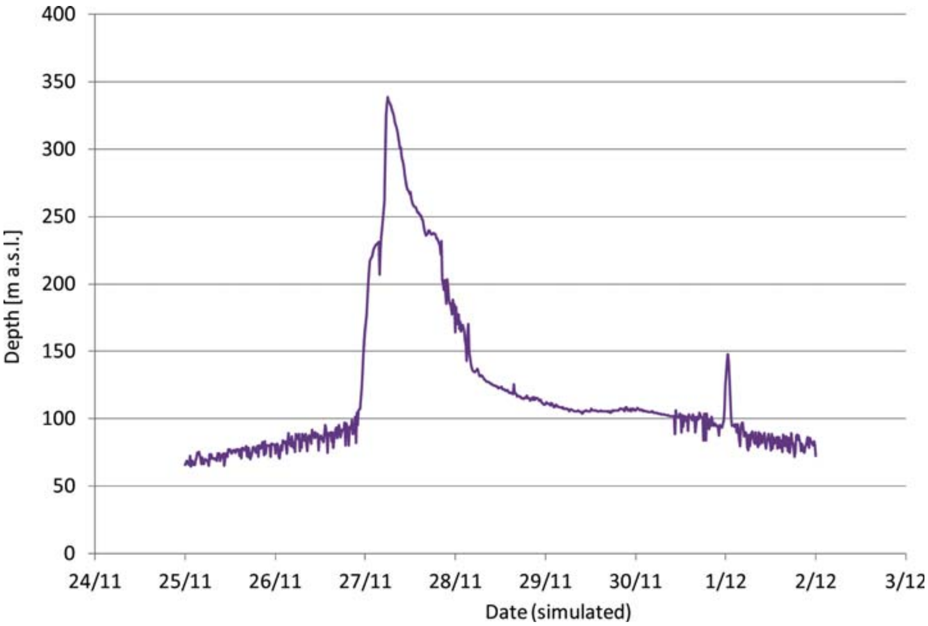

Figure 10: Simulated hydrograph for an event 200-year return period (section of the area at risk).

feasible because of social and political constraints, which cannot be discussed by technicians. Therefore, the professionals who performed the study were required to propose different solutions.

6 EARLY WARNING SYSTEMS

Given the difficulties related to the early warning, the problem needs better investigation. First, this event can be considered as a ‘flash flood’. For these cases even good decisions about warnings could be futile. In fact, the rainfall–runoff response time is short and warning is useless if there is not enough time to react. Second, one of the bigger weaknesses in flood warning practice lies in the uncertainties related to data accuracy and the procedures used for forecasting.

It is quite easy to assess the usual three warning levels of

- *alert*, when the plan provides a continuous surveillance (in time) with collection of input data and simulation model output evaluation;
- *alarm*, when field surveillance is also activated;
- *warning*, when mitigation actions to prevent damage to people and goods are implemented.

Because of the outputs of the model and of the mentioned uncertainties, three possible scenarios may be described [20]:

- *missed event*: when the flood happens but not forecast;
- *forecast event*: when the event is forecast and it happens;
- *false alarm*: when the event is forecast, but it does not happen.

In all cases, costs have to be evaluated. In the case of false alarms, apart from the warning costs, indirect damages have also to be evaluated which are, for instance, traffic and economy disruptions. Moreover, intangible damages also have to be evaluated, as the disruption, even if momentary, of normal life with the associated stress. However, different sub-systems have to be planned, such as:

- *monitoring and forecasting*, previously pointed out;
- *risk information*, which features the potential impact of an event;
- *communication*, to convey information about the event;
- *preparedness*, to develop strategies and actions required to reduce the damage;
- *response*, which consists of measures reducing the effects of exposure to a hazard and its duration.

The latter sub-system mainly focuses on alerting potentially affected people, rescuing victims, and providing assistance in case of need. With regard to the information procedures, an alert by the Civil Protection personnel to reach the area to warn and instruct people is not feasible, because time is limited. The only possible way is setting a sound alarm (and, if possible, a visual sign) to alert the community. This means a program of formation to have the community prepared to the event, considering that not everybody trusts the warning [21] and that they may not know how to react [22]. Given the particularity of this community, the persons in charge have to be instructed, giving them the moral responsibility of the safety of their community.

Because of the model calibration which, as above mentioned, tends to overestimate the consequences of rainfalls, missed events are unfeasible. On the other hand, problems related to the false alarm are very high. The problem is not given by the material costs of an evacuation, but by its psychological implications. How can uneducated people react to a number of false alarms? Would they evacuate anytime? If the false alarms would ‘train’ people to not react in case of risk, the costs in case of a real event happening would be very high.

Further studies to improve the model and reduce the risks of false alarms have to be devised.

7 CONCLUSIONS

In the design of a plan for flood risk management, the best solution is normally carried out by selecting consistent structural and non-structural measures. The first measure aims at reducing the challenge (i.e. the hazard) and the second enhances the coping capacity (i.e. the vulnerability).

In the paper, the case of the river Lambro is examined. This river crosses the city of Milano, which is one of the largest and most important towns in Italy, and whose defense plays a paramount important role.

Milano has considerably grown during the last decades, and so did it all its upstream catchment. Among the consequences of such a growth is the increased imperviousness of the catchment, which implies a larger water volume to be conveyed to the river and an increase of the velocity of wave formation (because of the reduction of the time of concentration). Both these facts lead to the increase in the peak of discharge in the river, and therefore the frequency of floods.

Structural measures have been taken at a catchment scale, where large structures have been built and others are in prevision and construction.

Beside these structural measures, the use of the land is managed on the basis of hydraulic simulations, which allowed the delimitation of the areas at different risk. These rules have been designed at the city scale.

At the local level, a specific case has been described in the paper, where the best technical solution is not feasible for social and political constraints, and where even an early warning system, very easy to be implemented, shows limits due to cultural inadequacy.

The solution requires the improvement of both the scientific tools and the users' education.

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