MITIGATION OF HYDROLOGICAL HAZARDS IN URBAN AREAS

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Abstract

The paper consists in the following four sections. In section 1, the characteristics of the Civil Protection policy in Europe is described. In such a context, since in Europe the development of national policies of disasters prevention are at different stages, it will be pointed out whether they are aimed to limiting the negative effects of a disaster or to removing the causes. In section 2, the role that the Italian scientific community plays with the national civil protection service is illustrated along with the relevant main research products. Specifically, attention is focused on the activities of the National Research Group for the Prevention from Hydro-geological Hazards (GNDCI) of the National Research Council of Italy. As a matter of fact, GNDCI promotes and develops coordinated interdisciplinary research directed towards the acquisition and improvement of scientific knowledge necessary in the sector of interventions for the containment of floods and landslides. GNDCI provides scientific and technical consultancy to interested ministries, regional authorities and other local departments, with particular reference to civil protection problems and educations of populations exposed to the dangers of floods and landslides. Moreover, GNDCI assures the coordination of action of scientific interventions during hydro-geological extreme events as well as it formulates proposal with reference to specific research programs. Within the GNDCI activity, the VAPI project merits a special mention. As a matter of fact VAPI project includes an extensive investigation covering the whole national territory, for the evaluation of the floods along rivers in Italy, performed with the techniques based on regional statistical analysis. In section 3, the results of a numerical model for forecasting and prevention of extreme floods in urban area of Rome are shown. Final remarks are reported in the conclusions.

1.0 Civil Protection Organization in Europe

The complexity and difficulty of the civil protection policy determines different approaches in the organizations of the Civil Protection structures for the15 EC Member States. In order to establish a framework for effective and rapid cooperation between national civil protection services when mutual assistance is needed and to enhance the coherence of actions undertaken at international level in the field of civil protection, a European General Office exists in Brussels. This office has carried on an intense cognitive activity about the measures taken by the Member States in order to deal with disasters. From the published documents [1] it's possible resume and compare the response of the Member States concerning the phases of Prevention, Warning, Alert/Alarm/Evacuation, Rescue and Reconstruction.

The approach to emergency planning is an all-hazard approach in United Kingdom and Ireland, an agent specific approach in France and Spain. As to planning for major accident hazards (required by the Seveso directive) the situation is similar in most countries with regard to on-site emergency plan. These are usually the responsibility of the manufacturer (sometimes in collaboration with local service or authorities). As to off-site plans the situation is instead quite differentiated, with regard to both their typology (for example there is a variety of plans in the cases of Belgium, Denmark, France, Ireland and Spain and just one type in the case of Greece), and level of implementation. On this latter aspect differences exist between and within countries, and

the efficiency may depend on many local factors, including attitudes towards safety issues on the part of manufactures and local authorities.
In term of emergency response, a multi-level model is often preferred, with the upper levels taking over when the lower ones have insufficient resources, as in the case of Belgium and the Netherlands. A distribution of responsibility throughout several organizations, with the main activity at the local level, is preferred in Ireland and the United Kingdom. In other cases a rather centralized organization is appreciated, although with some space provided for the local autonomies, as in the cases of Italy, France and Portugal.
While there is a certain similarity in all countries as to the type of services and agencies involved in emergency response (fire brigades, police, etc.), their autonomy, tasks and functions may vary considerably from one country to another. For example the police may depend on civil authorities as in the case of Italy, France and Spain, or have a great autonomous power as in the United Kingdom. In general a fire brigade officer is responsible for the management of an accident at the site: however the relations with other organizations involved may be regulated quite differently. In some cases, for example, the internal fire brigade maintains a certain control at the site (e.g. in Ireland), in other cases (e.g. in Denmark) formal responsibility rests always with the fire officer.
The attention for the issue of public information started at different points in time in the Member States, but it is now well established everywhere, although with many differences in practical implementation, both between and within countries. In some cases the necessity to make up for previous delays is acknowledged (e.g. Denmark, Germany, Greece, and Italy). The responsibility for risk communication is assigned to different actors (e.g. the manufacturer in Ireland and Germany, the prefect in France, the mayor in Italy, the municipal disaster staff in the Netherlands, the police in Denmark, the local or central authorities according to contingencies in Belgium). In all cases however, it is maintained that successful communication, both preventive and in the event, requires the full collaboration of many actors including manufacturers, emergency services, local, regional and central authorities, the mass media and, obviously, the general public.

2.0 Civil Protection Organization in Italy: the GNDCI

The Italian Civil Protection Department, following the directions of the Prime Minister and of the Minister for the Interiors as delegate, is organized in eight Offices. The Head of the Department supervises these offices, each one structured in different Services. The *Hydrologic and Hydraulic Risks Service* is one of the Services of the *Office for the planning, evaluation and prevention of risks*. In this Service, the *Office of the Large Risks Committee* manages the relationships with the Scientific Community and inside this structure works the "Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche – National Group for the Prevention from Hydro-geological Disasters", or GNDCI, under the auspices of Italian National Research Council. The organization of the Group ensures both multidisciplinary and interdisciplinary approaches to effective scientific and technical collaboration not only within academic and research institutions but also within relevant ministries, regional and local authorities.
The main activities of the Group are formulated under the following four research themes:

1. Forecast of hydrological extreme events and their control and mitigation;
2. Forecast and prevention of high risk landslide events;
3. Hydro-geological risk zoning and mitigation;
4. Groundwater hazard assessment.

About 100 operative units are working on relevant multidisciplinary themes, and special projects. The spatial distribution of operative units is homogenous on the whole territory of Italy. The main activities of the Group related to the continuing education, involving summer schools, workshops and other scientific meetings, aim to a possible reduction of the time lag between the acquisition of scientific knowledge and its subsequent transfer to the professional level. It is worth noting that in a period of almost a decade, the activities of the Group originated about 1.800 publications, including scientific papers in the most prestigious international journals, technical documents and workshop proceedings.
The main objectives of the group are:

- to promote and develop a coordinated interdisciplinary research, and the acquisition and improvement of the scientific knowledge in the field of interventions for the containment of floods and landslides;
- to provide scientific and technical consultancy in the field of hydro-geological hazards to ministries, regional authorities and other local departments, with particular reference to civil protections problems and the education of populations exposed to the dangers of floods and landslides;
- to assure the co-ordination of actions of scientific interventions during floods and landslides;
- to formulate proposals with reference to specific research programs;
- to maintain a liaison with public organizations charged with territorial development and, in particular, to assume the co-ordination of scientific activities related to the planning of river basins;
- to develop and promote connections and interchange with analogous research initiatives of other countries.

The activities of the research themes are briefly reported in the following sections.

2.1 Research theme 1: Forecasting and prevention of hydrological extremes and their control

The accurate evaluation of flood risk is the key point for a national program of reducing flood damages. Taking into consideration the fact that an absolute protection from flooding is not possible, a scale of intervention priorities is needed based on a homogeneous choice of flood risk and accurate methods of evaluation, as well as a homogeneous procedure for the evaluation of similar types of risks on a national basis.

In this regard, risks due to hydrological extremes may be subdivided with respect to three general objectives:

1. evaluation of instantaneous maximum flood of assigned duration which can be exceeded with a given risk of exceedence;
2. evaluation of the effect of floods triggered by structural interventions;
3. evaluation of the probability of flood forecasting.

A special program for the evaluation of floods corresponding to a given return periods for each river in Italy (VAPI program) was completed. This program involves studies based on the statistical analysis of the frequency of annual maxima of extreme rainfall and observed discharges, as documented by the Italian Hydrographic Services (S.I.I.). The VAPI project foresees an extensive investigation covering the whole national territory, for the evaluation of floods in Italy. The methodology adopted is the index flood method, modified according to a hierarchical approach, that utilizes three different spatial scale levels for the estimation of various parameters of the distribution adopted (1st level: interregional scale, for the estimation of the shape parameters; 2nd level: regional scale for the estimation of the coefficient of variation of the annual flood; 3rd level: basin scale, for the estimation of the index flood). The regionalization procedure is based on the Two Component Extreme Value distribution (TCEV), which is very useful and accurate to explain and understand extraordinarily high observed floods.

2.2. Research theme 2: Forecasting and prevention of high-risk landslide events

The activities of this research theme is programmed on the following phases of development:

1. cognitive investigation for a systematic collection of data regarding the phenomena of landslides and other centers of mass movements for an initial picture on the localization and recurrence of the events, together with the approximate dimension of the phenomena and the extent and magnitude of damages produced;
2. study of the phenomena landslides, for an integration and interpretation of the available data, with the recognition and delineation of the unstable zones, topographic definition of the movements, geological structural grouping in the local context and geotechnical characterization of soils.

The program SCAI has been promoted and partially completed under this research theme; SCAI, that is Special Project for the Study of Unstable Towns, was promoted in order to evaluate the instability conditions of Italian towns. Through detailed, site specific investigations, the instability conditions associated to various types of mass-movements affecting towns and dwellings are mapped and described, with particular emphasis to the safety conditions of buildings and inhabitants. This project constitutes the most important activity of this research theme. A preliminary analysis of the existing compilation of habitable areas subject to serious instability conditions showed a grave underestimation, in numerical terms, of the actual situation. For some regions (e.g. Emilia Romagna, Toscana and Marche) the inventories are all completed and published.

2.3 Research theme 3: Evaluation of hydro-geological risk and intervention zoning strategies for the mitigation of extreme event effects

The research theme 3 has as a general objective the evaluation and use of structural and non structural interventions based on a homogeneous procedure at the national level, and a documentation for the zoning of areas subject to the risk of inundation. The expected outcome of the activities of this research theme involves around the preparation of a scientific and technical report of areas vulnerable to flood risk, comprising in detail:

- the description of the cartographic, topographical, hydrographical, hydrological, hydraulic, meteorological, geological and geo-technical data in relation to the structure of the contents and obstacles to flow channels, and other descriptions of urban and socio-economic data base used in the evaluation of risk;
- the description of the procedure adopted in the hydrological and hydraulic evaluation used for risk mapping;
- the presentation of the results, in hydro-meteorological and hydraulic evaluations, their return periods and confidence intervals within which they are considered reliable.

Furthermore, the research is also addressed to investigate the physical causes and hydrological consequences of the so-called “tropical like storm”, that meteorologists have observed in extra tropical Mediterranean region since 1996; it is possible that they may be responsible of very high hydrological impact on the territory.

In addition, a series of cartographic maps have been prepared in which the areas prone to inundation are delineated in a homogeneous way with its associated return period. In particular, very interesting flood risk maps of Florence and Rome have been carried out.
The programme AVI (Inventory of Areas affected from Floods and landslides events in the past) has been completed under this research theme.
The AVI Project was commissioned by the Department of Civil Protection to GNDCI, the scope of the project consisted in an inventory and an analysis of areas affected by landslides and floods in Italy, for the period 1918-1990. The inventory currently contains more than 17,000 information on landslides and more than 7000 information on inundations. In spite of the limitations due to the complexity of the Italian territory, the different awareness of the impact of landslides and floods on the territory, and the limited time available, the results of the inventory represent the most comprehensive archiving of mass-movements and floods ever prepared for Italy. In 1996 a first map of sites affected by mass-movements and inundation was published [2]. On December 1998 a second revised version of the synoptic map [3] showing the location of more than 15,000 sites (9086 landslides and 6456 floods) affected by catastrophic events for the period 1918-1994 has been published. Information at municipal, provincial and regional scale have been published as reports, and also CD-Rom are available. The data and some thematic maps are available on GNDCI WEB Site: http://www.gndci.pg.cnr.it

2.4 Research theme 4: Evaluation of aquifer vulnerability

The objective of this research theme is the study in space and time of the phenomena of pollution of underground water bodies, with a view to obtain research and operative products for a rapid and efficient assessment of intervention programs for forecasting and safeguarding population at risk.
The studies, conducted on selected relevant sample areas, serve as a basis for to develop methodologies for the preparation of vulnerability maps for aquifers and to provide the central and peripheral state agencies with proposals for the defense and protection of the national territory.
The VAZAR Project (Vulnerability of Aquifers in High Risk Zones) was conceived and launched in 1985 with clear intentions posed by the Department of Civil Protection (information base for the prevention and prediction of contamination of drinking water sources). The fundamental objective of this program was the creation of a Vulnerability Map of aquifers covering representative and sample pollution areas selected in such a way as to represent, as much as possible, all the major hydrogeological, environmental and anthropic aspects of the territory of Italy. In this way, base planning documents can be contemporarily and integrally produced for the prevention and protection of ground water including their respective methodologies of investigation, data banks and processing, thematic cartography both traditional and automatic and subsequently presented to users and administrators (Civil Protection, Ministry of Environment, Ministry of Public Works, Regional, Provincial and Community Authorities, Agricultural and Reclamation Consortiums etc.).

3.0 A numerical model for the simulation of the urban area of Rome flooding

Propagation of extreme flood events has remarkable impact on structures and urban infrastructures. The anthropization which has progressively affected the river valleys more and more intensively, has caused an increase in damage and in number of casualties. Most effects can be seen in infrastructures mainly because the large number of casualties during a flood is due to water flow in the streets. The presence of water flowing in the streets can jeopardize the efficiency of infrastructural networks and hinder rescue teams from transporting victims to safer areas.
To analyze such effects and in general to determine the risk of vulnerable elements within an urban area, whether specifically important buildings or service networks, it is necessary to know how the flood will affect the urban street network.

3.1 The numerical model

During flood propagation in urban areas, flow enters the street network and it divides into a system of channels, linked to the river. This kind of phenomenon is clearly not one-dimensional, being impossible to draw a single stream line for the whole flow. Flow can be considered as propagating in an irregular one-dimensional open-channel network, where channel geometry is derived by street geometry. As a result, the governing equations for unsteady free surface flow may be written as:

$$a_i \frac{\partial z_i}{\partial t} - \sum_{j=1}^{k} Q_{ij}\left(z_i, z_j\right) - Q_{ie} = 0 \qquad (1)$$

where z_i is the water level at the node i, positive upward; Q_{ij} is the discharge from node i to node j; and Q_{ie} is the flow rate entering or outgoing the domain at node i. In (1) the sum is extended to each j of the k nodes connected by a channel to node i. The free surface elevation at endpoints of each channel converging to node i, is assumed to be the same as that of node, z_i, reducing the number of the unknowns to the number of nodes, N.
Equations (1) my be discretized in time, yielding the non linear system of algebraic equations:

$$a_i \frac{z_i^n - z_i^{n-1}}{\Delta t} - \sum_{j=1}^{k} \left[\Theta Q_{ij}\left(z_i^n, z_j^n\right)\right] - \\ - \sum_{j=1}^{k} \left[(1-\Theta) Q_{ij}\left(z_i^{n-1}, z_j^{n-1}\right)\right] - Q_{ie} = 0 \qquad (2)$$

where: Θ is a temporal weighting coefficient, $1 \geq \Theta \geq 0$; Δt is the time step; and the n index denotes the time $n\,\Delta t$.
Both the Newton-Raphson method and the simplified method proposed by Cunge [4] have been used to solve the non linear equations system given by (2). The time step has been evaluated at each time, depending on maximum depth increment, on maximum Courant number and on the step iterations number when the Newton Raphson method has been used. The model, on the contrary of others, has not shown problems in wetting and drying nodes and can consider flood propagation over an initially dry area.

3.2 The case of Rome

Rome has been inundated by the Tiber River several times in its history, starting from the legendary inundation with the Romulus and Remus floating basket to the last one in 1937. The Milvio Bridge, in the northern part of Rome, has always played a crucial role in the inundation of the city. In the past, its acting as a dam, limiting the downstream discharge and inducing the water rising upstream, caused the flooding of the banks several times. As described by Frosini [5] on the basis of the available historical documentation, during the major floods in the left bank water flew along the Flaminia street up to Popolo Square and further, while in the right bank the water reached the Sant'Angelo Castle. In recent years, as in 1937, notwithstanding the noticeable river improvement around 1900, the Tiber flooded the right lower bank.
For these reasons the study is focused on the northern part of the city, where the Milvio Bridge is placed and, as already mentioned, the flow has been considered entering the street network both on the left and right side from the area upstream the bridge.
The street network of Rome has been obtained digitizing the existing maps of Rome at scale 1:500, along the Tiber River from Milvio Bridge to Sant'Angelo Bridge. Information gathered on both street elevations and widths resulted in the network topology and geometry. The channel network used for the simulation is shown in Figure 1.
As initial conditions, dry nodes have been considered everywhere. As boundary conditions, the hydrograph of one of the most important flood events, i.e. the one that occurred in 1870 [6], has been assumed as a reference. Specifically, the water level has been assumed increasing linearly for 14 h upstream the Milvio Bridge, up to 0.50 m above the high chord. Afterwards, the water level has been considered constant for 10 h and then decreasing linearly down to the initial value in 8 h.
In Figs. 2 and 3, the water depth distribution is shown after 6 and 24 hours from the beginning of the simulation, respectively. The water first flows above the right, lower bank, inundating a small area close to the bridge. Afterwards while in the right bank the extension of the flooded area grows slowly, on the left side water spreads rapidly and widely. At t=18 h most of the Flaminia road from Milvio Bridge to Popolo Square is flooded and the water reaches Spagna Square. Finally, at t=24h also the right bank is completely flooded up to Sant'Angelo Castle.
The way water flows is similar to what Frosini described and was mentioned before.
The simulations show that, depending on the valley morphology, the water over banking Milvio Bridge can reach the historical center in spite of the works performed at the beginning of the century. Furthermore, the flooded area around Popolo Square is approximately the same as the flooding in 1870. Even the flooding of Spagna Square as obtained in numerical simulations shows relations with the legend that narrates that Bernini's boat-shaped fountain was inspired by the boat which ran aground in the square brought there from a flood at the end of the 16th century.
This model may be considered as necessary for any risk estimation procedure concerning vulnerable targets in prone to flood cities and towns. It allows to turn the discharge associated with a given probability in water depths and inundated surfaces. Furthermore, the results for the examined case study prove that the reduced computational burden of the proposed hydraulic model allows its use in a more complex system for real time analysis of the flood evolution. Hence, this system could help in decision making and civil protections acting, analyzing and forecasting the transportation network efficiency.

4.0 Conclusions

In the Civil Protection field, referring to the hydro-geological risks (flooding and landslides), it is crucial taking together forecast/warning, prevention, alert/alarm/evacuation, and rescue, at the central level of coordination.

In fact, in this way damages can be reduced, lives preserved, and, hence, effects of catastrophic events mitigated; this is because very often catastrophes are induced by hydrological intense/extreme events, for which forecast is possible with a sufficient reaction time.

To improve actions we need:

- Better understanding of the natural phenomena, through an enhanced scientific effort;
- Specific Academic Curricula;
- Improved coordination at the national and local levels;
- Better definition of event scenarios, through improved simulations of possible (or probable) events;
- Field training exercises

At this moment it would be very important in Europe to transform the present General Direction into an Agency, like FEMA, capable of coordinating and to make homogeneous the various Civil Protection policies. When the European Prime Ministers met last December, they decided the creation of this Agency. In the next meeting in Barcelona, it will be decided which city is going to host the Agency. We can say that these facts mean that Civil Protection in Europe is considered as a priority.

5.0 References

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6.0 Biography of presenter

Lucio Ubertini is Professor of Hydraulic Works and Hydrology at the University of Rome "La Sapienza". He is also President of the Italian Group for the Natural Hazards Prevention (GNDCI) of the National Research Council (CNR) since 1985 and Director of the Institute for Hydrogeological Protection in Central Italy (IRPI-CNR) since 1978.

He is the author of more than 150 papers/book in the fields of Hydrological models, Sediment transport, Real time flow forecast, Irrigation and drainage, Water resources management, Soil-water-vegetation modelling.

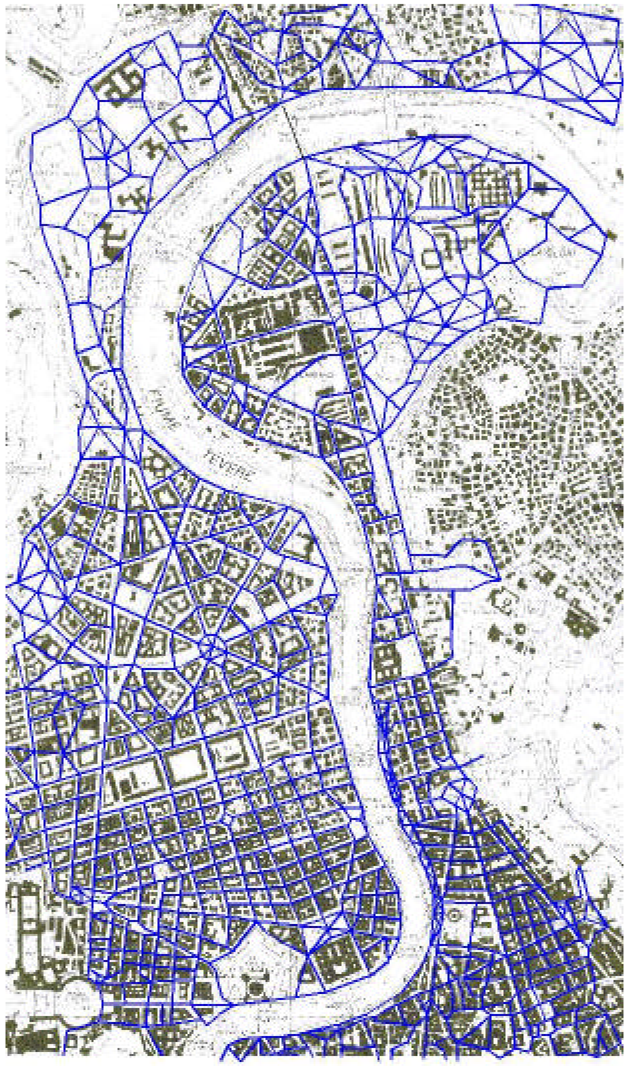

Figure 1 - The channel network used for the simulation

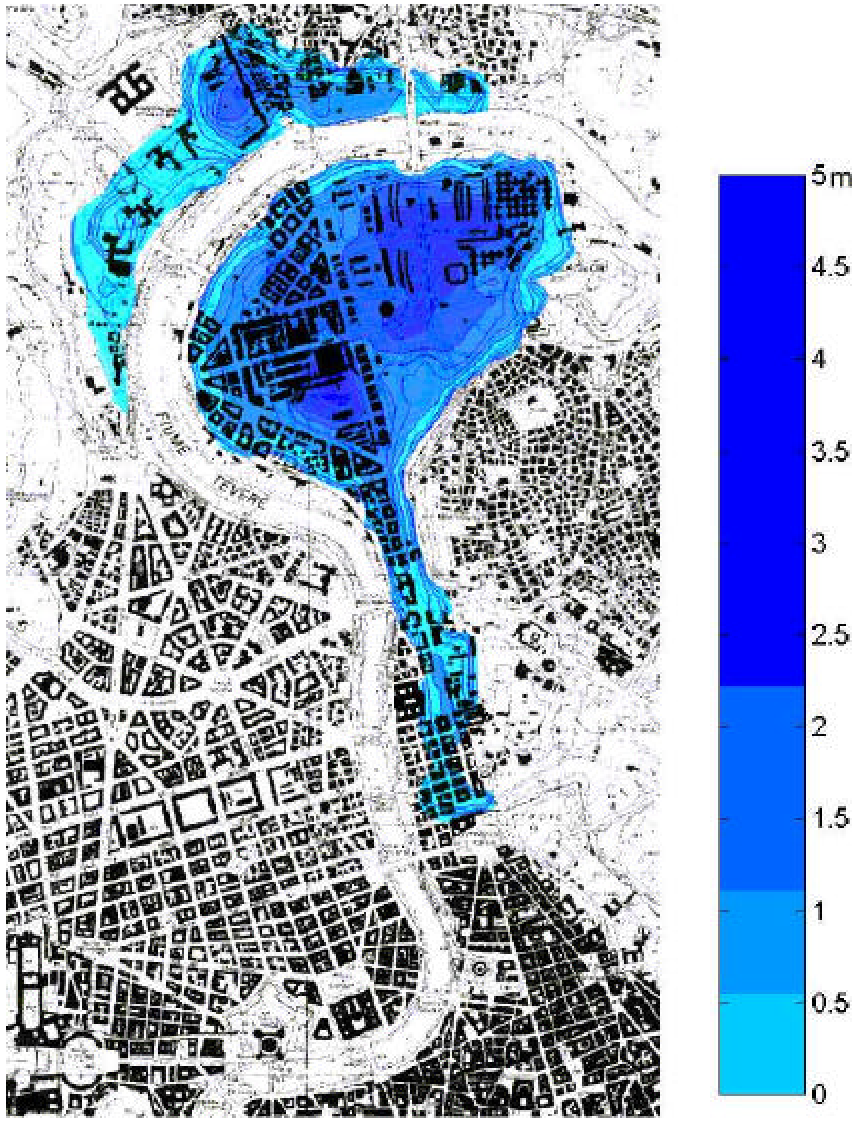

Figure 2 – Water depth distribution is shown after 6 hours from the beginning of the simulation.

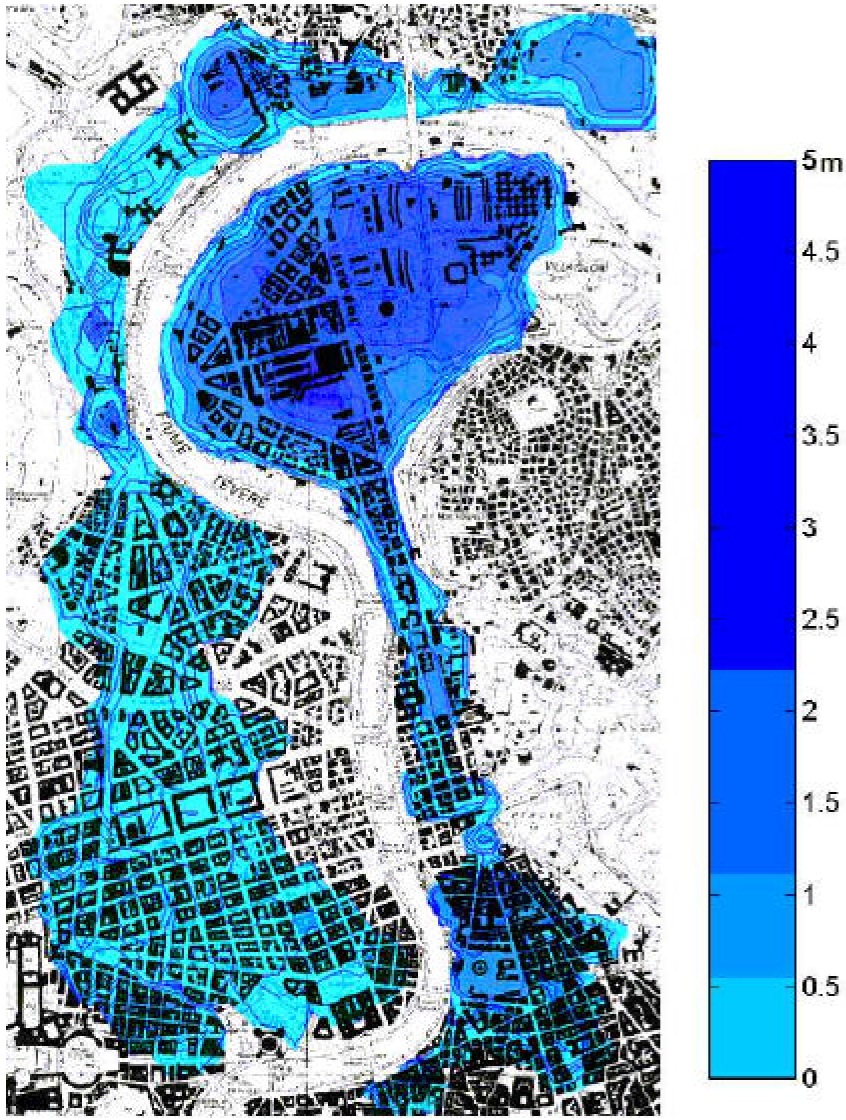

Figure 3 - Water depth distribution is shown after 24 hours from the beginning of the simulation.