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Flood risk assessment and quantification in the Piedmont Region, Italy

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Abstract: A major shift in flood management strategies is currently underway in many countries throughout the world. After the approval of the 2007/60 directive on floods, Italian government empowered the Po Basin District Authority to carry out certain activities that correspond to the actions required by the 2007/60 EU directive on flood risk management. The quantitative flood IRP risk assessment methodology has been proposed by Regional Piedmont Administration, in collaboration with the Politecnico of Turin, with the aim of developing a system to quantify flood risks throughout the entire Piedmont region. The IRP methodology is described in the chapter. Some study cases on quantitative risk assessment regarding the Po basin territory, in the Turin, Susa and Arona Municipalities, and in the Orco watershed basin are dealt with. The proposed IRP methodology can be considered a first step towards a quantitative analysis of risk and a valuable means of supporting decision making. It is currently being developed to help decision makers to compare different political strategy options and to improve risk mapping in preparation of the next review foreseen by the EU directive.

1. Introduction

A major shift in flood management strategies is currently underway in many countries throughout the world. The notion of flood risk management (FRM) is well established, as:

“The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk” (WMO, 2009).

The notion involves many elements, from integration with the management of water to emergency flood management, from local hazard assessment to the adoption of the best mix of strategies at a basin scale (Klinke et a. 2002).

The effective implementation of *FRM* requires an "enabling environment", in terms of policy, legislation and information.

From an organizational point of view, the definition of clear institutional roles and functions is a central point in taking the necessary steps for *FRM* implementation. As is well known by regional and local administrations, the nature of floods and the definition of *FRM* strategies generally create a complex situation of competing requests, and, particularly after major floods, poses some difficult questions about the kinds and the hierarchy of interventions necessary for risk management, pertaining to the choice of the most appropriate strategy, the targets and priorities, as well as the balancing costs and benefits.

In this frame the Po Basin District Authority (*PBDA*), in collaboration with governmental agencies (AIPO Agency) and the regional authorities, plays the most important role in decision making in the Po basin.

The legal framework consists of legislation act no.183/1989 (Italian Parliament, 1989), which enables the basin district authorities to implement PAI – the Hydro-geological Asset Plan- throughout the entire Italian territory. After the approval of the 2007/60 directive on floods, Italian government act no.49/2010 (Italian Government, 2010) empowered the *PBDA* to carry out certain activities that correspond to the actions required by the 2007/60 EU directive on flood risk management.

The first activity is related to the *preliminary assessment* of flood hazards and risks. The assessment includes maps of river basin districts, a description of the floods that had occurred in the past and an assessment of the potential adverse consequences of future floods on health, economy and culture. The second activity consists of the identification of the high-risk flood-prone areas. This activity has concluded recently, in December 2013, with the publication of *flood risk maps*. The third activity is focused on the implementation of *risk management maps*, and will conclude in 2015.

Some issues related to the second activity are discussed in detail in the following sections.

The Piedmont Region Administration (RPA) has already published qualitative risk assessment maps pertaining to the entire territory. The dissemination and confrontation phase, according to the flood directive roadmap, is underway, with the local administrations and the general public.

A quantitative flood risk assessment methodology has been proposed by RPA, in collaboration with the Politecnico of Turin, with the aim of developing a system to quantify flood risks throughout the entire Piedmont region (which covers about 25400 km^2), on the basis of the available knowledge and resources and within the frame of the aims and purposes of the 2007/60EU directive, according to which

“In order to have an effective tool for information available, as well as a valuable basis for priority setting and further technical, financial and political decisions regarding flood risk management, it is necessary to provide for the establishing of flood hazard maps and flood risk maps”

Quantitative risk assessment is of particular interest, considering that the total number of people living in flood prone areas (about 900km^2 for the 500 return period inundation) is about 700 thousand, that is, about the 16% of the total population. The most recent relevant floodings in 1993, 1994 and 2000 have consequently drawn the attention of administrations to soil use and consumption, and have led to the revision of municipality territorial regulator plans throughout the region.

The research results proved to be useful for practical application by technical practitioners (mainly engineers and geologists) and by public administrations, as a *“valuable basis*” for decision making. The different roles played by the factors that influence risk assessment, including climate changes, will be discussed thereafter. Some study cases on quantitative risk assessment regarding the Po basin territory, in the Turin, Susa and Arona Municipalities, and in the Orco watershed basin will be dealt with (fig.1).

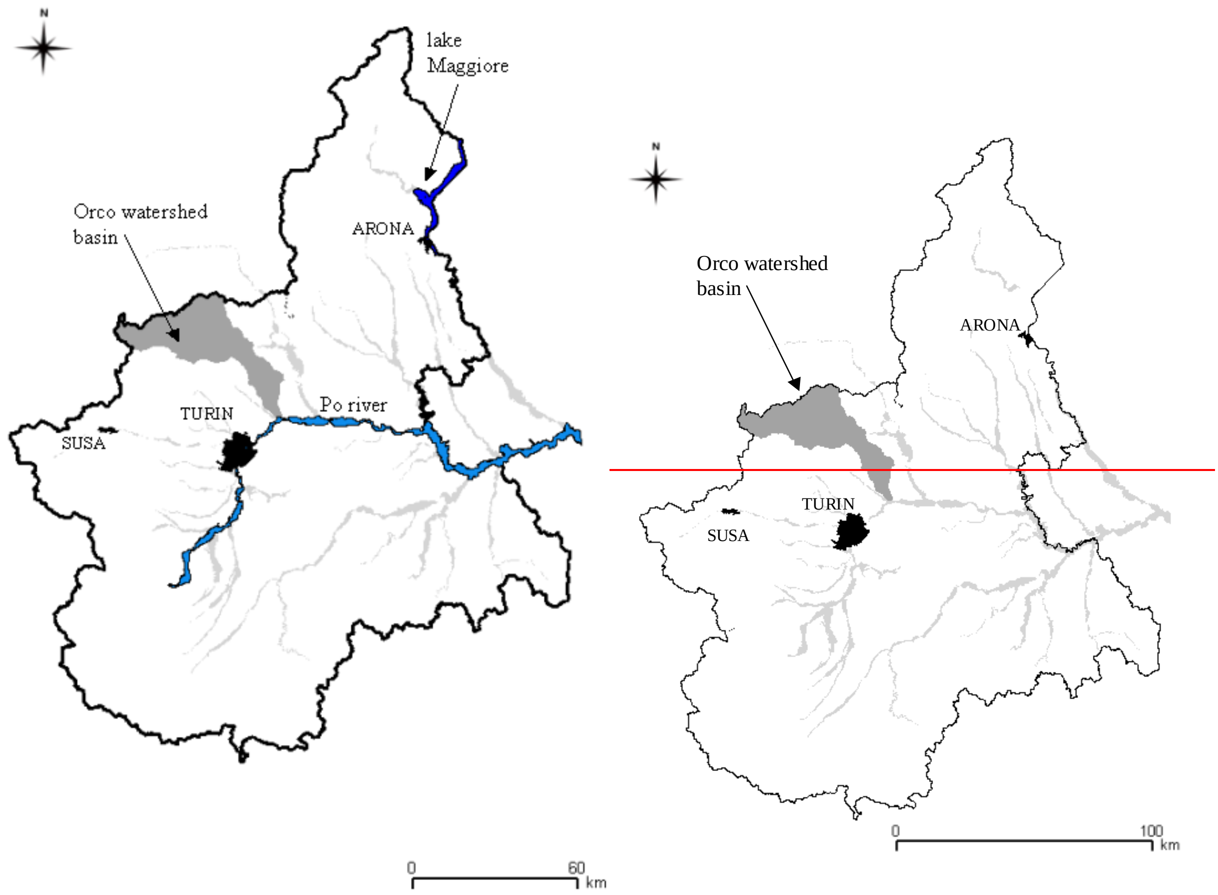

Figure 1. Map of the Piedmont region, showing the study case areas discussed in the chapter, i.e. the Turin, Susa and Arona municipalities and the Orco watershed basin.

2. Risk assessment quantification

From a technical viewpoint, the following definition is here assumed (*WMO*, 2009; Franzi, 2012) for flood risk:

"potential losses associated with a hazard or an extreme event in a given place within a given period of time, which can be defined in terms of the adverse consequences (damage/losses) and the probability of occurrence" .

Therefore, the concept of risk necessarily implies the concept of loss, of the probability of flood occurrence, the intensity of the phenomena, the produced damage and the vulnerability of the anthropogenic context. Risk can be considered the superposition of three factors, which are generally indicated as Hazard (H), Exposure (E) and Vulnerability (V) (figure 2).

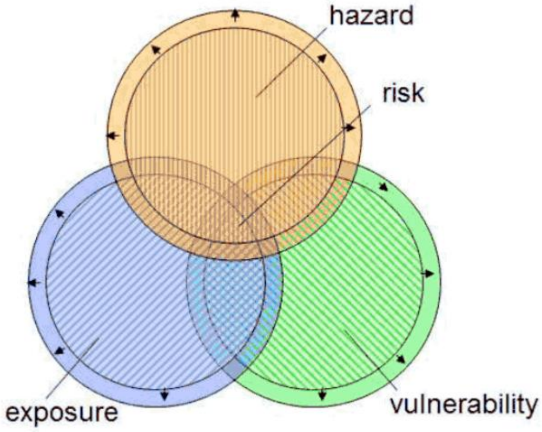

Figure 2. Risk considered as the superposition of three constitutive factors, H (hazard), E (exposure), V (vulnerability) (Franzi, 2012).

As shown in figure 2, risk assessment should entail the assessment of each constitutive factor, its variability in time and space, the complexity of natural/social/organizational factors and the social resilience against floods and natural disasters.

On one hand, this would allow a wide and comprehensive risk assessment to be made and thus provide a good framework for territorial planning and civil protection countermeasures, and this would also allow the best management strategies to be detected.

On the other hand, in risk assessment quantification and mapping, each national/regional/local Administration, including the District Authorities, faces the problem of constraints that substantially condition the decision makers in their choice of the most appropriate methodologies, as well as of the scale and of the extension of the territories where the flood risk is assessed, mapped and evaluated. The main constraints that condition public administration depend on the context (geographic, administrative) in which the directive is implemented, that is:

- the available *time* to fulfil legislation deadlines: the 2007/60 EU directive imposed the members to produce flood risk maps by December 2013;
- the available *information and datasets*, such as the total amount of information and data available at the time the administration starts to work; when planning its own activities, a public administration generally assumes that the discovery of new relevant resources (or deposits of known resources) should be excluded or is improbable;
- the *available resources*, i.e. at the time the work starts; resources should be intended from an extensive point of view from human resources (i.e. the number of workers that can work in the implementation of the directive, their technical abilities and formation, such as engineers, geologists etc.) to software resources (availability of free software, time

computing, CPU computing capacity, total number of personal computers) and to economic resources (possibility of outsourcing some work).

Therefore, the context extension (i.e. the total extension of the areas where the risk should be assessed and mapped) and the detail at which it can be mapped or assessed is a consequence of a careful balance of requirements. Several scientific aspects can result to have different relevance as far as organizational and time factors are concerned (figure 3). Rough estimations over a short time can sometimes prove to be preferable to detailed investigations, especially when they are time and resource consuming.

As will be shown in the following sections, scenarios concerning the impact of climate changes on precipitations, water runoffs, flood frequency and flood intensity are probably affected the most by great uncertainties and often the results obtained by means of climatic simulation models should be confirmed by more investigations over time (STRADA, 2013; ARPA, 2007).

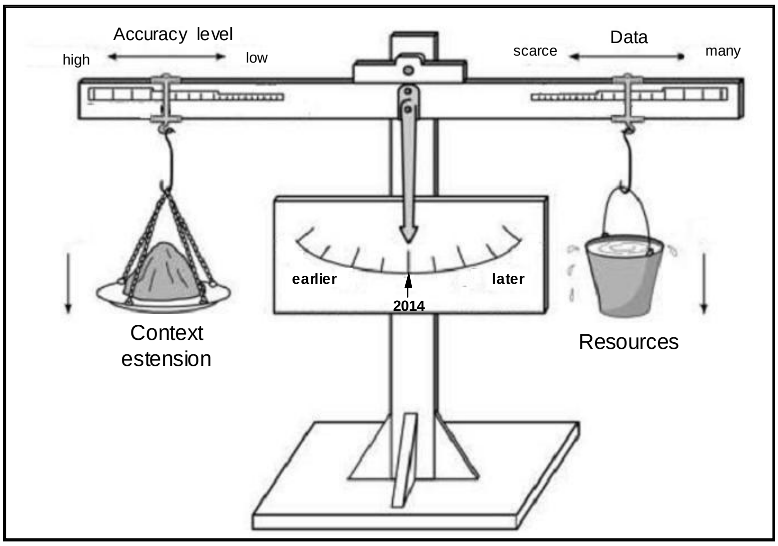

Figure 3. The so-called Lane balance (Lane, 1955), revised according to risk assessment mapping

An example of the necessity of simplification in order to fulfil the requirements of the *2007/60EU Directive* is that of the complexity of concepts, in particular the concept of damage and losses. Theoretically, as far as damage is concerned, it should be pointed out that direct and indirect losses should be considered equally. Direct losses concern human life, structural losses and the loss of functionality of the anthropogenic structures, such as houses, bridges, levees, roads, dams, etc.. Equally, indirect losses such as:

1. the psycho-social impact, that is, the psychological effects on people affected directly or indirectly by the flood due to the loss of property or of livelihoods, the displacement from one’s home, the disruption of economic, family and social affairs;

2. the functioning disruption, that is, the interruption of interconnections between people, services and webs, so that people and economic activities that are far from the place where the flood event occurs also suffered from the effects of the break in interconnections; this is the case, for example, of oil pipelines, water pipelines, railways;
3. the economic impact, that is, the hindering of economic growth and development, due to the high cost of relief and recovery, which may have an adverse impact on investments in infrastructures and the development activities in the area; both private and public sectors are generally discouraged from investing in recurrent high flooding conditions;
4. the economic cost of the emergency countermeasures taken for civil protection purposes and other actions taken to prevent flood damage and other losses;

should all be considered, but their evaluation and quantification may take time and this may not be compatible with the deadlines given in the 2007/60EU directive.

Therefore, a robust (Marijolein et a., 2011) risk assessment would be preferable for public administrations in charge of complex and long-term projects.

The research, in collaboration with the Politecnico of Turin, started with the definition of the constitutive elements of the risk concept. A discussion about the definitions of the H,E,V terms is provided in the following sections.

2.1 Hazard

Hazard (H) can be defined as: *"the probability of the occurrence, within a specific period of time in a given area, of a potentially damaging natural process"* (UNDRO, 1980), of a specific intensity.

The regional public administration in Piedmont has extensively debated flood hazards with local administrations, at a provincial and municipality scale since 2001, with the implementation of PAI (PBDA, 2001), basing the hydraulic and hydrological analysis on the different available data.

By applying hydraulic and geomorphologic models, the *PBDA* has proposed a classification of hazards that is mainly based on river corridor concept (fig.4), a concept that has been implemented since 2001 with the PAI and which was modified after the implementation of the 2007/60 flood directive; the river corridors are the following:

- corridors with a low flooding probability (L): this corresponds to areas that can be flooded by a design discharge of 500 years, Q_{500};
- corridors with medium flooding probability (M): this corresponds to areas that can be flooded by a design discharge of 200 years, Q_{200};
- corridors with high flooding probability (H): this corresponds to areas that can be flooded by a design discharge of 50 years, Q_{50}.

According to the most recent evaluations, published on line by *RPA* (hazard maps) and available for public confrontation , the H, M, L corridors extend over an area of about 400 km^2, 580 km^2 and 900 km^2 respectively.

Figure 4. River corridor approach, developed by the *PBDA*, referring to the Susa municipality. Legend for hazard: (High)=dark blue; (Medium)=blue; (Low)=light blue (free on line at http://osgis2.csi.it/webgisAtlante/qgiswebclient.html?map=qgis_cloud/direttiva_alluvioni)

According to (*Maione et a. 1976*), the mean occurrence probability per year of a given Q_{RP} flood is given by:

$$P= 1/RP \qquad (1)$$

All the information available on the corridor mapping (available on line at Regione Piemonte website), have been taken into account, especially that already contained in PAI, which has been in force since 2001. In this way the hazard maps, in the implementation of 2007/60 EU directive, are based on the hydrological evaluations and hydraulic modellings that are already available at a basin and local scale, and which are currently in force, amended in time and shared between public administrations.

An example of a hazard mapping methodology has been proposed by Franzi and Rinaldi who work at RPA (*PBDA*, 2012). This methodology is based on the interpolation of 1D hydraulic simulation results, in order to obtain flooding inundation maps in a reasonable time and on the optimization of the information available on flood inundations (*PBDA*, 2012). The approach is similar to those proposed in FEMA and *IACWD* (*IACWD* 1982; Noman et al. 2001; *FEMA* 2003, Merwade 2008) for flood inundation mapping. It involves the following procedure:

a. the design flow Q_{200} (i.e. the 200 year return period – RP -flow) is estimated using a calibrated hydrologic model and precipitation input, or through statistical analysis; as fas as Piedmont rivers are concerned, this means the estimates proposed by *ABDPO* in the *Design Flood Directive* (PBDA, 2001) (currently in force with amendments);

b. a water surface elevation from the hydraulic model is mapped on a digital terrain model, and a water surface (usually a *triangulated irregular network* - *TIN* format) is created;

d. the digital terrain model (*DTM*) is subtracted from the water surface to obtain a water-depth map[1];

e. the area with positive values in the water-depth map leads to the flood inundation map.

Flooding results are compared to an available dataset and maps and checked by means of (1) aerial picture photo-interpretation and (2) geomorphologic river assessments, based on recent and past river channel changes.

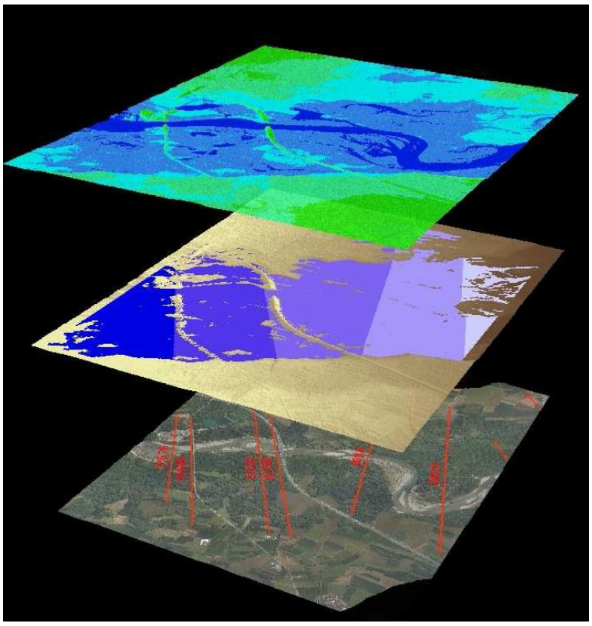

Figure 5. Flooding map methodology pertaining to the Orco river. A water surface elevation (middle) is superposed onto a *DTM* (below). Subtraction of the two layers allows the water-depths to be obtained.

The methodology allows flooding maps to be obtained in a reasonable time and optimizes the “best” resources available at present. Applications have shown that the results are basically affected by uncertainties on the ground elevation data, which are generally obtained by means of *LIDAR* and the semi-automatic procedures that allow a *DTM* to be obtained, starting from raw *DSM* data (see e.g. Gerstenecker et al., 2005**)**.

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[1] In this paper, the **digital terrain model** is intended as the representation of the bare ground surface without any objects, such as plants or buildings.

Other flooding mapping uncertainties arise from uncertainties in hydrology and hydraulics, which are, in turn, affected by the effects of climate changes on rainfall (Merz et a., 2009; Todini, 2007; Klinke et a. 2002).

The results from hydrological studies conducted according to the analysis adopted by the Environmental Regional Protection Agency (ARPA, 2007), on climate changes, have so far been inconclusive regarding the impact of climate change on rainfall and runoff. Different studies have been performed by ARPA to draw up scenarios on the effects of possible climate changes on rainfalls, runoffs, temperature, sea level, glaciers extension and snow coverage, based on simulation models (Tebaldi et al. 2006). These scenarios can be useful to suggest and implement strategies that can be used to cope with climate changes, to adapt to meteorological variations and to climate variability, and therefore can be considered a useful tool for decision makers to visualize the *possible* effects of climate.

ARPA's conclusions have been confirmed from the results of the recent *STRADA* project (*FESR* project; *STRADA*, 2013), which was focused on regional hydrology and hydro-meteorological models of Piedmont and Lombardy; the project did not led to the definition of *"robust"* conclusions:

> *"The study of the temporal rainfall distributions has actually highlighted elements of non-stationarity, due to either an increase in observational data, or to variations in climate, although it is difficult to discriminate between stable trends and fluctuations in the medium term (multidecadal)".*

Recent hydrological research in France (Dumas et a. 2013) on alpine watershed basins contiguous to the Piemonte Region, has shown that the effects of climatic changes on the estimates of the 100-yr return period discharge (1) depend to a great extent on the downscaling techniques that are used, and, for a given technique, (2) vary remarkably from region to region. In particular, the return period (RP) under climate change associated with the present 100-yr RP level, under the WT downscaling assumption (fig. 4 in the Dumas et al. paper) can be much higher than 100-yr, implying that climate changes could cause 100-yr floods to be less frequent in the near future.

Similar conclusion have also been shown by Kundzewicz et a. (2010); the recurrence interval (return period) of today's 100-yr floods in most of Piedmont's watershed basins might be less than 100-yr, when the Hirabayashi et al. (2008) results are considered as a basis of investigation, or higher that 100-yr if the Dankers and Feyen (2008) emission scenario is considered.

Robustness of evaluation is a crucial requirement for institutions and public bodies in charge of formulating flood risk management strategies for the river Po. *Robustness* can be defined (Marjoleine et a. 2011) as the ability of a system to remain functioning under disturbances, where the magnitude of the disturbance is variable and uncertain. The proliferation of methods for uncertainty analysis should be placed within a coherent framework (Merz, 2009). As well as estimating the amount of uncertainty associated with key decision variables, aids to the decision making should identify the most influential sources of uncertainty, and the implications of uncertainty on the ordering of preference between options. Moreover, even without considering the uncertainties due to climate changes, it is has been documented in literature that hydrological models suffer from uncertainties due to data incompleteness, etc..

Moreover, the uncertainties in climate changes should be compared with those due to hydrological modelling obtained in steady climatic conditions.

A simple analysis of the management due to uncertainties due to the use of hydrological models has been proposed by Franzi and Rinaldi and implemented in act no.2-11830 (RPA, 2009). The analysis is based on hydrological estimates obtained by means of the VAPI model, which was developed by CNR-CUGRI (Villani, 2001) and is based on the geospatial statistical approach. The VAPI model, which computes regional estimates of discharges Q_{200}, is free and available for practitioners and public administrations to compare the local hydrological Q_{200} estimations (obtained by means of an arbitrarily chosen hydrological model) with those of VAPI regional estimations. Two sets of estimations were considered in the analysis, for a dataset of 71 instrumented or not-instrumented watershed basins in the Piedmont region:

- the $Q_{200VAPI}$ set of estimations obtained by means of the *VAPI* model;
- the $Q_{200PBDA}$ set of estimations used by *PBDA* for flood mapping [2].

The $Q_{200PBDAi}$ and $Q_{200VAPIi}$ rates were compared for each basin in the dataset, in the following way:

$$\left(\frac{Q_{200VAPI}}{Q_{200PBDA}}\right)_i = f\left(Area\right)_i \tag{3}$$

where: *A* is the area of the i_{th} watershed, i=1,2,….71, Q_{200} is the computed flood discharge, the $_{PBDA}$ index refers to the vales used for the implementation of the directive and the $_{VAPI}$ index refers to the *VAPI* model. As shown in figure 6, the rate given by (3) ranges over a wide interval, from a minimum value of 0.65 to a maximum value of 2.05.

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[2] The Q_{200} values were published in 2001 and have been updated over time.

By looking at fig.6 and considering the deviance between the different estimates, different questions can arise: "*is the Q_{200} estimation uncertainty, associated with climate changes, higher than that associated with modelling? Under which hypothesis? For which watersheds?".* No conclusive answers have formally been given for the watershed basin in the Piedmont region. The method given in (3) shows that, heuristically, for the dataset regarding 71 basins and for a given hydrological model (VAPI), the *official* Q_{200} estimates can vary over wide range.

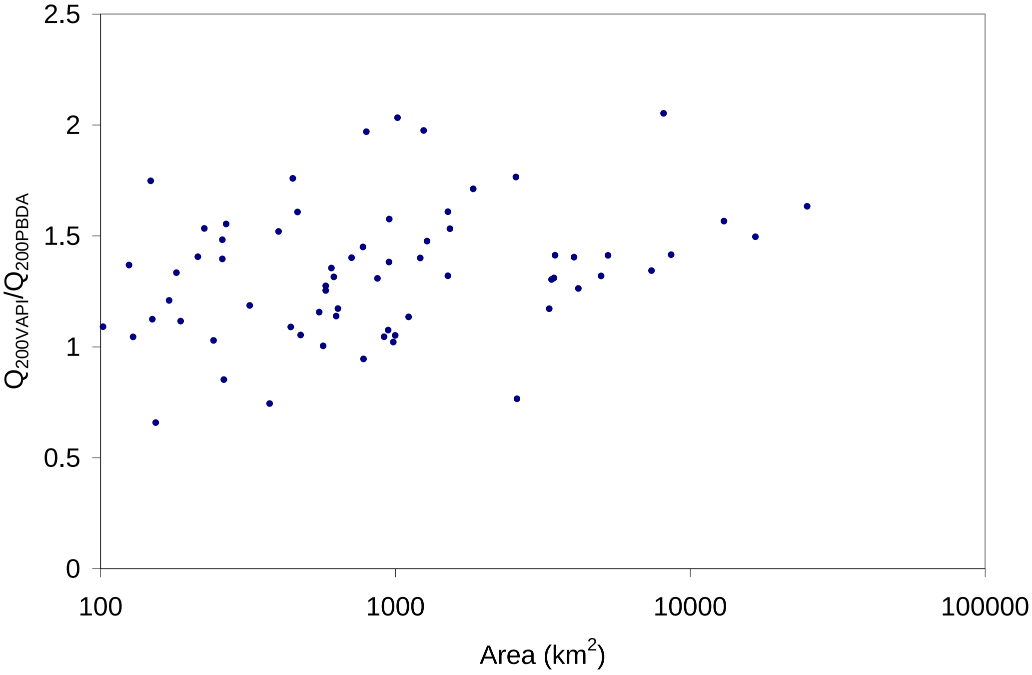

Figure 6. Comparison of the Q_{200} estimates, by means of two hydrological models.

Nevertheless, a research activity conducted within the *PBDA* is underway to detect the most appropriate strategies to adapt flood risk management to possible climate changes (*PBDA*, 2014). The activity has the aim of collecting recent hydrological data, evaluating possible trends in hydrology and possibly revising the 200-yr return discharge.

Evidence on soil use has induced decision makers to focus on the most relevant causes that have substantially and unquestionably increased risks in the Po watershed basin, i.e. the increasing number of receptors in the flood-prone areas, a process that started after the IIWW and is presently ongoing. Quantification of the exposure (E) and of the vulnerability (V) of receptors is therefore a crucial task, as will be shown in the next section.

2.2 Exposure

The definition of exposure in literature generally converges to "*elements at risk, or receptors, that is, people, properties and goods that can be lost, injured or damaged during an event*" (UNDRO, 1980). According to this definition, exposure varies according to the hazard level.

The RPA activities, which have been carried out in collaboration with the Politecnico of Turin, have focused on the exposure of structural elements at risk, which are generally referred to as *receptors*. At present, the total number of receptors in the Piedmont region is systematically updated through an analysis of aerial pictures (photo-interpretation). Identification of the use of receptors, such as commercial/industrial/residential ones, is not straightforward, as the same receptor can refer to different uses with different economic relevance. The analysis has shown an increase in the total number of receptors over the last few decades (fig. 7) in their economic value. The latter is constantly updated by the *Agenzia delle entrate (AdE).*

The *AdE* website (*OMI, observatory of the housing market*) allows the available information of the economic values e_i of residential/commercial/industrial categories of receptors, expressed per square meter (m^2) to be downloaded free of charge. Each Italian municipality has been divided into zones, which are considered to be homogeneous from an economic point of view. Subcategories have been created for a given zone and for a given category (residential/commercial/industrial), with minimum and maximum economic e_i values. The *OMI* e_i values are constantly updated and can obviously be used to estimate a medium housing market value. Therefore the available data should obviously be used in a proper manner. Moreover, the *OMI* datasets may only be representative of the property values, and disregard the content value. Other damage (indirect or direct as described above) need to be estimated by means of other parameters.

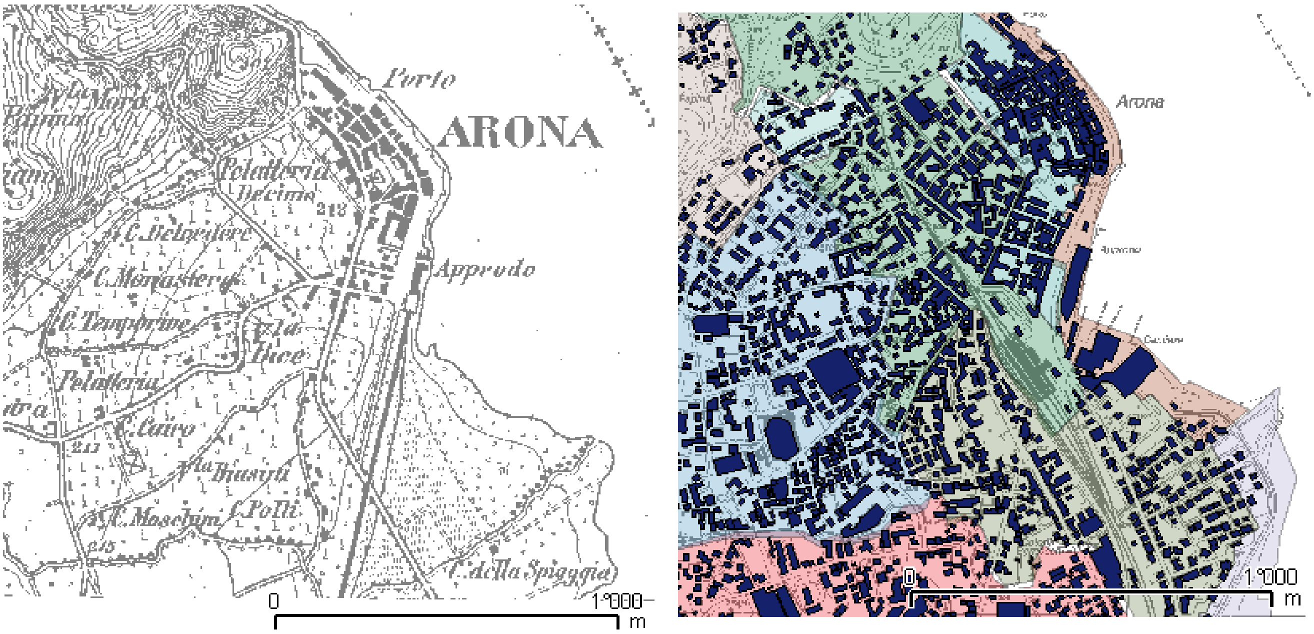

Figure 7. The figure shows Arona (lake Maggiore) in 1945 (left) and at present (right). The OMI zones have been highlighted with different colours (right). The present receptors at present time are shown in a dark colour (right). The inundation area is about 50 ha for TR=500 years. A comparison of the figures shows a clear increase in the receptors.

Assuming that the total exposure of the *i-th* receptor is proportional to its area, disregarding indirect damage and considering the *OMI* zone datasets, a robust assessment of exposure E_i can be computed as follows:

$$E_i = e_i S_i \tag{4}$$

where e_i is the mean economic value given by the *AdE* per unit area (m^2) in the corresponding *OMI* zone and S_i is the total surface of the element at risk. The minimum and maximum values can vary over a wide range for the same homogeneous *OMI* zone, and the e_i values can vary from zone to zone. For example, e_i values vary significantly for civil housing in Arona in *B2 OMI* zone, from a minimum of 1300 €/m^2 to a maximum of 1850 €/m^2, while, in the *B1* zone, they vary from a minimum of 1850 €/m^2 to a maximum of 2750 €/m^2 . In spite of this variability, the methodology described above, which refers to the mean value in a given *OMI* zone, allows a homogeneous evaluation to be made all over the entire region.

2.3Vulnerability

From a technical viewpoint vulnerability is defined as:
"*the degree of a loss to a given element at risk, or set of such elements resulting from the occurrence of a flood with a given intensity*" (UNDRO, 1980).

Vulnerability is a function of the hazard level. As mentioned for the risk concept, vulnerability shows the same conceptual complexity (Franzi, 2012) as risk, because structural, organizational and community vulnerability should all be considered and taken into account. Moreover, as far as structural vulnerability is concerned, no vulnerability curves have been proposed in literature for the Italian situation or derived from the data regarding the documented property losses after floods. Therefore, vulnerability quantification is affected by heavy uncertainties.

As established in the *STRADA* project (*STRADA*, 2013) a simplified formula for vulnerability, derived from those available in literature (USACE, 1992) has been implemented by *RPA*, according to which the vulnerability of the *i-th* element at risk is a function of the water depth *h*, i.e.:

$V_i = V_i(h)$ (5)

The water depth *h* is calculated at the barycentre of the receptor. For those receptors that are only partially enclosed within the flooding area, *h* is calculated by referring to the barycentre of the flooded area of the receptor.

The adopted vulnerability curve is that proposed by *USACE* (1992) (fig.8), that refers to *FIA* (1970) *"Two or more stories, with basement"* depth-damage curve (*USACE,* 1992, p.89).

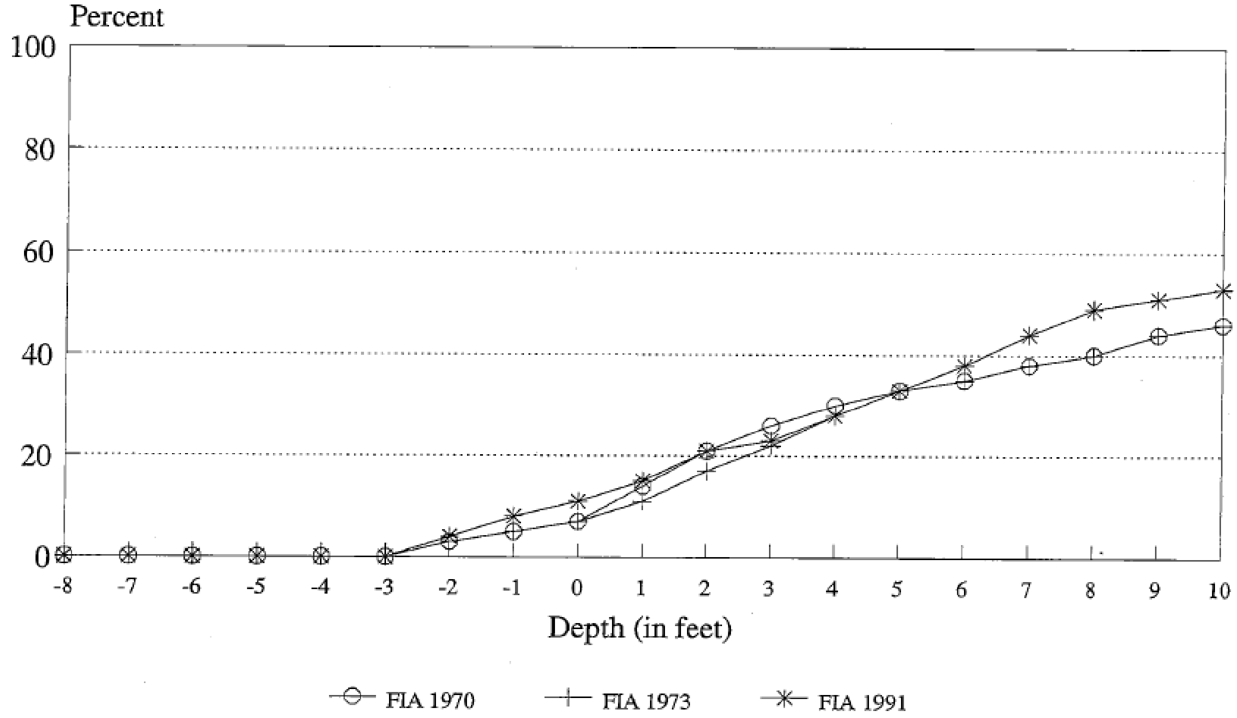

Figure 8. *"Two or more stories, with basement"* depth-damage curves (*USACE,* 1992, p.89). In the application that are shown in the chapter, the FIA (1970) curve has been used.

3. Application cases

The described methodology, developed by *RPA* in collaboration with the Politecnico of Turin, has been systematically applied to some study cases, which were chosen from different study cases in the Piedmont region territory. Selection of the application cases was influenced by the relevance of the situation, with respect to risk, and by the availability of consistent data.

Risk has been mapped by superimposing the three risk components, described in the previous sections, which allowed an *Index of Proportional Risk – IRP -* to be defined in the following way:

$$IRP_i = H_i E_i V_i = \frac{1}{RP} e_i S_i V(h)_i \tag{6}$$

where, together with the variables already defined and *IRP* is the proportional risk index, computed for the *i-th* receptor and for a flooding event which has a Q_{RP} flood discharge with return period *RP*. The total risk due to the presence of *N* receptors can be computed, for a given watershed basin, or for a given geographic area, as:

$$IRP = \sum_i^N H_i E_i V_i = \sum_i^N \frac{1}{RP} e_i S_i V(h)_i \tag{7}$$

where *N* is the total number of receptors in the considered geographic area and *IRP* is expressed in €/year. A similar approach can be found in Hall et al. (2008).

The following will be shown hereafter:

- *IRP* quantification at the confluence of the Po river and Dora Riparia, in Turin (Bruno, 2013);
- *IRP* quantification at the Dora Riparia river, in Susa (Foglino, 2013);
- *IRP* quantification at lake Maggiore.

All the study cases have been conducted according to the procedure described above to obtain hazard maps and risk maps.

The risk assessment in Turin has been conducted with the aim of evaluating the total risk for a low (L) probability of occurrence due to flooding of the Dora Riparia at the confluence with the Po river, where houses, properties and even a University building are prone to flooding and at present are not protected from inundation. The study is a good example of how risk assessment can be used as an effective tool for information and a "*valuable basis for priority setting and further technical, financial and political decisions regarding flood risk management".*

The risk analysis refers to the 500-yr RP Dora Riparia flood discharge (catastrophic discharge), as evaluated by the *PDBA* and published in the *Directive on design discharge*. Downstream levels in the Dora Riparia exclude contemporaneous of inundation by the Po river in the surrounding area.

The inundation map has been obtained (figure 9), at the confluence with the Po river, by applying the same procedure described in §2.1, t. The inundation map only refers to the inundation due to the flooding of the Dora Riparia river, and does not take into account the simultaneous flooding of Po river.

The study has proved to be useful to calibrate and modify the inundation maps obtained in 1991 and mapped in PAI (red lines in figure 9), which refers to the *state-of-knowledge* at that time.

The inundation maps of the Dora Riparia and Po river, which have been updated and published by the *PBDA* in 2013, are free on line.

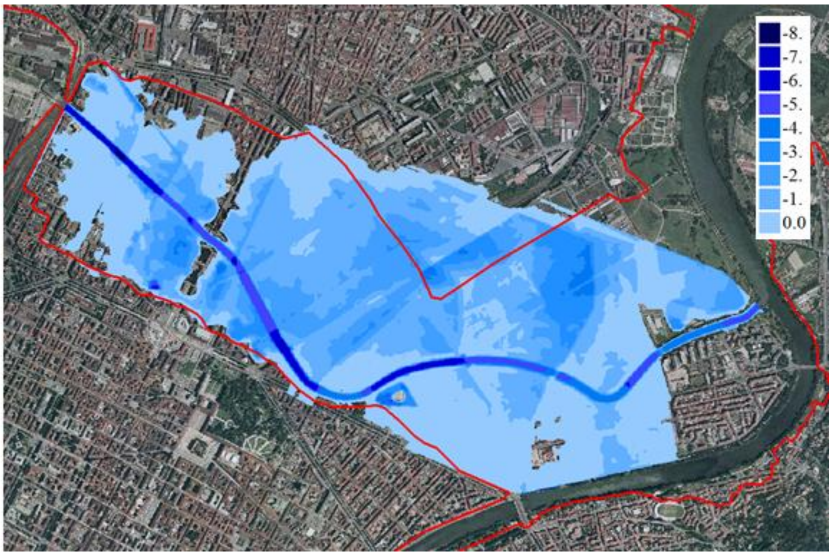

Figure 9. Inundation map due to Dora Riparia Q_{500} flooding. The depths are expressed in meters (Bruno, 2013).

IRP has been calculated for each receptor according to the procedure described in § 3. The receptors have been divided into four risk classes (R1, R2, R3, R4) as a function of the maximum computed *IRP* value, according to the following table.

IRP classes	assignment criteria
R1	$0 < IRP_j / IRP_{max} \leq 0,25$
R2	$0,25 < IRP_j / IRP_{max} \leq 0, 5$
R3	$0,5 < IRP_j / IRP_{max} \leq 0,75$
R4	$0,75 < IRP_j / IRP_{max} \leq 1$

Table 1. *IRP* classes of calculated on the basis of the *IRP* maximum value (taken from Foglino, 2013; Bruno, 2013).

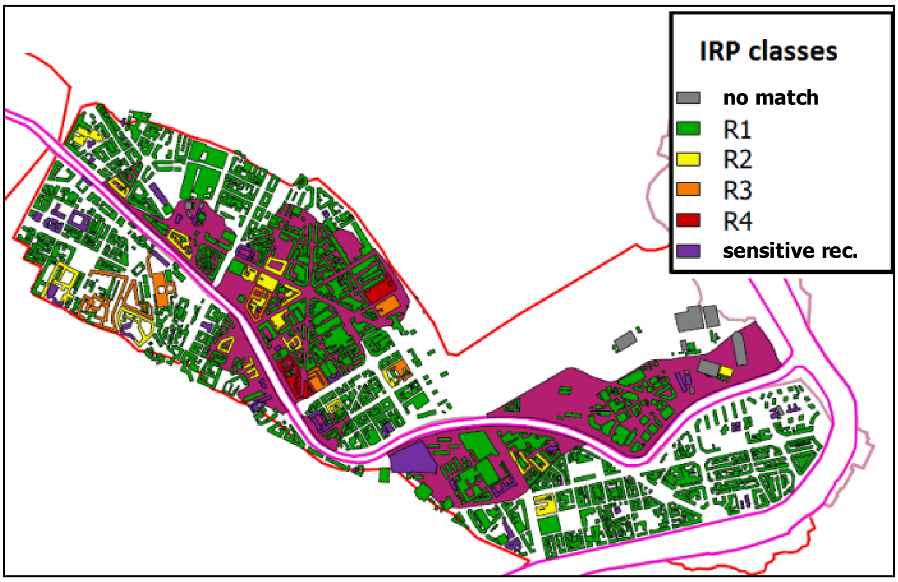

Figure 10. *IRP* map at the confluence of the Po and Dora Riparia rivers, RP = 500 years (Bruno, 2013).

The so-called “*sensitive receptors*” (e.g.: museums, libraries, schools, etc.) are not included In the risk class list in table 1, because the analysis was only focused on economic and residential receptors. However some receptors did not show a direct match with the receptor typologies in *OMI*.

The second case study deals with the Dora Riparia and in particular with the reach of the confluence of the Cenischia torrent that crosses the city of Susa, where some different protection alternatives have been considered and compared. In particular, a reduction in flooding (Foglino, 2013) has been evaluated for each different option, on the basis of technical feasibility. The risk, after the implementation of countermeasures, has been mapped and compared with the existing risk.

Figures 11 and 12 represent the current state and the design state risk maps and the limit of the Q_{200} flooded areas. The design state maps include the reconstruction of a bridge, the superelevation of river banks and the reconstruction of a check-dam. The effects due to the designed structural option have been mapped, in terms of *IRP*, and compared with the current state (figure 12).

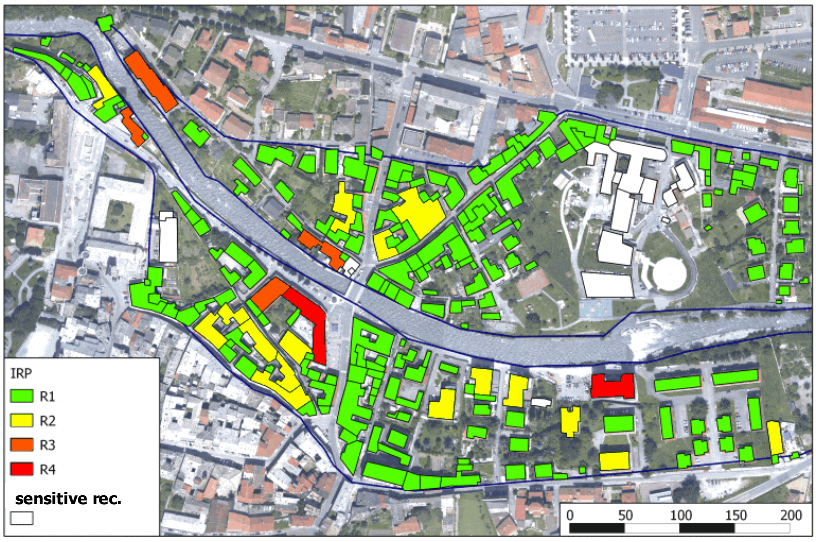

Figure 11. Map of *IRP* referring to the current state of the Dora Riparia in Susa (Foglino, 2013).

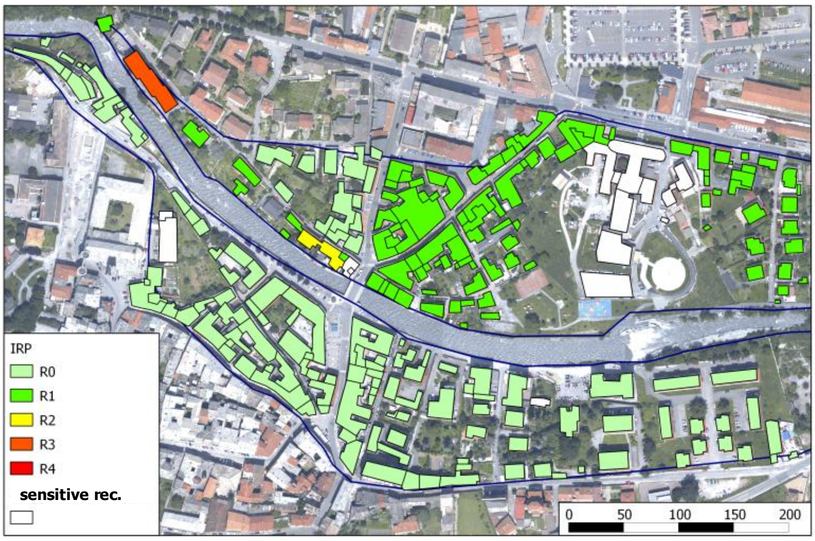

Figure 12. Map of *IRP* referring to the design state of the Dora Riparia in Susa (Foglino, 2013).

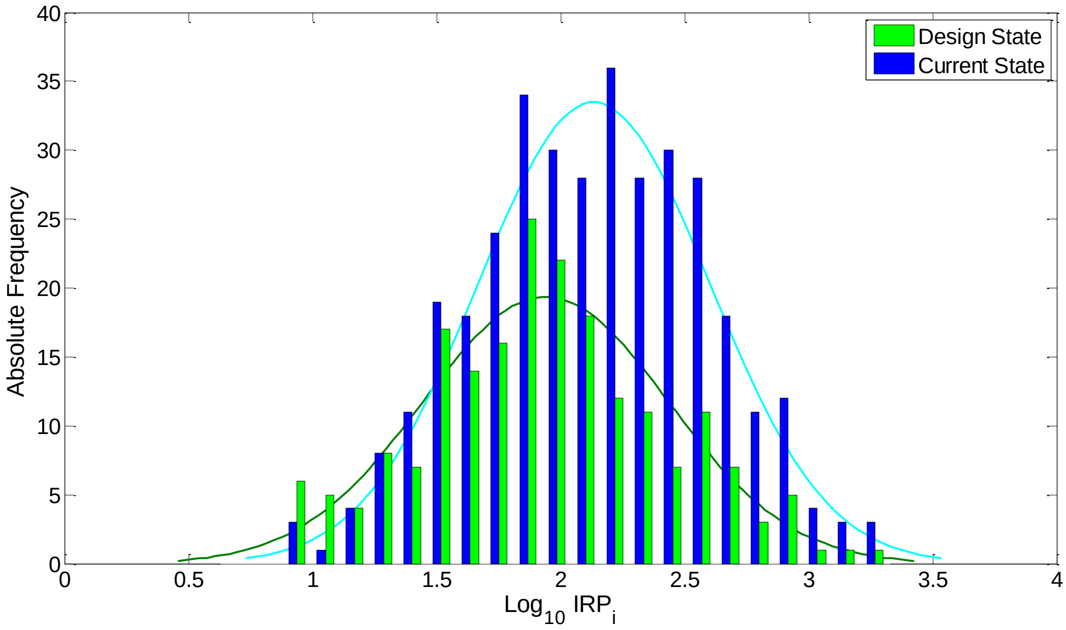

Figure 13. *IRP* comparison between the current and the design states. The lines represent Gaussian distributions (Foglino, 2013).

The effects of the designed countermeasures are (figure 12):

- a scale effect, due to the reduction in the total number of receptors affected by floods;
- a shift in the IRP distribution mode, which demonstrates that the most exposed receptors will draw benefits from the proposed design projects.

As far as Lake Maggiore is concerned, the study was principally motivated by the necessity of mapping hazards over a short period (three months). No official hazard maps were ever adopted for that region, up to 2013, and, in order to respect the roadmap and deadlines established by PBDA, it was necessary to start a close collaboration between the public regional administration (Piedmont and Lombardy regional administrations) and Canton Ticino (Switzerland), with borders the lake. In this case, it was necessary to reach a political and technical agreement about the lake levels the hazard maps refer to, in order to publish hazard maps before the end of December, 2013.

Inundation simulations were made in static conditions, that is, assuming that the water gradually flows into the surrounding areas. Only the areas hydraulically connected to the lake were considered in the risk evaluation.

The *IRP* results for Q_{500} can easily be mapped using GIS software (figure 13). The frequency distribution of the receptors versus *IRP* can be considered is a useful tool to describe understand the risk of flooding.

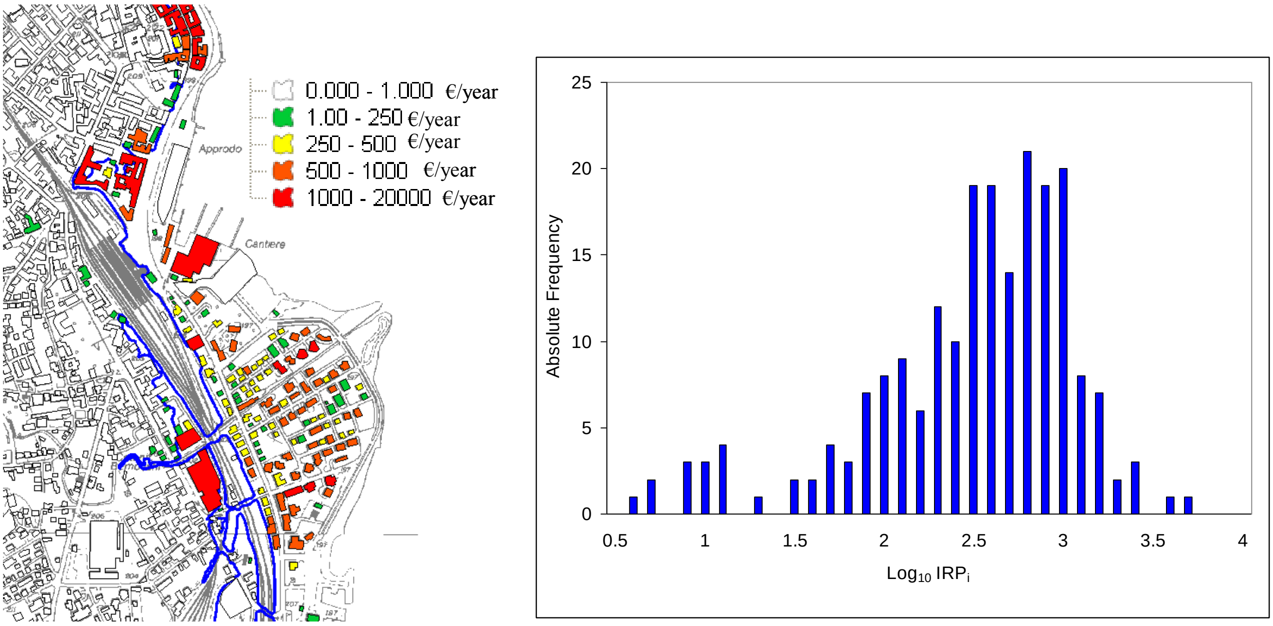

Figure 14. IRP Map and frequency distribution (expressed in log scale) referring to the receptors flooded in the Arona municipality. The values are expressed in €/year. The blue lines (left) indicate the inundation extension. Receptors partially enclosed in the inundation areas have been mapped.

4.Conclusions.

Risk assessment and mapping is a very complex topic and activity. It involves different expertise and makes it necessary for regional governments to set priorities, to define the scale and details of the investigations and to optimize the resources.

As far as the collaboration between RPA and the Politecnico of Turin is concerned, the studies that have been carried out, and completed, are a first step towards a comprehensive management of the risk of flooding. The proposed quantitative IRP methodology for risk assessment has proven to be useful for decision making and for the description of the flooding conditions, and has so far been extended to about 40 municipalities throughout the entire regional territory.

Implementation of the *IRP* methodology requires free software, a GIS-based operative approach, and the availability of databases, especially as far as soil use is concerned. Some of these database can be found on line (e.g. the OMI database), while others are not available directly for the public, such as *DTMs*, river topography, floods depths and receptor uses. Moreover, a technical/engineering approach is required , especially in order to obtain consistent inundation hazard mapping.

The results show that simplification is necessary to obtain reliable and *robust* estimations of hazards and risks. In this frame, the main uncertainties that can affect hazard, exposure and vulnerability are represented by the quality of the datasets that are available at the present *state-of-the-art*, especially as far as vulnerability and exposure are concerned. In particular proper vulnerability curves or vulnerability estimators should be proposed in scientific literature for practical use.

Hazard mapping is influenced by several uncertainties (Hall et a. 2008), most of which depend on the availability of updated information as far as *DTMs* are concerned.

Even without considering the effects of climate changes, the uncertainties in hydrological estimates result to be an important topic of discussion (Merz, 2009). It is well known that deviance of the hydrological models can significantly affect flood estimation and therefore risk assessment. As already mentioned, the hazard maps available on-line are based on hydrological estimates that are contained in official documents approved by the *PBDA*, and this topic has therefore not been systematically approached up to now. However, this topic could be discussed in the next updating of the maps (the 2007/60EU directive compels the member states to update maps every six years).

Uncertainty analysis, including the analysis of climate change uncertainties, should also lead to a qualitative and quantitative treatment of the available information. In particular, a quantified approach is required to understand the magnitude of the uncertainties and to focus on the resources necessary to reduce uncertainty. In the real world, where resources are finite, the available time is short and the risk protection requirements are pressing, public administration need to carefully balance requirements and actions, in order to at least mitigate the actual and documented risks.

At present, hazard maps and qualitative risk maps are available in the Piedmont Region and are on line for dissemination and confrontation with the public, politicians and local administrations.

The proposed *IRP* methodology can be considered a first step towards a quantitative analysis of risk and a valuable means of supporting decision making. It is currently being developed to help decision makers to compare different political strategy options and to improve risk mapping in preparation of the next review foreseen by the EU directive.

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