Flood Risk Management Plan for the Sardinia Hydrographic District

Sara Frongia[1], Marco Melis[2], Giovanni M. Sechi[3] & Roberto Silvano[4]
[1]*Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Cagliari, Italy, e-mail: frongiasara@tiscali.it*
[2]*Regional Water District Authority, Cagliari, Italy, e-mail: mamelis@regione.sardegna.it*
[3]*Department of Civil Engineering, University of Cagliari, Italy, e-mail: sechi@unica.it.*
[4]*Regional Water District Authority, Cagliari, Italy, e-mail: rsilvano@regione.sardegna.it*

Abstract: Following the European Council Floods Directive (2007/60/EC) and the Italian National Legislation (DL n. 49/2010), the Sardinian (Italy) Hydrographic District Authority defined the main directives on the assessment and management of flood risk in related basins. This planning phase is subsequent of a detailed flood risk mapping and consequent identification of flood prone areas. Recent historical events highlighted on this necessity as the Sardinia region was affected by important floods, typical of the Mediterranean area. In December 2004 the territory of Eastern Sardinia was the scenario of a massive flood event characterised by 500 mm rainfall in five hours. In October 2008 a storm hit the South-Eastern territory and 350 mm of rain was gauged in less than 3 hours. More recently, in November 2013 the Cleopatra hurricane affected the North East of Sardinia causing huge damage. Following these emergencies and legislation directives, the Sardinian Hydrographic Authority is working on flood risk management plans involving researchers, communities and stakeholders. In this paper we focused on a framework plan to describe the assessment of flood risk management plans and consider some pilot areas to define a decision support tool with priorities in flood mitigation measures. Preliminary results are illustrated for these pilot areas observing different mitigation options (structural and non-structural).

Key words: Sardinia Flood Risk Management Plan; Flood Directive 2007/60/EC; JRC Model economic assessment methodology; Costs-Benefits Analysis

1. INTRODUCTION

The Sardinian region (Italy) flood protection policy is characterised by two important flood plans: the Hydrogeological Settling Plan (P.A.I., 2008) and the Fluvial-Zones Definition Plan, (P.S.F.F., 2013). Nevertheless, these two plans are not enough in answering to the requirements of points raised in the European Flood Directive 2007/60 and the National Italian Legislation, DL 49/2010. As a matter of fact, the two already existing regional plans identify potential flood damaged areas (defined varying the return-time period) and damaged elements, but they need to be completed defining structural and non-structural actions to be provided in order to mitigate risk in flood prone areas.

Moreover, these requirements have been highlighted to political and stakeholders by massive flood disasters caused by recent floods and hurricanes. In December 2004 the Eastern Sardinian territory has been hit by extremely heavy precipitation: the rain gage of Villagrande Strisaili gauged 21.2 mm in 10 minutes and 86.4 mm in 1 hour between the 5:10 P.M. and the 6:10 P.M. (ARPAS, 2004). Four years later, in October 2008 a storm hit the South-Eastern territory: 58 mm of rain in 15 minutes and 350 mm in less than 3 hours were gauged in Capoterra territory. In November 2013 the Cleopatra hurricane ruined a big part of the Sardinia territory: a maximum of 440 mm of rainfall has been gauged in less than 24 hours causing 13 dead and a massive amount of damages, mainly around the Olbia town. The disasters consequently to the above cited storm events are just few examples of recent floods urging the Regional Government to specifically engage the Flood directive 2007/60 to Sardinian region requirements.

Flood-Risk management can be viewed as a process that involves three different set of actions, depending on aims and operators involved. The first set of actions is necessary to operate on an existing system achievable with a deep analysis of the actual system peculiarities (e.g. changes in land use, urbanization, climate change, etc.), while the second step starts planning for a new or revised system according with the changed conditions. Finally, the planning process step leads to decisions for the mitigation measures supported by an optimum design (Plate, 2002). All previous aspects are embedded in the Flood Directive approach running scheme. The definition of the concept of risk, as combination of flood hazard and flood consequences, and the way in which it is calculated should ideally run starting from the preliminary flood risk assessment, over the mapping of hazards and risks, up to the setting of objectives and planning solutions. Focusing the attention on the assessment and management of flood risks, the European Flood Directive requires the development of the three important reports: 1) The Preliminary Flood Risk Assessment Plan; 2) The achievement of the Flood Hazard Maps and Flood Risk Maps; 3) The Flood Risk Management Plans (FRMP).

In real-cases implementation, different methods will be used depending on the scale and level of detail of the assessments (F.Raymaekers, 2012). The second step is one of the most important aspects of the Flood Directive as maps are instruments not just for defining and communicating flood risks, but, mainly, for regulating territory uses and for rationalising the inevitable limits and failures of controls (Demeritt, 2012). In contrast to engineered defences designed to keep water away, it will be important to understand the potential consequences and help communities to become more resilient and adapt to changing levels of flood risk (Demeritt, 2012). Especially because of the lack of infrastructures completely controlling floods and the need of education on flood risks and related misunderstanding, the third step, the Flood Risk Management Plan, holds a relevant position on the Flood Directive 2007/60/EC.

In Sardinia we can consider the first two steps have been mainly settled. Relating to the third step, the project for Sardinian Flood Risk Management Plan is still under development. The Sardinian Government commissioned to Sardinian Hydrographic District Authority and Hydraulic Researchers of the University of Cagliari for the achievement of the Flood Risk Management Plans (FRMP) in order to define a clear framework made up not only by engineering ways to reduce flood risks, but also non-structural alternatives like flood warning, emergency response or land use planning (RAS-UNICA, 2013).

2. FRMP: FRAMEWORK IN SARDINIAN HYDROGRAFIC DISTRICT

The development of the Flood Risk Management Plan requires the analysis of the current regulations recognised by the Hydrographic District Authority. The European Flood Directive Italian implementation into the National Legislation, (DL 49/2010), expects the preparation of the FRMP by every Hydrographic District. These Hydrographic Districts were defined in a previous act of Italian Legislation (L.n. 152/2006). The main aim of the FRMP is to improve the knowledge and preparedness on flood events to avoid negative consequences in healthy conditions of human being, territory, environmental, historical and architectural heritages and, at the same time, to enhance business safety and social activities. According with the main features of hydrographic districts, a shortlist of non-structural measures has been defined in terms of prevention, protection and preparation to deal with potential flood events. The FRMP operating and governance tools (e.g.: guides lines, institutional agreements, dissemination knowledge, community involvement, etc) are focused on the flood management also in terms of flood emergency plan. In fact, the article n°67 of the D. Lgs. 152/2006 underlines the fundamental existence of a partnership with the Civil Protection Agency in order to improve the alert flood system. Moreover the D. Lgs. 152/2006 requires a clear assessment of every plan in terms of environmental to prevent possible nature devastation. Furthermore to make consciousness the population about the development of the framework project of the Flood Risk Management Plan, as public dissemination knowledge tool the Provisional Comprehensive Assessment (VGP) has been published. The VGP gives in advance an idea of the general potential framework of the FRMP and reveals its aims to reduce negative consequences of floods using structural and no structural mitigation measures.

The Sardinian region Flood Risk Management Plan proposed scheme, (RAS-UNICA, 2013), consists in ten sections starting with the European and national institutional politics framework, in order to stress the main aims into the plan. FRMP defines the potential mitigation measures and reconnaissance actions paying attention of flow rates, evaluated floodplains, stream ways and potential natural expansion flood prone areas, environmental aims pinpointed in D. Lgs. 152/2006, land and water resources management, natural, urban and business development, cost-benefit analysis, coastal and meteorological conditions. All of the specified points would be coupled with a solid support of strategic stations (prevision, monitoring, supervision types). Strategic actions are focused not only in management of hydraulic aspects but also in compelling emergency management aspects following the Alert Operating Instructions for Civil Protection Agency, AOICP (Sardinian Region, 2014). The AOICP considers the update of the actual regional flood plans, dam management plans contextualized for the Sardinian regional area.

The dissemination actions consist in different support works focused on the training of every Sardinian council and even more of every inhabitant. The Sardinian Hydrographic District Authority has activated an information distribution chain defined by informative material, weekly stakeholders meeting, training meeting, apps for Smartphone and pc. In addition the Regional District Authority is going to realise a website, “Sardegna Geoblog”, where citizens can improve their knowledge on flood risk management both in technical and social behaviours terms.

All of the previous described aspects of the FRMP make an introduction for the consecutive chapters more focused on the regional planning on hydro-geological field. Regarding this aspect, the Hydro-geological System Plan (PAI) has been recalled as aiming at the preservation, protection and enhancement of the territory against hydrogeological potential risk. The dynamic evolution of the territory is affected by long term changes as hydrological events, but also by sudden or short terms transformations determined by the man-make actions like urbanizations. For these reasons the PAI requires a continuous update of the hydrogeological risk maps underling their boundaries and identifying in which part of the territory can be applied law restrictions, structural e non-structural mitigation measures. The potential hydraulic or geological risks are defined with four levels described with a value between one to four in respect of the increase of the risk and pinpointed on the related flood maps.

Progressively, in FRMP need to be reminded the Fluvial-Zones Definition Plan, (PSFF) dividing the regional area of 24100 km^2 in seven river systems. The river systems consists in 58 main water streams for a total length of 1.120 km and 226 secondary streams for a total of 2.030 km, as shown in Figure 1. The hydraulic risk zones are highlithed in Figure 1 in blue color while the geomorphological risk areas are pinpointed with green. The PSFF is an improvement and integration of the PAI to outline the pertinence of river flows with the aim to protect the natural streams capacity, the safety and protection of the adjacent areas. The PSFF flood hazard maps are the basis to identify the area under flood risk and to start the Flood Risk Management Plan.

The FRMP extension of the flood hazard areas is based on this study considering four hydrologic scenarios in function of flood events return period of 2, 50, 100 and 200 years. Considering for each river stream hydrologic forecasts and river system characteristics, the hazard area extention at the four level, H_i1 (500 years return period) - H_i2 (200 years) - H_i3 (100 years) - H_i4 (50 years), has been defined. Following the PSFF, subsequently FRMP work aims to make available the flood hazard maps, flood potential damage maps and the flood risk maps.

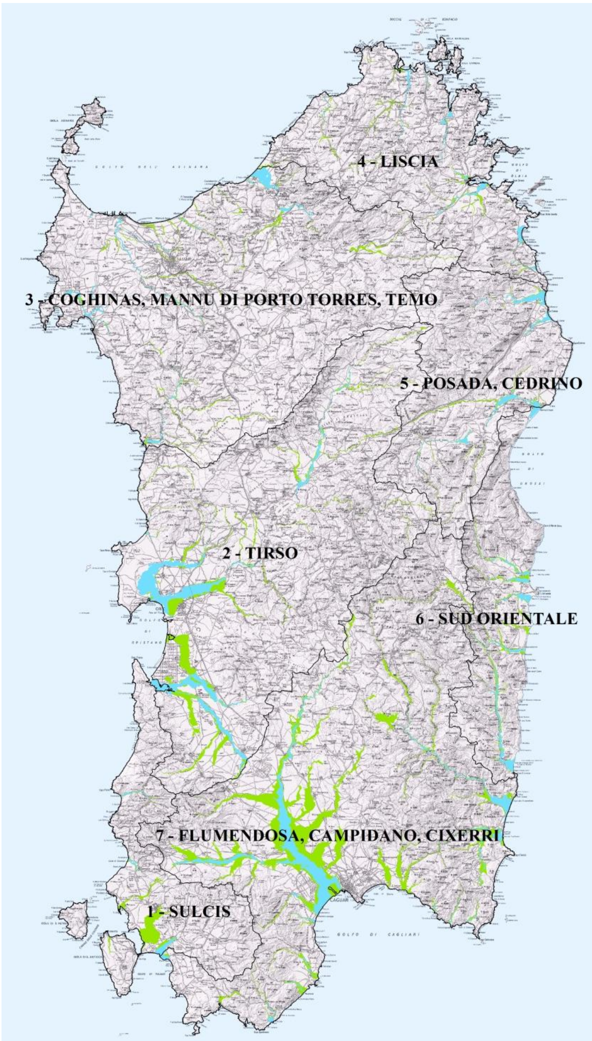

Figure 1 Sardinian Hydrographic Basins and Flood Hazard Maps according with P.S.F.F.

Coherently with the flood hazard levels, the Sardinian territory has been analysed in order to define properly four potential damage levels for flood events. These four potential damage levels consider the damage related to people, socio-economic elements and goods for which it is not possible to give a monetary amount of the damage, like the environmental or historical heritages. The output of the analysis provided a potential flood damage map for the whole Sardinia territory. A crosscheck of the hazard and damage values, defined in the Flood Hazard Maps and Flood

Potential Damage Maps, provided the flood risk categorisation and the related maps obtained by an overlay of the maps.

Moreover, the Civil Protection Agency defines the regional alert procedures in case of meteorological, hydrological and hydraulic risk providing the Alert Operating Instructions for Civil Protection. The operating instructions underline social, government and structural components with their tasks to perform the duties when the alert signal is activated. The risk signal consists in four different phases increasing by “Regular critical situation” to “High Risk”. The alert signals manage gradually the operations that should be achieved when the risk starts until it reaches the risk emergency status and the consecutive risk management scheme. For each Risk level the Operating Civil Protection Instructions also defines the required resources.

3. FRMP: SARDINIAN BASIN ANALYSIS AND CASE STUDIED

Among the seven river systems previously defined, the Coghinas river lowland valley (basin n° 3 in Figure 1) located in the North-East coast of the Sardinia island was chosen as pilot in FRMP. The main river stream path is extended over 115 km and the catchment area is about 2453 km^2. The flow rate discharged of the Coghinas river is controlled by two important dams currently under flood control management through the “Flood Lamination Plans”. The analysed Coghinas river path starts from the Casteldoria dam and, after 15.9 km, reaches the Gulf of Asinara near Valledoria town. The hydraulic parameters are the same used by the PSFF with a steady flow hypothesis and defined upstream and downstream boundary conditions. The upstream boundary condition assumes a steady flow rate for every return time period, Table 1, under the hypothesis of uniform flow and a bedriver slope of 0.003. While the downstream boundary condition considers a free water surface at 1.8 meters above the standard sea level.

Table 1 Flow Rate in m^3/s of the Return time Period assigned as upstream boundary conditions

Tr = 2 anni	**Tr = 50 anni**	**Tr = 100 anni**	**Tr = 200 anni**
433	2950	3745	4460

The Coghinas river flood flows has been studied with a one dimensional hydraulic simulation applying the hydraulic simulation software HEC-RAS 4.1. The hydraulic simulation has been developed three times to trace the flood hazard risk zone according with what defined in the PSFF: flood hazard maps description for the three return time period of 50, 100 and 200 years, Figure 2. The floodplain related with the return time period of 2 years is considered to pinpoint the river banks and Manning rough coefficient of the riverbed and adjacent area coupling that with the information obtained through digital orhophotos analysis at a scale definition of 0.20 m. The hydraulic simulation, analysing the river lowland valley and comparing the available orthophotos taken in different periods to observe the land evolution, make a deep analysis using the DTM with a scale of details of 1 m and intensify the cross sections near the critical points as bridges and urban areas. The simulation has been run checking carefully the geometric information and dividing the river path in four parts.

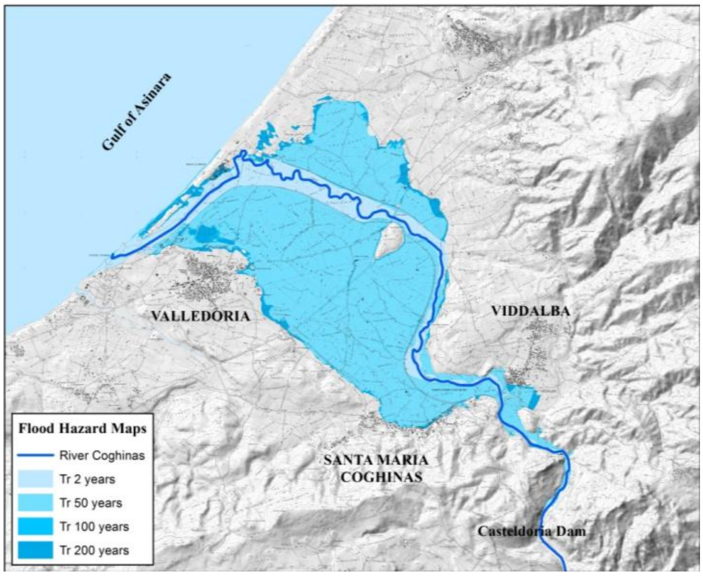

Figure 2 P.S.F.F. Flood Maps of the Coghinas river lowland valley sub-basin.

The flood prone areas obtained for the target return periods are the basis to developed the flood risk management as required on the Flood Directive 2007/60/EC to calculate flood risk of a certain area under the baseline and after that recalculate the risk once the realisation of risk management measures (F.Raymaekers, 2012). The flood risk protection measures aim to decrease the flood risk and resulting damages/costs and, at the same time increase the benefits produced by their realisations. These aspects have been translated using a costs-benefits optimization tool.

The economic evaluation of flood risk management is based, by the majority, on the application of flood depth-damage curves. The nowadays research on economic flood risk assessment makes available few models as the Multi Coloured Manual of the Middlesex University (UK), USACE curves, Federal Insurance Administration (FIA) curves, FLEMO Model (Germany), JRC Model (European Commission/HKV Consultants) (B.Jongman, 2012) (A.Pistrika, 2014). The present paper assesses the economic damage on the basis of the JRC Model depth-damage curves developed in 2007 by H.J. Huizinga of the HKV Consultants under commission of the Joint Research Centre. The JRC Model curves had been studied for five macro categories of land use (Residential buildings, Commercial, Industrial, Infrastractures and Road, Agricultural) based on the Corine Land Cover 2000 and Moland Dataset. The “Flood Damage Functions for European Member States” guideline studied different flood events that hit European territory and the collected data had been analysed in order to obtain representative absolute depth-damage functions for each macro category. The absolute functions are defined by a direct proportionality between the evaluated damage value (€/m^2) and the water depth that increases within a range from zero to six meters. The JRC model depth-damage functions had been later studied in order to trace a relative depth-damage function represented by a flood damage coefficient, that grows up between zero and one, proportionally with the same water depth range considered for the absolute depth-damage curve.

The aim of JRC modeling approach was to obtain harmonised depth-damage curves apply for the whole European territory. The large variance of the flood damage values among the Europen Member States does not allow to apply a basic mean of the found flood damage value but induced the study to find a curve that describes on average the available curves. Once that the harmonised relative depth-damage functions had been obtained and considering that the majority of the european country does not have own depth-damage curves. In order to reach this aim the calculation of maximum damage values for each european member state was based on the Gross Domestic Product per Capita PPS of each European country. The JRC Model guidelines gives back the Maximum Damage Value, (€/m^2), for each land use category.

The JRC Model functions and land use categories have been subjected to two main changes working on the Coghinas river. The first change considers the water depth chose to describe the depth-damage increase. The flood damage coefficient reaches the maximum damage value around a water depth of five meters for each land use category in exception for the Residential bulding land use category. For this reason the JRC Model curves have been under an arrangement considering the water depth range between zero to five meters and, the same points defined in the JRC Model guidelines. The curve trends have been retraced, as in Figure 3.

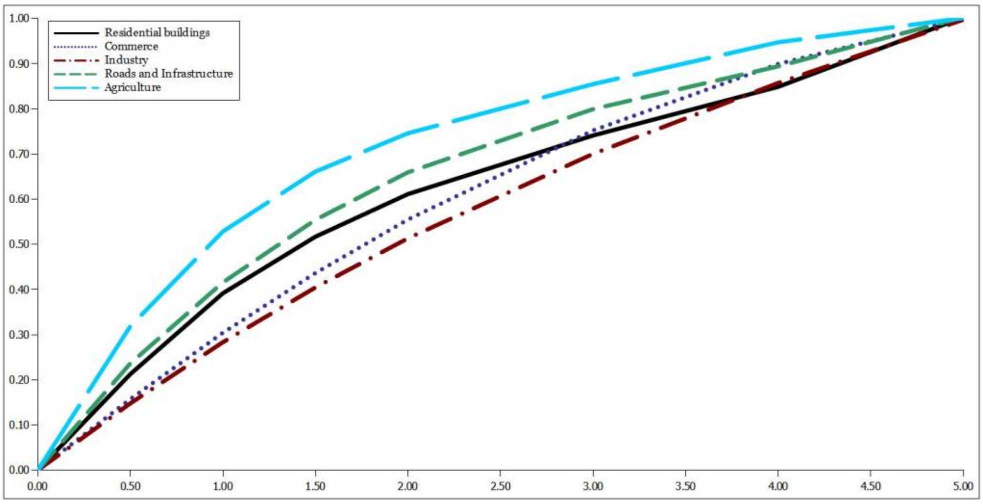

Figure 3 Flood Damage Approximate Harmonise Functions for EU Member States

The Flood Potential Damage Maps have been updated in order to describe in detail the Sardinian territory in terms of land use. The second main integration considering the JRC methodology regards the land use subdivision. The five macro categories of the JRC Model have been seen too restrictive describing Sardinia territory and this lead the researchers to increase the groups of macro categories from five to twelve. The news category list takes under analysis the land use type that would be subjected of direct tangible damage and even more defines protected areas (i.e.: environmental heritage areas, historical heritage areas, etc.) and water bodies for which it is not already possible to assign a Maximum Damage Value. The land use macro categories without defined Maximum Damage Value have been set to identify the areas where the flood can cause intangible damages and because a proper evaluation of these areas is not available due to the lack of data, the value of 0 €/m^2 has been assigned, as reported in *Table 2*

Table 2 Land use Categories and related Maximum Damage Value for Sardinia Region

Land use category	Label	Maximum Damage Value (€/m2)
1.Residential Buildings	R	618
2.Commerce	C	511
3.Industry	I	440
4. Agriculture	A	0.63
5.Council Roads	N	10
6.Provincial Roads	P	20
7.Other Roads	S	40
8.Areas with water supply network, electricity grid and similar systems	T	40
9.Dams, rivers and similar areas	H	0
10. Environmental heritage areas	J	0
11. Historical and archaeological heritage areas	K	0
12.Area subjected of other intangible damages	X	0

The potential flood damage of the Coghinas river basin baseline scenarios have been evaluated considering the JRC Model with proper changes for the Sardinian territory. The flood prone area for each return period after a prearranged GIS process, Figure 2, has been converted in shape file with cell with a scale of detail of 3 x 3 meters and described each one by water depth and land use category within the few parameters required by the Flood Directive 2007/60/EC as explained above on the Flood Potential Damage Maps description. The flood damage coefficient depends on the water depth and land use. The available flood plain area configuration allows to define for each cell the proper flood damage coefficent based on the water depth and land use category related at each cell. Once the flood damage coefficient has been calculated for each cell through an alghoritm added in ArcGIS, the total potential flood damage is assessed for the whole flooding area and described for each macro category. The description of the potential flood damage for each land use category helps to decide which protection measures, structural and/or non structural, would be better to define.

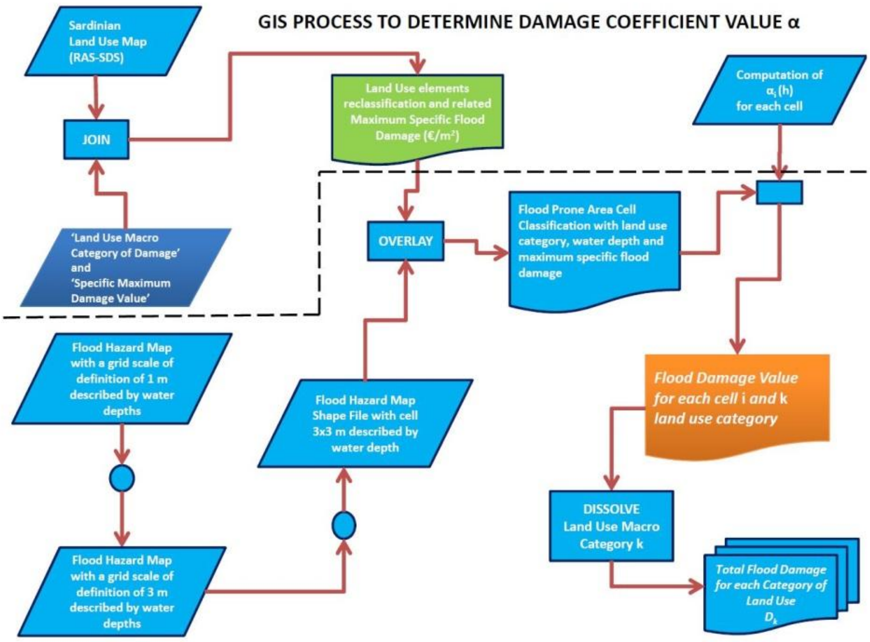

Figure 4 GIS Flow Chart to determine the flood damage coefficient

In the following step of the economic flood damage assessment is located the definition of potential mitigation measures. The scenario with the mitigation measures would be characterised by a different flood prone area of the baseline case. A new analysis is necessary to recalculate the potential flood damage in the new scenario. The importance of this second step is underlined after its realisation by the decrease of the flood area. In fact the comparison between the baseline scenario and the scenario with mitigation measures (including protection measures construction costs and contigent other mitigation measures) is analysed with a costs-benefits analysis as decision making tool. Obviously if the realisation of the mitigation measures does not return a benefit amount adequate to justify the mitigation measures costs, then the baseline scenario will be prefered between the two. For example, the fourth of the five hipothezised potential mitigation scenarios is based in four interventions: new embankment of 1390 meters on the right river bank to protect the urbanised area of Viddalba, demolition of the old bridge along SP146 road near Viddalba and demolition of the bridge along the SP90 roads (Valledoria), improvement and new realization of embankment for a length of 11101 meters on the left river bank in order to protect the urbanised areas of Santa Maria Coghinas and Valledoria. At this point the four interventions are applied on the hydraulic model developed for Coghinas river lowland valley path and the economic assessment has been re-run with the scenario mitigation measures. A cross check on the total economic damage obtained from the simulation underlines a huge improvement considering the simulations related at the floodplain area of 200 years, in fact the flood damage decreases by 71 Mln € to around 37 Mln €, *Table 3*. The Figure 5 shows the achievement of the target.

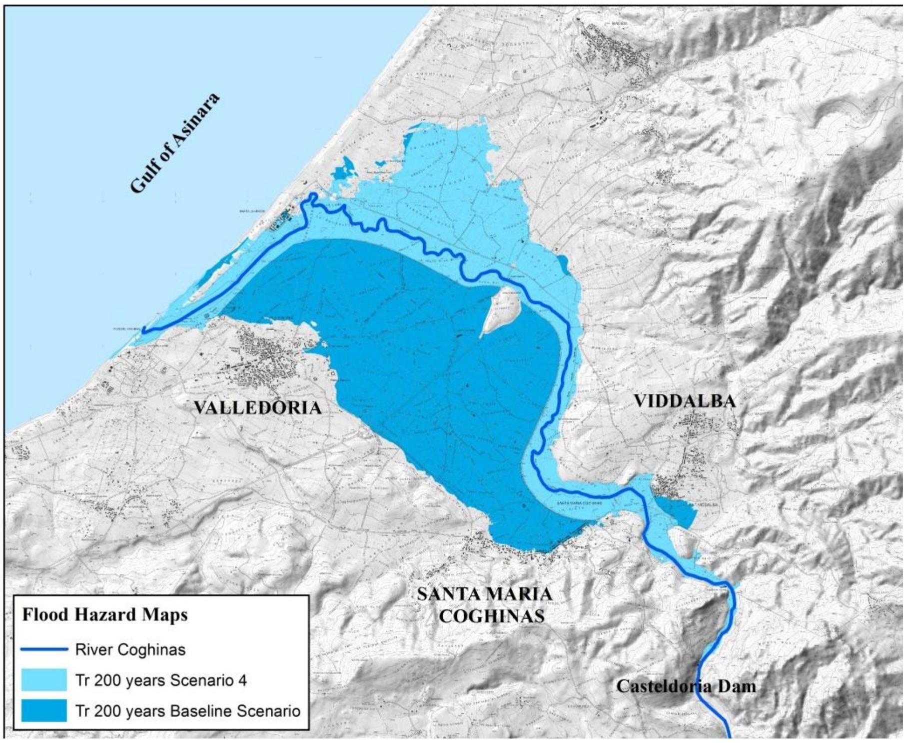

Figure 5 Flood Maps of the Coghinas river lowland valley sub-basin at 200 years of return period and the related mitigation scenario

Table 3 Results Comparison between Coghinas baseline scenario at 200 years of return period and the related mitigation scenario

Label Land-Use Category	Baseline Scenario		Mitigation Measure Scenario	
	Area (m^2)	Damage (€)	Area (m^2)	Damage (€)
A	13'319'222	6'019'251	4’396’981	2'634’604
C	42'396	10'304'961	19’359	7'956’705
I	73'184	10'950'897	11’983	3'843’127
J	2'119'113	-	2'616’783	-
K	40'014	-	34’736	-
N	45'786	232'406	28’629	252’514
P	111'261	1'137'800	23’967	291’544
R	148'135	37'856'384	58’371	19'842’025
T	220'499	4'504'593	80’929	2'742’693
X	673'836	-	648’948	-
Total	16'793'446	71'006'292	7'920’688	37'563’213

4. EMERGENCY MANAGEMENT AND MITIGATION MEASURES

The Civil Protection Agency is the qualified public utility to manage the flood emergency when this happens. The synergy planning tools to reach the Flood Risk Management Plan aims to avoid negative consequences for human health, goods, environment, cultural heritage and related social and economic activity and requires a strong connession between planning, prevention and prepardeness processes after the potential disasters and the emergency management at the moment of the calamity. The achievement of these targets is managed by the Civil Protection Agency in order to educate the populations and supervise the potential emergency situations. One imporant intervention organised by the Civil Protection Agency consists on the redaction and update of a website platform, “Floodcat”, where previous flood important events had been recorded. The Alert Operating Instructions for Civil Protection Agency includes the Regional Dam Framework and related reconnaissance “Flood Lamination Plans”. To take under control every potential flood risk, each Sardinian council have to update their own maps and fill a prearranged synthetic sheet about the local emergency plans, on a specific platform “ZeroGIS”, to appraise the Civil Protection Agency about the actual emergency plan situation. In addition the Authorities are making plans to improve the Regional alert system, rain gauge and hydrometric stations network.

The prepardeness on flood risk management had been recently carachterised by structural flood mitigation measures. The last years have been stage of a changed way of thinking that is focalised on non-structural measures, renovation of the existing mitigation structures and reconnaissance of the mitigation measures in construcion or on in pending approval. All these aspects turns on a better management of flood decrease risk and prepardeness of Sardinian Authorities. Moreover the Flood Risk Management Plan considers as non-structural measures some already defined in terms emergency plans, social dissemination with meeting time-tables, reconnaissence and update defined plans. A strategic position is given at the costs-benefits tools in order to support Regional Stakeholders to determine which of the potential mitigation scenarios, described for each Sardinian basin, is the most useful and later make the best economic planning for subsidise structural mitigation measures.

5. CONCLUSIONS

The paper aims to illustrate the framework development of Flood Risk Management Plan for the Sardinian Region, coherently with the requests of the Flood Directive 2007/60/EC. Since every Hydrographic District Basin of the European territory are arranging their own Flood Risk Management Plan, it can be very useful to give a comparison on how different plans and related methodology of structural and non-structural mitigation measures settlement have been taken into account. The Sardinian Flood Risk Management Plan bases the mitigation measures on the Flood Risk Maps information conveniently processed. The analysis on the land use maps and their cross-checked and related flood hazard maps allow the Sardinian Hydrographic District Authority to focalise attention on areas subjected at the highest flood risk. Moreover, the decision support tool helps the Authorities in charge in the arrangement of mitigation measures list steered by the flood risk level. In the non-structural measures are counted the potential mitigation measure developed for each of the Sardinian basins. The provision of these potential scenarios and the comparison of their costs and benefits, obtained using a Costs-Benefits Analysis, is one of the most important tools to induce the Sardinian Regional Authorities to dispose public financing and improve the mitigation measures settlement.

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