Definition of flood exposure indexes for the IT test site

Final Version

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Introduction

The present report aims at reporting available data on the flood risk exposure for Ferrara territory, according to the Deliverable 3.1.1 of the Activity 3.1, within WP 3 of the Interreg PMO-GATE project. Indexes of exposure are presented, in accordance with the European and national decrees that regulate the matter of flood risk.

The first part concerns the definition and presentation of the flood hazard, i.e. the probability of occurrence of a flood event, whereas the second part regards the definition and presentation of the flood risk, which identifies damages caused by the flood event. Every presented data within these documents concerns directly the territory of Ferrara municipality. Both for flood hazard and flood risk, methods for the evaluation are presented, as well as the categorisation introduced by the law, and the available maps are shown.

In accordance with current legislation, the Italian decree that defines and regulates the analysis and the modelling of the flood risk and the subsequent flood risk management plan is the *D.Lgs. 49/2010*. This Italian law is the Italian execution of the EU Floods Directive 2007/60/EC [1].

Definitions regarding the flood hazard and risk, according to the D. Lgs. 49/2010 [2]:

- *Flood* is a temporary inundation, involving transport namely mobilisation of high-density sediments, of typically dry areas. It includes inundations caused by lakes, rivers, creeks, eventually artificial drainage networks, every other superficial watercourse also in a temporary regime, natural or artificial, and flooding of low-lying coastal regions due to sea level rise. It excludes flooding not directly caused by meteorological events.
- *Flood hazard* is the probability of occurrence of a flood event in a determined time interval and in a determined area
- *Flood risk* is the combination of the probability of occurrence of a flood event and the potential negative consequences – in terms of human health, territory, assets, environment, cultural heritage and economic and social activities – derived from the event.

Ferrara characteristics

In this section, the land characteristics of the territory of Ferrara are introduced, which strictly influence and determine the probability of flood occurrence. Territory of Ferrara is the Italian study site appointed by the Interreg PMO-GATE project, therefore, a brief but detailed presentation of the territory is necessary.

The following data have been collected from both the Consorzio di Bonifica Pianura di Ferrara and the Municipality of Ferrara websites [3,4]. The Consorzio di Bonifica Pinaura di Ferrara is the authority in charge of the management of the land reclamation system of the territory.
The territory of Ferrara municipality is located at the north-easterly extremity of the Pianura Padana (a flatland area in the north part of Italy), and it is bathed by the Adriatic Sea on the east side. Ferrara territory is characterised by minimum land slopes and its altimetry is mainly under the sea mean level. In specific, more than 40% of the territory is under the mean sea level, as it is represented in Figure 1. Moreover, the eastern part of the territory is affected by ground lowering phenomena as well. These soil modifications, caused mainly by anthropic and artificial actions, produced lowering until 2.5 m depth.

The rainwater runoff is artificially regulated by a complex system of canals that converge in a great number of water-lifting plants, which permit the runoff lifting toward the sea. Without these water-lifting plants, the entire territory, finite among Po, Reno and Panaro rivers and the sea, would be entirely flooded.

The complex system of canals, divided in the territory between “Acque alte” and “Acque basse” systems, connected by water-lifting plants, permits to maintain the land in a dry state, to lift water toward the sea, and regulate the water needed for irrigation, deriving it from the rivers and canals reticulation surrounding the area.

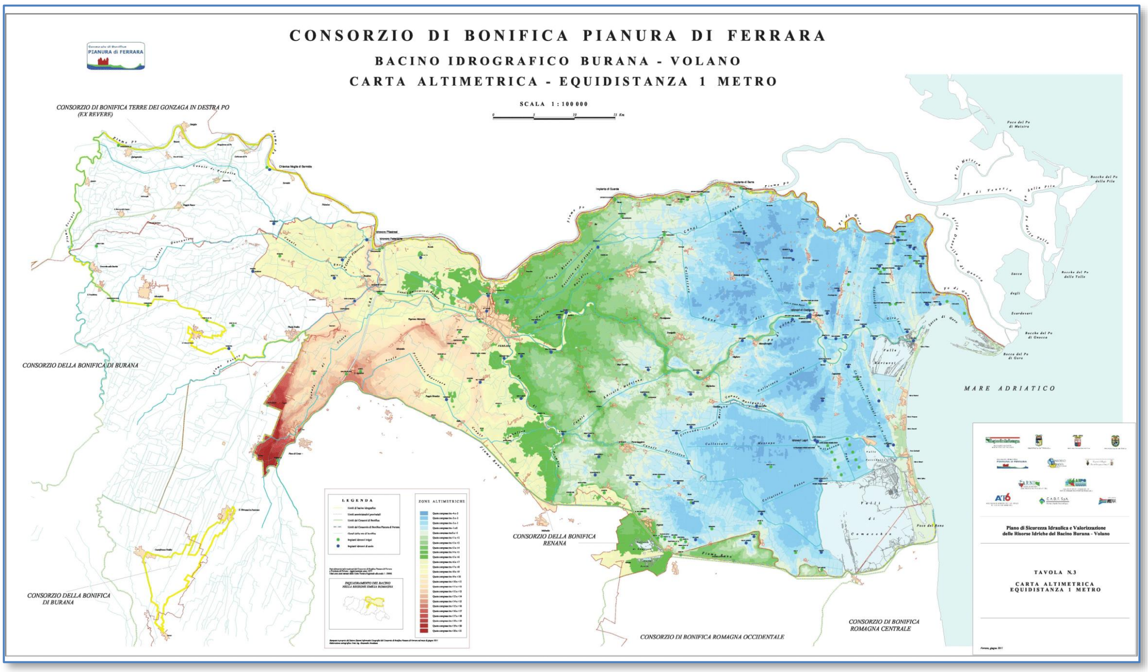

Figure 1. Ferrara territory altimetry

The complex-regulated hydraulic regime of Ferrara municipality is, therefore, one of the most important element for the safety and the valorisation of the territory.
Numerous floods occurred periodically in this area. The causes of these floods can be found in river embankments breaches, in the force of storm surges and high-water sea level, which can disrupt land protections and overflows toward the inner land, as well as in strong rainfall events that cause difficulties in water disposal toward the sea.

Some of the most disastrous floods that occurred in the territory, originated by the above-mentioned phenomena are Po flood in 1951 and Reno flood in 1949 and 1951. Other floods occurred the following years, such as in 1966, in 1979, in February 1986, in 1995 and in 1996 and in spring 2004 in the same or nearby area. These latter submersed mainly agricultural areas, but also some important inhabited districts. Floods that are more recent occurred in Cento (FE) in October 2005, June 2007 and September 2008. In two other close municipalities of Ferrara, Argenta and Comacchio, floods occurred in June 2008, in 2009 and in during summer 2010.

Given all these past flood events, it is clear how the land-drainage system of Ferrara assumes a vital relevance. Indeed, the reclamation system consists of a 4153 km long canals network, 170 water lifting plants and a great number of hydraulic infrastructures such as weirs,

syphons, hydraulic intake systems, detention basins and others, and it is continuously active in order to guarantee the hydraulic safety condition in the territory of Ferrara.
Having said the above, it appears clear that Ferrara is a prone-flood area, due to its natural characteristics, such as morphology and altimetry), and the proximity to some of the most important rivers and to the sea. The complex reclamation system that guarantees the continuity of life in the territory is vital and its failure would be surely responsible for the flood.

The delicate hydraulic system of the territory of Ferrara usually shows some critical issues during intense rainfall events, often associated to the difficulty in outflowing water from the territory to the Adriatic Sea, caused by the mean sea-water level increase. During these situations, floods occur due to a water overflow from the riverbank or because of a breach in the levee. In some of the most neuralgic canals and rivers in the territory of Ferrara flood events have been avoided thanks to specific interventions and an optimised management of the water lifting plants operating on those watercourses, in addition to the severe control of mechanical discharges in the adjacent drainage watersheds.

Despite those interventions, it is worth underline that the inner watercourses network presents some critical issues, caused by the presence of several factors:

- A reduction in the storage volume in the network caused by improper use of the canals network;
- The increase in urbanisation, with a consequent increase in the waterproof soil area, causing the augmentation of flows and a reduction in concentration time;
- The subsidence phenomenon, which decreases their efficiency and affects water-heights regime in canals and moats. Moreover, most of the watercourses are therefore eliminated or without maintenance.

In addition, other two critical issue must be considered. The first concerns the interconnection between the secondary watercourses network and the urban sewer system, causing quite frequently the occurrence of diffuse floods affecting city centres. These phenomena have a seasonal recurrence, in summer and in spring. In fact, during these seasons the irrigation is fundamental for agriculture, therefore all canals and watercourses are filled with water. Consequently, intense rainfall events that are not drained properly by the urban drainage systems stress the secondary watershed causing the overflow from canals and moats.

In this context, climate change plays a significant role: the pluviometry regime is changed and now rainfalls have a shorter duration but a greater intensity, whereas hydraulic infrastructures had been designed in the face of the previous different conditions. This causes floods to happen more frequently because the peak flows have increased. The last element

that must be borne in mind is that the ageing of hydraulic infrastructures worsens the situation.
Following sections aim at depicting the cognitive framework regarding flood hazard in Ferrara territory. The introduction of these topics follows the disposals of the legislation decree D. Lgs. 49/2010 [2] , which is the Italian execution of the EU Floods Directive 2007/60/EC [1] .

Watercourses networks layout in Ferrara territory

To better understand how flood hazard and flood risk are evaluated for this territory, it is of primary importance to present the different types of watercourses network affecting the territory of Ferrara.
It is significant to make this introduction because the definition of the flood hazard, and consequently of the flood risk, depends on the characterisation of the Ferrara flatland watershed.
All the introduced available data are collected from the Italian authorities working in the land protection and management services, such as the Po River Basin Authority, Consorzio di Bonifica and Civil Protection. The Po River Basin Authority (the Italian *Autorità di Bacino del Fiume Po* AdBPo) is the institution in charge of the management and the control of all aspects related to the watershed of Po River and its tributaries; moreover, the identification, delimitation and outlining of the boundaries of areas that present flood probabilistic hazards and risks are under its competence. In fact, Po River Basin Authority has a section dedicated entirely at the Flood Risk Management Plan [6].
The implementation of this Plan is carried out accordingly to the EU Floods Directive 2007/60/EC, and, therefore, to the D. Lgs. 49/2010. Consorzio di Bonifica is the institution in charge for managing the flatland reclamation system. Civil Protection is the organisation in charge of the mobilisation and coordination of all useful national resources in case of critical emergencies. Every region has its own Civil Protection service [7].

The implementation of flood risk maps has specific and determined methods introduced in the EU Floods Directive 2007/60/EC. As said also in the above, the Italian execution of this directive occurred in 2010, with the D.Lgs. 49/2010, aiming at an Italian regulation of the matter in line with European directives. The Italian decree is an update of the previous one, therefore it follows European directives, but it has some features that are specific for the Italian case, due to the complexity of the watercourses' layout in this country.

Among these features, it is important to highlight that the Italian execution of 2007/60/EC Floods Directive divides the territory, and therefore, the evaluation of hazard and risk maps, in different classes depending on the territory characteristics and on the main hydraulic phenomena occurring in each area. The Po River watershed Authority drafted a complete

documentation regarding the classification of the territory in different watercourses networks, from which data are gathered and presented in the present report [8].
In particular, since the Interreg PMO-GATE project is focused on the territory of Ferrara as far as concerns the Italian site, in the following, this document will examine the characterisation of this specific area according to the D.Lgs. 49/2010.

The territory of Ferrara is part of the so-called "A-type flood" area, in which flood phenomena are the most expanded, caused by sudden river levees breaches. Typically, this type of flood can inundate the entire surrounding flatland area. This flooding area involves from 30'000 ha to 100'000 ha, carrying huge water volumes and sediments. Flood occurrence depends on the duration, the intensity and the expansion of the rainfall event at a regional level, therefore, frequent and detailed analysis of the pluviometry regime of the territory is strongly recommended for flood hazard analysis. In fact, the Italian authorities in charge of depicting the flood hazard framework in Italy often update their rainfall dataset and rainfall-runoff models.

Within the eastern part of the flatland Pianura Padana, where Ferrara is located, two main watersheds are identified. The first one is the Primary watercourses network (in Italian *"Reticolo primario"*), consisting of the biggest watercourses whose flow-rates are not mechanically regulated, so the motion is given just by the favourable altimetry, i.e. the gravity. This network contains the Po River and its main tributaries. The other watershed affecting Ferrara is the Secondary watercourses network (in Italian "*Reticolo secondario*"). It consists of the network of the land reclamation system managed by authorities such as Consorzio di Bonifica Pianura di Ferrara. This network comprises channels, water-lifting plants and other hydraulic objects always operating for the regulation of water heights within the network.

Between these two, it is more likely a flood occurrence due to the failure of the Secondary watercourses network. This is because the functioning of this network is based on several hydraulic infrastructures, such as weirs, syphons, hydraulic intake and drop intake systems, detention basins, floodgates and several water-lifting plans. If only one of these latter do not work for any reason, the system would fail, affecting city centres and relevant infrastructures. Moreover, the Secondary watercourses network is composed by canals, channel and culverts, so the embankment system is not well-structured and well-designed as the one of the rivers within the Primary watercourses network. Consequently, flood occurrence probability is more likely for the Secondary watercourse system rather than for the Primary watercourse system and, although the flow-rates in channels are smaller than in rivers, it would anyway affect all the surrounding area. The Primary watercourses system, due to its flow-rates has an entirely constructed embankment system to make least likely possible a flood occurrence. Indeed, a levee breach would be disastrous.

Flood hazard and risk maps are evaluated for both the Primary network and the Secondary network. Moreover, maps are assessed for the coastal area as well, this permits the evaluation of a flood event caused by the astronomical tide simultaneously to a high wave, e.g. due to storm surges. Flood hazard and flood risk maps for coastal areas are not reported in this document, so the reader is referred to the website of the Autorità di Bacino del Fiume Po (AdBPo), within its Flood Risk Management Plan project.

The identification of flood scenarios is led by different studies, also depending on the concerned network. In relation to the Primary watercourses network flood flow-rate values are appraised using different methodologies, such as hydrological rainfall-runoff models, statistical regularisation of time-series available at the measurement stations, regionalisation methods. These values are identified at closing sections of both the upstream and the downstream watersheds of the watercourse in analysis and in some halfway section as well, wherever it is present a confluence, a hydraulic infrastructure or a significant city centre. Water levels are evaluated using 1-D hydraulic models for the entire watercourse; 2-D simulations are available only for some local sections. Hydraulic modelling is implemented in the light of the transversal sections of watercourses, topographically surveyed.

Concerning the Secondary watercourses network, at a regional level, the evaluation of flood-wave values is carried out by the analysis of the last 20-30 years-old historical events, namely through an historical-inventory method. These events are considered the most suitable and representative ones for the nowadays set-up of the land reclamation system. Nevertheless, it has been pointed out that some specific areas may fail with rainfall events characterised by return period greater than 50 years. These areas need more accurate analysis because climate change is influencing and modifying the intensity of rainfall events, causing the diminishing of the return period of the great rainfall events. These areas can be found in most sectors of the flatland within the watershed. In fact, authorities working directly on these specific areas, such as the Consorzio di Bonifica Pianura di Ferrara for Ferrara territory, uses ore detailed method for assessing flood hazard, as rainfall statistical analysis, rainfall-runoff models and hydrodynamic models.

For a detailed explanation of methods used for the flood risk maps evaluation, it is recommended to read the entire EU Floods Directive 2007/60/EC and the technical report of the Po River Basin Authority.

Flood hazard

According to the EU Floods Directive (2007/60/EC), flood hazard exposure is characterised by three levels of flood probability. Every class of occurrence is determined by the return period of the specific flood event. In relation to that, floods can be divided as follows.

- *P1*, rare floods or low probability events. These events are characterised by a return period, between 200 and 500 years. For this reason, these events are considered extreme scenarios.
- *P2*, medium probability events. These occurrences consider floods with return period between 100 and 200 years.
- *P3*, high probability events. This class takes into consideration all scenarios with a return period between 20 and 50 years.

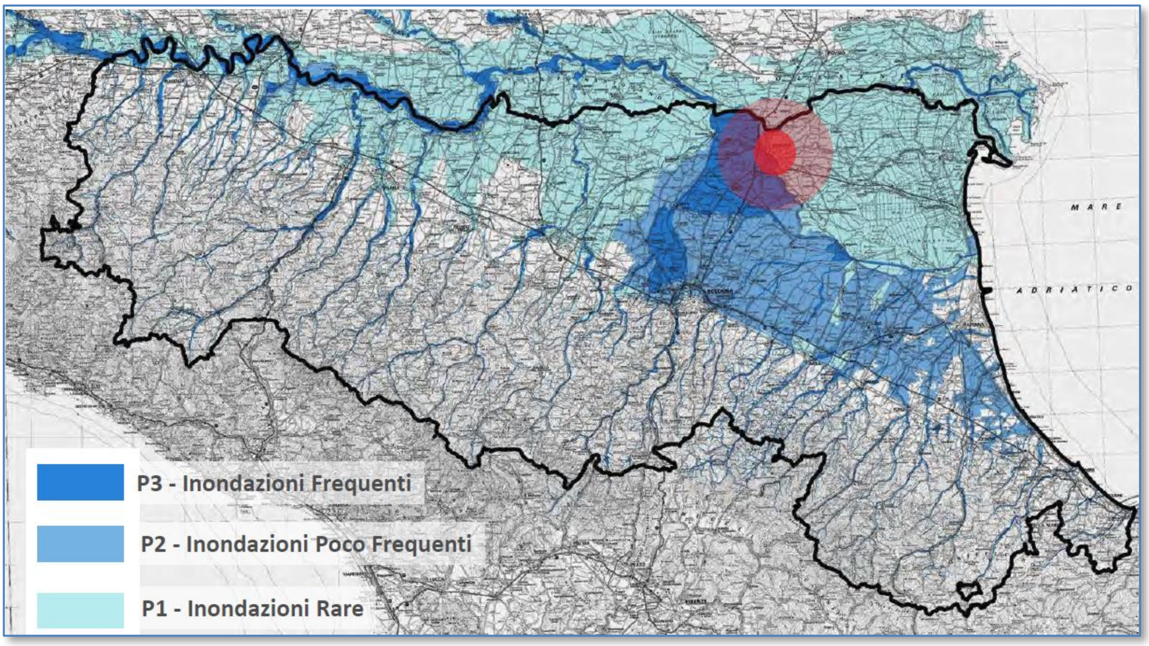

Figure 2. Flood hazard in Emilia Romagna (2015) [9]

Figure 2 shows the flood occurrence probability for the Emilia-Romagna Region territory. As noticeable in the figure, the city of Ferrara is in a P3-P1 area. This is a consequence of the characteristics of this territory. In fact, the proximity of the city to some of the most important watercourses of the flatland Pianura Padana (such as Po River and Reno River), and the complex drainage system that works to maintain the life-condition in the territory, are elements that expose the city to a high flood probability. The flood occurrence probability represented in Figure 2 indicates the 2015 flood condition for the region.

In the following, flood hazard is examined more in detail for the entire Ferrara territory.

Table 1 reports some data regarding the population involved by each of the flood hazard classes, the area of the territory involved, as well as schools and cultural heritage.
The Population value indicates the population living in a dangerous area, therefore potentially exposed at flood risk, with consequent life threat and goods damages. The Territory value expresses the area of the territory for each class of flood hazard. Schools and Cultural Heritage data are the numbers of those elements exposed in each class.

	Population	Territory	Schools	Cultural heritage
P1	353395 (100%)	2621 km^2 (99.5%)	345 (100%)	2648 (99.8%)
P2	35344 (100%)	2627.6 km^2 (99.7%)	345 (100%)	2649 (99.8%)
P3	87286 (24.7%)	525.1 (19.9%)	75 (21.7 %)	257 (9.7%)

Table 1. Flood hazard data for Ferrara territory [10]

As an example of flood hazard map delivered by the authority Autorità di Bacino del Fiume Po (AdBPo), within its sector Flood Risk Management Plan, and according to the D. Lgs. 49/2010, two hazard maps are reported concerning the area of the city centre of Ferrara and its neighbouring lands [Figure 3] represents the flood hazard evaluated for the Ferrara territory. In particular, Figure 3 (a) shows the flood hazard for the Primary watercourses network, whereas Figure 3 (b) shows the flood hazard for the Secondary watercourses network. The figure, as well as in Table 1, indicates the flood hazard level with different colours: the darker is the blue, the more frequent is the flood. Analysing these maps permits to identify the most flood prone areas.

Concerning the methodology that the AdBPo used for the assessment maps in Figure 3, the unidimensional hydraulic model of the river channel is an essential tool for the assessment of flood hazard and, in particular, for assuring hydraulic continuity and coherence among hydraulic phenomena upstream and downstream of the channel. The unidimensional model does not give information regarding velocity or water heights of the flooded area, but it represents only the area affected by flood. More specific information can be assessed with bi-dimensional models, at specific sites.

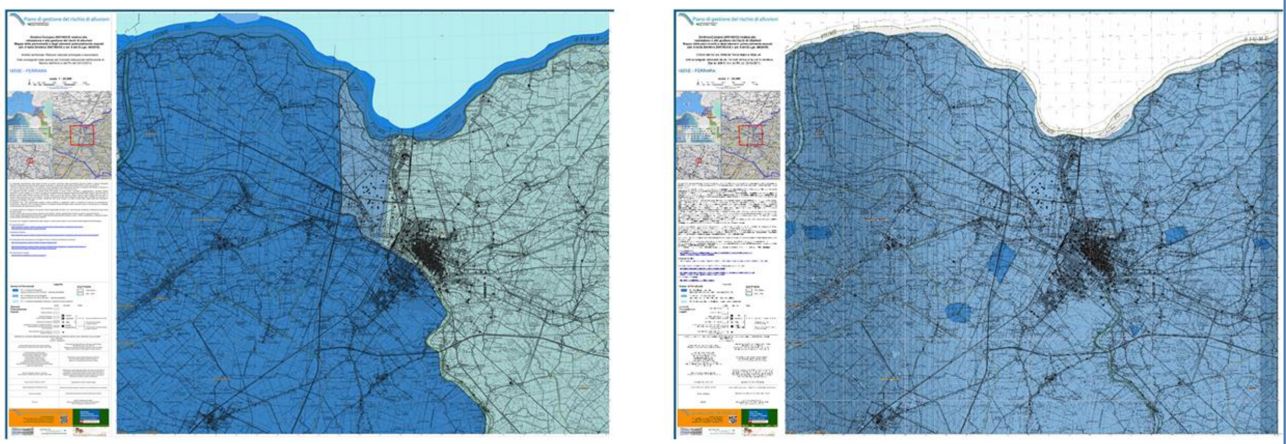
(a) (b)

Figure 3. Flood hazard maps in Ferrara territory evaluated for the Primary watercourses network (a) and the Secondary watercourse network (b) [11]

From maps in Figure 3 it is possible to see that the Secondary watercourses network presents only P2 and P3 hazard classes. The 'extreme events' P1 area is just related to the Primary watercourses network, according to the Italian Flood Risk Management Plan, decree D. Lgs. 49/2010. In fact, the Secondary watercourses network is structured in a dense network of canals and culverts; therefore, its flow-rate is not comparable with the Primary network one, hence the inundation damage cannot be as spread as the one produced by the Primary network.

Within the Po River watershed, flood hazard and flood risk maps are evaluated for the three main territorial layers: (a) Primary and watercourses network, (b) Secondary flatland watercourses network, and (c) Coastal area (not reported here). AdBPo divided each of these territorial layers into several cells in order to split the entire flood hazard (and flood risk) map in more detailed maps, to describe every part of the land with a high-scale representation. In the Emilia-Romagna Region website [12] it is possible to download the .pdf file containing all tables that compose the watershed, as represented in Figure 4, which is an example of the subdivision of the Secondary watercourses network. Every table has the direct link to the .pdf flood hazard map and to the .pdf flood risk map. This is a useful tool because the user can directly identify the portion of the territory in interest and select the corresponding table.

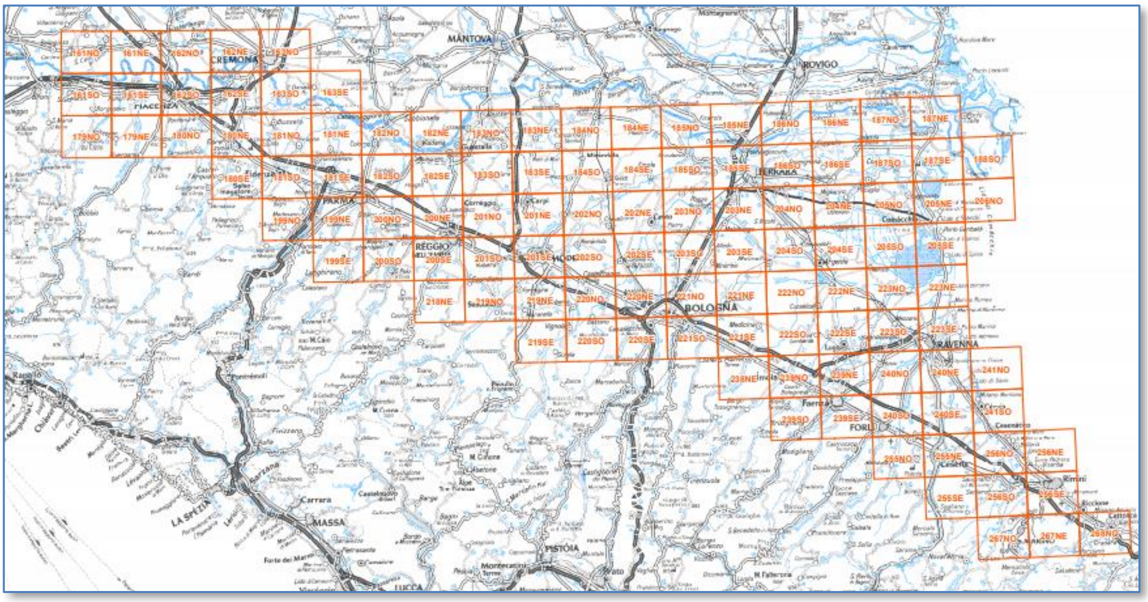

Figure 4. Watershed subdivision for the Secondary flatland watercourses network. [12]

Flood risk

Flood risk evaluation is the final step of the method presented in the EU Floods Directive 2007/60/EC [1] in order to understand the most dangerous areas for human life and the most vulnerable sites for all the economic, social and industrial activities, as well as for cultural heritage. The commitment to this step leads directly to a good elaboration of the Flood Risk Management Plan, aim of the EU Flood Directives. The Plan identifies all the strategies and actions in order to reduce the risk in the critical sites.

From the analytical point of view, the discrete equation used for the evaluation of the flood risk is the following Equation 1.

$$R = P \times V \times EE = P \times PD$$

Equation 1

Where R stands for the risk, P is the probability of occurrence of the flood with assigned intensity within a specific area and specific time interval, i.e. the flood hazard according to the classification of the law D.Lgs. 49/2010, V is the vulnerability of the site, intended as its capacity to cope with the flood event, and EE represents the exposed elements, namely people/goods/activities exposed to the flood within the specific site and the time interval. The product between the vulnerability and the exposed elements is called potential damage (PD), that is the level of damage and loss predictable in the face of the specific event. The superimposition of the different factors in Equation 1 is directly made by the computational model for risk assessment.

Looking at Equation 1, and as also said in the above, flood hazard maps (Figure 30) must be evaluated, since the flood risk is strictly connected to the probability of flood occurrence. Indeed, flood hazard is an unavoidable step for the evaluation of the risk: operationally, the territory is divided into several cells for which the probability of flood occurrence (P) must be superimposed with other data that represent the density and importance of assets and goods present in the same sites.

In particular, the other important factor in the evaluation of the flood risk is the potential damage (PD). This factor depends on the exposed elements (EE) and the vulnerability (V). Exposed elements are assets, goods and valuable and strategic buildings located in the floodable area. The exposed elements are assessed through the evaluaton of the land use, namely population density, type of buildings present in the area, type of activities carried out in the area, presence of historical heritage etc. At first, it is conducted a census of all the exposed elements, and then they are grouped in homogeneous classes of potential damage depending on the vulnerability of each. The vulnerability is intended as the coping capacity of an element, and its value is comprised between 0 (maximum coping capacity, i.e. the hazard does not affect the exposed element) and 1 (maximum vulnerability of the element, so the potential damage can be great in case of flood).

As mentioned in the above, from a computational point of view, the risk assessment is processed through a superposition of different layers, each of which representing a factor in Equation 1. Figure 5 shows the scheme of this process, where every grid, i.e. layout, is connected to a specific area of the territory.

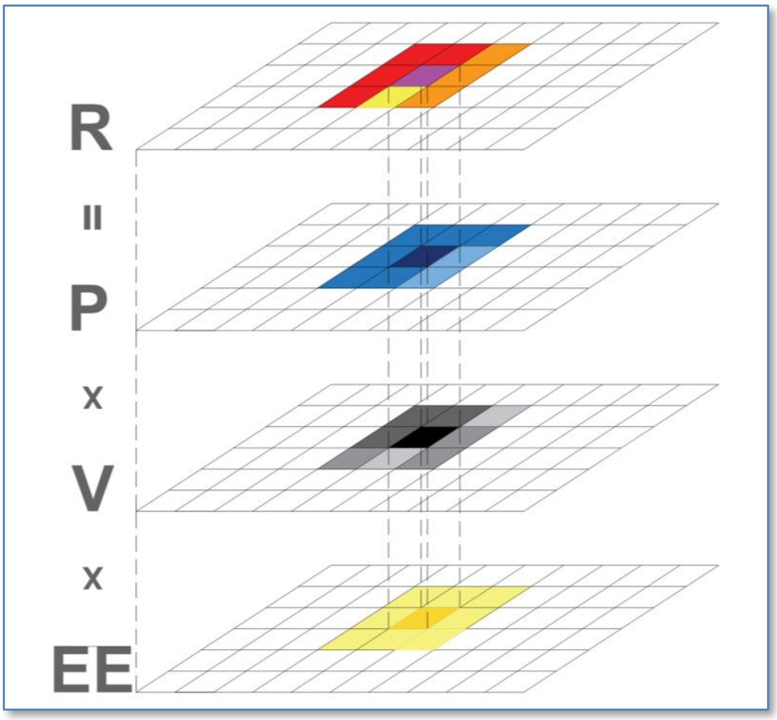

Figure 5 - Risk assessment scheme.

The potential damage is divided into four classes: from Class D1 to Class D4, with an increasing weight depending on the class of land use importance: D1 is assigned to the fewest valuable sites, with low or null population density and no important activities or assets, whereas D4 represents the most to-be-preserved sites, with strategic buildings and remunerative economic activities or cultural heritage. Class D1 is assumed for vegetative areas, without any building or residential sites. This class contains spaces such as woods, grasslands, beaches, fluvial areas or water basins. On the contrary, Class D4 stands for the most strategic, valuable and important sites. This class considers hospitals, schools, cultural heritage sites, residential sites, protected areas for the extraction of potable water. Moreover, in D4 class there are also harbours, industrial sites, railway networks, sports centres, army buildings etc. Practically, every type of location characterised by life and human activities is part of this class.

Combining the three flood hazard classes (i.e. the probability of flood occurrence) with the four potential damage classes, namely applying Equation 1 to the site in analysis, allows the evaluation of appropriate risk matrices which directly gives the risk class (R_i) given a specific probability of occurrence class (P_i) and a specific damage class (PD_i). Risk classes are determined by the national directive and they are ranked from from the *very high risk* (R4) to the *moderate or null risk* (R1), passing through P3 and P2 with a decreasing risk value. These four classes of risk are coloured differently, following the palette from violet (very high risk, R4) to yellow (moderate or null risk, R1), passing through red (high risk, R3) and orange (medium risk, R2), as shown in Table 2, 4 and 5. Hence, it is clear that the risk value is a function of both the flood hazard and the potential damage of the exposed elements.

Each risk matrix is calculated for a determined type of watercourses network. Therefore, it is possible to distinguish different impacts in terms of danger for human life and damage for human activities, in relation to different intensity and evolution modalities of the flood processes in different territorial sites. Table 2, 4 and 5 represent the three risk matrices considered in D.Lgs. 49/2010 for the evaluation of the flood risk, each of them concerning a specific watershed: Table 2 regards the Primary watercourses network and the Secondary watercourses network in the Alps area, Table 3 concerns Coastal and Maritime area and the Secondary watercourses network in the Apennines area, and Table 4 indicates the risk for the Secondary watercourses network in the flatland area [8].

Considering that the territory of Ferrara consists in different sites, from the flatland area to the coastal one, and within the flatland area both the Primary and Secondary watercourses networks cross the territory, all the following three matrices are meant to be taken into consideration for evaluating the flood risk in this water-connected territory.

RISK CLASSES		HAZARD CLASSES		
		P3	P2	P1
DAMAGE CLASSES	D4	R4	R4	R2
	D3	R4	R3	R2
	D2	R3	R2	R1
	D1	R1	R1	R1

Table 2. Risk matrix for the Primary watercourses network. [8]

RISK CLASSES		HAZARD CLASSES		
		P3	P2	P1
DAMAGE CLASSES	D4	R4	R3	R2
	D3	R3	R3	R1
	D2	R3	R2	R1
	D1	R1	R1	R1

Table 3. Risk matrix for Coastal and Maritime areas. [8]

RISK CLASSES		HAZARD CLASSES	
		P3	P2
DAMAGE CLASSES	D4	R3	R2
	D3	R3	R1
	D2	R2	R1
	D1	R1	R1

Table 4. Risk matrix for the Secondary watercourses network. [8]

The Secondary watercourses network in Table 4, contrarily to Table 2 and 4, considers just the P3 and P2 categories of the flood hazard. As discussed also in the above, this is a decision of the Italian directive D. Lgs. 49/2010. It is just reminded here that the Secondary watercourses network consists in the land reclamation system, therefore it is composed of canals and streams and the magnitude of the flood flow-rate cannot be as big as the one running in a river.

Risk maps are obtained applying these matrices, following the same distinction among different territorial watersheds identified in the D. Lgs. 49/2010. Risk maps are a useful tool because they clearly indicate which parts of the floodable area are most vulnerable and, therefore, they would produce the greatest loss, in terms of both human life and economy.
As an example of flood risk map, the following Figure represents the flood risk map for the territory of Ferrara. The development of this map is carried out following the flood hazard map (Figure 3) for the same area of the Ferrara municipality, so accordingly to specific land uses and exposed elements in the area. Therefore, equally to flood hazard maps, Figure 6 (a) is flood risk for the Primary watercourses network and Figure 6 (b) is for the Secondary watercourses network. According to the matrix in Table 4, in the Secondary watercourse network there is not any R4 area.

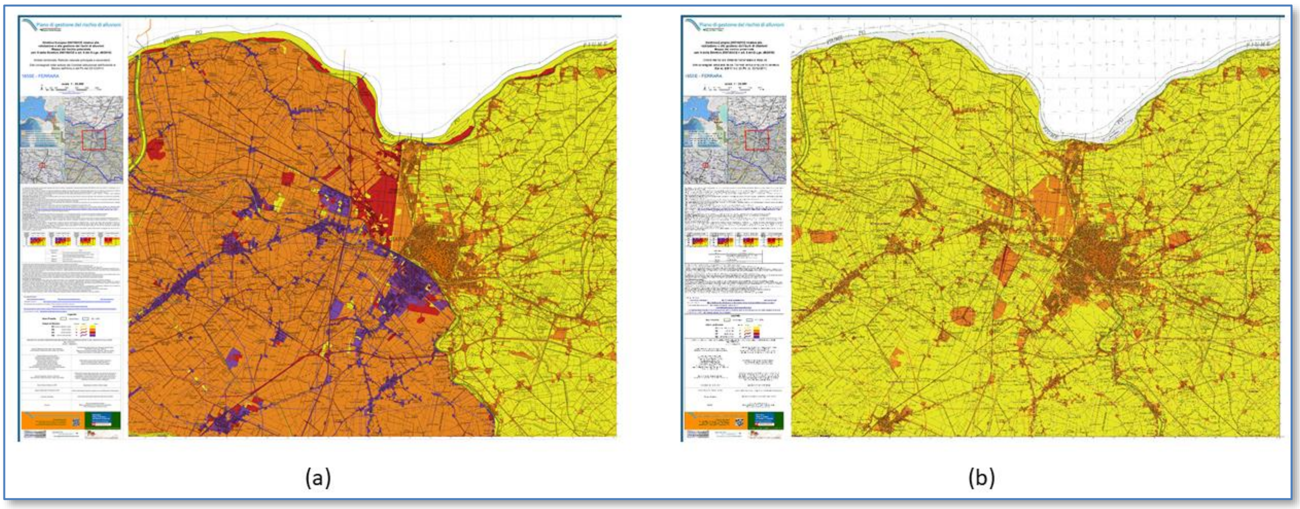

Figure 6. Flood risk maps in Ferrara territory evaluated for the Primary watercourses network (a) and the Secondary watercourse network (b) [11]

The Flood risk evaluation and management plan, D. Lgs. 49/2010 (Article n. 7 of the EU Floods Directive 2007/60/EC) can be analysed in order to see the classification of the exponential damage and the matrices created to assess the flood risk.

Flood risk in the coastal area

The Po River Basin Authority identified the coastal area of the territory of Ferrara as a critical site regarding flood hazard and risk [13]. The site is called "Costa Emilia-Romagna" and it is represented in Figure 8 and Figure 8, which show flood hazard and flood risk maps.

The significant risk area "Costa Emilia-Romagna" includes the territory between the Po di Goro outlet and the Reno River outlet, with an overall length of 40 km. The width of the interested land from the coast is extremely variable, from few tens of meters to more than 2 km, and it depends on the topography and the artificial defence system, which is one of the oldest within the entire regional coast.

The critical site includes municipalities of Goro, Codigoro, Comacchio, reaching the close territory of Ravenna. The inhabited centres included in this region are Gorino, Goro, Lidi Ferraresi and touristic centres that becomes populated during the winter period.

The morphology of the territory is characterised by wide valleys, which present the soil altitude lower than the sea level, in fact they are kept in a dry-state thank to the land reclamation system, and they are protected toward the sea by coastal dunes and the beach, which are the only natural defences against the marine ingression. The progressive fragmentation of the coastal dune caused by both the urban and the tourist centres growth increased the vulnerability of these territories. Consequently, these lands have been protected by increasingly complex and wide infrastructures.

First "sea-embankment" systems aimed the protection of the Goro municipality, and they were constructed in the 40s; in the same period, defence infrastructures to protect Porto Garibaldi were disposed as well. Between the 50s and the 70s, the embankment were reinforced and widened. After the inundation occurred in 1966, another embankment was constructed, extending from Volano to Porto Garibaldi, at a distance from the coastline from 500 m to 1.5 km. This structure aimed at the defence of the inner land to new storm surge events. In the following period, between the 70s and the 80s, the massive urbanisation process brought the construction of houses and buildings in the eastern part of the defence, regardless of the meteo-marine vulnerability of the land. In the same period, in Porto Garibaldi longitudinal defences were developed in order to overcome the problem of the coastal erosion.

The high vulnerability of the territory to the marine ingression led the municipalities to the construction of new defences structures, both in Lido delle Nazioni (north of Volano) and in Lido di Spina.

It is important to underline that only with a continuous coastal defence, or with defence embankments close to the water, it is possible to guarantee the safety of the majority of this territory. Therefore, embankments need to be kept in a high-efficiency status.

The technical report of the AdBPo regarding the coastal risk in Emilia-Romagna [13] reports all the data of the most recent inundation events in the critical site, the analysis of hazard and risk maps and the related critical issues, as well as measures and criteria for the management of the risk in the area.

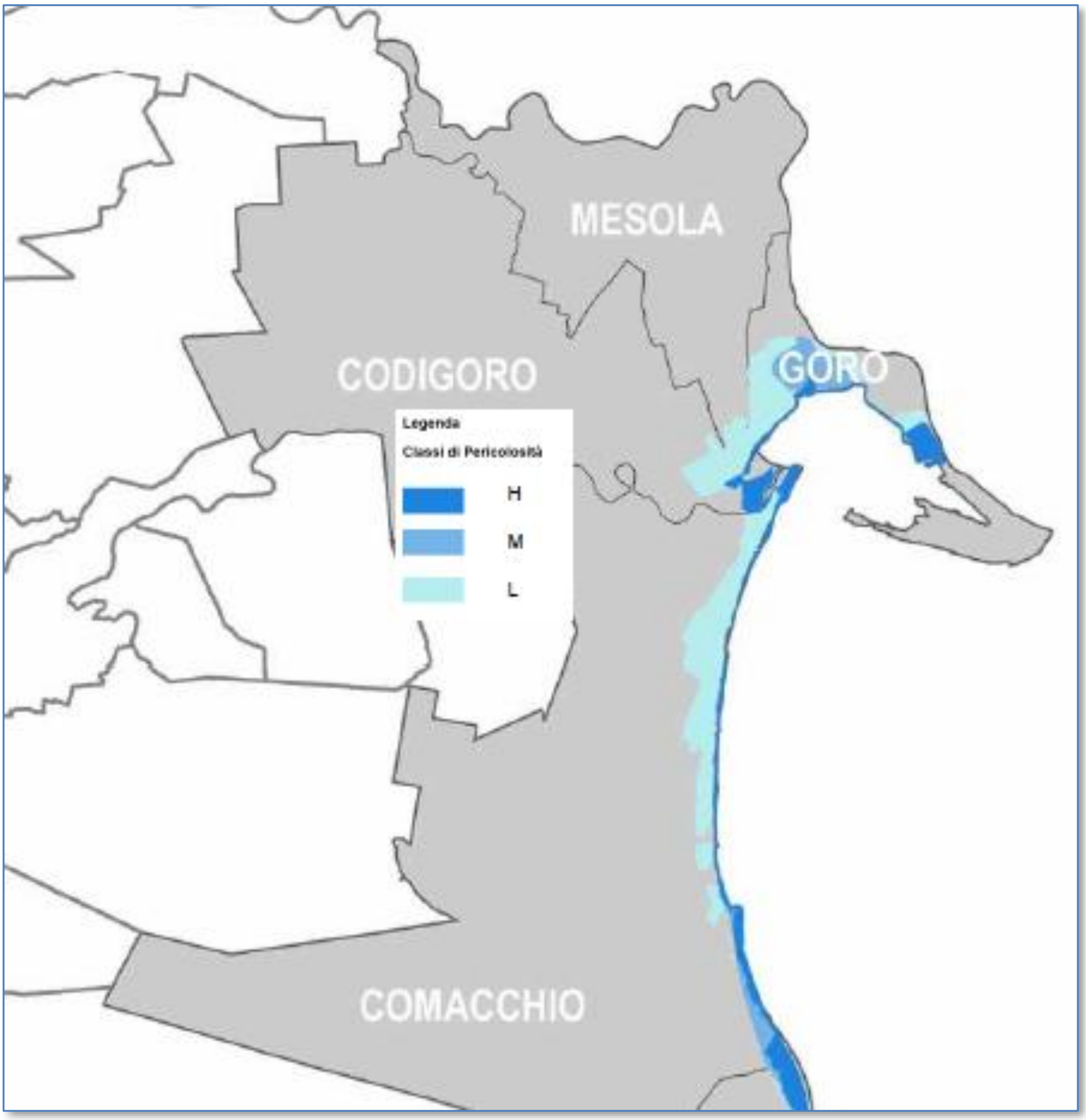

Figure 7 - Flood hazard assessment for the coastal side of Ferrara territory

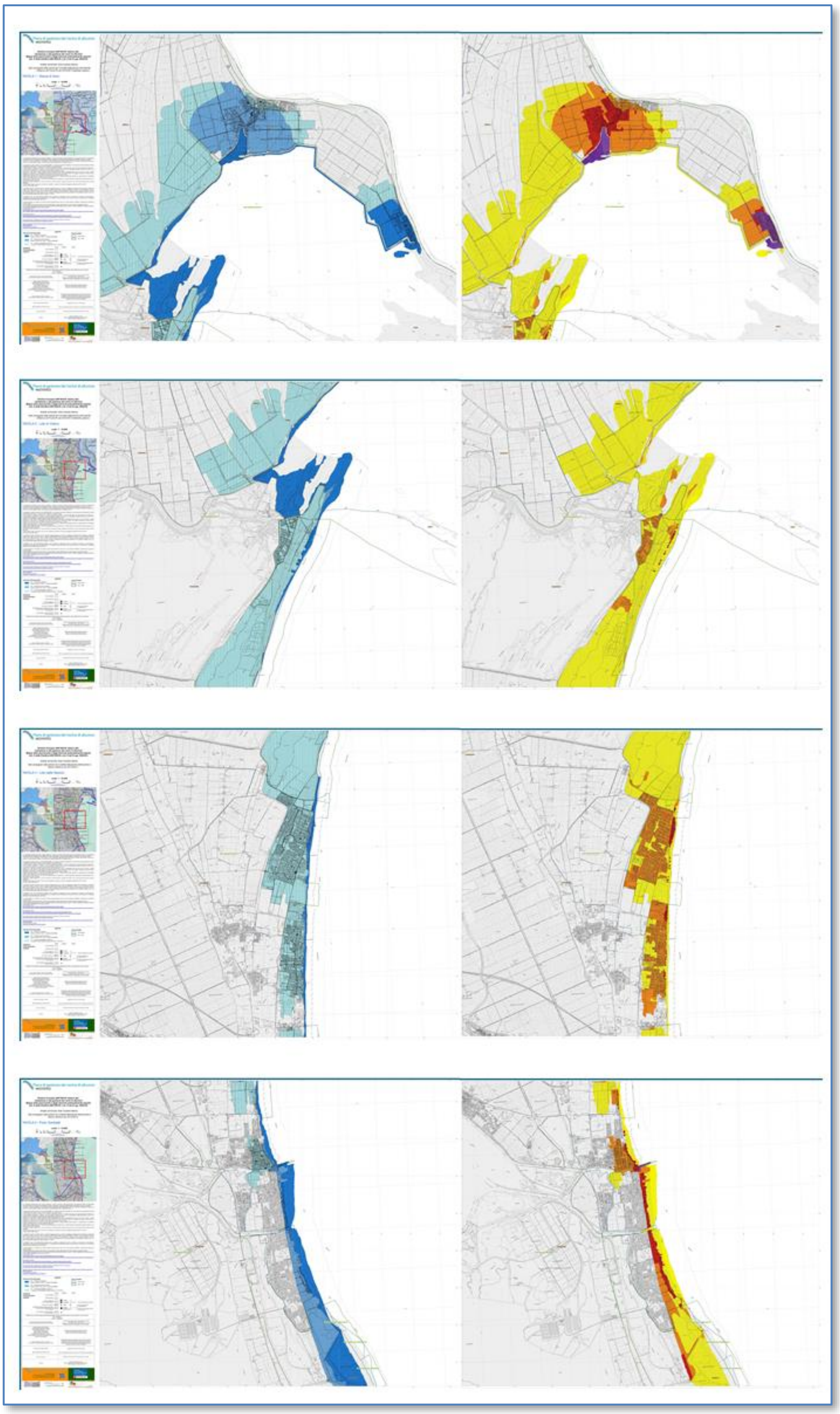

Figure 8 - Flood hazard and flood risk maps for “Costa Emilia-Romagna”

Proposal for risk maps improvement

According to the Flood Risk Management Plan, D. Lgs 49/2010 (Article n. 7 of the EU Floods Directive 2007/60/EC) [1,2,8], future studies concerning flood hazard maps will surely involve climate change consideration. This problem will cause changes in the pluviometry regime. In fact, lately has been observed a decrease in the frequency of rainfall but an increase in intensity and therefore in the water height precipitated on the soil. This fact, in addition to the continuous urbanisation, will stress the watercourses systems, especially, concerning the territory of Ferrara, the Secondary network. This latter, as also said in the above, is regulated by several different hydraulic infrastructures. Most of them have been set-up accordingly to different rainfall conditions and diverse waterproof land extension. Therefore, changed boundary conditions must be considered in the analysis of flood risk, also in order to understand how these hydraulic infrastructures should be updated.

Furthermore, the present flood hazard maps do not consider the possibilities of levee breaches for the main watercourses or the possibility of a malfunctioning of water lifting plants or hydraulic structures. These aspects might be integrated into the risk evaluation of different scenario. For example, from a multi-hazard analysis point of view, a seismic occurrence might cause a malfunction of a water-lifting plant. If this occurrence happens contemporary with a severe rainfall event, the flood hazard would be greater than the predicted, and consequently the risk as well.

In addition, the detailed analysis at regional and local scales of flood hazard and risk is very important for the improvement of risk maps. The local-scale analysis needs a detailed study regarding preliminary information given by cartography but synergistically within the hydrograph basin characteristics. Regarding the local scale, it is important to develop some two-dimensional models in order to evaluate the velocities and water heights of events. Regarding this aspect, both the Civil Protection and the operational sector on flood risk of Emilia Romagna Region request a more detailed analysis of the secondary watercourses network.

Moreover, the Flood Risk Management Plan states that another aspect that should be considered in the future analysis is the residual risk. Residual risk consideration requires the optimisation of hydraulic models that now are applied just at some pilot-basins.

In relation to the coastal site, the marine ingression is a phenomenon that may have an important role in the flood risk analysis; therefore, it should be considered as well in future updates of flood risk maps.

The authority AdBPo aims at improving of flood risk maps also regarding the methodology for potential damage assessment. Current studies are elaborating a procedure for the quantification of risks as a function of the vulnerability that permits the estimation of risk in terms of expected economic damage. This will lead to a more appropriate assessment of interventions priority and better costs-benefits analysis. Therefore, both at the European level and within the Po River watershed the work will be based on, on one hand, the use of the vulnerability function with an appraisal of involved people and, on the other hand, the application of a multi-criteria method that aims at assessing different damage components through the application of pre-defined criteria (such as application of weights). Moreover, another goal is the better differentiation of some categories of exposed elements to propose more adequate and more economically sustainable objectives and management actions.

Data source

[1] DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the assessment and management of flood risks, Official Journal of the European Union
[2] DECRETO LEGISLATIVO 23 febbraio 2010, n. 49, Attuazione della direttiva 2007/60/EC relativa alla valutazione e alla gestione dei rischi di alluvioni.
[3] Website Consorzio di Bonifica Pianura di Ferrara – Territorio (http://www.bonificaferrara.it/index.php/it/il-consorzio/il-territorio)
[4] Website Municipality of Ferrara (http://servizi.comune.fe.it/7536/rischio-idraulico-e-idrogeologico)
[5] Website Consorzio di Bonifica Pianura di Ferrara – Cartografia (http://www.bonificaferrara.it/index.php/it/sitl1/cartografie-scaricabili)
[6] Piano di Gestione del rischio di alluvioni – Autorità di Bacino Distrettuale del Fiume Po (https://pianoalluvioni.adbpo.it/)
[7] Website Regione Emilia-Romagna – Agenzia per la sicurezza territoriale e la protezione civile (https://protezionecivile.regione.emilia-romagna.it/)
[8] Piano di Gestione del Rischio Alluvioni – Piano per la valutazione e la gestione del rischio di alluvioni, Art. 7 della Direttiva 2007/60/EC e del D.lgs. n. 49 del 23.02.2010 – II A. Mappatura della pericolosità e valutazione del rischio
[9] M. Guida, M. Mainetti – "Piano di Gestione del Rischio Alluvioni" – Convegno Nazionale Acqua di qualità e sicurezza idraulica – Bologna, 20 marzo 2015
[10] http://mappa.italiasicura.gov.it/#/home
[11] Website Regione Emilia-Romagna – Ambiente (https://ambiente.regione.emilia-romagna.it/it/suolo-bacino/sezioni/piano-di-gestione-del-rischio-alluvioni/mappe-peric-rischio-all)
[12] Website Regione Emilia-Romagna – Ambiente (https://ambiente.regione.emilia-romagna.it/it/suolo-bacino/sezioni/piano-di-gestione-del-rischio-alluvioni/cartografia#Moka%20PGRA)
[13] Piano di Gestione del Rischio Alluvioni – Piano per la valutazione e la gestione del rischio di alluvioni, Art. 7 della Direttiva 2007/60/EC e del D.lgs. n. 49 del 23.02.2010 – IV A. Aree a rischio significativo di alluvioni, ARS Distretturali – 2. Schede monografiche, Ambito costiero marino (Emilia-Romagna)