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Economic evaluation of flood damages and identification of priorities defining mitigation measures actions

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University of Cagliari

REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA

HR Wallingford
Working with water

ABSTRACT

Flood risk is one of the most important topics under study of international researches usually associated at climate changes and unrestrained urbanisation resulting in a strong instability of weather conditions that require a better control and forecast of climate trends and land use. A glance on current disasters around the world shows the relevance of flood risk and a continuous adjournment guarantees the awareness of the population about the dangerousness of flood effects.

The analysis of potential floods shows several and different types of flood that could be grouped mainly in flash flood, fluvial flooding, coastal flooding and urban flooding. The most part of damages caused by these floods are linked with gaps on urban regulations that allow the realisation of built-up areas on unstable land as reclaimed lagoon, banks river area that create river path diversions, on coastal area as dunes or close to beaches, or even along river paths used to discharge volume of dams when the water level is close to the acceptable maximum level. Even though the improvement on technology, the impossibility to predict accurately weather conditions and the consequent uncertainty are worsening the situation of areas usually under flood risk.

The deepened analysis conducted on flood event registered in the globe underlines the necessity to enhance the management of the flood risk forecasting the disasters and modelling potential scenarios with adequate hydrologic and hydraulic models in order to ensure right depicting of flood process development. The modelling of results as flow rate, water depth and flow velocity is fundamental to get hazard and risk flood maps that act as a springboard on a success predisposition of flood risk management plans.

In fact, in the flood risk management plans, the identification of flood hazard and flood risk maps are used to define mitigation measures, usually divided in two main groups: structural and no-structural measures. The choice on the activation of structural and no-structural mitigation measures is mainly based on financial availability, time-step in measure realization, stakeholders preferences and government authority decisions. The considerable costs in realisation of mitigation measure is usually shore up by costs-benefits analysis methodologies that represent a relevant support tool for decision makers.

This research project is focused on the definition and implementation of methodologies to evaluate potential flood damage of a baseline scenario and to support definition of mitigation measure scenarios. The work aims to identify the magnitude of the flood in terms of potential damages assessed considering the two main categorises of tangible and intangible damages.

The flood damage evaluation is, herein, conducted with methodologies that allowed an economic appreciation of the damage and implementation of models able to evaluate the potential number of fatalities and injuries due to flood meant as intangible damages reducible with efficient warning and evacuation issuances of flood emergency plans. These methodologies include different fields of research as hydrologic, hydraulic, agrarian, social, geological and political subjected at relevant uncertainties data included on the study.

As asserted above, the damage reduction could be obtained implementing no-structural mitigation measures as the predisposition of flood damage management plans that should include rules and tasks proper of flood emergency plans. The observation of recent floods reveals that a correct preparedness of population and authorities about flood emergency gives rise to a relevant decrease of damages and in particular of victims and wounded. In fact, the civil protection actions are significant in the emergency management to prevent damages so much to require the development of a second aim in this project focused on the identification of proper warning and evacuation time issuance disseminated by the civil protection and local authorities as result of a monitored climate conditions and management of people moves towards safe haven.

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Introduction

Flooding disasters occurring every year in many countries in the globe have led the Governments to deal with consequent critical conditions and flood risk assessment resulted to be an essential component of natural disaster management (Flores I., 2013).
A flood is identified as a hazard that bring misery to those that live in affected areas determining loss of life and great disruption of daily life. The water spread by the flood could come into houses, causing break down of drinking water, electricity and telecommunication supplies, road can be blocked, people cannot go to work or to school (FLOODsite Consortium, 2009). An extreme natural event becomes a disaster when it has a large impact on human settlements and activities (Genovese E., 2006) and the post-flood situation is usually characteristed by long-lasting effects leaving the countries in critical conditions where people have to tackle with losses of goods or grieve the loss of dears.
Flood risks cannot be completely eliminated and Governments are supported in reaching targets for flood risk management by the development of methods to estimate the risks to people, as well as risks to economic and environmental damage (Wade S., 2005).

Currently, in the Mediterranean regions, flash flooding is the most common type of inundation, since the majority of flood events are induced by intense rainfall that occurs in short time periods and quickly reaches an impressive flow rate (Pistrika A., 2014). In addition to climatic changes, nowadays movement of people from rural areas to cities is increasing the level of urbanization, and consequently emergency or disaster management plans are necessary for preparation, support, and reconstruction when natural or man-made disasters occur (Price R.K and Vojinovic Z., 2008). The European Commission, National government, Regional and County Authorities tackle these problems with proper flood directives and flood protection policies that study and manage the territory and river systems. In fact, the directives require the definition of flood risk management plan viewed as a process that involves three different set of actions depending on the aims and involved operators. 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 to the changed conditions. Finally, the planning process step leads to decisions regarding the structural mitigation measures supported by an optimum design (Plate E.J., 2002), justifying relevant aspects such as the costs and benefits achievable by analysing mitigation measures (European Commission, 2007). All previous aspects are embedded in the implementation scheme of the Flood Directive 2007/60/EC aiming to prevent the risk in the European territory. The definition of the concept of risk, as a combination of flood hazard and flood consequences, and the way in which risk is calculated should ideally be performed starting from the preliminary flood risk assessment, followed by the mapping of hazards and risks, and finishing with 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 three main reports: 1) the preliminary flood risk assessment plan; 2) the achievement of flood hazard maps and flood risk maps; 3) the settlement of the Flood Risk Management Plans, FRMP.

In the implementation of real cases, different methods will be used depending on the scale and level of detail of the assessments (Raymaekers F. et al., 2012). The required second step of the Flood Directive is one of the most important aspects, as maps are instruments not only for defining and communicating flood risks but also for regulating territory usage by rationalizing the inevitable limits and failures of controls (Demeritt D. And Porter J., 2012) and facilitating awareness of the potentially affected floodplain areas. The resulting water depth maps are, in fact, the launch pads to start the flood assessment and the estimation of potential flood damages (Frongia S. et al., 2015b). 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 adaptable to changing levels of flood risk (Demeritt D. And Porter J., 2012). Especially because of the lack of infrastructure for controlling floods, the need of education on flood risks and related misunderstandings, the third step, the Flood Risk Management Plan, holds a relevant position in the Flood Directive 2007/60/EC.

Significant is the definition of the damage categorisation that at international scale is categorised in the two classes of tangible and intangible damage. In detail, the categorisation of the damage in tangible type requires the definition of an economic value associable at the losses of elements. International researches differ among many options that could be summarised as identification of market prices, benefit transfer, replacement costs, willingness to pay by authorities and communities (MCM Model, 2005). Alternatively, the intangible damage is defined as the damage related to elements whose monetary value is not easy to quantify. Both tangible and intangible damage categories are split in the two classes of direct and indirect damages. In case of flood the direct damage

occurs with a direct contact between the water and the element, while the indirect damage is a consequence of the direct damage.
The tangible damage which requires a conversion in terms of quantitative amount could be identify as parameter of the order of magnitude of potential flooding disaster. Even though, the intangible damage evaluation is still under analysis and the loss of life caused by the flood event could be considered as type of direct intangible damage for which an economic evaluation method can be to carry out by an analysis of flood insurance, which has recently increased (Penning-Rowsell E. C., 2014). An example of indirect intangible flood damage could be the trauma caused by losses after flood events. Because of the uncertainty of many aspects on the economic evaluation of flood damages, the economic assessment linked with the tangible flood damage is the one of the main field under study in this research.

In addition, in the FRMP is underlined the necessity to use a rational decision-making tool defining specific mitigation systems in terms of new works and rules, then a cost–benefit analysis make it possible identifying which of the available solutions could be considered the best in economic terms. This step should be supported by the appreciation and evaluation of the damage that a potential flood scenario could cause.
A deepened study on flood damage assessment background underlines the importance of water depth–damage functions as one of the elements of the decision-making tool obtained to evaluate the amount of economic damage and to help authorities and stakeholders in making financing decisions (Pistrika A., 2014) (Scorzini A.R., 2013) (Merz B., 2004). In fact, stage-damage relationships are one of the fundamental pieces of information upon which decisions concerning the expenditure of large sums of money for flood control are base (Appelbaum S.J. and A.M. ASCE, 1985). Unless stage-damage functions do not rely on information from an actual flood event, they are based on hypothetical analysis for differing land use (Smith DI., 1994).

Seven of the most used models for the tangible damage evaluation are described by Jongman B. et al. (2012): FLEMO, Damage Scanner, Rhine Atlas, Flemish Model, Multi-Coloured Manual (MCM), HAZUS-MH, and the JRC model. These models assess the direct tangible flood damage in function of the flood water depth as hydraulic parameter. According to the majority of researches, the most common hydraulic variable used to develop the flood-damage analysis is the water depth, although flooding is a complex process determined by a large number of hydraulic, environmental, and socio-economic

factors that should be used analysing the flood risk to better understand the flood spread in the territory (Jongman B. et al., 2012) (Smith DI, 1994).
In addition, the identification of a proper methodology for indirect tangible damage appreciation led to evaluate it as a percentage of the direct tangible damage as asserted in the JRC Report. This advice has been coupled with the MCM handbook observation that identify the flood emergency and support services costs equal to 10.7 % of the direct tangible damages (Huizinga H.J., 2007) (MCM Model, 2005). Indirect tangible damages consider type of damages that impede the regular daily conditions of public services and people lives. These aspects led the research to evaluate the total indirect damage as the 30% of the direct tangible damage including post-flood event costs related with immediate emergency condition to restablish regular daily works and people support services.

The most important loss due to flood are the number of victims. The number of fatalities registered in Sardinian after the flood events of the 22nd October 2008 and the 18th November 2013 induced the research to identify a methodology for the evaluation of the potential number of victims (Frongia S. et al., 2016b). For this reason, the implementation of the software Life Safety Model (LSM) represents a relevant step on the project improvement. LSM studies the dynamic interactions among people, vehicles, buildings with the flood wave and assesses potential flood damages supporting the predisposition of Flood Evacuation Plan in case of an emergency identifying also evacuation routes adopted by people and vehicles to reach safe locations. This enables emergency managers to avoid evacuation bottleneck problems and identify areas of potential high mortality where the flood acts with high velocities or deep water levels. The impact of changes on baseline scenarios such as road network improvements and proper location of safe havens in the territory with accurate timing of flood warnings can be assessed in terms of potential loss of life reduction. In fact, efficient flood warning system usually results in significantly lower damage and loss values (MCM Model, 2005).

Type of flood

A first step on the flood damages analysis consists on the identification of the different type of flood occurred and registered so far by international research. The Federal Emergency Management Agency (FEMA), agency of the United States Department of Homeland Security, identifies different types of floods unless communities experience only few of them grouped in: riverine flooding, urban drainage, ground failures, fluctuating lake levels and coastal flooding linked with consequent erosion (FEMA). The FLOODsite project confirms these groups of flood types and adds at the riverine floods the flash flood type (FLOODsite Consortium, 2009).

Riverine or fluvial floods are usually governed by terrain and rainfall characteristics. In general, hilly and mountain areas are described by significant slopes and when they are coupled with intense rainfall give back copius flow rate discharges that could determine overflow of the river banks. The river bank overflow depends by the river bed dimensions and by the rainfall duration. In fact, fluvial floods could occur with excessive rainfall in extended period of time determing the excess of the river capacity that could be worsen by heavy snow melt and ice jams. In the last two decades fluvial floods occur because of flash floods determined by rains that happen in short time with intense and sudden rainfalls. Flash Floods are able to produce damages more severe than the ordinary riverine floods because of the speed with which flooding occurs and the high velocity of the water usually associated at debris flood, landslides and mudslide flooding due to territory subjected at fire emergency or drought conditions (FEMA) (FLOODsite Consortium, 2009).

Coastal flooding occur when the coast is flooded by the sea characterised by surges caused by severe storm usually formed in low pressure areas. The coastal flood results in waves that move to inland on an undefended coast or overtop or breach the coastal defence works like dunes and dikes. Depending upon local topography, a storm surge may inundate only a small areas or may inundate coastal lands for a mile or more inland from the shoreline. Storm surge is usually estimated by subtracting the regular/astrological tide level from the observed storm tide. In addition to storm surge, wave action is an important aspect of coastal storms consisting of wave set-up and wave run-up actions, where wave set-up is the superelevation of the water surface over normal surge elevation and is caused by onshore mass transport of the water by wave action alone, while wave run-up is the action of a wave after it breaks and the water "runs up" the shoreline or other obstacle, flooding areas not reached by the storm surge itself. Coastal flood could be associated at erosion actions especially when storms generate large waves (FEMA) (FLOODsite Consortium, 2009).

Urban flood could be the result of few types of flood as riverine, coastal, flash flood or even drainage flood when the cause is a lack of drainage in an urban area due to a uncorrect evaluation of potential rainfall or because of the unexpected rainfall discharged that determine a inadequacy on the urban drainage and sewage systems to ensure regular water flows (FEMA) (FLOODsite Consortium, 2009).

Flood Risk Legal Framework

The attention of the present research follows European Community regulation defined with the Flood Directive 2007/60/EC who requires the predisposition of Flood Risk Management Plans (FRMP) for each hydrographic district basin of the European territory. The Water Directive 2000/60/EC required the division of the European territory in hydrographic district basins. Sardinian Region consists of a unique hydrographic district basin for the regional territory.

The main aim required in the FRMP is the improvement of the knowledge and preparedness in case of flood events to avoid negative consequences for healthy conditions for human beings, territory, and environmental, historical, and architectural heritage and, at the same time, to enhance business safety and social activities (Flood Directive 2007/60). According to the main features of Hydrographic Districts, a shortlist of structural and 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., guidelines, institutional agreements, dissemination of knowledge, community involvement, etc.) are also focused on the flood management in terms of emergency planning.

A partnership between the Hydrographic District Authority and the Civil Protection Agency in Sardinian territory has been formed to carry out these improvements.

In fact, the proposed regional FRMP scheme (RAS-UNICA, 2013) consists of 10 sections starting with the European and national institutional policies framework to stress the main aims of the plan. FRMP defines the potential mitigation measures and reconnaissance actions, paying attention to flow rates, evaluated floodplains, stream ways, potential natural expansion of flood-prone areas, and environmental, land-use, and water resources management, as highlighted in the national law DL 152/2006. All of the specified points would be coupled with solid support for strategic actions (prevision, monitoring, alert, etc.). Moreover, the dissemination actions are focused on the training of the local councils and, moreover, of every inhabitant in the flood-prone areas. The Sardinian Hydrographic District Authority has activated an information distribution chain defined by informative material, weekly stakeholder meetings, training meetings, and applications for smartphones and PCs. The flood risk preparedness action will be supported by a dissemination action that include the realization of a website through which citizens can improve their knowledge of flood risk management especially in case of emergency.

In defining the FRMP, the results given by previous studies need to be considered. One of the main Sardinian management plan preventing flood event is the Hydrogeological System Plan (Piano di Assetto Idrogeologico – PAI) developed aiming at the preservation, protection, and enhancement of the territory against hydrogeological risk. That plan is continuously updated in terms of the hydrogeological risk maps, identifying their boundaries and the part of the territory in which land-uses restrictions and structural and non-structural mitigation measures can be applied. The potential hydraulic or geological risks are defined at four levels with values between one and four, increasing proportionally with the risk increment. Another previous study has been also considered setting Fluvial-Zones Definition Plans (PSFF). The PSFF plan divided the regional area of 24100 km^2 into seven river systems characterised by 58 main water streams with a total length of 1120 km and 226 secondary streams with a total length of 2030 km. The PSFF flood hazard maps even provide a basis to identify the areas under flood risk and to start the following FRMP. The extensions of flood hazard areas are given considering five hydrological scenarios of flood-event with return-time (Tr) of 2, 50, 100, 200, and 500 years. Subsequently, the FRMP works on hydrologic information provided by the PSFF, aiming to make potential flood damage maps, flood risk maps, and planning mitigation measures available for the flood hazard territories according with the regulation to protect environmental heritages.

Regarding people's safety, the Civil Protection Agency established the regional alert procedures in case of meteorological, hydrological, and hydraulic risk by providing the Alert Operating Instructions (RAS- Civil Protection, 2014). The alert signal consists of four different phases increasing from "regular critical situation" to "high risk". The alert signals provide gradual management of the operations that should be achieved from when the risk starts until it reaches emergency status and the consequent risk management scheme. In addition, for each risk level, the Operating Civil Protection Instructions also define the required resources and authorities involved at each risk level. The Alert Operating Instruction of the Civil Protection have been deeply analysed in the present research to implement the given regulation on potential flood emergency plan.

Motivation and objective of thesis

The PhD project started parallel with the collaboration between the DICAAR Department of UNICA and the Hydrographic District Authority of the Sardinian Region addressed to define the Regional Flood Risk Management Plan. The analysis of the requirement defined in the Italian legislation (D.L. February 23rd, 2010 n. 49) and European Flood Directive (Dir. 2007/60/EC) underlined the necessity to identify proper methodologies for the appreciation of costs and benefits related to flood mitigation measures involved in the Flood Management. Moreover, the Flood Directive attention on people preparedness in case of emergency underlines the issue to organise a potential management of the receptors in the territory to reduce potential losses in case of flood.

In particular, point 3 in the Article 7 of the Chapter IV, of Dir. 2007/60/EC - ‘Flood Risk Management Plans’- asserts that “Flood risk management plans shall take into account relevant aspects such costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure”. The identification of costs and benefits due to flood event should be supported by a flood damage analysis that gives an evaluation of the amount of damage in quantitative terms, both for strictly economically terms and not. This requirement led this research project to accurately analyse recent international studies and developments on flood risk damages evaluations. Main aims of this research can be then summarized in developing activities in order to get documentation on the available methodologies, confirming their correspondence to Flood Directive requirements in terms of flood event description (water depth, flow velocity, flood rate, flood extension) and planning requirements, and specifically, in developing methodologies in order to asserts that Flood risk management plans will take into account most relevant aspects in population protection, correct use of the territory and heritages and environment protection.

Moreover, point 3 of the Article 7 of Flood Directive requires that “Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basins, flood risk management plans may also include the promotion of sustainable land use practises, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event". Because of this, the last part of this research is focused on the investigation of the predisposition of an accurate early warning systems and people evacuation plan. People, building and infrastructures distribution in the territory is preliminary investigated in order to identify their interaction with the flood when it occurs. The research is focused to pinpoint proper evacuation routes and sites to be set as shelter points after the flood alert. The predisposition of an accurate early warning systems, supported by controlled weather forecast systems, is a basic support for the Civil Protection agencies ensuring population preparedness for an efficient flood-victims prevention action.

Outline of the thesis

The PhD thesis sums up three parts consisting of necessary steps to identify and analyse the recognizable flood damage. These three main steps of the project could be briefly summarised with the key concepts of 'categorisation', 'evaluation methodologies' and 'study case', Figure 1.

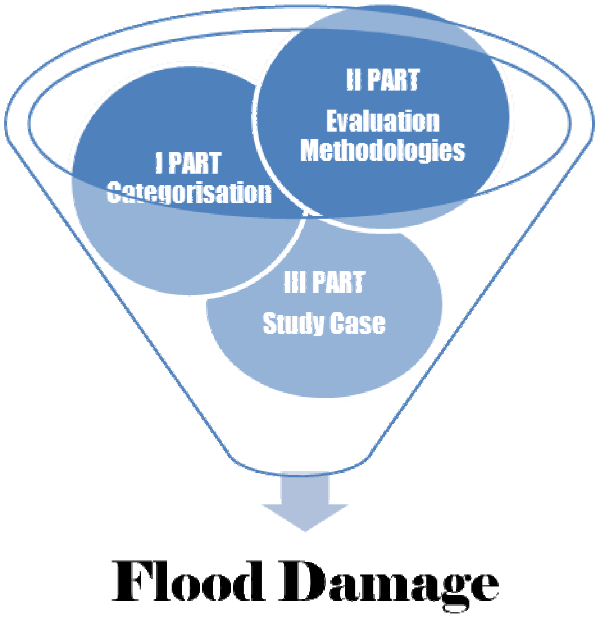


Figure 1. PhD Thesis Main Outline

In particular, the first part, "Damage Categorisation", explains the concept of flood damage as outlined according in the international researches. The categorisation of the flood damage considers the possibility to convert the damage in economic terms and should be grouped considering the element potentially damaged, Figure 2.

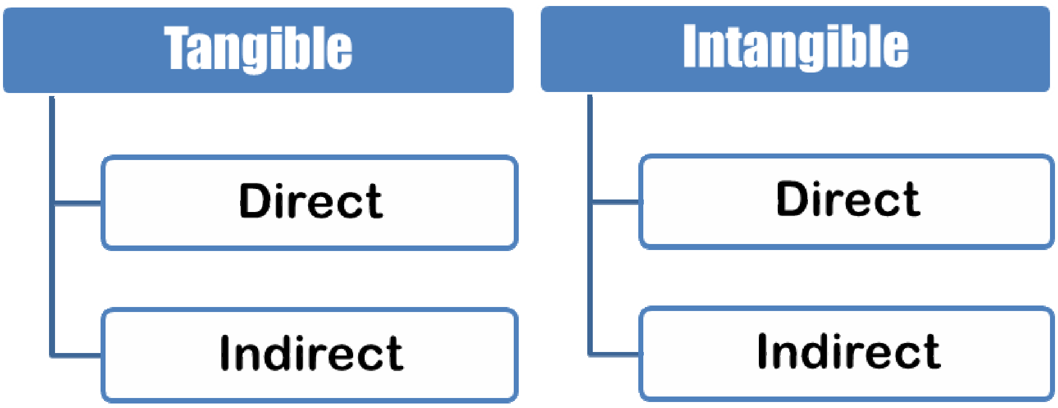


Figure 2. Flood Damage Categorisation

The second part, "Evaluation methodologies", identifies the available methodologies at international scale of research for the flood damage evaluation. That part of the dissertation describes in detail which of the considered methodologies turn out to be implementable and applicable in European areas underlining relevant properties of each model especially as support for decision-makers and improvement of flood mitigation measures, as drafted in Figure 3.

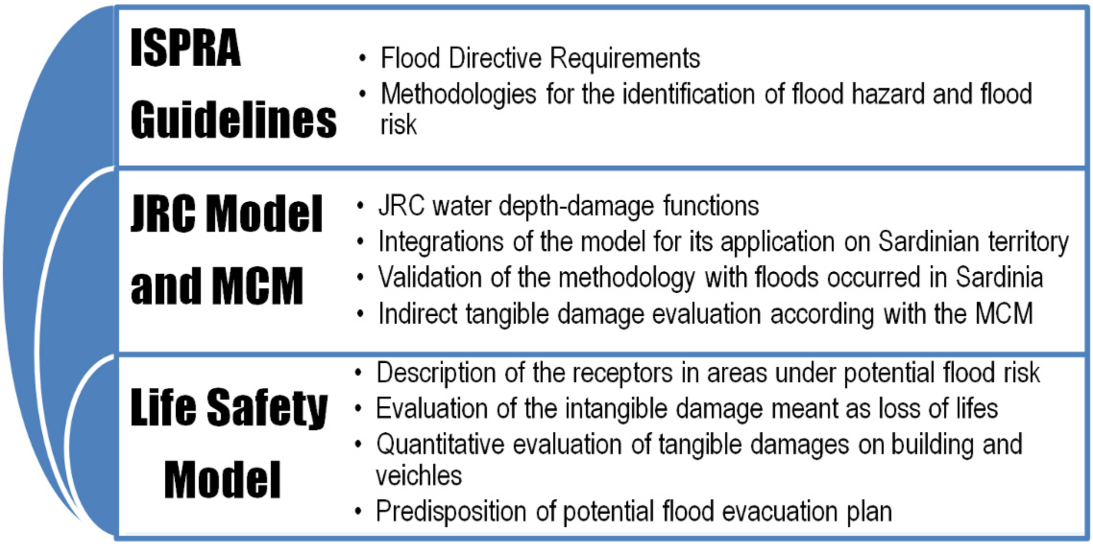


Figure 3. Flood damage evaluation methodologies

The third part of the research, "Study Case", shows how the chosen methodologies could be implemented in the study case. The study case considers a basin located in Sardinia, Italy. Firstly, the analysis illustrates the basin features. Subsequently, the available regional hydraulic models developed on the pilot basin have been described and new hydraulic models have been studied to deeply analyse the case. These studies are the base for the damage evaluation and for the predisposition of an adequate emergency plan applying the models described in the second part of the research project, as drafted in Figure 4.

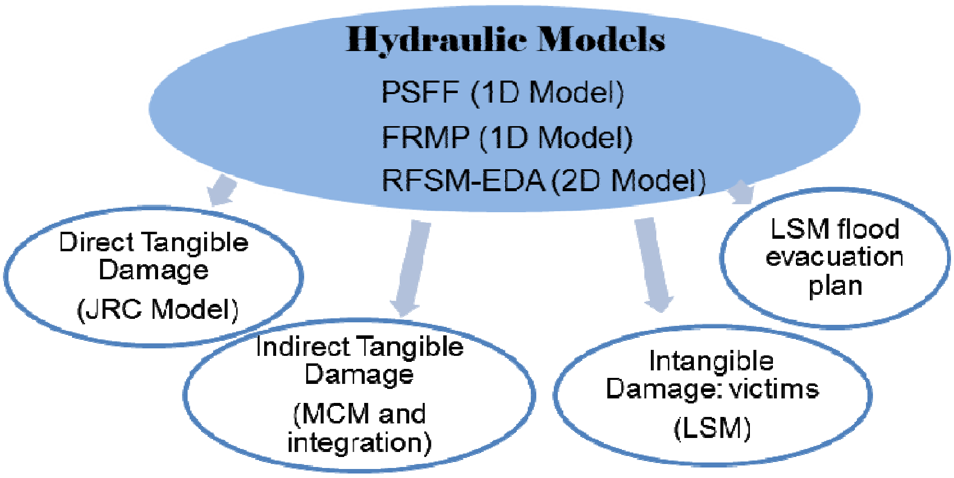


Figure 4. Phase of the damage evaluation of the study case

1. Flood Damage Typology

The process of flood damage assessment aims to identify consequent benefits deriving from flood damage reduction through mitigation measures implementation. The flood analysis requires the identification of the type of damages and how they occur. That step of the analysis should be considered as base on the flood damage evaluation and should be supported by the definition of the damageable element allocated in the area under potential risk.

The research developed so far does not always allow an economic evaluation of the damage because of the complexity related with its conversion in monetary terms. Consequently the damage is usually defined in the two classes of “tangible” or “intangible” damage when, respectively, an economic evaluation of the loss is possible. Each class of damage is then divided in other two groups identified as direct and indirect damage considering if it is caused, respectively, by the direct contact of the water with goods or if it is a consequence.

In the Multi Coloured Manual Handbook a complete description of each class of damage has been provided (MCM Model, 2005). In Chapter 3 of the MCM Handbook different types of damages are described in detail. The authors claim that direct damages result from the physical contact of the flood water with damageable property and its contents. The losses of items because of flood depends by the nature and extention of the flooding, including its duration, velocity and the contamination of flood waters by sewage and other contaminants. These affect damages and losses, while the location of the flood will affect the network and social activities disrupted causing indirect losses (MCM Model, 2005). Table 1-1 reports the summary of the type of flood damage mentioned in the MCM Handbook giving examples of each class. The flood damage analysis should consider effects on properties not directly damaged as telecommunications, roads and rail traffic disruption occurred many kilometers from the flood plain, as a flood can cause disruption to those communication and economic linkages and that disruption ‘spills over’ to communication links not themeselves flooded (MCM Model, 2005).

		Measurement	
		Tangible	Intangible (i.e. difficult to quantify)
Form of loss	Direct	Damage to building and contents	Loss of an archaeological site
	Indirect	Loss of industrial production	Inconvenience of post-flood recovery

Table 1-1. Direct, indirect, tangible and intangible flood impacts (MCM Handbook (MCM Model, 2005))

The research developed by the Middlesex University and shown in the MCM Handbook consists of different methodologies suggested for the flood damage assessment based on damaged elements as residential properties, non-residential properties, road disruption, emergency costs, assessing of agriculture and environmental potential costs due to damages and mitigation measures, but it considers also intangible damages related at losses on population affected by flood. Examples of potential type of damages are reported more in detail in Table 1-2.

Direct tangible losses for flooded households	Intangible losses for flooded households	Indirect losses for flooded households (summary)	Indirect losses for non-flooded households
Damage to building fabric; Damage to household inventory items; Clean-up costs.	Worry about future flooding; loss of memorabilia and irreplaceable items and pets; Damage to physical and/or mental health, death or injury; Loss of community; Loss of confidence in authorities and services	Permanent evacuation; Evacuation costs; Disruption due to flood warnings or alarms: Loss of utility services; Loss of income; Loss of leisure and recreational opportunities; Additional communication costs; Increased travel costs	Increased travel costs; Loss of income/earnings; Loss of utility services; Loss of other services; Loss of leisure and recreational opportunities; Increased cost of shopping and recreational opportunities

Table 1-2.The range of possible flood impacts on households (MCM Handbook (MCM Model, 2005))

In the MCM Handbook flood damage to non-residential properties are broken down in five components of damage meant as building structure and fabric, services, fixtures and fittings, moveable equipment, and stock/raw materials in order to identify possible direct and indirect tangible damage. The additional costs related to disruption of road traffic is analysed considering vehicle time costs and resources costs due to limits on vehicle's speed. These aspects should be evaluate taking into account which roads would be cut by floods and their volume of traffic, but also possible diversion routes that could increase the time commuting.

Potential flood losses on agriculture land are mainly identified as direct tangible damages. When the territory is characterised by absence of flood defence due to impossibility of their realisation or the cost could be excessive, the MCM Model suggests to estimate economic losses in terms of likely reduction in the value of the agriculture land establishing the impact of flooding regimes on these agriculture productivity. This damage evaluation process requires the definition of type of agriculture as arable crops or grassland related with the number of livestocks.

Moreover, the MCM Handbook includes potential costs determined by a flood as emergency costs represented by police, fire and ambulance service costs, local authority costs and environmental agency costs. These additional costs have been quantified at 10.7% of property damages and considered as indirect tangible damages.
More difficult is the evaluation of intangible damages. MCM Handbook considers a potential intangible loss caused by coastal erosion as the damage that could determine the losses of future uses of land, properties or, considering Sardinian case, the impossibility to benefit of beaches and environmental protected areas subjected every year at relevant tourism. Moreover, it is relevant the potential loss of recreational areas evaluable in function of local visitors, day visitors and staying visitors who benefit of enjoyment of landscape, wildlife and natural amenities.
The most important type of direct intangible damage is the identification and, threrefore, reduction of loss of life, field that is mainly under consideration by international research.The economic appreciation of the loss of life is not still reliable considering the relevant importance of this damage. But, the prevision of the number of victims due to flood is a complex research topic that should be improved coupling the study with a accurate emergency management. In fact, as asserted by Price R.K and Vojinovic Z., climate change increases the unpredictability of the flood events and the current trend of people moving from rural areas to cities increases urbanization and, as a consequences, an emergency or disaster management plan is necessary in terms of preparation, support and reconstruction when natural or man-made disasters occur (Vojinovic Z. and Price R.K., 2008). The main factors that affect death or injury to people during floods include flow velocity, flow depth, and the degree to which people are exposed to the flood. The potential exposure of people to the flood is related to such factors as the ‘suddenness’ of flooding and amount of flood warning, the extent of the floodplain, people’s location on the floodplain, and the characteristics of their accommodation. In addition, potential risks to people are affected by social factors including their vulnerability and behaviour (MCM Model, 2005) (Wade S., 2005) and consequent stress and anxiety conditions could worsen the situation when flood is occurring (Nascimento N. et al., 2006).
Models for the loss of life estimation have been developed considering the relation between people, structure distribution and their interaction with the flood development, ususally implemented as two-dimensional models in order to identify the receptor conditions during the increase of the emergency situation and their reactions when reached by the flood wave. One of these models is Life Safety Model (LSM), a detailed micro-modelling tool that can aid in assessing risk to people and evacuation times from a range of

flood events. It has been firstly developed by BC Hydro and now it is in improvement at HR Wallingford Ltd (Lumbroso D. et al., 2010). Moreover, the United States Army Corps of Engineers (USACE) developed HEC-FIA a stand-alone, GIS-enable model for estimating flood impacts due to a specific flood event and to calculate how much time is required for evacuation and determine the effect of traffic management during the evacuation process on the required evacuation time (Lehman W. and Needham J.) (Jason T.). Another model for estimating and reducing life-loss is LIFESim, a modular, spatially-distributed, dynamic simulation system useful evaluating potential victims in case of flood due to dam and levee failure sponsored by the USACE and Australian National Committee on Large Dams (ANCOLD) (Aboelata M. and Bowles D., 2008).

The intangible damage evaluation could be overpass by methodologies as WTP, shows prices, consumer surplus, edonic models of contingent valuation that allow an economic evaluation of the damage including the damage categories in the tangible class based in particular on the willingness to pay to reduce the damage or a refund of the damage.

In the category of indirect intangible damage could be included the trauma left by the flood damage as the worry about future flooding, loss of memorabilia and irreplaceable items and pets, damage to mental health due to death or injury, loss of confidence in authorities and services. These damages require a more deep analysis that should be supported by psychological consultation sessions.

The identification and evaluation of flood damage, as asserted above, is the first step for a costs-benefits analysis interpreted as relevant tool to support stakeholder of flood risk management. The costs-benefits analysis results the base in the mitigation measures decision and do-nothing scenarios that should be supported by an accurate pre-feasibility study stage (MCM Model, 2005).

2. Flood Damage Evaluation Methodologies

The subdivision of the damage in the two classes of tangible and intangible damage results at international scale of analysis in two different classes of flood damage assessment methodologies. The choice of the methodology for the flood damage evaluation differs widely considering the elements under risk and the hydraulic parameters involved describing the flood development and, conveniently, evaluable with hydraulic models.
B. Jongman et al. consider the evaluation of the direct tangible damage in the "Comparative flood damage model assessment: towards the European approach" affirming that there is a wide variety of flood damage models in use internationally and they differ substantially in their approaches and economic estimates (Jongman B. et al., 2012). The Jongman B. et al. dealt with uncertainty involved on the use of flood damage models useful for investments decisions and aim to develop an harmonised European approach with respect to the EU Flood Risk Directive analysing qualitatively and quantitatively seven flood damage models (Jongman B. et al., 2012). The analysed seven damage models are: FLEMO (Germany), Damage Scanner (The Netherlands), Rhine Atlas (Rhine basin), the Flemish Model (Belgium), Multi-Coloured Manual (United Kingdom), HAZUS-MH (United States) and the JRC Model (European Commission/HKV). All of these models consider the water depth as hydraulic parameter for the flood damage evaluation and are assessed on the three main aspects of scale of application, input data and damage calculations.
The most part of the researches, identified so far, evaluate the indirect tangible damage as aliquot of the direct component of the direct tangible damage. In particular, the attention on the available model used for the indirect tangible damage evaluation is focused on the Multi Colour Manual developed by the Middlesex University (MCM Model, 2005). The MCM Handbook summarises the flood damage approach described in detail in the Multi-Colour Manual intended to support a costs-benefits analysis on the identification of plans and scheme required in the risk management. This methodology underlines the importance of value definition asserting that "the value of some 'good' is given by the individual and reflects his or her subjective preference for that 'good' represented by any commodity, resource or item which an individual prefers or desires reflecting the relative contribution that this good makes to an individual's 'utility' or wellbeing" (MCM Model, 2005).
An overview on recent law regulation shows the relevance of the Flood Risk Directive 2007/60/EC that manage the flood risk at European scale of analysis and that has been implemented in Italy with the LD 49/2010. In short, the flood regulations raised

requirements for the development of three significant reports: Preliminary Flood Risk Assessment; Flood Hazard Maps and Flood Risk Maps definition; Flood Risk Management Plans. Requirements of each report have been analysed to identify in the international research which guidelines, software and methodologies could be helpful on the goals achievement.

At Italian national scale of detail, The Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA, supplied in 2012 the report n° 82 titled "Proposta metodologica per l'aggiornamento delle mappe di pericolosità e di rischio". Attuazione della direttiva 2007/60/CE relativa alla valutazione e alla gestione dei rischi da alluvione (49/2010)" herein named "ISPRA Guidelines" and are focused on flood risk management.

ISPRA Guidelines consists of two main parts. The first part underlines fulfilment of duties required at each hydrographic district basins, while in the second part models and methodologies have been proposed to define potential method of flood analysis and description of hazard and risk (ISPRA, 2012).

The research of methodologies for the flood damage evaluation identified in the JRC Model a potential method for the appreciation of the direct tangible damage. That model has been chosen, firstly, because commissioned and accepted by the JRC Institute of Environmental and Sustainability, Research centre of the European Community, and secondly due to its results obtained through the accurate analysis of collected data of flood event around the European territory to define water depth-damage functions applicable to each European Country thanks to economic values provided by the JRC Model itself (Huizinga H.J., 2007).

Than the JRC Model has been coupled with the MCM Model to complete the definition of the tangible damage and appreciate also the indirect component of the tangible damage. As asserted in Chapter 2, MCM Model considers indirect tangible damages related to emergency and support services costs as the 10.7 % of the direct tangible damage. The present research evaluated the total indirect tangible damage as the 30 % of the direct tangible damage in order to include the 10.7 % of damage defined by the MCM Model and also considers indirect damages due to disruption of lifelines systems as road network, telecommunication and public services in and out of the flood plain area (MCM Model, 2005).

At this point of the research the flood damage category has been associated at methodologies able to supply quantitative and economic results about the potential damage due to flood events. In fact, the assessment and management of the risk from flooding should explicitly include estimation of impacts to people (Di Mauro M., 2012).

The research of methods for the evaluation of the intangible damage results in the identification of Life Safety Model (LSM), a useful support for the intangible damage estimation meant as number of fatalities and injuries determined by floods. The analysis of the LSM code underlines its quality describing people, structures and vehicles condition, analysed step by step during the flood development accordingly with the description of water depth and flow velocity changes at each step. In fact, LSM implementation required the predisposition of the two-dimensional maps of water depths and velocities as input information. These requirements result in as relevant support considering that allow to take advantages of LSM property on the definition of a potential flood evacuation plan useful when the Civil Protection authorities have to manage the emergency phase of a flood disaster. In fact, LSM assesses at each step of the flood event the location of each receptors determining possible people moves towards safe haven feasible driving or walking. The evacuation action should be supported by early warning systems that disseminate the warning issuance in the territory under risk. The definition of an accurate warning system led to analyse regulation in Sardinia defined by the Civil Protection Agency in the Alert Operating Instructions in case of flood emergency.

Following, the main reports analysed in this research are described in detail.

- ISPRA Guidelines
- JRC Model
- Life Safety Model
- Alert Operating Instructions in case of flood emergency

2.1. ISPRA Guidelines

ISPRA Guidelines "Proposta metodologica per l'aggiornamento delle mappe di pericolosità e di rischio" is developed as guideline to support Italian authorities on the Flood Directive 2007/60/EC fulfilment that requires the definition of approaches for the assessment and management of the flood risk aiming to prevent potential consequences to the territory described also in terms of cultural heritage, economic activity and environmental aspects.

As defined in the European Flood Directive, and therefore in the Italian implementation LD 49/2010, the process of analysis of potential flood should follow the development of three main levels:

1. Preliminary Flood Risk Assessment;
2. Flood Hazard Maps and Flood Risk Maps definition;
3. Flood Risk Management Plans.

ISPRA Guidelines consists in two main part which underline, firstly, the fulfilment of duties under the Flood Directive 2007/60 and, secondly, the identification of the level of criticality and relative applicable methodologies.

2.1.1. Fulfilment of the Flood Directive 2007/60/EC and LD 49/2010

The first part of ISPRA Guidelines analyses the development of Preliminary Flood Risk Assessment and European and Italian rules for the definition of Flood Hazard and Flood Risk Maps.

2.1.1.1. Preliminary Flood Risk Assessment

The Preliminary Flood Risk Assessment consists on the identification of areas where floods could occur and the potential levels of risk. The necessary information to fulfil the Preliminary Flood Risk Assessment come from accurate survey of available data, study of the baseline situation also in terms of climate changes (geomorphologic data or also aerial photographs of the territory) and historical data. In fact, the identification of potential flood risk areas requires the analysis of the actual and historical situation of the river network, duty implemented to all Italian territory with the development of Hydro-geological Settling Plans required by the Italian Directive 180/1998, known as “Legge Sarno”. These studies underline that flood hazard areas identification should be investigated not only in terms of flood risk but also defining potential debris flood risk that could obstruct, partially or completely, the river path. All of these aspects should be contextualised with cartographic reference for the river network and the catchment system.

2.1.1.2. Flood Hazard Maps

Flood Hazard shall cover geographical areas which could be flooded due to the river network features and, in the LD 49/2010 it has been stated that the flood hazard has to be represented by the probability of a flood event during a given time in a given area.

Flood Hazard Maps provide, in shape file format, the floodplain areas under conditions of low, medium or high probability of event occurrence. According with the Flood Directive 2007/60, all the analysed scenarios have to be described in terms of intensity and magnitude of the event through hydraulic information as the return-time period that determine water depth maps, velocity and flow rate. Moreover, ISPRA Guidelines compares the categorisation of the probability of occurrence levels among the Flood Directive 2007/60/EC and the LD 49/2010 according with return-time period associated at each scenario, Table 2-1.

Probability	Flood Directive 2007/60/EC	Italian Directive 49/2010	DPCM 1998
Low (Extreme events)	-	$T_r \leq 500$ years	300 years $\leq T_r \leq$500 years
Medium	$\geq$ 100 years	100 years $\leq T_r \leq$500 years	100 years $\leq T_r \leq$200 years
High	-	20 years $\leq T_r \leq$ 50 years	20 years $\leq T_r \leq$ 50 years

Table 2-1.Return-time period for each scenario of probability of occurrence (ISPRA Guidelines, 2013)

In addition, the debris flood should be included in the definition of the flood hazard maps considering areas where the river flow could be characterised by transport sedimentation due to the shape of the river or the characteristics of the territory. Flood Directive 2007/60/EC underlines the necessity to assess potential climate changes in the hazard areas that could affect relevant increment of flood.

2.1.1.3. Flood Risk Maps

Flood Risk Maps result from the combination of flood event probability of occurrence and the potential adverse consequences for human health, environment, cultural heritage and economic activity connected with the event according with the Flood Directive 2007/60/EC.

Considering the formulation of the risk as assumed in the DPCM 1998, (D.P.C.M. 29/09/1998), the total risk is defined by the Equation 2-1:

$$R = P \times E \times V$$

Equation 2-1.Definition of the total risk in the DPCM 1998 (ISPRA Guidelines, 2013)

where P represents the hazard or the probability of occurrence of an event, E is the value of the element under risk in the flood area and V is the vulnerability of the element under the risk interpreted as the capacity of an element to resist or be damaged against the event represented by a coefficient with values between 0 and 1. The product of Vulnerability and Element values represents the potential damage D.

ISPRA Guidelines remarked the damage categorisation in terms of tangible and intangible damage due to the possibility to appoint a pecuniary value at the flood consequences. Each class of damage is split in two class of direct and indirect damage. The direct damage means the direct contact between the water and the element exposed to the risk. The indirect damage does not derive from the direct contact with the water and could be considered as consequence of the direct damage meaning loss of products, decrease of economic or physical connections, traffic interruption. The study of how the direct damage occur highlights its relation with many variables as land use, susceptibility to the flood event, flood spread, heights and duration of the event, water velocity and sediment transport related to the flood. Following this aspects ISPRA Guidelines defined three causes of damages:

- Floods: potential damage related with the leakage of water from the drainage areas;
- Morphologic dynamics: potential damage due to erosion and/or sediment process caused by the interaction among water flow, sedimentation and woody material transport;

- Pollution: results of contaminant load in the water and sediment.

Moreover the Flood Directive 2007/60/EC in the Article 6 of the Chapter III establishes which elements should be defined in the flood risk maps and the LD 49/2010 integrated the list of elements requiring additional categories of element as cultural heritage and a detail description of protected areas as represented by the categories listed below:

- Indicative number of inhabitants potentially affected;
- Type of the economic activity in the area potentially affected;
- Structures that could determine accidental pollution in case of flooding;
- Protected areas defined in the Water Directive 2000/60/EC;
- other information which the Member State considers useful such as the indication of areas where floods with a high content of transported sediments and debris floods can occur and information on other significant sources of pollution;
- Infrastructure and strategic structure (highway, railway, hospital, school,...);
- Environmental, cultural and historical heritage of the area potentially affected;
- Distribution and typology of economic activity of the area potentially affected;
- Protected areas potentially affected;
- Other information of the river basin related with sediment transport and/or debris transport potentially polluting.

The Italian Directive 152/2006, "Norme in materia ambientale", (LD 152/2006), aims to preserve the quality of the human being working on the protection and improvement of the environmental and controlling the use of the natural resources. The LD 49/2010 and ISPRA Guidelines take in consideration the protected area defined in the LD 152/2006 and listed in Table 2-2.

1	assigned areas for the water extraction allocated for human usage (Article 7)
2	assigned areas for the protection of aquatic species and economically relevant
3	water areas designed for recreational purpose as bathing water on the application of the Directive 76/160/CEE (Bathing Water)
4	areas characterised by the presence of nutritious elements on the application of the Directive 91/676/CEE (Nitrates) and the Directive 91/271/CEE (Urban Waste Water)
5	designed areas for the habitat and species defence, in these areas it is necessary to maintain and improve the water conditions on the application of the Directive 92/43/CEE (Habitats Directive) and 79/409/CEE (The Birds Directive)

Table 2-2.Potentially affected protected areas individuated at the Annex n°9 in the third part of the LD 152/2006 (ISPRA Guidelines, 2013)

2.1.2. Level of criticality and relative applicable methodologies

The second part of ISPRA Guidelines identifies level of flood criticality to take in consideration during the predisposition of Flood Hazard Maps and Flood Risk Maps and suggest potential methodologies to obtain homogeneous results.

2.1.2.1. Flood Hazard Maps

The predisposition of Flood Hazard Maps is strictly related to the hydrological analysis of the probability of occurrence of an event and, secondly, to the hydraulic and geomorphologic evaluation of the system subjected at the water flow. One of the main aspect to take under consideration is the dynamic behaviour of the territory continuously under changes. During a flood, levees could collapse, river could not contain the flow determining new river flow path and/or the hydraulic system could be interested by debris flood that increment the flood volume. ISPRA Guidelines analysed a second critical point about the representation of water depth, velocity and flow intensity obtainable with simple graphic representation and one- or two-dimensional models.

The DPCM 1998 requires the analysis of areas protected by levee whit low probability of flood occurrence unless the levees should not be overflow by event with return-time period of 200 years. A second requirement is the explanation of hydraulic methods used to identify in thematic maps potential failure of levees.

The Flood Directive 2007/60/EC requires uniformity on the water depth and velocity representation, therefore, ISPRA Guidelines supply two methods to describe univocal range of water depth and velocity values. One hypothesis considers the water depth representation divided in five classes with a constant steps of 0.5 m and represented with blue shade, Table 2-3.

h(m)	Colour	R	G	B
$h < 0.5$		182	237	240
$0.5 < h < 1$		116	180	232
$1 < h < 1.5$		31	131	224
$1.5 < h < 2$		29	68	184
$h \geq 2$		9	9	145

Table 2-3.Water Depth representation in five classes (ISPRA Guidelines, 2013)

The second hypothesis considers cases when a detailed description of the water depth is not available and a water depth threshold should be set. The categorisation considers the water depth map split in two areas, one under the overflow threshold value and the second one over this value defined equals to 1 m, Table 2-4.

h(m)	Colour	R	G	B
h < 1		116	180	232
h ≥ 1		31	131	224

Table 2-4.Water depth representation in two classes considering the potential overflow of a water depth threshold (ISPRA Guidelines, 2013)

The European Flood Directive does not require the representation of velocities and ISPRA Guidelines suggest to identify only areas where velocities are higher than 2 m/s. This velocity representation consists in diagonal net with transparency that does not cover the water depth layer, Table 2-5.

Table 2-5.Velocity representation with values higher than 2 m/s (ISPRA Guidelines, 2013)

ISPRA Guidelines suggest to study accurately water depth and velocity maps obtained with mono-dimensional models considering the uncertainty of process development.
Huge debris flood with potential sediment transport and woody transport flow that could partially or total obstruct the river path could be taken into account of the regular water flow applying an amplifying factor.

2.1.2.2. Flood Risk Maps

ISPRA Guidelines identify the definition of homogeneous methodologies for the appreciation of the flood risk as the most difficult task for Flood Directive implementation. Italian Authorities are supplying this limit studying and adopting international methodologies.
An analysis of the current situation shows the vulnerability value chosen, at national scale uniformly, with a value of 1 considering the receptor under the maximum level of risk every time the event occurs and if it is located in the hazard area. Looking for detailed analysis the vulnerability should be categorised in four classes.
A detail description of the territory allows the predisposition of reliable flood risk maps where every element is described. The level of accuracy on the element map representation depends by the characteristics of the area and areas rich of element, as urbanised or industrial areas, should be described accurately than areas with a lower amount of element under risk as agricultural areas.
Exposed elements should be collected from reliable sources in order to define an itemized categorization of them and the potential damage. ISTAT website supplies information about populations, residences, industries (http://www.istat.it/it/archivio/104317). Multinet or NAVTEQ commercial software update regularly the infrastructure and roads network creating cartographic maps with detail information of each element. Cultural,

environmental and historical heritage element could be achieved through MIBAC (Ministry of Cultural Heritage and Activities) and ISCR (Istituto Superiore per la Conservazione e il Restauro) that create a GIS database to list protected heritage goods.

All of the elements are categorised in four main classes: populations, economic activity, archaeological-cultural heritage and environmental heritage. The environmental heritage class is included in the section other information of the Flood European Directive and it could be managed coherently with the third level on the Corine Land Cover maps. Table 2-6 and Table 2-7 show ISPRA Guidelines categorisation of the element analyses in the Italian territory, respectively, for economic activity and for environmental, cultural and historical heritage.

A	agriculture, forestry and fishing	agricoltura, silvicoltura e pesca
B	mining and quarrying	attività estrattiva
C	Manufacturing	attività manifatturiere
D	electricity, gas, steam and air conditioning supply	fornitura di energia elettrica, gas, vapore e aria condizionata
E	water supply; sewerage, waste management and remediation activities	fornitura di acqua; reti fognarie, attività di trattamento dei rifiuti e risanamento
F	construction	costruzioni
G	wholesale and retail trade; repair of motor vehicles and motorcycles	commercio all'ingrosso e al dettaglio; riparazione di autoveicoli e motocicli
H	transportation and storage	trasporto e magazzinaggio
I	accommodation and food service activities	servizi di alloggio e di ristorazione
J	information and communication	servizi di informazione e comunicazione
K	financial and insurance activities	attività finanziarie e assicurative
L	real estate activities	attività immobiliari
M	professional, scientific and technical activities	attività professionali, scientifiche e tecniche
N	administrative and support service activities	attività amministrative e di servizi di supporto
O	public administration and defence; compulsory social security	amministrazione pubblica e difesa; assicurazione sociale obbligatoria
P	education	istruzione
Q	human health and social work activities	sanità e assistenza sociale
S	other service activities	alter attività di servizi
T	activities of households as employers; undifferentiated goods- and services producing activities of households for own use	attività di famiglie e convivenze come datori di lavoro per personale domestico; produzione di beni e servizi indifferenziati per uso proprio da parte di famiglie e convivenze
U	activities of extraterritorial organisations and bodies	attività di organizzazioni e organismi extraterritoriali

Table 2-6.Statistic Classification of economic activity for European Community (ISPRA Guidelines, 2013)

ID	Land use classes
1	Residential (includes all of the element in urban areas except the elements at the point 3,4,8,9)
	CLC classes 1.1.1, 1.1.2, 1.3.3,1.4.1,1.4.2
2	Commercial (includes artisan activities) not included in category 1 and industrial (including mining and quarrying activities)
	CLC classes 1.2.1, 1.3.1
3	Hospitals, health care, social assistance, (includes rehab centres, retirement home, rehab centres, etc..), schools e universities
4	Relevant public structures (town halls, prisons, barracks, prefectures, etc.., public structures not included in categories 1 and 3)
5	Industrialised agricolture
	CLC classes 2.1,2.2,2.4.
6	Extensive Agriculture (woodlands,, fields, pastures)
	CLC classes 2.3,3.
7	Tourist-Recreational (camping, beach resort, sky slope, cinema, theatre, sporting centres, game fishing, etc., no included in category 1)
8	Relevant communication and transport network (airport, port, highways, railway)
	National 'Geoportale' website of the MATTM using Web Feature Service (WFS), URL: http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Rete_stradale.map (Road network) http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Rete_ferroviaria.map (Railway network)
9	Communication and transport network at province and council level of analysis
	National 'Geoportale' website of the MATTM using Web Feature Service (WFS), URL: http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Rete_stradale.map (Road network) http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Rete_ferroviaria.map (Railwaynetwork)
10	Telecommunication and service network (gas, electricity, water, waste water, telephonic system, etc., no included in category 1)
11	Support structures for the element in categories 8, 9, 10.
12	Landfill, garbage sump, purification system, structures that could be considered as pollution sources and not included in category 13
13	Structures grouped in the Annex I of the DL n. 59 18th February 2005
	Structures subjected at check scheme defined in the AIA procedures by the government authorities and conveniently update the 31st May 2010 in the MATTM website: sito:http://cart.ancitel.it/index.html?progetto=32598B49-3B4C-4843-A6A6-ED943A2AEE14&map=EEC7E870-CA34-6140-9BA8-1F85DE09C552 WFS = http://cart.ancitel.it/wfs/32598B49-3B4C-4843-A6A6-ED943A2AEE14/EEC7E870-CA34-6140-9BA8-1F85DE09C552
14	Protected areas grouped and described in Annex 9 part III of the DL n. 152/2006
	Italian Information System for Water Protection (SINTAI)– ISPRA (Management Plan)
15	Historical-Cultural and archaeological heritage
	MIBAC

Table 2-7.Land use classes and data sources including environmental, cultural and historical heritage for Italy (ISPRA Guidelines, 2013)

The evaluation of the damage is given by the product of the exposed element value per its vulnerability in function of the flood probability of occurrence. Its analysis depends by the scale of definition of the element in the area under study. The scale of representation could be list in the three levels of micro-scale, when the study area contains an accurate description and each element as people, structures, vehicles area described; meso-scale, when the sources make available information of classes representative of the territory; and macro-scale if the territory is analysed in council or regional areas.

ISPRA Guidelines applies a damage evaluation based on the meso-scale levels of analysis, using the categorisation of the element in the four classes listed above for the vulnerability, and assigning at the damage parameter the value 1 when the loss of the element occurs, a value between 0 and 1 in case of partial damage of the element, and the value 0 if the element is not damaged.

The appreciation of the damage value is strictly related to the evaluation of the element vulnerability. The vulnerability is usually set with the value 1 if the element is in the hazard area, but this aspects is not always true because the vulnerability is in function of many parameters as the social, cultural, economic, environmental importance of the element but especially it is related with the characteristics of the event in terms of water depths and velocities.

Following the uncertainty and difficulty on the evaluation of the damage, ISPRA Guidelines supplies a methodology for the evaluation of the damage, and therefore of the vulnerability, for each class of element base on international research.

2.1.2.2.1. Population

The investigation of the population in the area under analysis could be developed studying ISTAT sources and land use maps. Flood Directive 2007/60/EC and LD 49/2010 require the identification of the potential number of people subjected at the flood event on the territory and their identification in the maps could be made using proper symbols as suggested in Figure 2-1.

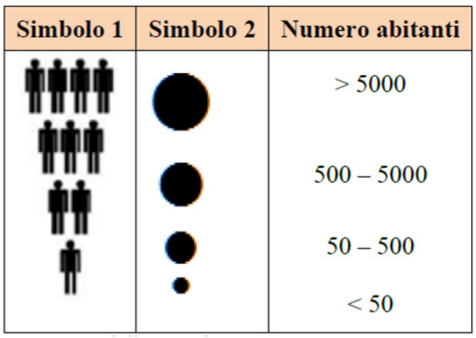


Figure 2-1.Example of population representation in the area (ISPRA Guidelines, 2013)

People vulnerability is evaluated considering the interaction of water depth and velocity with human being. The most part of the researchers evaluate human instability in function of flow intensity, *hv*, determined by the product of water depth and velocity.

Abt et al. compared human instability with monolith instability obtaining a curve in function of height (m) and body mass (kg) of the person and identifying critical values of flow intensity, *hv*, with the Equation 2-2, (Abt et al., 1989):

$$hv_c = 0.0929\,(e^{0.001906\,LM+109)})^2$$

Equation 2-2.Critical value of flow intensity, hv, for human being (ISPRA Guidelines, 2013)

RESCDAM project shows results within a range of *hv* critical values of 0.64 m^2/s and 1.29 m^2/s, (RESCDAM, 2000), and represented by Equation 2-3.

$$hv_c = 0.004LM + 0.2$$

Equation 2-3.hv critical value curve in RESCDAM project (ISPRA Guidelines, 2013)

Federal Emergency Management Agency (FEMA, 1979) considers that a person with a medium body mass starts to lose the stability in a water depth around 0.91 m and with a flow velocity of 0.61 m/s, therefore characterised by a flow intensity of 0.56 m^2/s (Abt et al., 1989) (FEMA), 1979) (Jonkman S.N. and Penning-Roswell E.C., 2008).

Following researches showed that people start to lose the stability in a range of flow intensity between 0.6 m^2/s and 2 m^2/s.

While considering also the debris flood component, the studies developed by Ramsbottom D. and Penning-Roswell E.C. gave a proper expression of Flood Hazard Rating in terms of water depth (m), flow velocity (m/s) and Debris Factor, DF, Equation 2-4 (Ramsbottom D., 2004) (Penning-Rowsell E.C., 2005). The Department for Environmental, Food and Rural Affairs (DEFRA) of the United Kingdom applied the Equation 2-4 for Flood Hazard Rating evaluation and in Table 2-8 and Table 2-9 supplied its categorisation in function of water depth, velocity and land use. Figure 2-2 shows critical curves for human stability under same condition of h(v+0.5) values.

$$Flood\ Hazard\ Rating = h \bullet (v + 0.5) + DF$$

Equation 2-4.Flood Hazard Rating based on water depth, velocity and debris flood (ISPRA Guidelines, 2013)

h * (v+0.5)	Degree of Flood hazard	Description
< 0.75	Low	Caution. “Flood zone with shallow flowing water or deep standing water”
0.75 ÷ 1.25	Moderate	Dangerous for some (i.e. children) “Danger: Flood zone with deep or fast flowing water”
1.25 ÷ 2.5	Significant	Dangerous for most people “Danger: Flood zone with deep fast flowing water”
> 2.5	Extreme	Dangerous for all “Extreme danger: Flood zone with deep fast flowing water”

Table 2-8.Flood Hazard Rating in function of water depth and velocity (ISPRA Guidelines, 2013) (Ramsbottom et al. 2004) (Wade S., 2005)

h	Pasture/Agriculture	Wood	Urban
0 ÷ 0.25m	0	0	0
0.25 ÷ 0.75m	0	0.5	1
h > 0.75m e/o v > 2m/s	0.5	1	1

Table 2-9.Flood Hazard Rating in function of different water depth, velocity and land use (ISPRA Guidelines, 2013)

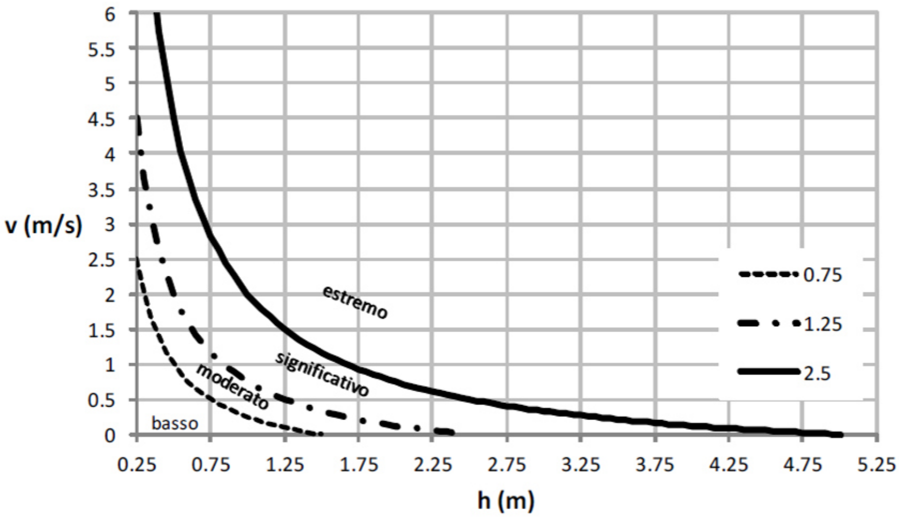


Figure 2-2.Critical curve of people stability under same conditions of h(v+0.5) (ISPRA Guidelines, 2013)

Moreover, DEFRA underlines that the human instability could arise in static water conditions with a level of 1.5 m, while the most part of the experimental studies had been developed with a water depth of 1.2 m for adults, 0.5 m for children and using flood velocity of 3 m/s.

Under the enumerated hypothesis above, ISPRA Guidelines assumed to appreciate the Vulnerability of a person following the expressions in Table 2-10 when water depth and velocity values are known, or the functions in Table 2-11, when only water depth values are available.

$V_P(h,v) = 0$	for $h \leq 0.25$ m
$V_P(h,v) = [h(v+0.5)] + 0.25$	for $h > 0.25$ m

Table 2-10.Person Vulnerability expression in function of water depth and velocity(ISPRA Guidelines, 2013)

$V_P(h) = 0$	for $h \leq 0.25$ m
$V_P(h) = h - 0.5$	for $h > 0.25$ m

Table 2-11.Person Vulnerability expression in function of water depth(ISPRA Guidelines, 2013)

ISPRA Guidelines analyses the exposed value associated to the human presence in the area based on the two cases of the population density, and supplies five classes of population density in habitants/km^2 coupled with a weight factor, Table 2-12, and with how long during 24 hours people could be located in the area due to land use, Table 2-13.

Classes (habitants/km^2)	People density factor
1 ÷ 40	0.9
40 ÷ 80	0.93
80 ÷ 140	0.95
140 ÷ 320	0.98
> 320	1

Table 2-12.Classes of population density (ISTAT 2001)(ISPRA Guidelines, 2013)

Land Use ID	Land Use	Duration (h)	Duration factor
1	Residential	24	1
2	Commerce and Industry	12	0.5
3	Hospital, health and social assistant structure, schools and universities	24	1
4	Council and public structures	24	1
5	Specialised agriculture area	4	0.2
6	No-Specialised agriculture area	2	0.1
7	Tourist-Recreational	10	0.4
8	Main infrastructure network services	24	1
9	Secondly infrastructure network services	12	0.5
10	Technologic and service network	-	-
11	Structure on support of communication and transport services	8	3

Table 2-13.Examples of range of presence of people during 24 hours for different land use classes(ISPRA Guidelines, 2013)

2.1.2.2.2. Economic activities

The damage analysis for economic activities suggested by ISPRA Guidelines considers to localise activities in the area identifying elements of each activity in order to define their relevance in the territory. For example urbanised areas are analysed in function of buildings and inventory, agriculture areas in function of harvest field loss and possible damages to buildings, while areas characterised by infrastructures and roads should studied considering also possible interruption of the public services.

The vulnerability of economic activity is evaluated considering three levels appreciated in function of water depth (h), flood velocity (v) and flow intensity (hv).

ISPRA Guidelines states that the buildings could collapse under different conditions of water depth and velocity. DEFRA considers that partial damage could be created if the difference of the water depth between the internal and external side of a buildings is higher than 0.5 m, or huge damages could occur if the water depths difference is around 1 m or if it is equal to 0.5 m but the flood velocity is significant as around 3 m/s. Moreover, DEFRA underlines that grave conditions could realise irreparable damages with water depths difference around 2 m and low flood velocity as 3 m/s, but also with water depths difference of 1 m and high flood velocity around 6 m/s.

Clausen and Clark studies consider three categories of potential damage to brick and masonry buildings associated at three range of water depth and flood velocity (Clausen and Clark, 1990). Table 2-14 describes the categorisation of the three levels of damage in terms of hydraulic parameters and defines the type of damage simplifying the description shown in Figure 2-3.

$v < 2$ m/s or $hv < 3\ m^2/s$	simple damage	damage from simple flood: it is caused by a natural flood with low velocity and without relevant structural damage
$v < 2$ m/s or $3\ m^2/s < hv < 7\ m^2/s$	partial structural damage	partial structural damage: moderate damage windows fixtures and lower damage to main structural elements
$v < 2$ m/s or $hv > 7\ m^2/s$	structural failure	structural failure: huge damages requiring demolition and rebuilding of the structure

Table 2-14.Clausen and Clark categorisation of damage for buildings under different flood conditions(ISPRA Guidelines, 2013)

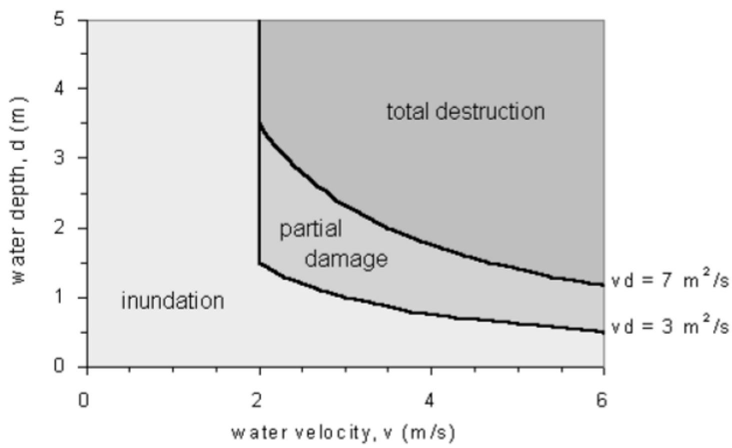


Figure 2-3.Categories of flood damage to buildings. Clausen and Clark studies(ISPRA Guidelines, 2013)

ISPRA Guidelines mentions other international studies as the one developed by Roos (2003) that assumed building collapse for different building typology and found that partial damages are created with a water depth of 0.5 m and a flood velocity higher than 2 m/s. RESCDAM project used data collected on Finnish buildings study where the vulnerability, evaluated in terms of water depth and velocity, causes damage to structures and the level of damages are summarised in Table 2-15.

Building Typology	Partial Damage
wooden building	
non anchored	$hv > 2\ m^2/s$
anchored	$hv > 3\ m^2/s$
stonework, brick and concrete building	$v \geq 2$ m/s and $hv > 3\ m^2/s$

Table 2-15.Damage levels to Finnish buildings mentioned in RESCDAM project (ISPRA Guidelines, 2013)

The evaluation of damages on building inventory have been studied by the Natural Hazards Research Centre concluding that a water depth of 0.5 m could determine losses on inventory around the 50 % and structural damage around 12 % as it is possible to observe in the water depth-damage curves for Risk Frontiers shown in Figure 2-4.

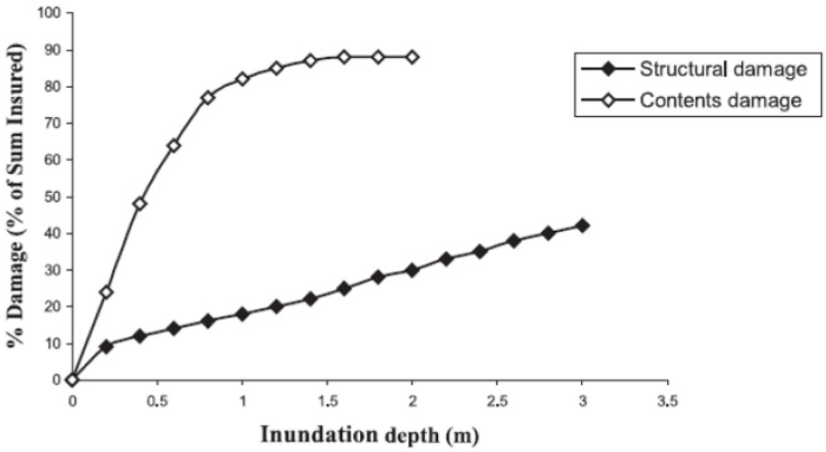


Figure 2-4.Water depth-damage curve for building and inventory Natural Hazard Research Centre(ISPRA Guidelines, 2013)

Moreover, RESCDAM project analysed damages on vehicles. The project evaluated vehicles conditions during test developed in laboratories and through empirical studies testing them under different values of water depth, velocity and flow intensity and obtaining the critical values shown in Table 2-16.

Small Damages Low Hazard	Medium Damages Medium Hazards	Collapse Very High Hazard
hv< 0.3 m^2/s	0.5 m^2/s <hv< 0.6 m^2/s	hv> 0.6 m^2/s

Table 2-16.Vehicle Damage due to flow intensity, hv, RESCDAM project(ISPRA Guidelines, 2013)

Moore and Power identify the following stability limits for a vehicle (Moore K. A. & Power R.K., 2002):

- $h \leq (0.4 - 0.0376v)$ when [$v \leq 1.81$ m/s];
- or $h \leq 0.6$ when [$v > 1.81$ m/s].

While, accurate studies have been conducted in Australia for the Australian Rainfall and Runoff project where the following three categories of vehicles were identified and are listed below:

- Small vehicle size: h = 0.3 m and v = 0 m/s; h = 0.1 m and v= 3 m/s; $hv \leq 0.30$ m^2/s;
- Medium vehicle size: h = 0.4 m and v= 0 m/s; h = 0.15 m and v= 3 m/s; $hv \leq 0.45$ m^2/s;
- Big vehicle size: h = 0.5 m and v= 0 m/s; h = 0.2 m and v= 3 m/s; $hv \leq 0.60$ m^2/s.

ISPRA Guidelines analyses potential damages for agriculture areas that are generally lower than urban losses, for this reason simplified approach are used for agriculture category. The analysis of agricultural area considers the growing period of the year when the flood happen, water depth, flood duration and velocity, pollutant and harmful substances. The upper water depth level accepted depends on the plantation and vegetation height. It is relevant to consider also that huge flood velocity could cause soil degradation by erosion and compromise land fertility.

Finally, economic activity vulnerability is categorised in terms of type of activity and hydraulic parameter involved as shown Table 2-17.

<table>
<tr><th>Land Use ID</th><th>Land use</th><th colspan="3">Vulnerability – V_e h(m); v(m/s)</th></tr>
<tr><td>1</td><td>Residential</td><td colspan="3" rowspan="3">Ve(h) = 0.5h</td></tr>
<tr><td>2</td><td>Commercial and Industry</td></tr>
<tr><td>3</td><td>Hospitals, health services, schools and universities</td></tr>
<tr><td>4</td><td>Public Structures</td><td rowspan="4">Ve(h,v) =</td><td colspan="2"></td></tr>
<tr><td>7</td><td>Tourist Structures</td><td>0.5h</td><td>per v < 2</td></tr>
<tr><td>10</td><td>Technologic and Services Network</td><td colspan="2"></td></tr>
<tr><td>11</td><td>Supported network for communication, transport, technological services</td><td>0.35h (1+0.25v)</td><td>per v ≥ 2</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Industrialised Agriculture</td><td colspan="3">Ve(h) = h</td></tr>
<tr><td colspan="3">Ve(h,v) = h per v < 0.25
Ve(h,v) = h (1+ v) per v ≥ 0.25</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Extensive Agriculture</td><td colspan="3">Ve(h) = 0.5 h</td></tr>
<tr><td colspan="3">Ve(h,v) = 0.25h per v < 0.25
Ve(h,v) = 0.25h (1+ v) per v ≥ 0.25</td></tr>
<tr><td>8</td><td>Primary communication and transport network</td><td colspan="3">Ve(h) = 1.25h</td></tr>
<tr><td>9</td><td>Secondary communication and transport network</td><td colspan="3">Ve(h,v) = 1.25h per v < 3
Ve(h,v) =1.25h (1+ v) per v ≥ 3</td></tr>
</table>

Table 2-17.Economic activity vulnerability due to water depth and/or velocity(ISPRA Guidelines, 2013)

Each economic activity should be evaluated in terms of exposed value to flood due to its relevance in the area. ISPRA Guidelines suggests an appreciation based on ISTAT values of number of employees per activity.

2.1.2.2.3. Archaeological and Cultural heritage

The Italian Directive LD 49/2010 requires the identification of cultural heritage elements in the territory, while the Flood Directive 2007/60/CE does not underlines this category unless it is named in the Annex 1 for the development of the Preliminary Flood Risk Assessment. Unfortunately no approach are available. ISPRA Guidelines set the damage value 1 and requires to define a proper layer to consider Archaeological and Cultural heritage in the maps independently by the water depth and flood velocity values.

2.1.2.2.4. Environmental heritage

Flood could determine negative effects on the environment damaging the ecologic integrity of many natural systems. Three negative parameters are considered: contaminant/pollutant (caused by industry, waste water (human/animal) or stagnant flood water), erosion (caused troubles to soil and vegetative cover degradation or to infrastructure) and open spaces (meant as recreational and touristic areas and also reserves).

ISPRA Guidelines suggests to consider these aspects in a layer of protected areas unless the arise complexity in the determination of its vulnerability and unless a proper methodology for the evaluation of the values is not found out yet.

2.1.2.2.5. Risk determination.

ISPRA Guidelines evaluate the risk in two main steps aiming to reply at the Reporting Sheet on February 2011 calculating the risk for each macro category and, then, to the LD 49/2010 appreciating total risk of the area under analysis.

The risk for each macro category, called in the ISPRA Guidelines as Specific Risk, derives by the relation between the damage and the probability of occurrence related to three different scenarios depending on proper return-time period and considering the information represented in grid format.

The Specific Risk value could be evaluated considering the three values of the probability per damage in each i cell as expressed in Equation 2-5.

$$R_i = \frac{\sum_{j=1}^{3} P_{i,j} \times D_{i,j}}{\sum_{j=1}^{3} P_{i,j}}$$

Equation 2-5.Specific Risk expression (ISPRA Guidelines, 2013)

$P_{i,j}$ is the hazard associated at the i cell and j return period (j cell is equal to 0 when there is not flood) and $D_{i,j}$ is the corresponded damage for the exposed category.

The Total Risk value is evaluated overlaying the layer of each category and for each cell the assigned damage is the maximum value observed comparing the four damage values of each category as expressed with the Equation 2-6.

$$D_i = \max(D_{P_i}, D_{e_i}, D_{c_i}, D_{a_i})$$

Equation 2-6.Total Risk expression(ISPRA Guidelines, 2013)

ISPRA Guidelines categorises the risk in four classes and requires to represent them on the map with polygonal areas. Moreover, the shape file should be set following risk values and relative colour defined in Table 2-18.

Degree of Flood Risk and Description	R_i	Colour	R	G	B
Low (R1) No relevant damages to social, economic and environmental heritage	$0<R_i\leq0.25$		245	245	0
Moderate (R2) Limited damages at buildings, infrastructures and environmental heritages without damages people and compromise building and economic activities use	$0.25< R_i\leq0.50$		245	122	0
Significant (R3) Possible damages to the population, relevant damages to buildings and infrastructures compromising their use, interruption of socioeconomic activities and relevant damages to environmental heritage.	$0.50< R_i\leq0.75$		200	0	0
Extreme (R4) Possible losses of lives and injured, significant damages to buildings, infrastructure services, environmental heritage and destruction of socioeconomic activities	$0.75< R_i\leq1.00$		112	48	160

Table 2-18.Risk categorisation and relative range of values (ISPRA Guidelines, 2013)

2.2. Assessment of the direct tangible damage: the JRC Model

'Flood damage functions for EU member states' report was published in 2007 by the Joint Research Centre Institute for Environmental and Sustainability, developed by the HKV Consultants company and, in particular, by H.J. Huizinga. This work, herein named JRC Report for simplicity, could be considered as one of the European Guidelines created to support the EU Civil Protection actions providing harmonised EU-wide methodologies and information toward the prevention and prediction of weather-driven natural hazards (Huizinga H.J., 2007) and it could be useful to support what required by the Flood Directive 2007/60/EC on the flood damage assessment.

The JRC Report identifies flood damage functions as important element for flood damage assessment and impact studies (Huizinga H.J., 2007) and through these functions couples the flood water depth with economic damage aiming to describe and appraise the direct tangible flood damage.

Two indicators are chosen to define the damage: a damage factor relative to the maximum damage with a range of development between 0 and 1, and an absolute damage estimation expressed in Euros per square meters. Therefore, two types of water depth-damage functions are obtained and described in the JRC Report. In this research the two type of water depth-damage functions are called "Absolute water depth-damage function" (when the damage indicator is the absolute damage estimation in €/m^2) and "Relative water depth-damage function" (when the damage is described by the damage factor and herein named α), aiming to mention them easily during the dissertation and their description.

JRC water depth-damage functions are characterised by a gradual increment of the flood damage indicator that increases proportionally with the water depth evaluated in a range between 0 and 6 meters of flood wave, meaning that at 6 meters the maximum value of the damage indicator is reached.

The study aims to apply the JRC water depth-damage functions on potential flood event that could occur in 26 European state members and in addition Norway, Switzerland, Croatia and Turkey, Table 2-19.

1	Germany	11	Denmark	21	Bulgaria
2	United Kingdom	12	Greece	22	Lithuania
3	France	13	Ireland	23	Cyprus
4	Italy	14	Finland	24	Latvia
5	Spain	15	Portugal	25	Estonia
6	Netherlands	16	Czech Republic	26	Malta
7	Belgium	17	Hungary	A	Switzerland
8	Sweden	18	Romania	B	Turkey
9	Austria	19	Luxembourg	C	Croatia
10	Poland	20	Slovenia	D	Norway

Table 2-19.Countries under study for the JRC Model application(Huizinga H.J., 2007)

JRC Report describes the study development asserting that was based on Internet sources, literature available at HKV Consultants and flood damage assessment from many countries. Achieved data and methodology underlined that only eleven countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and UK) gave available information and, therefore, they contributed to obtain JRC water depth-damage functions, while many countries had not data available. In a second step, questionnaires were sent asking Authors detailed information about their works and aiming to get clarifications requiring additional information if available.

The study required an analysis of the economic situation of each country contemplated in the JRC Report to identify a proper economic indicator of the damage. The analysis is based on data collected by EUROSTAT and Worldbank information that had been reported in terms of Gross Domestic Product (GDP) per capita Purchasing Power Standard (PPS) of the nation. The experts identify for the GDP a strong relation to prosperity and, prosperity has a strong relation to build size, -luxury, -inventory. Moreover, the economic analysis recognizes that the residential house category contributes strongly to total damage (Huizinga H.J., 2007), but the values to be representative for the price-level requires an economic correction based on the inflation due to a comparison of the considered years.

Progressively, the project analysed data collected by each country or by relevant studies (IKSR, Floodsite, Belgian studies and others mentioned in the JRC Report) considering the land use categories hit by the flood and aiming to identify which of them could determine the most part of the damage. Therefore, in the JRC Report, five land use categories are defined:

- Residential houses including inventories;
- Commerce;
- Industry;
- Infrastructures and Roads;
- Agriculture.

For these five categories all data had been adjusted making them comparable. In fact, maximum damage values of adjacent countries should be comparable in terms of land use. Data were elaborated removing the lowest and the highest values from the samples when they appeared with exceptional values, then the average of the maximum values was calculated and a second check had been made to confirm that the lowest and highest values had been removed correctly.

The harmonization process was applied to obtain representative damage values aims to create heterogeneity among the results of the Member states. Figure 2-5, Figure 2-6, Figure 2-7, Figure 2-8 and Figure 2-9 show the trend of the JRC Absolute water depth-damage functions obtained with the harmonised process for each land use category. Table 2-20 shows the average maximum damage values obtained for each land use category for the whole European territory and the process used to reached the maximum damage value for each country that contributed in the analysis.

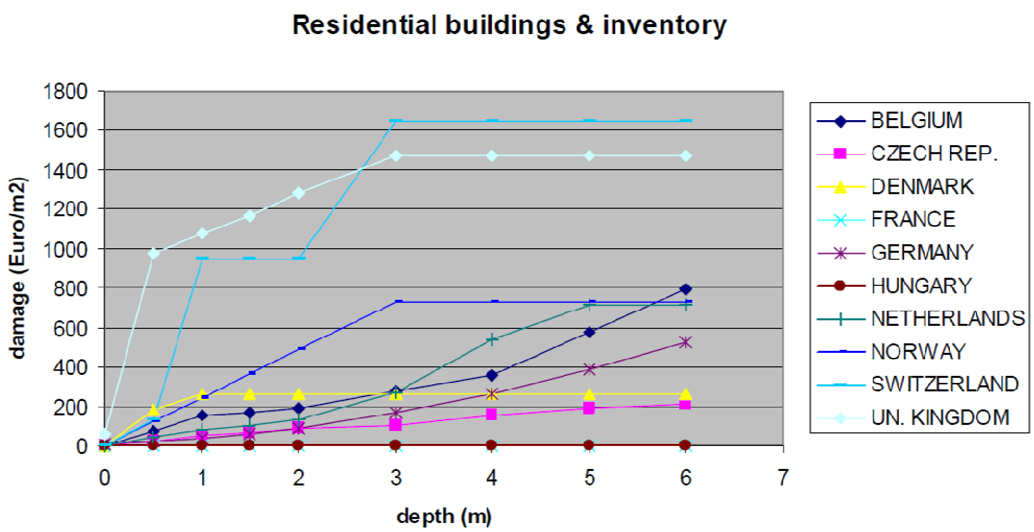


Figure 2-5. Damage in €/m²for residential buildings including inventory (Huizinga H.J., 2007)

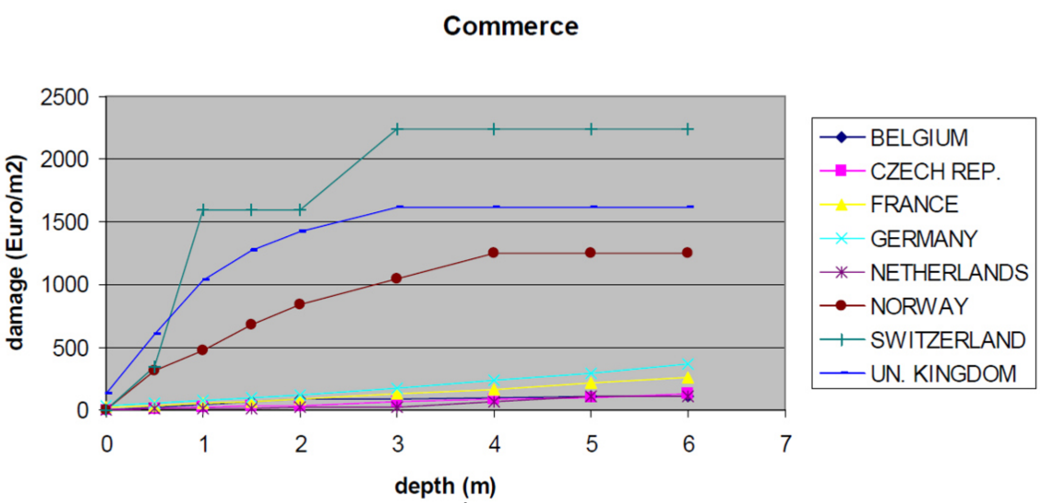


Figure 2-6. Damage in €/m² for commerce (Huizinga H.J., 2007)

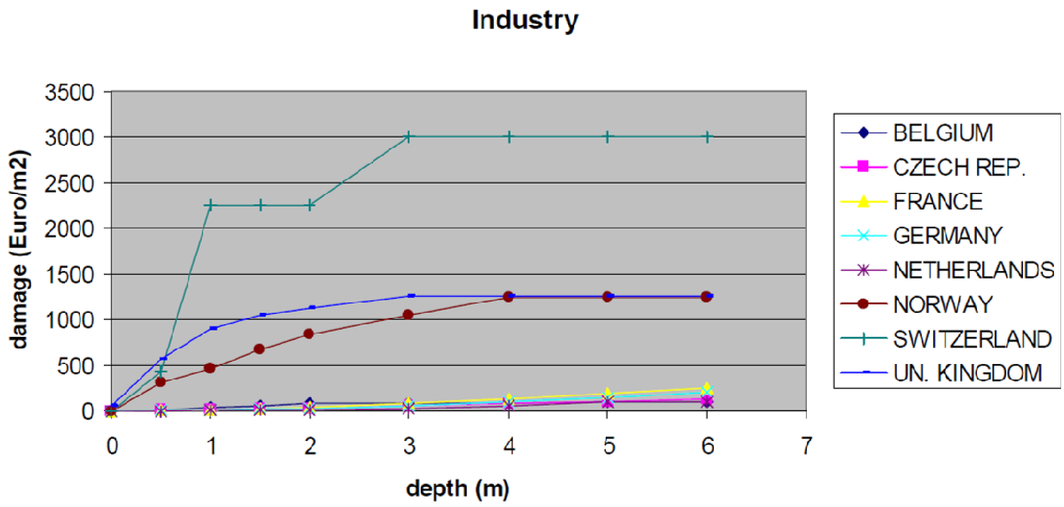


Figure 2-7.Damage in €/m² for industry (Huizinga H.J., 2007)

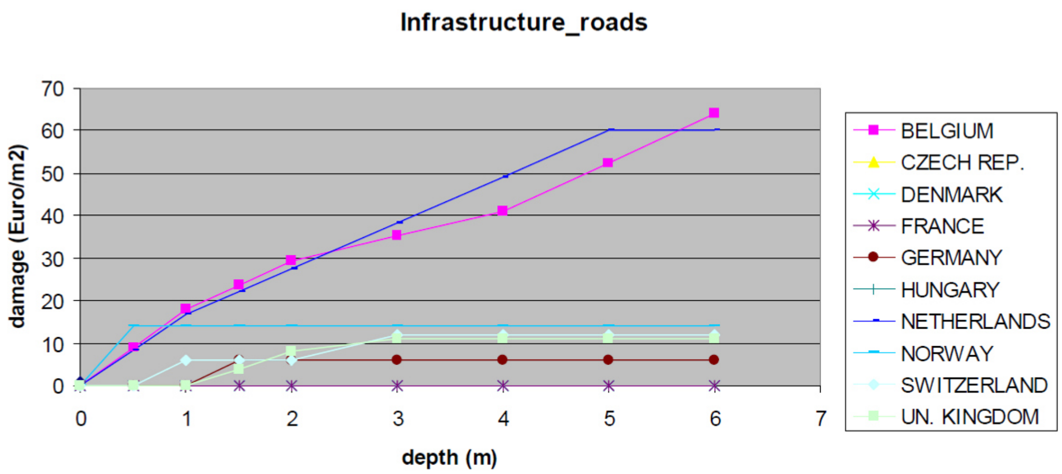


Figure 2-8. Damage in €/m² for infrastructure and roads (Huizinga H.J., 2007)

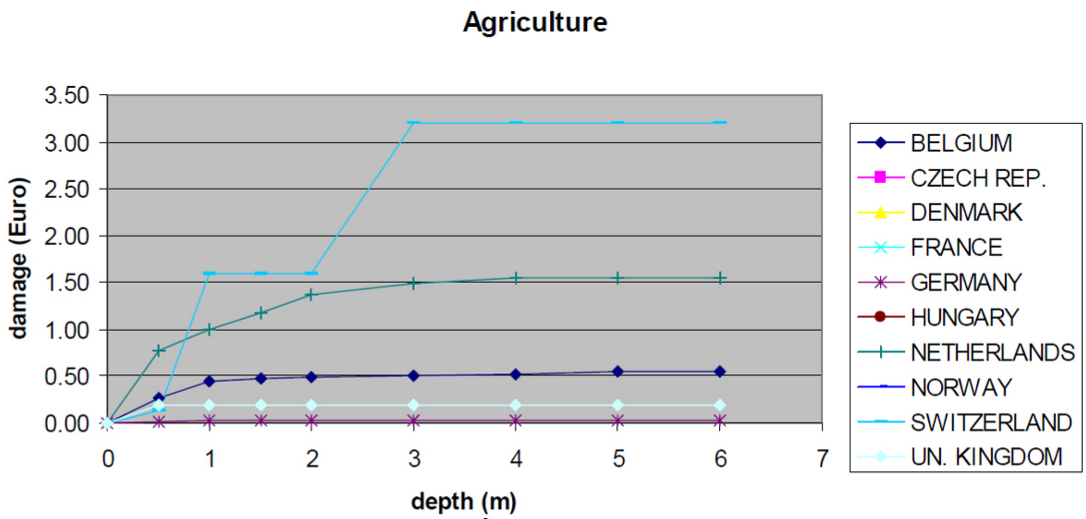


Figure 2-9. Damage in €/m² for agriculture (Huizinga H.J., 2007)

Average maximum damage value	Euro/m^2
Residential buildings	750
Commerce	621
Industry	534
Infrastructures and Roads	24
Agriculture	0.77

Table 2-20. Average max damage values for each land use category in the European territory(Huizinga H.J., 2007)

A mathematical process helped to harmonize the maximum damage values available for each land use category. It was not possible to apply the same process to obtain harmonised water depth-damage functions. In fact, the JRC Relative water depth-damage functions are the result of a process that checked and reworked to one 'average' damage function per damage category for all categories and, for all explored countries, are based on the individual functions. The harmonised JRC Relative water depth-damage functions were obtained with a visual harmonisation. That means a visual average representation of the trend of the collected functions. Countries with own water depth-damage function followed to use their own functions considering that the JRC report aims to obtain water depth-damage functions for all of the European countries without own functions.

The JRC Relative water depth-damage functions are shown in Figure 2-10, Figure 2-11, Figure 2-12, Figure 2-13 and Figure 2-14 where the red lines represents the harmonised function. Table 2-21, Table 2-22, Table 2-23, Table 2-24 and Table 2-25 represent numerically the categorisation of the harmonised relative water depth-damage functions for steps of water depths and for each step the relative damage factor α has been defined.

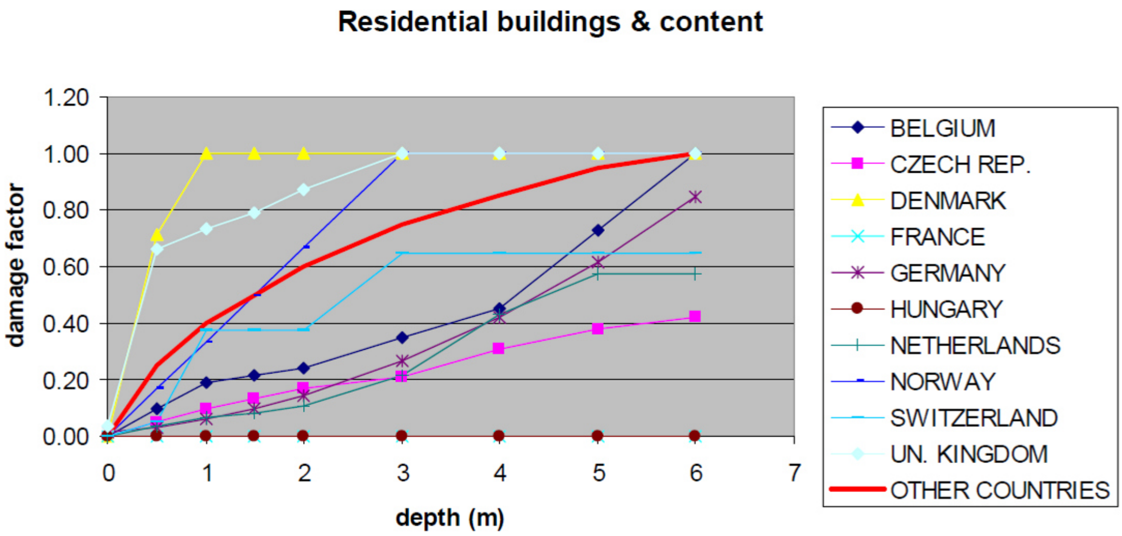


Figure 2-10. Harmonised Relative water depth-damage function for Residential buildings land use category including inventory (Huizinga H.J., 2007)

Residential buildings and inventory	
Water depth (m)	Damage factor (α)
0	0
0.5	0.25
1	0.4
1.5	0.5
2	0.6
3	0.75
4	0.85
5	0.95
6	1

Table 2-21. Damage factor values at each water depth step JRC Relative Residential function(Huizinga H.J., 2007)

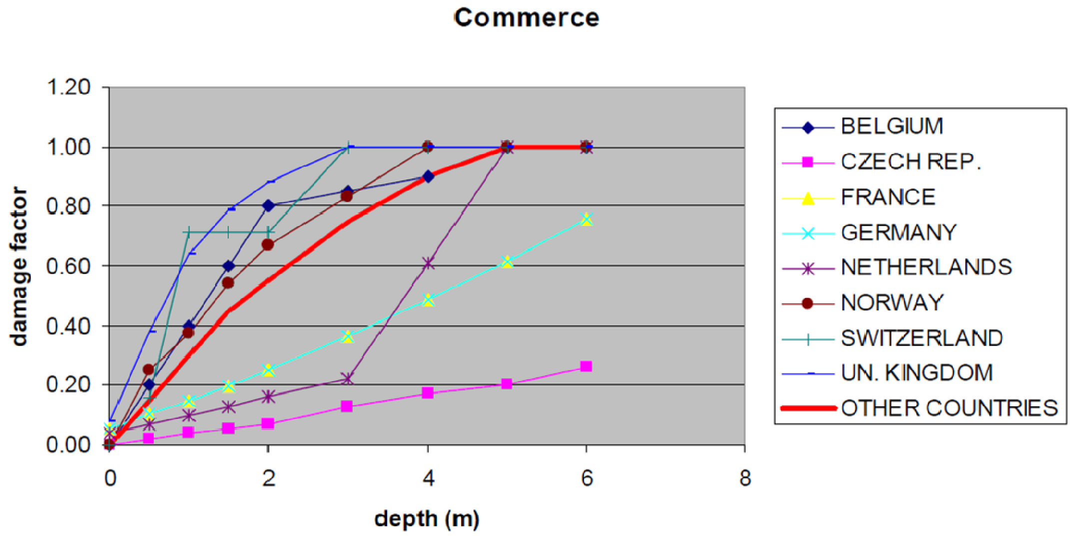


Figure 2-11.Harmonised Relative water depth-damage function for Commerce land use category including inventory (Huizinga H.J., 2007)

Commerce including inventory	
Water depth (m)	Damage factor (α)
0	0
0.5	0.15
1	0.3
1.5	0.45
2	0.55
3	0.75
4	0.90
5	1
6	1

Table 2-22.Damage factor values at each water depth step. JRC Relative Commerce function(Huizinga H.J., 2007)

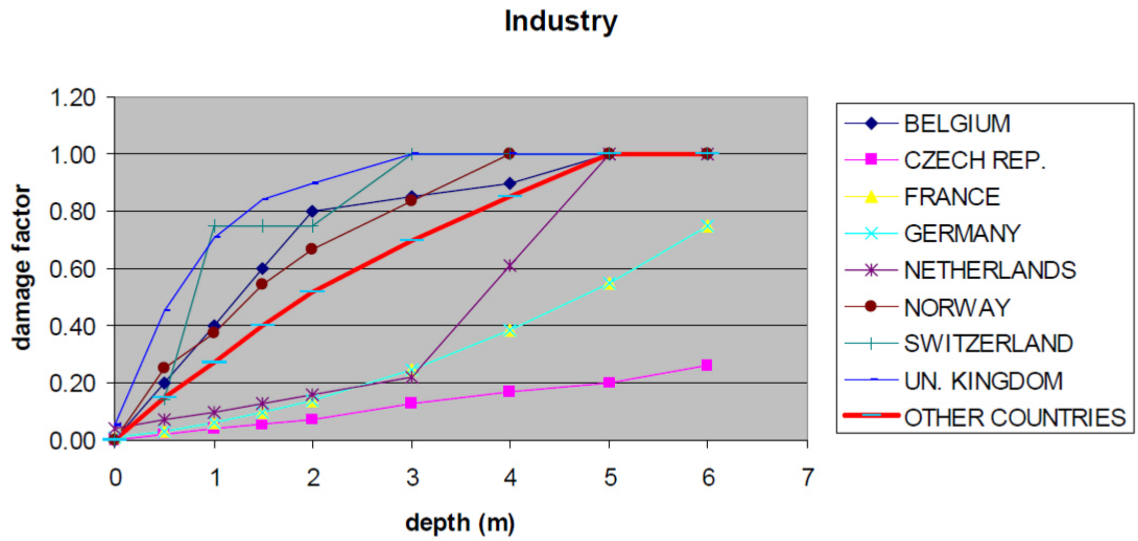


Figure 2-12.Harmonised Relative water depth-damage function for Industry land use category (Huizinga H.J., 2007)

Industry including inventory	
Water depth (m)	Damage factor (α)
0	0
0.5	0.15
1	0.27
1.5	0.4
2	0.53
3	0.7
4	0.85
5	1
6	1

Table 2-23.Damage factor values at each water depth step. JRC Relative Industry function (Huizinga H.J., 2007)

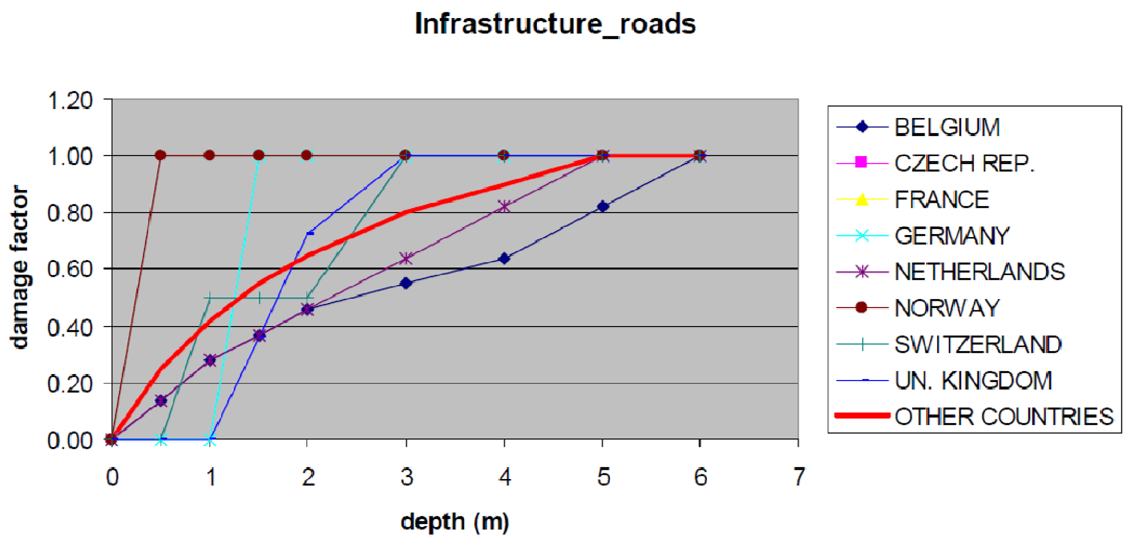


Figure 2-13.Harmonised Relative water depth-damage function for Infrastructure and Roads land use category (Huizinga H.J., 2007)

Infrastructures and Roads	
Water depth (m)	Damage factor (α)
0	0
0.5	0.25
1	0.42
1.5	0.55
2	0.65
3	0.8
4	0.9
5	1
6	1

Table 2-24.Damage factor values at each water depth step. JRC Relative Infrastructures and Roads function (Huizinga H.J., 2007)

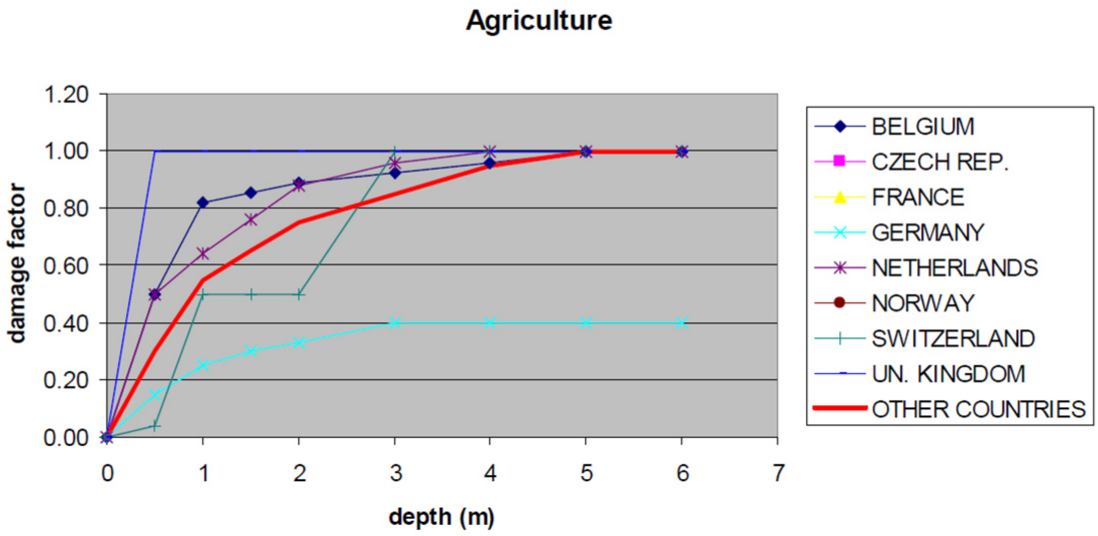


Figure 2-14.Harmonised Relative water depth-damage function for Agriculture land use category (Huizinga H.J., 2007)

Agriculture	
Water depth (m)	Damage factor (α)
0	0
0.5	0.3
1	0.55
1.5	0.65
2	0.75
3	0.85
4	0.95
5	1
6	1

Table 2-25.Damage factor values at each water depth step. JRC Relative Agriculture function (Huizinga H.J., 2007)

The values in Table 2-21, Table 2-22, Table 2-23, Table 2-24 and Table 2-25, representing the JRC Relative water depth-damage functions, could be used to trace the Relative water depth-damage functions of Countries without own functions using the economic key-indicator calculated in terms of maximum damage values in Euros per square metres based on the GDP per capita PPS of each country shown in Table 2-26.

Country		Maximum damage value (Euro/m^2)				
		Residential buildings	**Commerce**	**Industry**	**Infrastructure and Roads**	**Agriculture**
1	Germany	666	551	474	21	0.68
2	United Kingdom	707	586	504	23	0.73
3	France	646	535	460	21	0.66
4	Italy	618	511	440	20	0.63
5	Spain	579	480	412	19	0.59
6	Netherlands	747	619	532	24	0.77
7	Belgium	716	592	509	23	0.73
8	Sweden	692	573	492	22	0.71
9	Austria	740	613	527	24	0.76
10	Poland	292	242	208	9	0.3
11	Denmark	716	593	510	23	0.73
12	Greece	488	404	347	16	0.5
13	Ireland	813	673	579	26	0.83
14	Finland	664	550	473	21	0.68
15	Portugal	430	356	306	14	0.44
16	Czech Republic	432	358	308	14	0.44
17	Hungary	368	304	262	12	0.38
18	Romania	195	162	13	6	0.2
19	Luxembourg	1443	1195	1028	46	1.48
20	Slovenia	479	397	341	15	0.49
21	Bulgaria	191	158	136	6	0.2
22	Lithuania	294	243	209	9	0.3
23	Cyprus	526	435	374	17	0.54
24	Latvia	262	217	186	8	0.27
25	Estonia	320	265	228	10	0.33
26	Malta	450	373	321	14	0.46
A	Switzerland	829	686	590	27	0.85
B	Turkey	189	157	135	6	0.19
C	Croatia	293	243	209	9	0.3
D	Norway	944	781	672	30	0.97

Table 2-26.Maximum damage values per land use category for countries under JRC study (Huizinga H.J., 2007)

2.2.1. Elaboration of the JRC Model for the Sardinian Regional territory

An accurate analysis of the JRC Model underlines the necessity to adjust it at national, or even, local scale. As assert in the model description, the model should be developed evaluating the use of the territory of each country provided by own water-depth damage functions associated each one at a particular land use category. At a second step, the study should provide to homogenise the land use categories categorising them in five land use classes: Residential, Commercial, Industry, Road/Infrastructure and Agriculture. The analysis of the territory is not a complete description of it and, as suggested by the JRC Report, every European country and related Region should analyse deeply and accurately its territory using the last version of the Corine Land Cover to identify which land use categories describe in detail the area under study. Moreover, the water depth-damage functions, collected by European countries provided of them, are based on studies of flood events specifically characterised by precipitation of the North Europe where high water depth are usually registered.

These considerations lead this research to integrate the JRC Model with changes proper for the Sardinian territory considering land transformation during the previous years due to environmental or man-made actions. The land use analysis has been conducted identifying in the territory urbanised areas, different categories of roads due to their different construction or replacement costs, protected areas of environmental-archaeological-historical heritages and, in addition, the infrastructures and services network, representing lifelines systems, have been included in the industry use category. Following this steps of analysis, 201 main land use elements are identified in the territory working on the Corine Land Cover 2003 and updating it with the support of observation on the territory through digital orthophotos of 2006 and 2008, digital orthophotos AGEA 2003, Ikonos 2005/6 images and others sources (ARDIS, 2014). The study resulted in a land use categorisation defined by twelve classes. Residential, Commercial, Industry and Agriculture classes are not subjected at any changes. The Roads and Infastructure class has been split in four new classes: Council Roads, Provincial Roads, Other Roads and the Infrastructure component consisting of areas with drinking water, drainage, electric, telecommunication and similar lifelines systems. This subdivision has been conducted because of the different cost of each class in case of damages due to disasters. In fact, three different values of flood maximum damage value has been set for the roads classes, while the last class has been considered as Other Roads, Table 2-27. Moreover, Table 2-27 shows the description of each land use category identified in the Sardinian territory, the label set for their identification in the maps and the associated flood maximum damage value in €/m^2 as defined for Italy in the

JRC Report. Four more classes of land use are shown in Table 2-27: lakes, rivers and similar areas - Environmental heritage areas - Historical and archaeological heritage areas - area subjected of other intangible damages. ISPRA Guidelines underlines the necessity to define in the maps protected and environmental areas as required in the Flood Directive 2007/60/EC and LD 49/2010.

This research includes the analysis of areas potentially subjected at flood intangible damage taking into account the evaluation of these classes in terms of territory extension looking forward to an improvement of the research and on their appreciation in economic terms.

Land Use Category	**Label**	**Maximum Damage Value (€/m^2)**
Residential buildings	R	618
Commerce	C	511
Industry	I	440
Agriculture	A	0.63
Council Roads	N	10
Provincial Roads	P	20
Other Roads	S	40
Infrastructural and network systems	T	40
Water Bodies	H	-
Environmental heritage areas	J	-
Historical and archaeological heritage areas	K	-
Area subjected of other intangible damages	X	-

Table 2-27.Land use Categories and related Maximum Damage Value for Sardinian Region

A second integration considers the JRC harmonised water depth-damage functions. The analysis of Table 2-21, Table 2-22, Table 2-23, Table 2-24 and Table 2-25 shows that flood damage factor α reaches the maximum value 1 at five meters of water depth except for the Residential land use class for which the value is 0.95, close to 1. This consideration conducted the research to decrease of 1 meter the water depth range in the water depth-damage functions.

JRC functions have been redrawn as shown in Figure 2-15, Figure 2-16, Figure 2-17, Figure 2-18 and in Figure 2-19, and their mathematical expressions are respectively described by Equation 2-7, Equation 2-8, Equation 2-9, Equation 2-10 and Equation 2-11.

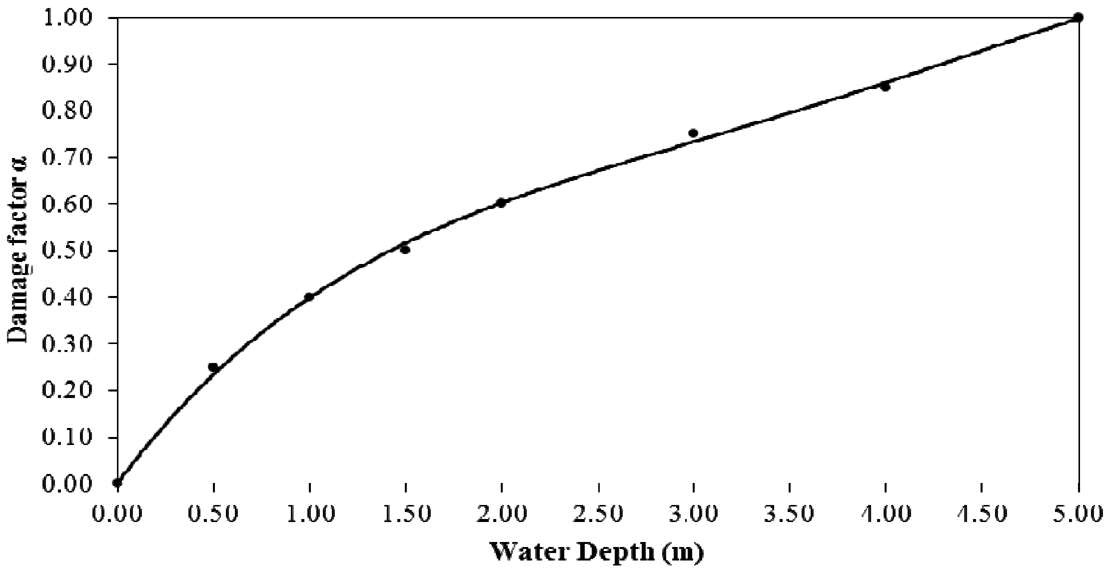


Figure 2-15.JRC Harmonised Relative water depth-damage function. Residential category changed for Sardinian territory

$$\alpha_R = -0.0020646 * h^4 + 0.029964 * h^3 - 0.165641 * h^2 + 0.526177 * h + 0.0082022$$

Equation 2-7.Flood Damage Factor α. Residential category including inventory

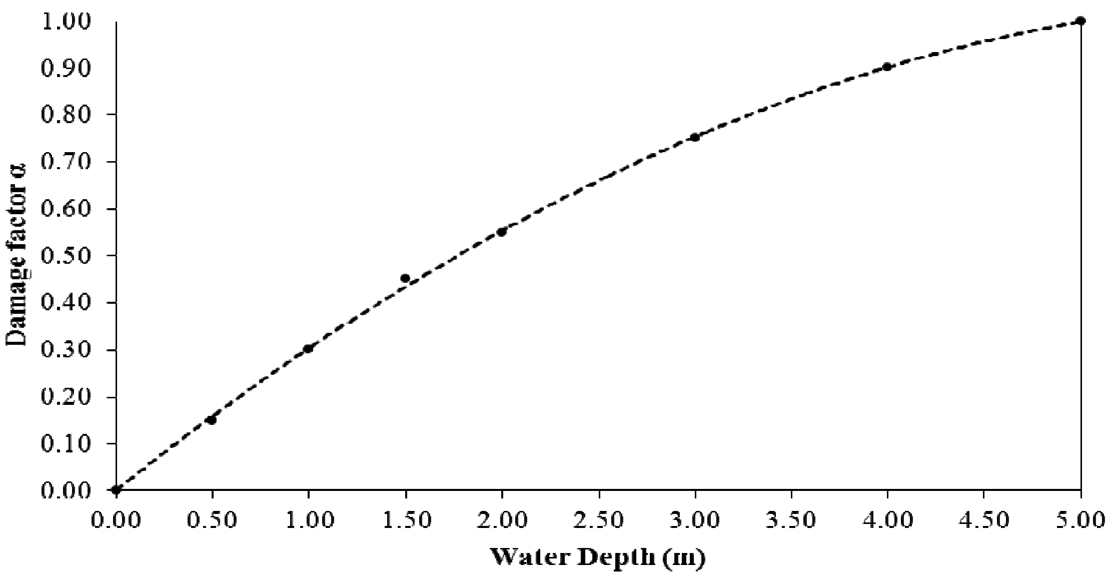


Figure 2-16.JRC Harmonised Relative water depth-damage function. Commerce category changed for Sardinian territory

$$\alpha_C = -0.0291056 * h^2 + 0.345184 * h - 0.014648$$

Equation 2-8.Flood Damage Factor α. Commercial category including inventory

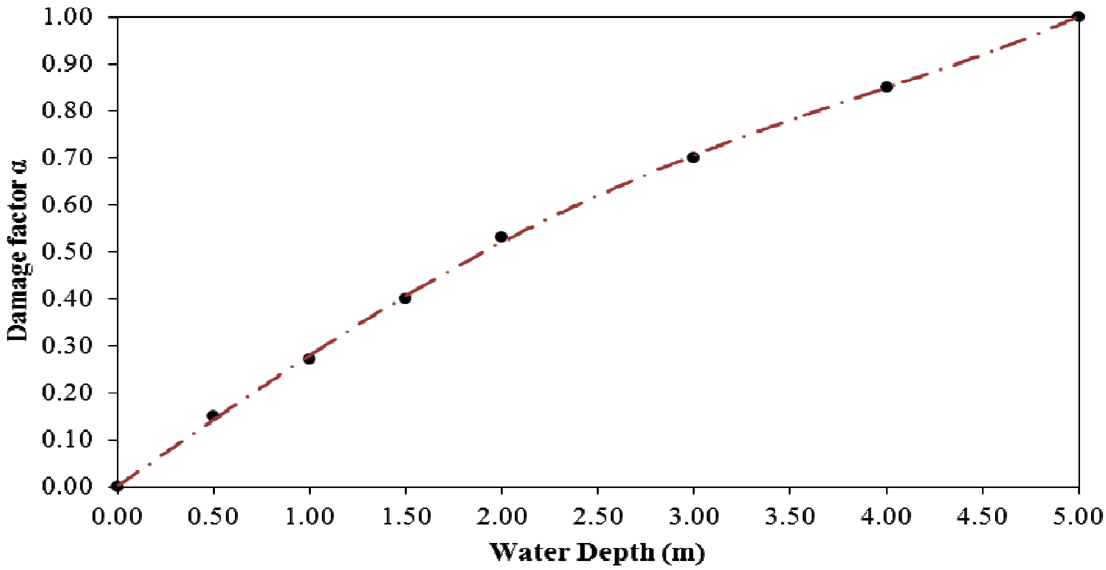


Figure 2-17.JRC Harmonised Relative water depth-damage function. Industry category changed for Sardinian territory

$$\alpha_I = \alpha_T = -0.00112838 * h^4 + 0.0120864 * h^3 - 0.0601298 * h^2 + 0.337384 * h - 0.0041365$$

Equation 2-9.Flood Damage factor α. Industry category including inventory and Infrastructures

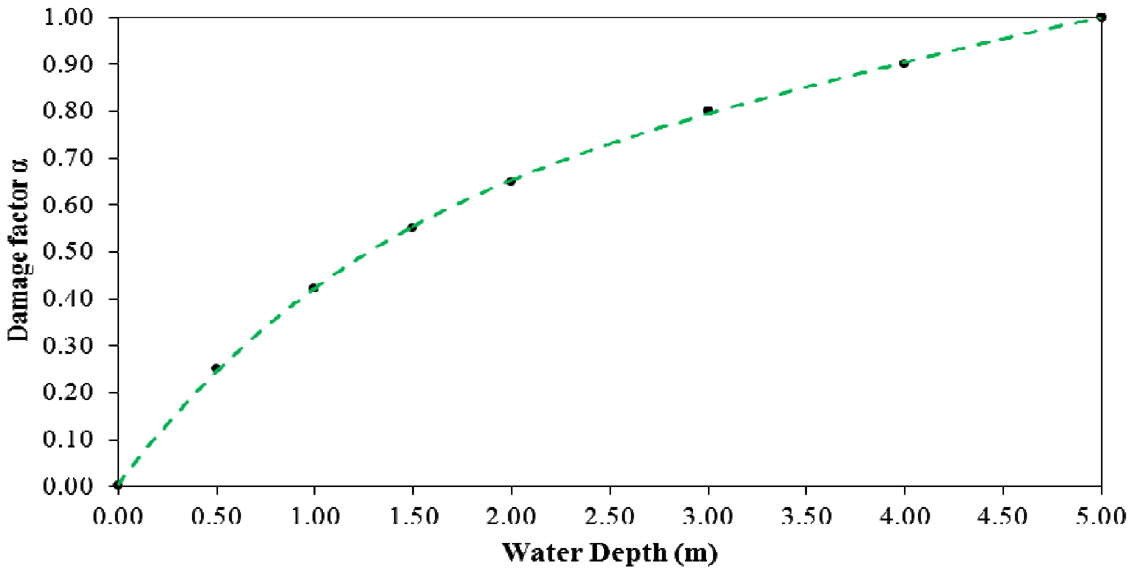


Figure 2-18.JRC Harmonised Relative water depth-damage function. Roads and Infrastructures category changed for Sardinian territory

$$\alpha_N = \alpha_P = \alpha_S = -0.00230344 * h^4 + 0.0323194 * h^3 - 0.178199 * h^2 + 0.569831 * h + 0.0012923$$

Equation 2-10.Flood Damage factor α. Council, Provincial, Other Roads and Infrastructure categories

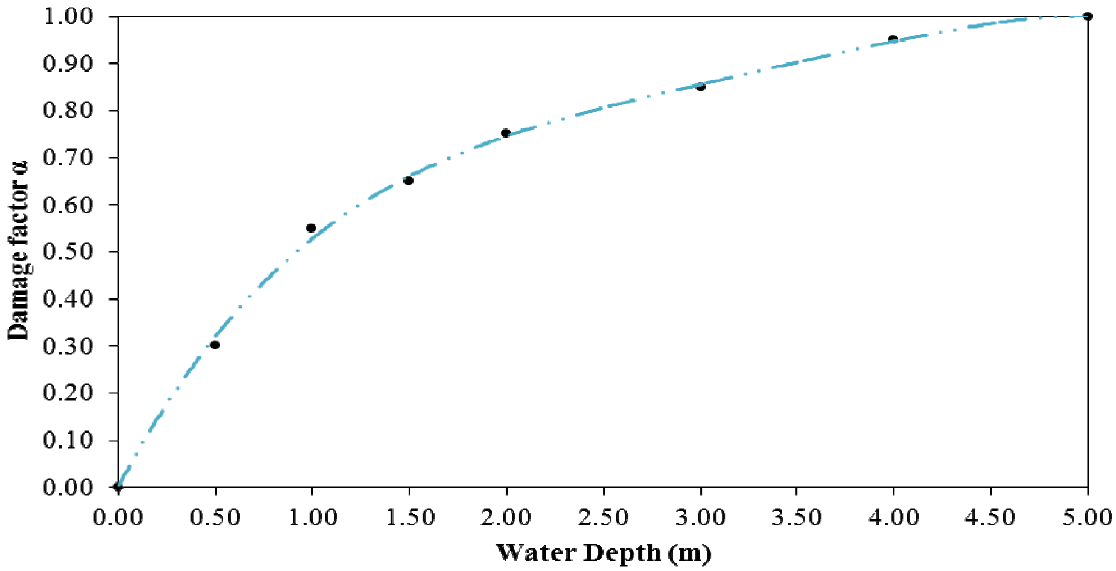


Figure 2-19.JRC Harmonised Relative water depth-damage function. Agriculture category changed for Sardinian territory

$$\alpha_A = 0.000314215 * h^5 - 0.00812378 * h^4 + 0.0747696 * h^3 - 0.32839 * h^2 + 0.793532 * h - 0.00496939$$

Equation 2-11.Flood Damage factor α. Agriculture category

The JRC Model variables and functions related with water depth map information allow the appreciation of the flood damage. In fact, considering the water depth map as a grid of defined cells dimension, the JRC methodology has been, herein, elaborated in mathematical expression to evaluate the damage caused by a flood.

The process requires an overlay of the water depth map with the land use map characteristic of the area under exam. Each cell is set with information of water depth and land use and would be associated with the proper relative water depth-damage function that, through its mathematical expression, gives back the proper flood damage factor α. The hypothesis used by the JRC Model estimating the flood damage considers that a water depth from a level of 6 meters, or for Sardinian territory 5 meters, could cause the maximum flood damage in economic terms. Therefore the appreciation of the damage of each cell it is possible knowing the flood damage factor α, the maximum damage value associated at its land use category and its area as summarised in Equation 2-12.

$$D_{i,k} = \alpha_k(h_i) \times A_{i,k} \times MaxDamage_k$$

Equation 2-12.Flood damage expression for a cell of given land use, h and A information

Where:

- i index identifies the cell;
- k is the index that pinpoints the specific category under exam;

- $D_{i,k}$ is the damage caused by the water depth h in the cell i of assigned land use category k;
- A is the area of the cell i of assigned land use category k;
- MaxDamage is the maximum damage value set for the land use category k;
- α is the flood damage factor with a value between 0 and 1 evaluated with the water depth-damage function associated at the land use category k of the cell under analysis.

The evaluation of the potential flood damage due to an event of defined return-time period could be evaluate starting from the Equation 2-12. At a second step the flood damage per land use category could be evaluated summing the damage of cells defined by the same land use category k, Equation 2-13. Finally, the sum of the damage per land use category allows to be aware of the potential damage that a flood could determine, Equation 2-14.

$$D_k = \sum_{i=1}^{Ni} D_{ki}$$

Equation 2-13.Flood damage per land use category

Where N_i is the number of cell associated at the same land use category k.

$$D_{T_r} = \sum_{k=1}^{N_k} D_k$$

Equation 2-14.Flood damage caused by a flood of defined return-time period T_r

Where N_k is the total number of land use category, D_k is the total damage evaluated for the total area of the land use category k (5 for the JRC Model and 8 for the JRC Model modified for the Sardinia territory inasmuch 4 of the 12 categories are defined only in terms of flood damage area).

2.2.2. JRC Model Validation Process for the Sardinian Regional territory

In the “Conclusions and Recommendations” Chapter of the JRC Report is asserted that the validation model gave back good results and similarities after that the methodology has been tested on a floodplain region in the Southern part of Netherlands. Unless these results, “it is recommended to test also other areas and make a distinction between natural flooding of floodplains and flooding caused by disasters”.

The JRC Model application on the Sardinian Region has been supported by its validation based on collected data from the two main flood events that hit Sardinian territory the 22nd October 2008 and the 18th November 2013 properly defined in the following paragraphs.

2.2.2.1. Flood event of the 22nd October 2008 in Capoterra council area

The 22nd October 2008 a significant storm hit Sardinian Region causing 5 victims in Capoterra and Sestu councils located in the Southern area of Sardinia as documented in detail in the Sardinian Flood Significant Event Report-Volume 1 developed as support of the Sardinian Flood Risk Management Plan (RAS-Vol.1, 2015). The most part of the damages and risks determined by that event have been localised in Capoterra Council territory and, in particular, in the area interested by Rio San Girolamo basin on the southerner territory of the council with 28.1 km^2 of area. The damaged area is characterised by an extended wooded and slope surface interested by relevant water flow runoff where Poggio dei Pini urban centre has been built, and by a plain agriculture area subjected at a concentrated urbanisation during the last 30 years. The analysis of the flood event required an accurate study of the territory underlining geological instabilities which cause relevant debris flood characterised by boulders movement due to the high acclivity of the territory. The instability conditions has been aggravated by the Rio Masone Ollastu River water path deviation made to force its flow into Rio San Girolamo River path before to flow into the Gulf of Cagliari. Moreover, the Italian Army Geographical Institution made the IGMI cartography map of the 1897 confirming the original river path split in two distinct paths. A deep study of the man-land use from 1968 to 2006 shows a strong urbanisation along the two Rivers and on the coast that determine a reduction of green areas worsening the territory stability against flood events.

The investigation of flood event occurred in Sardinia from 1795 to 2008 describes 8 significant flood events that hit Capoterra Council territory during October/November 1961, 1965, 1985, 1986, 1990, 1999, 2005 and in 2008 when the territory has been badly damaged. In particular the event of 2008 caused 4 victims and the comparison of its floodplain with the one caused by the flood of 1999 shows similarities in the floodplain extension (RAS-Vol.1, 2015). The latest event has been forecasted by the Regional Monitoring Forecast Authority and by the Civil Protection Authority that monitored the convective precipitation development due to temperature gradient and depression areas typical of the Mediterranean area in the early autumn caused by the interaction of the two air masses from the North Sea (cold air) and from the North Africa (warm air) that also determined the flash floods.

In particular, the 22nd October 2008 flood hit mainly the South-Eastern Sardinian area in correspondence of Jerzu and Cardedu councils and Capoterra council as shown in Figure 2-20.

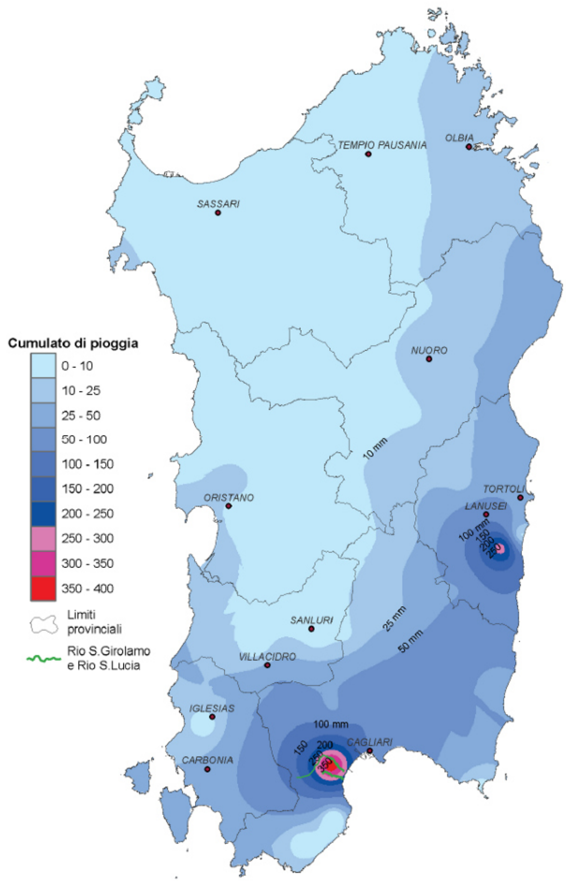


Figure 2-20.Daily precipitation in mm registered by the Sardinian Authorities rain gauges (RAS-Vol.2, 2015)

Capoterra rain gauge registered 148 mm of rain fell from the 7 A.M. to the 8 A.M. and 372 mm were fallen in the first 8 hours. The Sardinian Regional Authorities rain gauges registered 276.4 mm of rain from the 3 A.M. to 10 A.M. in the station of Santa Lucia in Capoterra Council, while the rain gauge station in Capoterra suburban area of Poggio dei Pini reached a total value of 372.0 mm fallen from 3A.M. to 10 A.M., Table 2-28 and shown in Figure 2-21.

Rain gauge Station	Hours (h)												Total (mm)
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
Capoterra (Santa Lucia)	0.0	0.0	0.0	1.8	8.2	28.6	71.4	68.4	80.6	15.8	1.6	0.0	276.4
Capoterra (Poggio dei Pini)	0.0	0.0	0.0	0.6	0.8	2.6	90.0	148.2	94.2	34.8	0.8	0.0	372.0

Table 2-28.Precipitation gauged during the first 12 hours of the 22nd October 2008 in Capoterra territory (RAS-Vol.2, 2015)

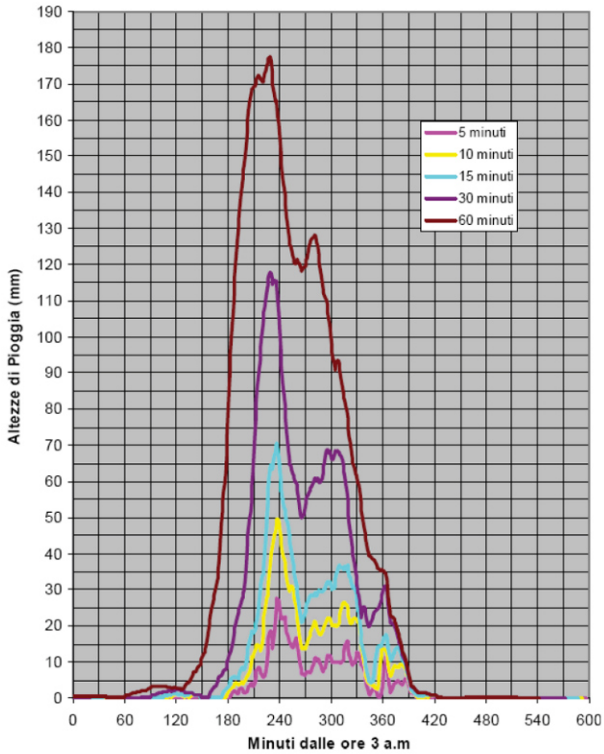


Figure 2-21.22nd October 2008 precipitation hydrograph describing the mm of rain fallen from the 3 A.M. to the 12 A.M.(RAS-Vol.2, 2015)

Figure 2-22.Flood events damages on Poggio dei Pini (right side) and dam failure (left photo)

The volume of the massive precipitation has been evaluated around 750’000 m^3. It gave rise to Poggio dei Pini dam failure and stoked huge debris flood volume that has been appreciated approximately at 250’000 m^3. The registered volume of sediment transport has been incremented also by land instability due to limited vegetation because of summer fires and land aridity that limited water infiltration. The Sardinian Hydrographic District Authority and the Sardinian Forestry Corp modelled the event identifying in Capoterra territory the flooded areas and flood paths, Figure 2-23. The Capoterra Town Centre is described more in terms of flow paths along road segments and the flood analysis was mainly concentrated on the San Girolamo River and Masone Ollastu River areas as described in the Sardinian Flood Significant Event Report-Volume 2. In the description of the flood event, in fact, it has been asserted that the upstream of the river, characterised by rill and gully erosion, fomented the debris flood dropping off sediment in the Poggio dei Pini dam and limiting its water volume that turned out to an increment of the flood volume discharged in the downstream area of Rio San Girolamo and La Maddalena suburban areas as defined above.

Figure 2-23.22nd October 2008 flood in Capoterra Council territory

The research is focused on the study of the flood damage identified as economic support by the authorities and, herein, used for the JRC water depth-damage function validation. The Sardinian Regional Decree n°15 of the 29 October 2008 deliberated that Sardinian Regional Authorities planned 20 M € as economic support to urgent recovery actions, remedial actions infrastructures of the public heritages and to private and commercial enterprise to restore damages caused by the flood at dwellings and infrastructures (RAS-D Lgs. 15/2008, 2008). The founds have been assigned for the flood hazard assessment of the areas hit by the event to identify areas under high flood and landslide risk, for commercial and industry activities considering a found of 30.000 € for each applicant, while residential properties have been supported for 15.000 € to restore damages on chattels as cars and for 25.000 € to restore damages on dwellings. The Sardinian Flood Significant Event Report-Volume 2 asserts that 700 dwellings have been damaged by the flood, 596 of them were main dwellings, 104 have been identified as second residential houses, while 64 refund requests have been not accepted. In addition, the Regional Decree 15/2008 designated part of the funds to the families of the five victims of the flood, (RAS-Vol.2, 2015).

The Regional Decree 15/2008 considered refundable only requests where the detail of the property and of the applicant were reliable. A proper format was supplied to the population to declare personal information, type of residence (as primary or secondary use), goods and foods damaged or lost, declare if the kitchen, bathroom, bedrooms and living room were damaged or destroyed, if car or motorbike were damaged or destroyed and if the applicant was provided by any issuance for the losses.

Capoterra council provided economic damages samples required by the population for the residential and commercial/industry land use categories, while the Sardinian Regional Division for Agriculture Handout Administration (ARGEA) supplied fund information required by the population for damages caused in the agriculture land use category. Each samples of damage refunds have been studied in the present research aiming to validate JRC water depth-damage functions.

These information have been used to identify the mean and maximum value of damage registered expressed in € per square metres for the whole flooded Capoterra territory and, at a second step, the analysis has been improved to associate each damage value at the maximum water depth identified by the reconstruction of the flood event. The reconstruction of Capoterra event has been made with the two-dimensional software MIKE under commission of the Sardinian Regional Hydrographic Authority to identify the water depth levels reached during the flood development in correspondence of each damaged property declared in the refund requests and it describes the flood development only in the downstream coastal area of San Girolamo and Masone Ollastu Rivers, Figure 2-24, (RAS, 2010).

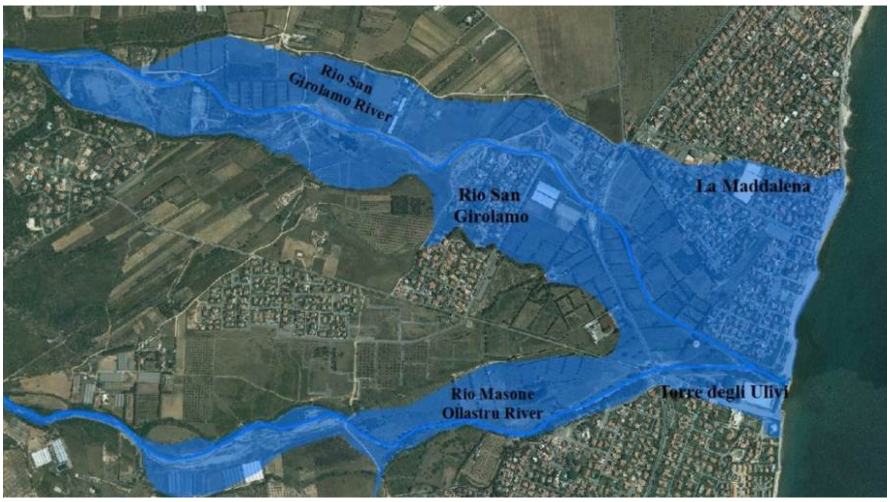


Figure 2-24.Capoterra downstream area where the 2D flood model is available

Figure 2-25.Rio San Girolamo urbanised area on the right side of San Girolamo River

Figure 2-27.La Maddalena urbanised area

Figure 2-26.Rio San Girolamo urbanised area on the left side of San Girolamo River

The 2D MIKE model supplies a video of the flood development supported by the hydrographs of San Girolamo and Masone Ollastu Rivers. The San Girolamo River hydrograph is characterised by two peaks reached, respectively, at 8:00 A.M. and 9:00 A.M., while the Masone Ollastu River hydrograph reaches the peak around 10:00 A.M., Figure 2-28.

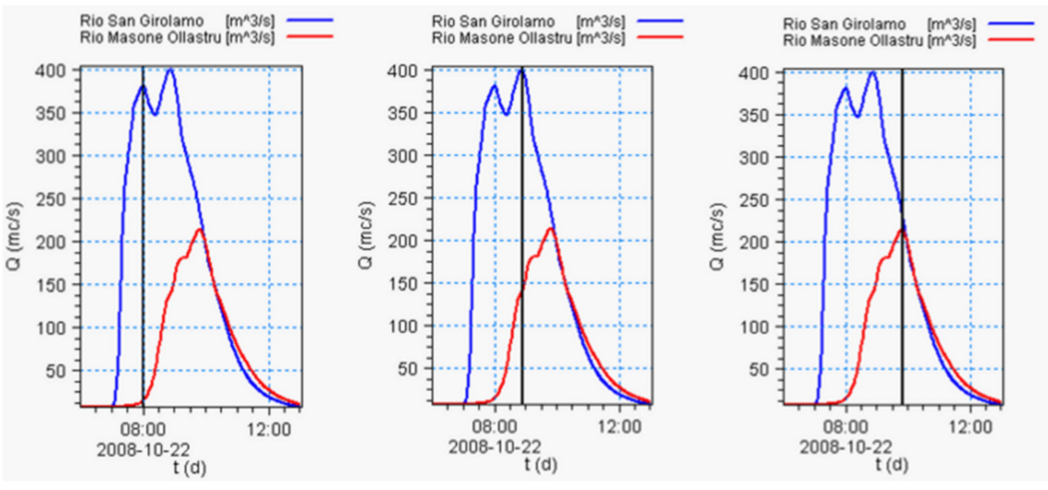


Figure 2-28.Hydrographs of the flood event of 22ndOctober 2008 and description of the reached peaks

The video of the flood has been analysed in correspondence of the three peaks and stopped to the identify the road segments interested by the flood and the maximum water depth level range described by the model. The water depth range used in the 2D MIKE model considers eleven steps recognised with different colours.

The analysis of the 2D MIKE model simulation shows, in correspondence of the first peak of San Girolamo River hydrograph, that in correspondence of Via Barcellona, Figure 2-25,the flood reaches water depth levels between 2 and 2.5 m nearby the river and 1.5 and 2 m at the other side of the road, Figure 2-29. In both cases the high water depth are identified along the infrastructure, while the water depth level are between 1-1.5 m and 0.5-1 m in the residential properties. The flood distribution along the left side of San Girolamo River reached water depth levels between 1.5-2 m along Via Berlino, Via Praga, Via Budapest and between 1-1.5 m in the residential properties, Figure 2-26.

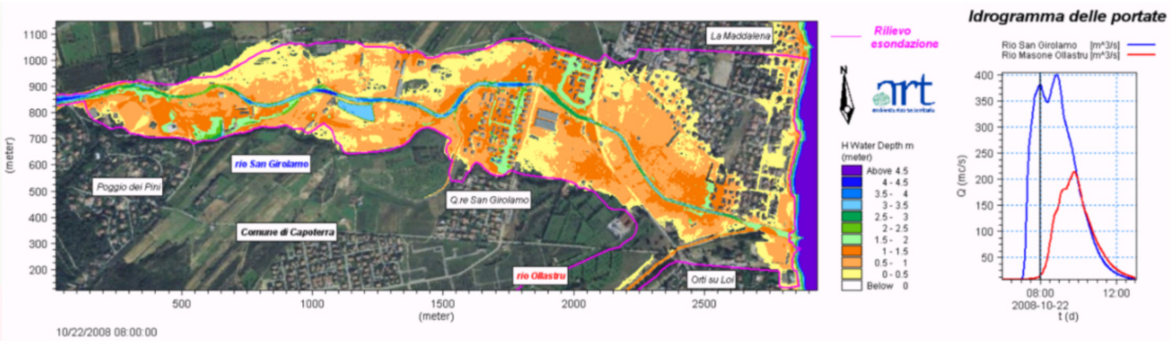


Figure 2-29.Flood condition at 8:00 A.M. when San Girolamo River reached its first peak

The analysis of the 2D MIKE model video in correspondence of the second peak of San Girolamo River hydrographs shows similar conditions to the situation described for the first peak, Figure 2-30. Via dei Fagiani and Via del Mare were hit by a water depth level of 0.5 m nearby the SS195 road segment, Figure 2-27, the water depth reaches levels between 0.5-1 m in Via dei Colombi increasing to a range between 1-1.5 m up to Via dei Cigni and between 2-2.5 m nearby Via Rondini. The analysis of the area nearby Via Rondini shows water depth levels between 1.5-2 m till reach Via delle Cicogne where the levels decrease to a range of 1-1.5 m along the road segment and between 0.5-1 m nearby the sea. The maximum water level has been registered between Via del Mare and Viale degli Albatross with a range of 1.5-2 m.

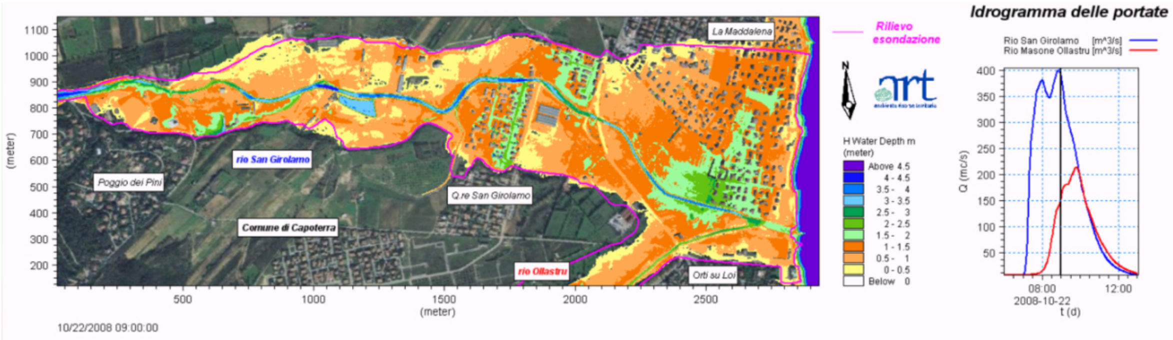


Figure 2-30.Flood condition at 8:00 A.M. when San Girolamo River reached its second peak

The analysis of the Masone Ollastu River flood in correspondence of its peak, Figure 2-31, underlined hazard conditions lower than the situations described previously for San Girolamo River flood.

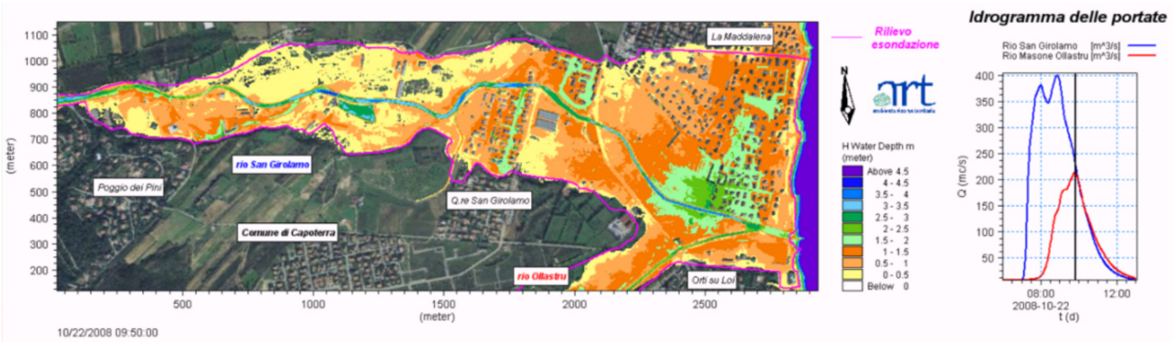


Figure 2-31.Flood condition at 8:00 A.M. when Masone Ollastu River reached the peak

2.2.2.1.1. Residential refunds samples analysis

Capoterra Council office supplied the residential sample of requested claims for damages on dwellings, chattels, furniture and cars. The original sample consisted of 758 refund requests and only 699 were admissible. The main information usable and supplied in the Capoterra residential database for each claim are the unique ID, economic damage appraisal and location provided with the address. Sardinian region authorities provides cadastral shape file from which the area of each claim allotment could be extracted, Figure 2-32, and then associated with the economic damage appraisal information to identify the damage in Euros per square meters for each claim and their distribution in the territory in relation with the boundaries of the flood event. Correspondence of declared address and localisation in the cadastral map has been confirmed checking each claim with Google Street. The check has been developed verifying the correct location of the claim in the map not only paying attention at the road name but also confirming the address number and that each claim falls in the proper allotment. In this way each claim has been georeferenced and the original sample of 699admissible requests decreased to 552. The georeferentiation process of each sample allowed to identify claims distribution in the territory, Figure 2-33, while the analysis of data information with ArcGIS gave back a total damage of 11.54 M € associated at a total area of residential properties allotment equals to 507946 m^2.

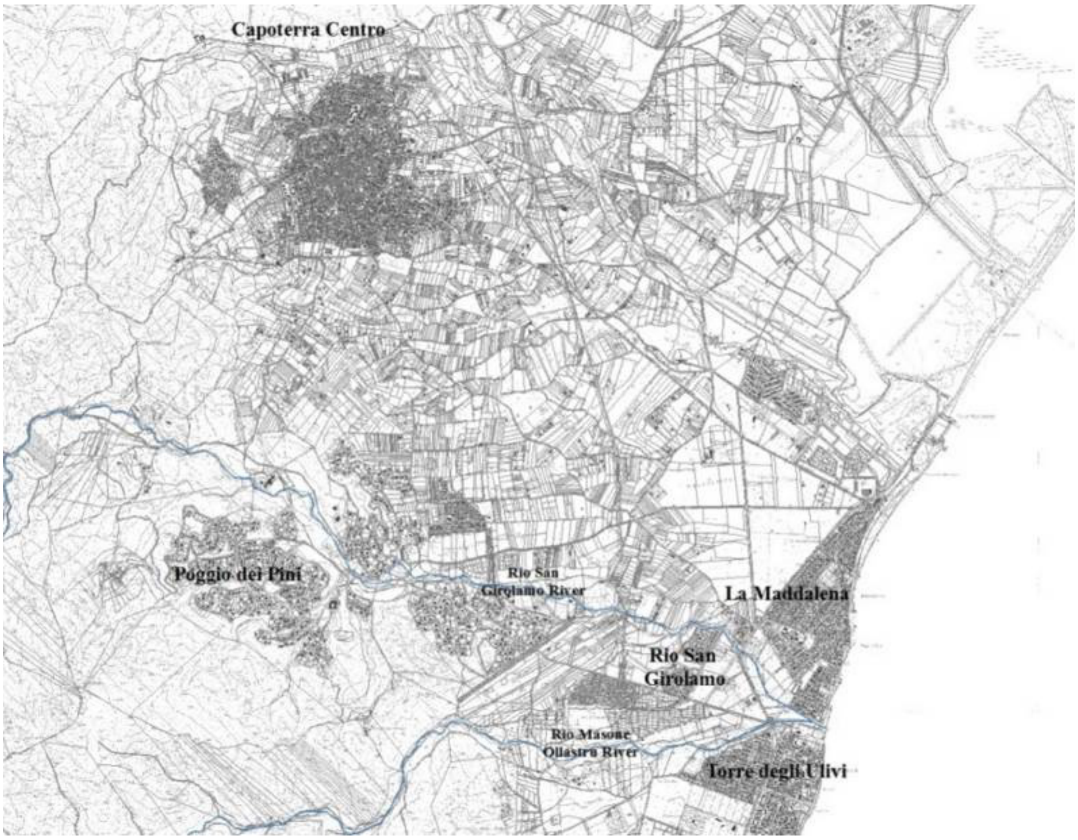


Figure 2-32.Capoterra cadastral map

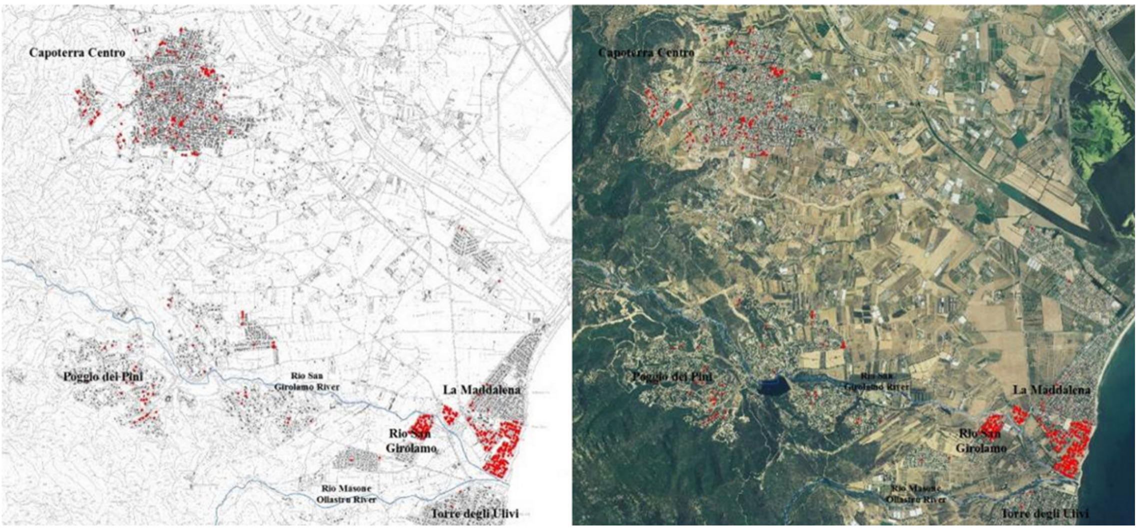


Figure 2-33.Distribution in the territory of Capoterra Residential sample of damages

The data analysis allows to identify for each claim the damage in Euros per square meters, €/m^2. The results have been statistically studied to know the maximum and mean damage value of the residential sample and, then, compare the results with damage values identified for Italy by the JRC Report. The mean damage value of the sample is equal to 40.78 €/m^2, while the maximum damage value in the whole Capoterra town territory reaches the 630.58 €/m^2 value close to the JRC value assessed for the residential land use category of 618.00 €/m^2, Table 2-29. The low mean value could depend by different type of building distributed in the territory from villas closed to the coast to small and old dwelling located in the town centre and by the different dimension of the allotments. This sample properties is underlined by the high skewness coefficient value, 4.87, characterised by a stressed asymmetry represented in Figure 2-34. The maximum and mean damage value have been studied in relation with the JRC Residential water depth-damage curves to identify their location in comparison with water depth and JRC maximum damage value. In Figure 2-35 the comparison is shown. The mean damage value could be determined by a water depth of 0.13 m considering the damage trend described by the JRC curve, while the representative maximum damage value exceeds the JRC value staying closed to the assigned value for Italian territory.

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	$\mu + \sigma$	$\mu + 2\sigma$	Skewness Coefficient
40.78	50.99	0.14	630.58	27.55	91.76	142.75	4.87

Table 2-29.Statistical parameters of the refund sample in €/m^2.Residential category

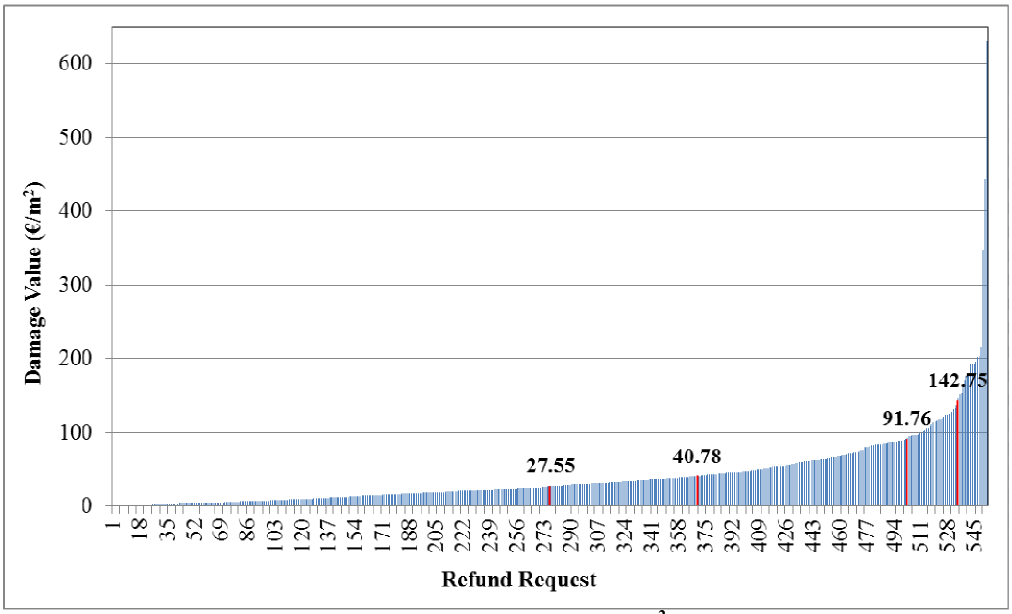


Figure 2-34.Histogram of the refund requests in €/m². Residential category

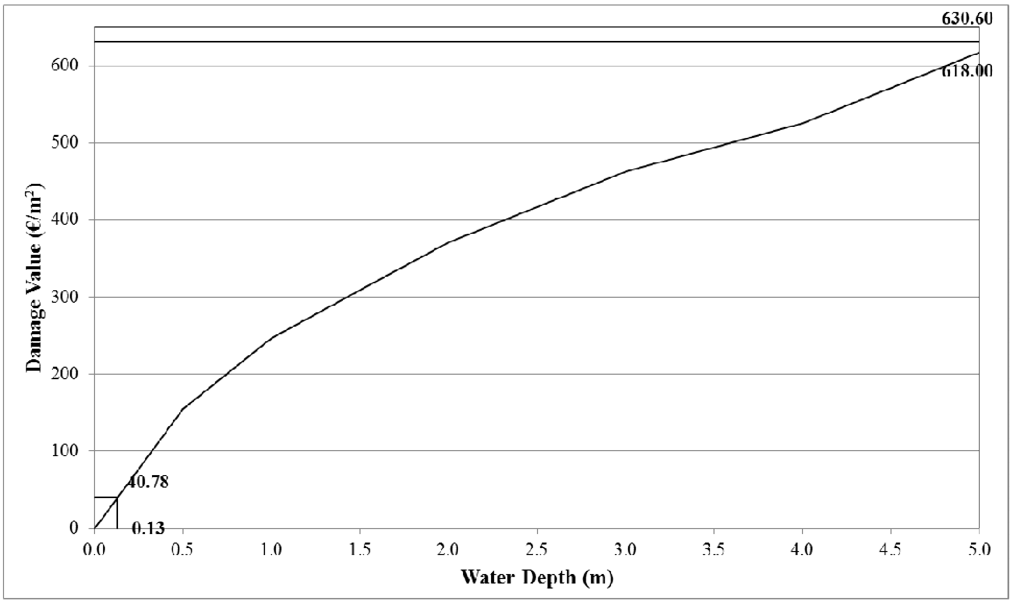


Figure 2-35.JRC Residential water depth-damage curve and mean and maximum damage values of the sample. Residential category

Figure 2-36 shows the boundaries of the flood event that hit Capoterra the 22nd October 2008 and the distribution of the residential claim data in the territory. The flood event map underlines that only data on the downstream area of Rio San Girolamo River and its main tributary, Rio Masone Ollastu River, could be associated at a water depth level. Therefore, the analysis has been improved studying data on the coastal area where the water depth levels are known.

The sample decreased from 552 data to 341 claims located mainly in the suburban areas of La Maddalena and Rio San Girolamo as shown in Figure 2-31 and Figure 2-37.

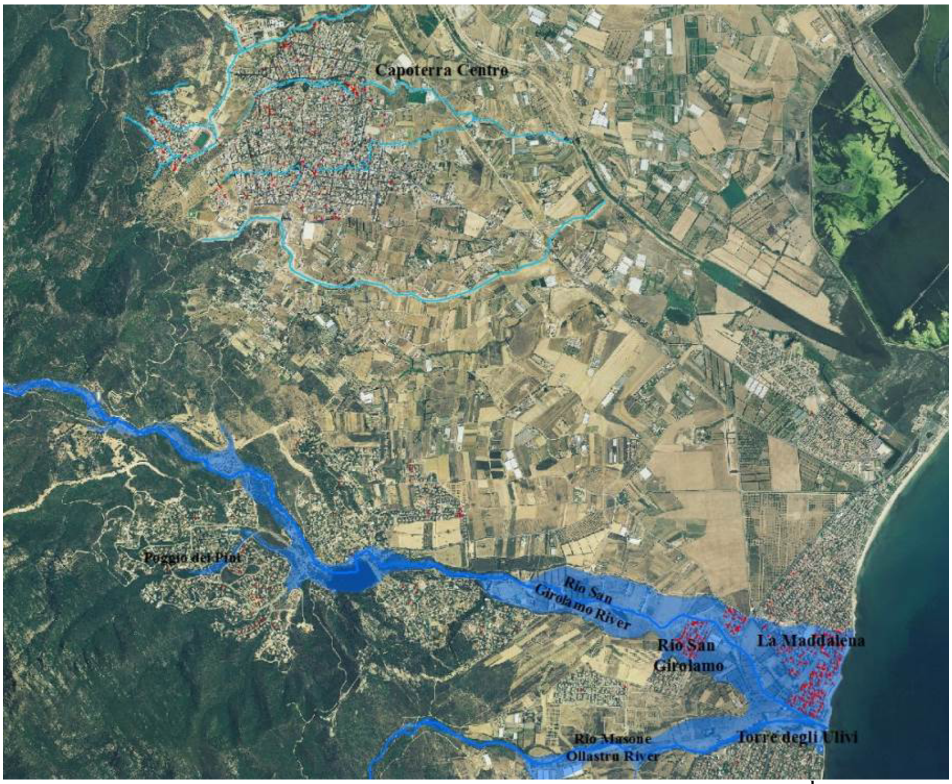


Figure 2-36.Capoterra Residential claim sample and hydraulic model of the 22nd October 2008

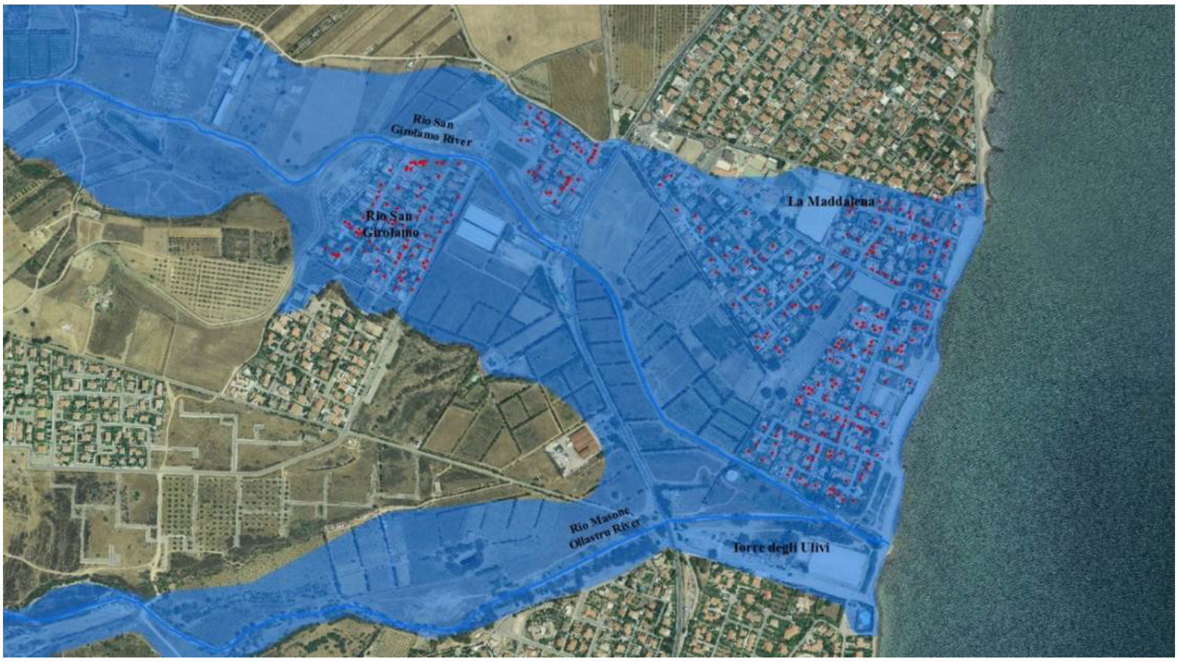


Figure 2-37.Capoterra Residential claim sample on the coastal area

The Rio San Girolamo and La Maddalena sample of data has been statistically analysed and Table 2-30 shows the sample parameters as the mean damage value of 43.90 €/m^2, associable at a water depth of 0.14 m in the JRC Residential curve, and the maximum damage value of 203.06 €/m^2 that in the JRC Residential curve could corresponds at 0.76 m of water depth, Figure 2-38. The sub-sample is still described by a high skewness index with the value of 1.64 unless lower than the value obtained analysing the whole sample of claims. In addition, Figure 2-38 shows a data distribution no coherent with the JRC Residential curve due to values lower than its trend.

The JRC Model has been applied using the available information to compare the potential damage with the total claimed damage and it gave back a potential total damage equals to 101.73 M of €, value particularly higher than the claimed economic damage of 9.21 M of €.

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	μ + σ	μ + 2σ	Skewness Coefficient
43.90	36.21	0.14	203.06	35.38	80.11	116.32	1.64

Table 2-30.Statistical parameters of the refund sample in €/m^2 and associated water depth. Residential category

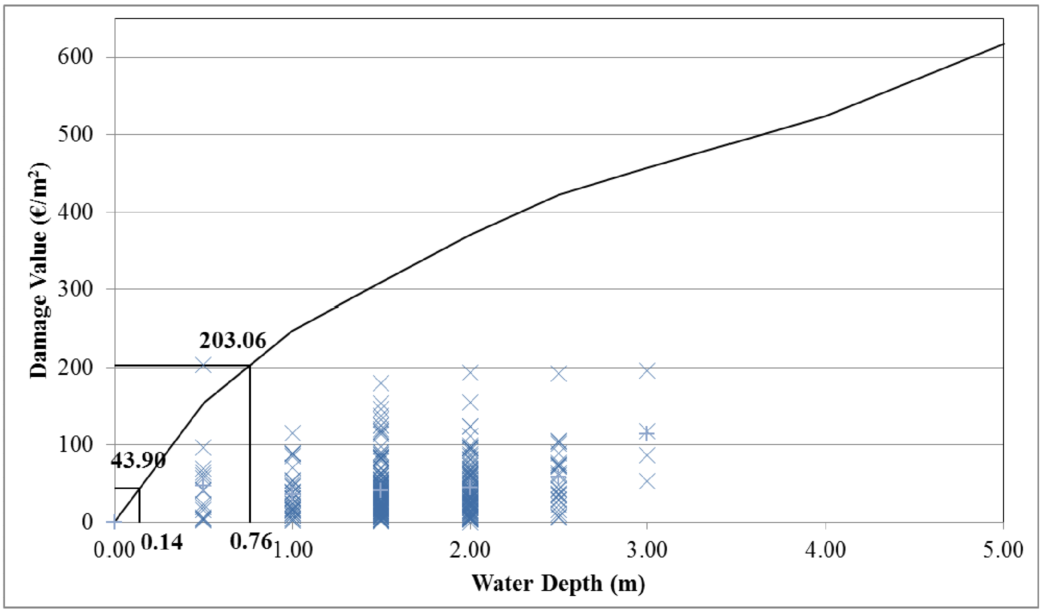


Figure 2-38.JRC Residential water depth-damage curve and distribution, mean and maximum damage values of the sample. Residential category

The low maximum damage value representative of the Rio San Girolamo sample and the high potential damage assessed with the JRC Model led to a check on data information. The check underlined high value of residential allotment areas because the typical dwelling of the area is the villa with big gardens that could reach a total value of 1 hectare. These observations led to an improvement of the study focused on the evaluation of the damage in €/m^2 of each claim based on the built area.

The improvement of the analysis required the achievement of council zoning law that manage the urbanization of Capoterra town. Capoterra zoning law provides a residential zoning map where the area is divided in zones described by different percentage value representing the potential area for construction of each allotment and called IdC Index, Figure 2-39.

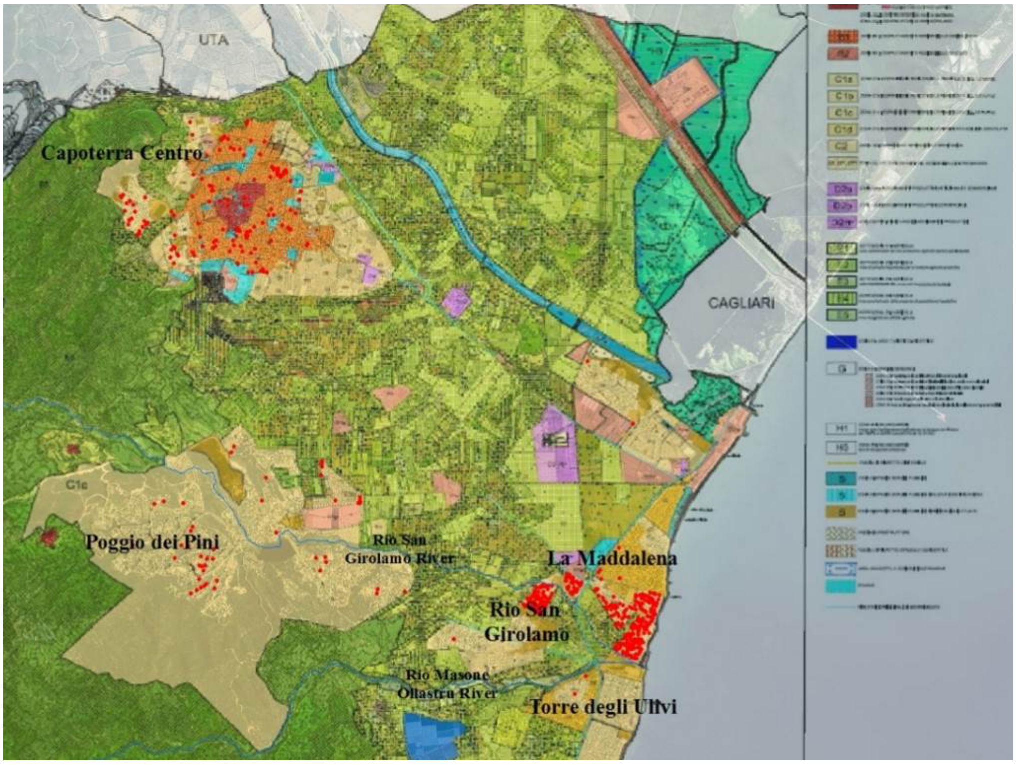


Figure 2-39.Capoterra Residential zoning map and claim data distribution

The data information have been improved defining the zones and the IdC Index according with Capoterra residential zoning map depending on the nature of the area, new building or historical area. The overlay of claim data and residential zoning map allowed to assign at each claim the proper zone and, therefore, the proper IdC Index with a code run in ArcGIS, Figure 2-40. The Capoterra zoning map reliability was verified on 61 random data of the sample for which the built area has been drawn for each residential allotment using cadastral and image maps, this value has been divided per the total area of the allotment in order to identify the percentage of area really built and compared this result with IdC Index assigned by the council zoning law. Table 2-31 shows the results of the comparison and the check on the IdC Index gives back similar values between the assigned and the evaluated IdC Index for each zones.

```
Dim C, IdC

C=[CodicZoniz]

select case C
case "A1": IdC=0.9
case "B1": IdC=0.6
case "C1": IdC=0.3
case "C1a": IdC=0.3
case "C1b": IdC=0.3
case "C1c": IdC=0.3
case "C1d": IdC=0.3
case "C2": IdC=0.25
case "C3": IdC=0.25

end select
```

Figure 2-40.Code for the attribution of the value percentage at each data based on the residential zoning map

Code of the Zone	IdC Index (m^2/m^2)	IdC Index evaluated (m^2/m^2)
A1	0.90	0.84
B1	0.60	0.56
C1	0.30	0.30
C2	0.25	0.25

Table 2-31.Results of the check on the IdC index

The application of the IdC Index at each claim lead to recalculate the total value of the damaged area. The new analysis underlines that the total damage of 11.54 M € is caused in a built area of 165869.59 m^2 with a reduction higher than the 50% of 507945.57 m^2 firstly evaluated as shown in Table 2-32. The statistical analysis developed on the improved sample of damage values shows a relevant increment of the maximum damage value for the whole Capoterra territory that reaches 1050.97 €/m^2. The same observation takes place for the mean damage value that reaches 117.97 €/m^2, Table 2-33, at which could be assigned at a water depth value of 0.38 m in the JRC Residential water depth-damage curve, Figure 2-42.

Damage (M €)	Damaged Area (m^2)	Damaged Built Area (m^2)
11.54	507945.57	165869.59

Table 2-32.Total Damage in Millions of € and relative damaged areas considering total allotment area or the built area. Residential category

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	$\mu + \sigma$	$\mu + 2\sigma$	Skewness Coefficient
117.97	127.11	0.46	1050.97	78.35	245.07	372.18	2.43

Table 2-33.Statistical parameters of the refund sample in €/m^2 and associated water depth evaluated applying the IdC Index. Residential category

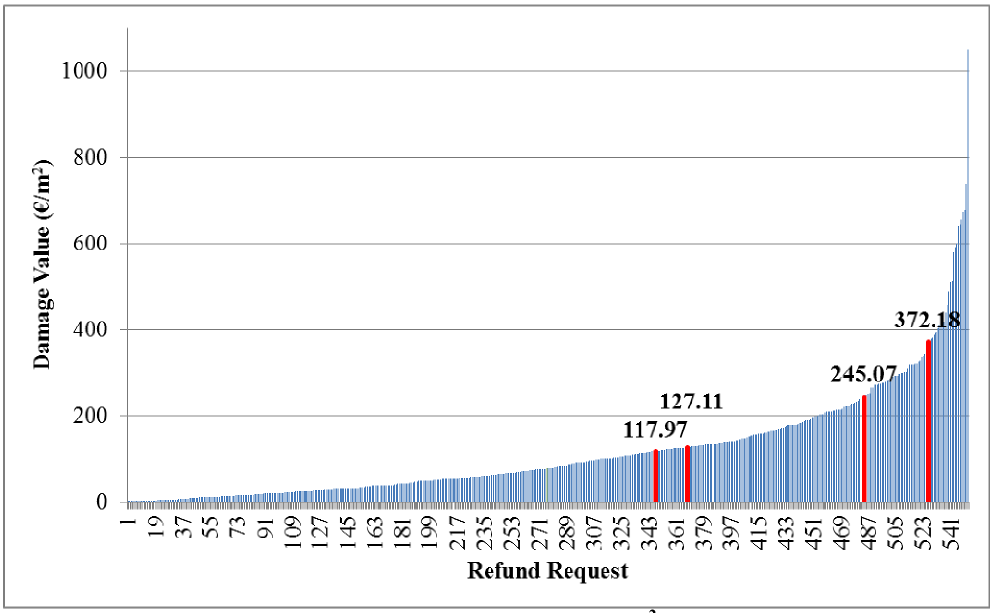


Figure 2-41.Histogram of the refund requests in €/m². Residential category

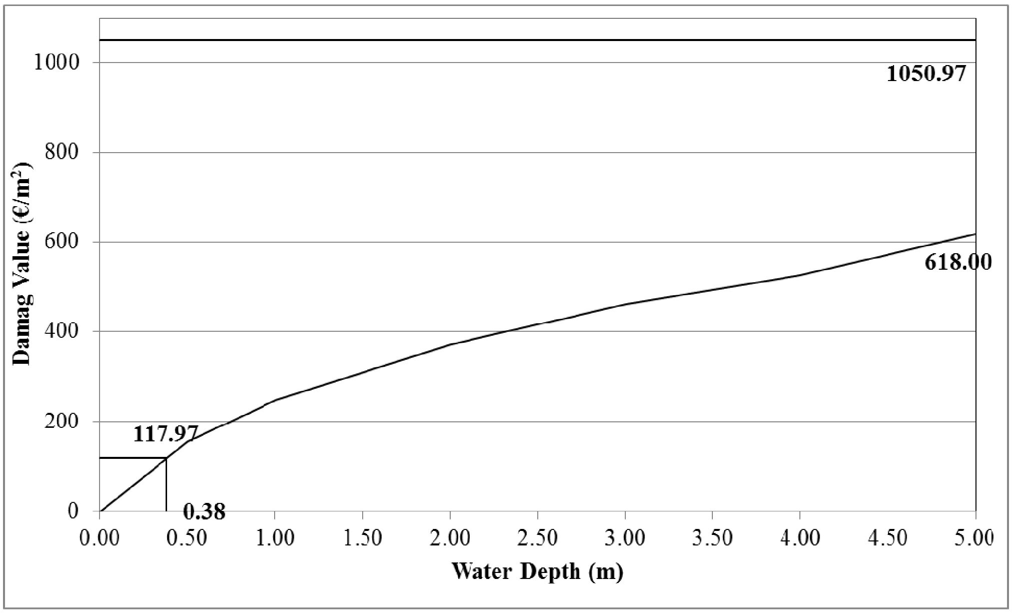


Figure 2-42.JRC water depth-damage curve and mean and maximum damage values of the sample. Residential category

The comparison of the damage based on the water depth level caused by the event have been reprocessed considering the new value of damages in €/m². Therefore the statistical analysis have been reapplied on the 341 refund data on the area at the downstream of Rio San Girolamo River and Rio Masone Ollastu River. The statistical analysis identifies a mean damage value of 146.37 €/m² associable at a water depth of 0.47 m considering the JRC Residential water depth-damage curve trend, Figure 2-43, and a maximum damage value of 676.87 €/m² close to the value defined in the JRC Model for a water depth level of 5 m.

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	μ + σ	μ + 2σ	Skewness Coefficient
146.37	120.69	0.46	676.87	117.94	267.05	387.74	1.64

Table 2-34.Statistical parameters of the refund sample in €/m² and associated water depth evaluated applying the IdC Index in Rio San Girolamo River and Rio Masone Ollastu River downstream area. Residential category

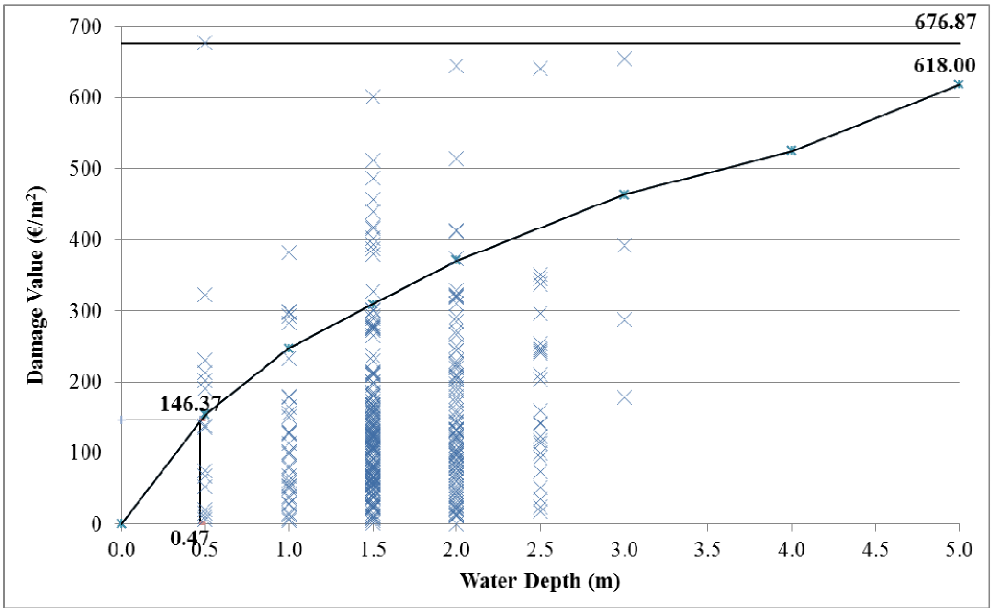


Figure 2-43.JRC Residential water depth-damage curve, mean and maximum damage values of the Capoterra sample in Rio San Girolamo River and Rio Masone Ollastu River downstream area evaluated applying the IdC Index. Residential category

The claimed total damage of 9.21 M € for the downstream area is associated in the new analysis with an area of 91279.01 m², instead of 304403.93 m² of the initial analysis. These information allowed to reapplied the JRC Model as conducted on the first residential claim database. The JRC Model application gave back a potential total damage of 30.51 M € considering damages only on the allotment area really built. The comparison with the results of the first analysis, 101.73 M €, underlines a new more reliable potential economic damage. In addition, the new potential economic damage is more adequate at the claimed value of 9.21 M € that is limited by regional authorities consideration on type of building, use of building and categorisation of chattels, Table 2-35.

Claimed Damage (M €)	JRC Damage based on the allotment area (M €)	JRC Damage based on the built area (M €)
9.21	101.73	30.51

Table 2-35.Comparison of the claimed damage with the potential damage evaluated with the JRC Model based on the whole allotment area and on the built area in the Rio San Girolamo e La Maddalena areas

The residential sample has been refined excluding from the analysis data with damage values particularly high after a deep analysis of the sample. The sample size decreases from 341 to 329 data and has been analysed grouping the damage values in function of water depth step of 0.5 m. The refined sample is characterised by a mean damage value of

175.55 €/m^2 and a maximum damage value of 862.00 €/m^2. Table 2-36 shows the statistical parameters of the damage value groups. The attention is focused on the mean damage values (μ) and on the mean plus the standard deviation ($\mu+\sigma$) damage value of each group. In particular, the analysis works to identify a representative curve of the Capoterra flood event. The trend of the curves follows the JRC curve trend mainly for water depth step within 0.5 m when, considering the type of building in the analysed area, the main damages on furniture, heating systems and stored goods are determined. Observing the curves, Figure 2-44, their trend has a stable behaviour for water depths between 0.5 m and 2 m and follows with a relevant increment after water depth of 2 m justifiable because at these levels of water depth the flood causes structural damages on buildings. The Capoterra curve obtained by the $\mu+\sigma$ is taken into consideration unless does not confirm perfectly the JRC curve trend, but they represent how the damages occur in residential properties when hit by flood and, in particular, they describe the damage increment for building as 1-floor villa type characteristics of Capoterra coastal area.

Water Depth (m)	Mean Value (μ)	Standard Deviation (δ)	$\mu+\delta$	$\mu+2\delta$
0.50	134.80	129.54	264.34	199.57
1.00	162.09	144.96	307.05	234.57
1.50	168.09	140.15	308.24	238.16
2.00	178.95	141.42	320.37	249.66
2.50	220.55	154.43	374.98	297.76
3.00	336.99	139.16	476.15	406.57

Table 2-36.Statistical parameters for each water depth class with step of 0.5 m. Residential category

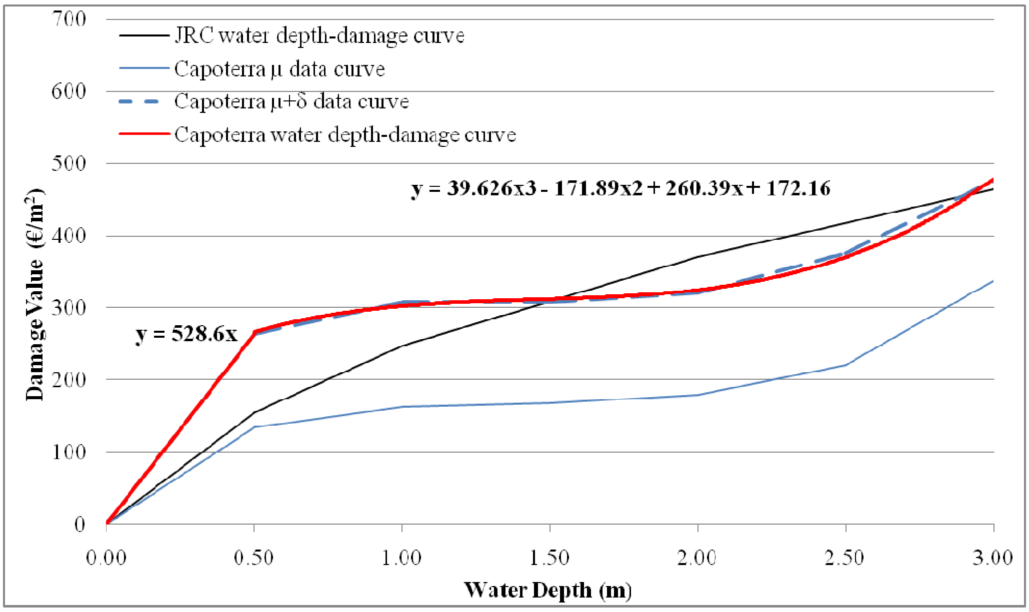


Figure 2-44.Comparison of the JRC water depth-damage curve, the Capoterra μ data curve and Capoterra $\mu+\delta$ data curve. Residential category

2.2.2.1.2. Commercial refunds samples analysis

Commercial sample of requested claims supplied by Capoterra Council for damages on commercial structures and inventory consisted of 98 refund requests and only 72 of them were admissible. The main information usable and supplied in Capoterra commercial database for each claim are the unique ID, economic damage appraisal and location provided with the address. The economic damage appraisal was associated to its cadastral allotment using in ArcGIS the cadastral map provided by Sardinian regional authorities, Figure 2-32, to identify the damage in Euros per square meters for each claim and their distribution in the territory in relation with the boundaries of the flood event. Correspondence of declared address and localisation in the cadastral map has been confirmed checking each claim with Google Street as made studying the residential claim sample. The check has been developed verifying the correct location of the claim in the map not only paying attention at the road name but also confirming the address number and that each claim falls into the proper allotment. In this way each claim has been georeferenced and the original sample of 72 admissible requests decreased to 50. The georeferentiation process of each sample allowed to identify claims distribution in the territory, Figure 2-33, while the analysis of data information with ArcGIS gave back a total damage of 0.37 M € associated at a total area of residential properties allotment equals to 37606.10 m^2.

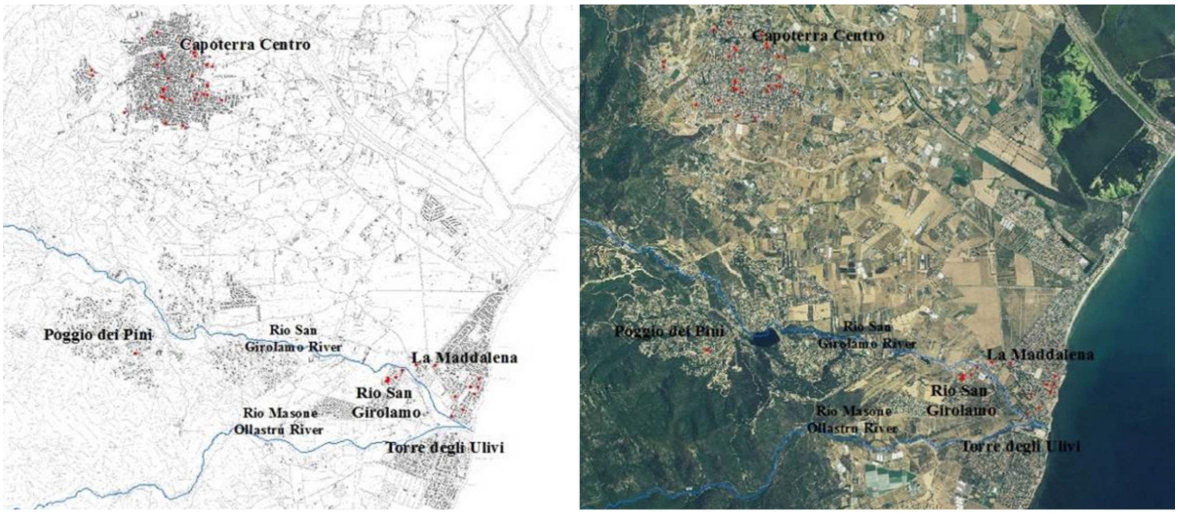


Figure 2-45.Distribution in the territory of Capoterra Commerce sample of damages

The damages in Euros per square meters, €/m^2, for each claim have been statistically studied to know the maximum and mean damage value of Capoterra commercial sample and, then, compare the results with damage values identified for Italy by the JRC Model Report. The mean damage value of the sample is equal to 16.87 €/m^2, while the maximum damage value in the whole Capoterra town territory reaches the 172.05 €/m^2 value very different compared to the JRC value assessed for the commercial land use category of 511.00 €/m^2, Table 2-29. The low mean value could depend by different type of activities distributed in the territory mainly small shops. This sample properties is underlined by the high skewness coefficient value, 4.28, characterised by a stressed asymmetry represented in Table 2-37. The maximum and mean damage value have been studied in relation with the JRC Commercial water depth-damage curve to identify their location in comparison with water depth and JRC maximum damage value. In Figure 2-47 the comparison is shown. The mean damage value could be determined by a water depth of 0.11 m considering the damage trend described by the JRC curve, while the representative maximum damage value of 172.05 €/m^2 corresponds at a water depth of 1.12 m in the JRC curve.

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	μ +σ	μ + 2σ	Skewness Coefficient
16.87	27.30	1.13	172.05	9.88	44.17	71.46	4.28

Table 2-37.Statistical parameters of the Capoterra sample in €/m^2.Commercial category

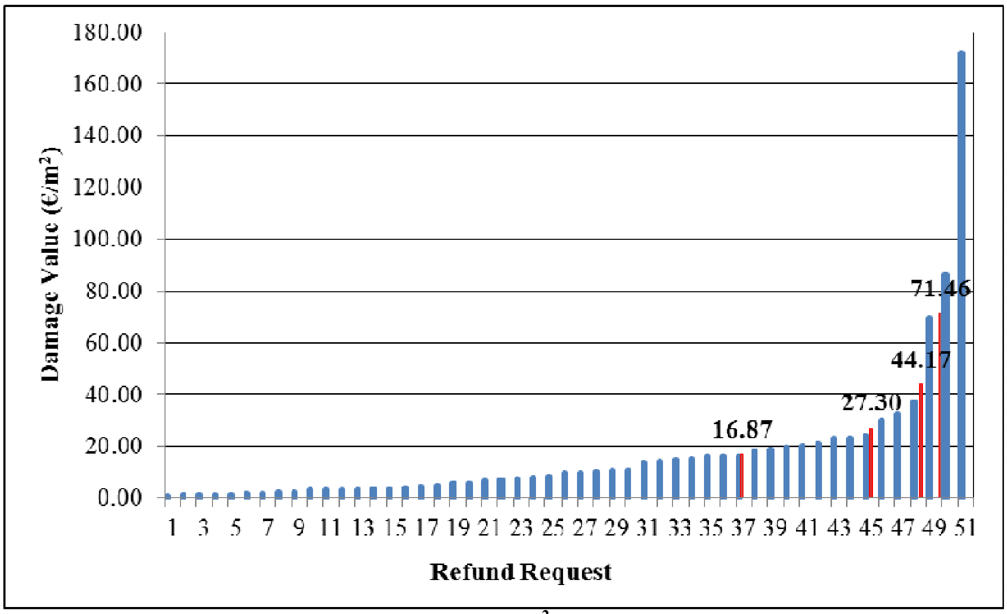


Figure 2-46.Refund Damage Value in €/m^2 histogram. Commercial category

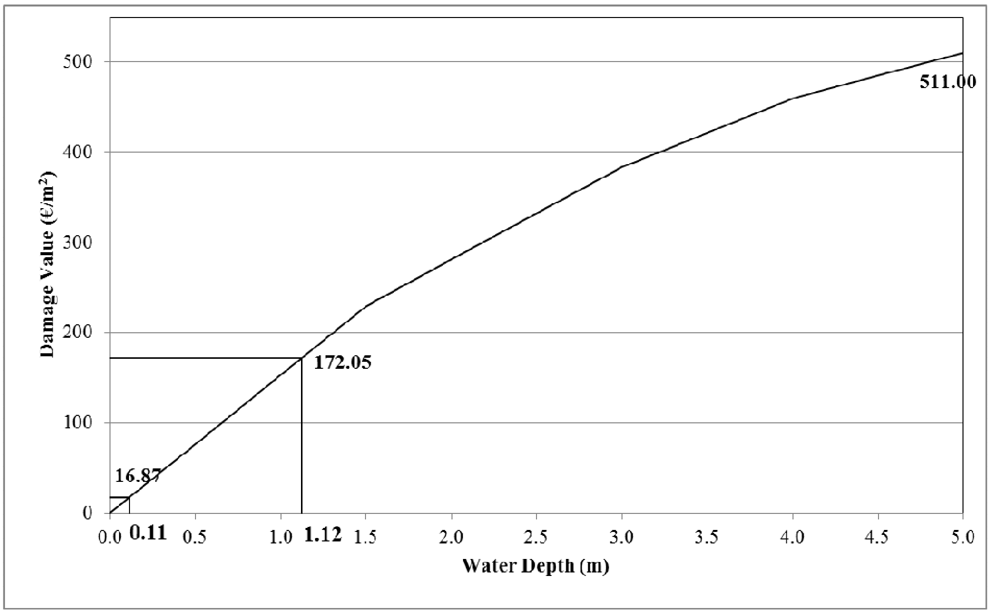


Figure 2-47.JRC water depth-damage curve and mean and maximum damage values of the Capoterra sample. Commercial category

The commercial sample of collected damages has been studied following the same process applied on the residential sample of damages. The hydraulic model reconstruction of the flood event has been related with the commercial data distribution in the territory and only data on the downstream area of Rio San Girolamo River and its main tributary, Rio Masone Ollastu River, have been associated at a water depth level.

The sample decreased from 50 data to 16 claims located in the suburban areas of La Maddalena and Rio San Girolamo as shown in Figure 2-48. The statistical analysis of the sample limited at the coastal areas gives back a mean value of damage of 8.72 €/m^2 and a maximum damage value of 23.35 €/m^2. These low value of damages have to be related with the lack of relevant commercial activity in Capoterra territory as shopping malls. In addition, the JRC Model application on the commercial sample gave rise at an improbable value of potential total damage of 4.90 M € considering that the claimed total damage in the coastal area reached only 0.13 M €, in fact, although the shortage of data, the JRC Commercial water depth-damage curve shows a trend very distant from the Capoterra commercial sample distribution, Figure 2-49.

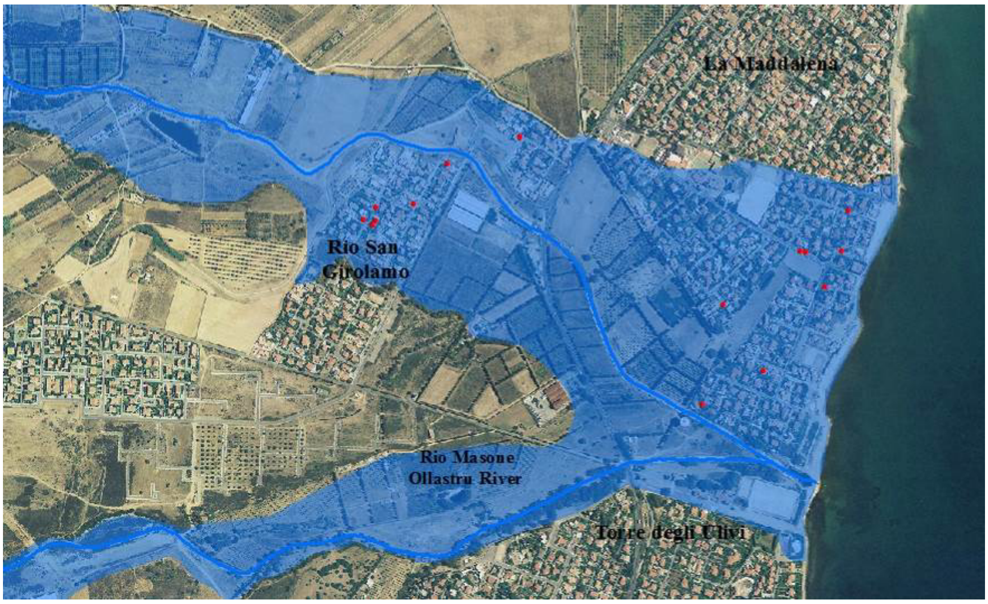


Figure 2-48.Capoterra refund sample on the coastal area. Commercial category

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	μ + σ	μ + 2σ	Skewness Coefficient
8.72	6.82	2.00	23.35	7.05	15.54	22.36	0.96

Table 2-38.Statistical parameters of the Capoterra sample in €/m² in Rio San Girolamo River and Rio Masone Ollastu River downstream area. Commercial category

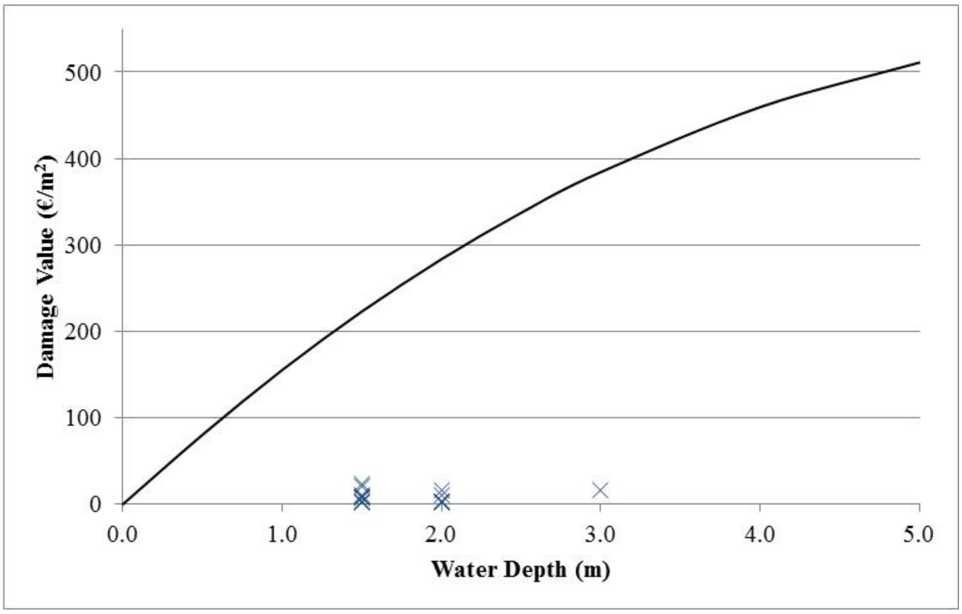


Figure 2-49.JRC water depth-damage curve, mean and maximum damage values of Capoterra sample in Rio San Girolamo River and Rio Masone Ollastu River downstream area. Commercial category

The study of the commercial sample have been improved evaluating the damage in relation with the built area of the allotment as developed for the residential sample. That process describes the refund damage in function of the area really damaged and excluding gardens in the assessment. The total damaged area decreased from 37606.10 m² to 15678.54 m², Table 2-39. The increment of the damage in €/m² of each claim determined an increment on the statistical parameters of the sample. In fact, the mean damage value increases to

36.01 €/m^2 and the maximum damage value reaches 289.56 €/m^2. The analysis of these values in relation with the JRC water depth-damage curve identifies the mean damage value associable with a water depth level of 0.23 m and the maximum damage value associable with the water depth of 2.08 m, Figure 2-51.

Damage (M €)	Damaged Area (m^2)	Damaged Built Area (m^2)
0.37	37606.10	15678.54

Table 2-39.Total Damage in Millions of € and relative damaged areas considering total allotment area or the built area. Commercial category

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2SD	Skewness Coefficient
36.01	56.83	1.89	289.56	20.18	92.84	149.66	3.73

Table 2-40.Statistical parameters of the Capoterra sample (€/m^2) evaluated applying the IdC Index. Commercial category

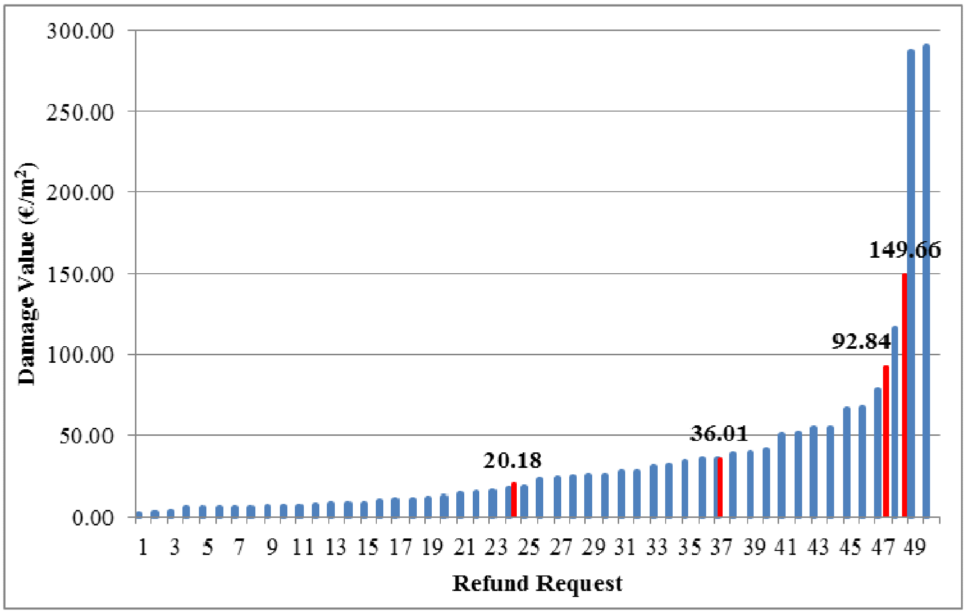


Figure 2-50.Refund Damage Value in €/m^2 histogram. Commercial category

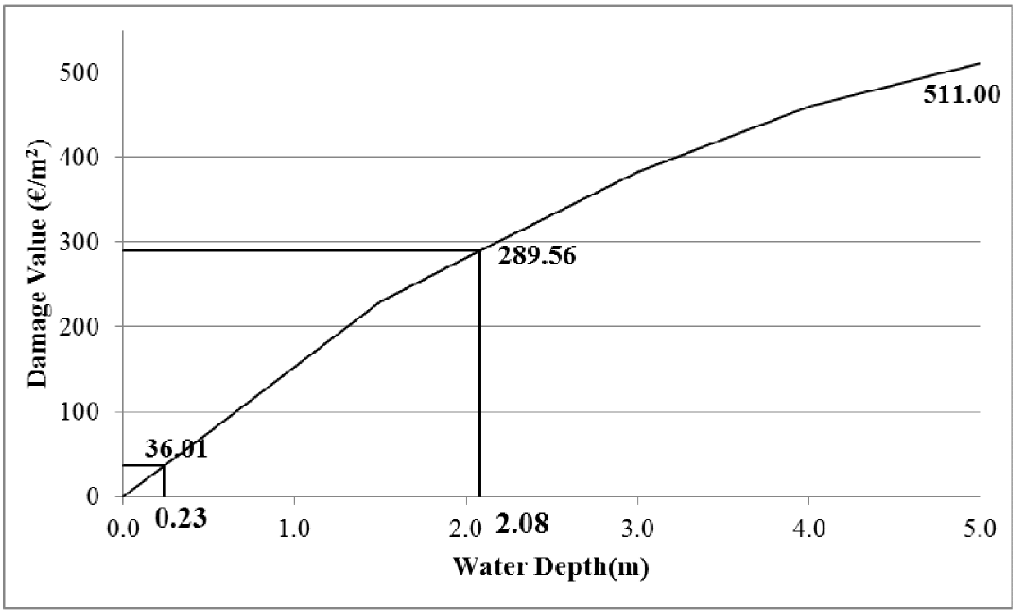


Figure 2-51.JRC water depth-damage curve and mean and maximum damage values of Capoterra sample. Commercial category

The damage in €/m^2 of each claim has been analysed only on the coastal area where the maximum water depth of the flood are known. The sample of 16 data still gives back low statistical parameter values. The mean damage value increases to 28.15 €/m^2 that in the JRC Commercial water depth-damage function could be associated with a water depth of 0.18 m, while the maximum damage value reaches 77.83 €/m^2 associable with a water depth of 0.51 m in the JRC Commercial curve, Figure 2-52 and Table 2-41.

The JRC Model implementation on the refined sample of commercial data gives back a potential total damage that could reach 1.53 M €. This value is more reliable than the previous value of 4.90 M € evaluated studying the damage in function of the whole allotment areas, but it is still no reliable if it would be compared with the total requested refund of 0.13 M €, Table 2-42.

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	μ + σ	μ + 2σ	Skewness Coefficient
28.15	23.02	6.68	77.83	18.56	51.17	74.20	1.04

Table 2-41.Statistical parameters of the Capoterra sample (€/m^2) evaluated applying the IdC Index in Rio San Girolamo River and Rio Masone Ollastu River downstream area. Commercial category

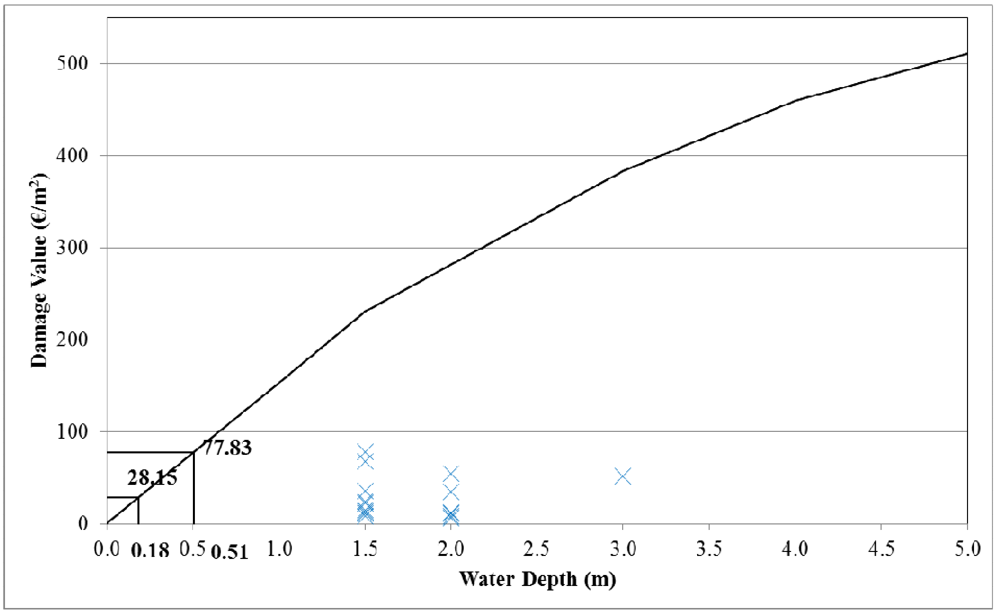


Figure 2-52.JRC water depth-damage curve, mean and maximum damage values of Capoterra sample in Rio San Girolamo River and Rio Masone Ollastu River downstream area evaluated applying the IdC Index. Commercial category

Claimed Damage (M €)	JRC Damage based on the allotment area (M €)	JRC Damage based on the built area (M €)
0.13	4.90	1.53

Table 2-42.Comparison of the claimed damage with the potential damage evaluated with the JRC Model based on the whole allotment area and on the built area in the Rio San Girolamo e La Maddalena areas. Commercial category

2.2.2.1.3. Agriculture refunds samples analysis

The 10th December 2008 Sardinian Regional Authority with the Regional Decree n°69/28 approved the allocation of funds to claim and restore the damage on agriculture area caused by the flood of the 22nd October 2008. The economic support considered the damages on agriculture land and inventory as buildings, equipment, pastures, livestock, food and provender. The funds subsidised consisted of 22 M € conveniently appraisal and verified by the Sardinian authorities for all of the towns hit by the flood in the regional territory. 189 farmers applied to be supported, but only 36 of them were provided by requirement defined in the Regional Decree 69/28.

The Sardinian Regional Division for Agriculture Handout Administration (ARGEA) supplied the necessary information for the analysis of the collected sample in terms of economic claim, cadastral data information, declared damaged area, appraisal damage and approved funds.

The claims have been elaborated with ArcGIS to be localised in Capoterra territory according with the cadastral map of the area. This process led the research to analysis only 17 claims, Figure 2-53, that have been related with the flood map, Figure 2-54.

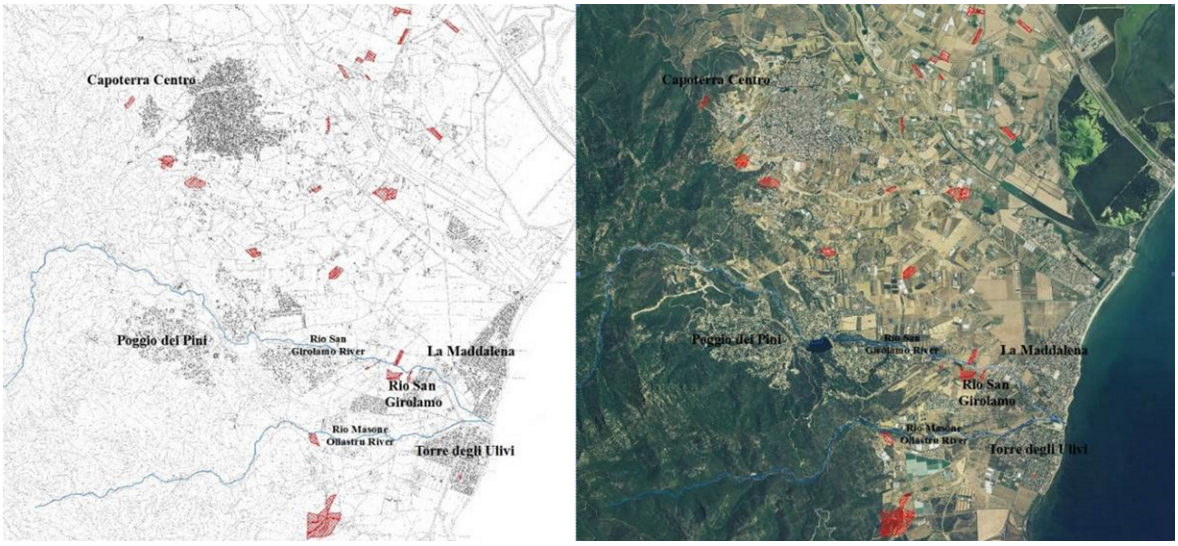


Figure 2-53.Distribution in the territory of Capoterra Agriculture sample of damages

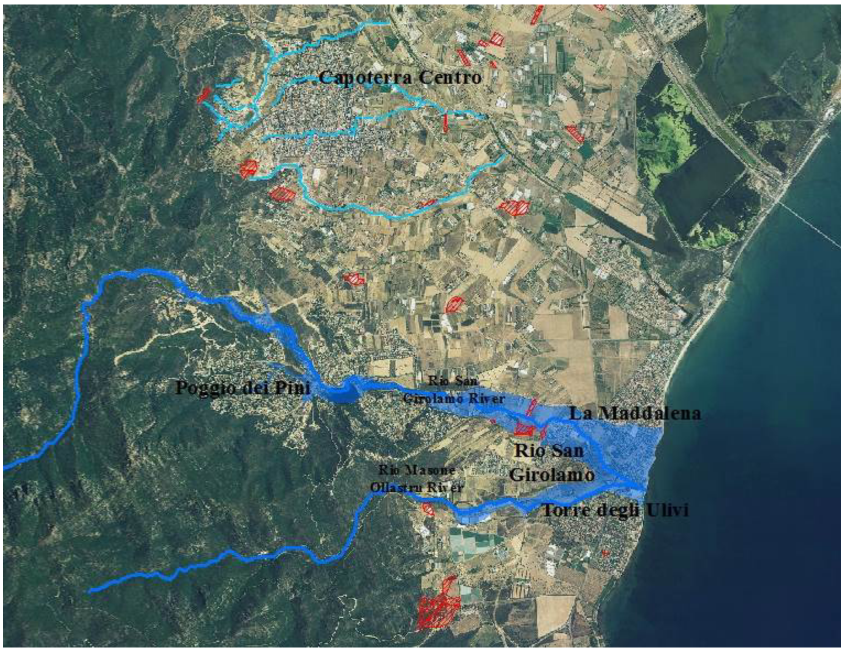


Figure 2-54.Agriculture damage claimed distribution in Capoterra territory and flood event

The analysis of the agriculture sample allowed to evaluate the total approved damage of 2.36 M €, associated to an area of 4347.22 m^2, and to identify for each claim the damage in Euros per square meters, Table 2-43. The sample has been statistically analysed identifying a mean damage value of 1101.01 €/m^2 and a maximum damage of 9932.02 €/m^2, Table 2-44. These statistical values are completely out of the range identified by the JRC Model for Italian territory that is equal to 0.63 €/m^2, Figure 2-56.

Refund ID	Refund Damage (€)	Damaged area (m^2)	Damage (€/m^2)
1.00	81608.44	117.00	697.51
3.00	143756.40	196.00	733.45
4.00	844221.30	85.00	9932.02
6.00	138226.99	130.00	1063.28
10.00	187144.28	133.82	1398.48
12.00	33275.00	211.42	157.39
17.00	3575.15	65.00	55.00
18.00	11984.61	61.00	196.47
19.00	4752.95	26.00	182.81
20.00	229255.33	95.00	2413.21
21.00	42271.79	79.98	528.53
23.00	138485.00	617.00	224.45
29.00	45250.00	471.00	96.07
30.00	24499.49	471.00	52.02
31.00	385199.22	1478.00	260.62
32.00	32754.24	62.00	528.29
33.00	9481.50	48.00	197.53

Table 2-43.Refund Database of the localised claim. Agriculture category

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2SD	Skewness Coefficient
1101.01	2355.83	52.02	9932.02	260.62	3456.84	5812.67	3.70

Table 2-44.Statistical parameters of the Capoterra sample in €/m². Agriculture category

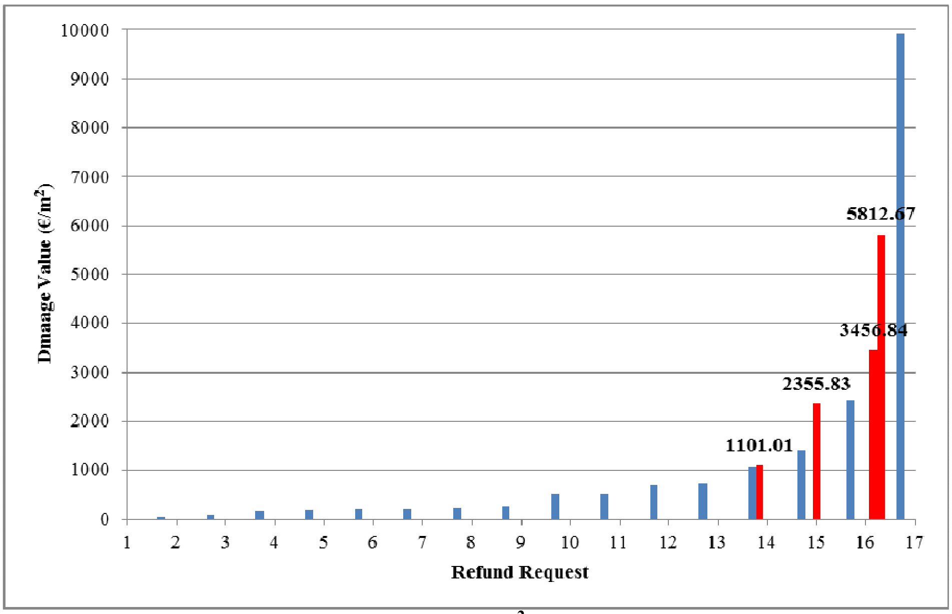


Figure 2-55.Refund Damage Value in €/m² histogram. Agriculture category

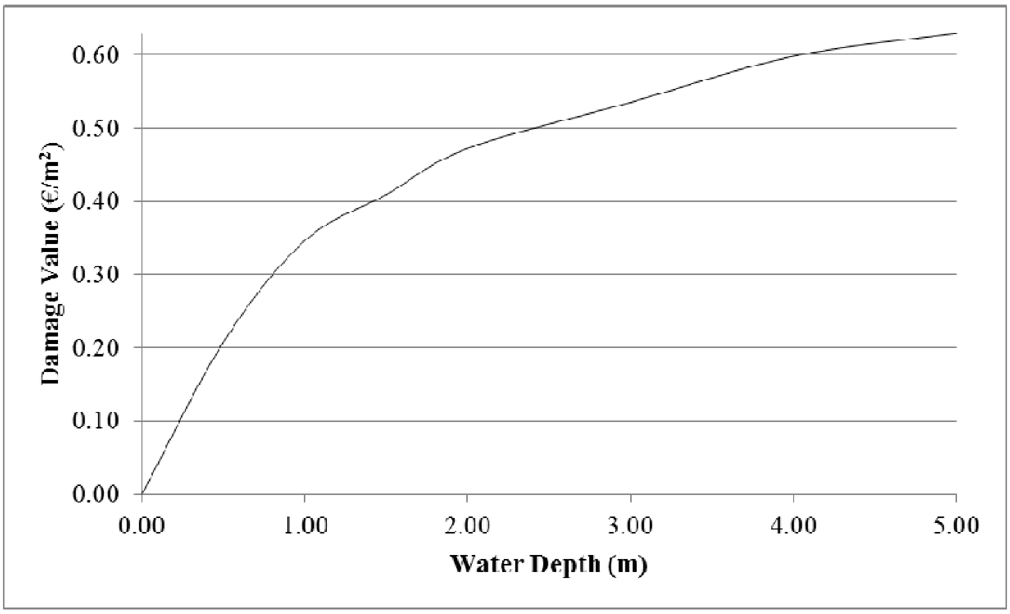


Figure 2-56.JRC Agriculture water depth-damage curve

A deep analysis of the sample allowed to identify an incongruity on the declared damaged area that have been recalculated using the cadastral map. The analysis identified a total damaged area of 405445.40 m² and the Table 2-45 shows the recalculated damaged areas of each claim that allowed to evaluate the damage in €/m². The statistical parameters have been revaluated and the sample is now described by a mean damage value of 6.38 €/m² and a maximum damage value of 52 €/m², Table 2-46. The sample statistical values are still out of the range defined by the JRC Model. This aspect could be justified by the refund requirement accepted by the Regional Decree 69/28 that considered refundable goods as equipment and livestock considerable as industrial properties.

The agriculture claim location on the map does not allow the analysis of the sample in relation with the flood map 2D model because only 1 of the 17 claims could be associated with the water depth, Figure 2-58. This limit impeded to compare the agriculture claims information with the JRC Agriculture water depth-damage function.

Claimed ID	Request Claimed (€)	Cadastral Damaged Area (m^2)	Damage (€/m^2)
1	81608.40	37025.70	2.20
3	143756.00	31461.68	4.57
4	844221.00	16234.46	52.00
6	138227.00	37214.37	3.71
10	187144.00	21951.34	8.53
12	33275.00	19001.24	1.75
17	3575.15	5576.36	0.64
18	11984.60	15113.85	0.79
19	4752.95	8146.70	0.58
20	229255.00	18472.25	12.41
21	42271.80	14453.34	2.92
23	138485.00	31450.31	4.40
29	45250.00	13661.56	3.31
30	24499.50	13151.71	1.86
31	385199.00	107227.50	3.59
32	32754.20	10830.80	3.02
33	9481.50	4472.23	2.12

Table 2-45.Refund Database of the localised claims and with recalculated area. Agriculture category

Mean Value (μ)	Standard Deviation (σ)	Minimum Value	Maximum Value	Median	$\mu + \sigma$	$\mu + 2\sigma$	Skewness Coefficient
6.38	12.12	0.58	52.00	3.02	18.50	30.63	3.74

Table 2-46.Statistical parameters of the Capoterra sample in €/m^2 based on the recalculated areas. Agriculture category

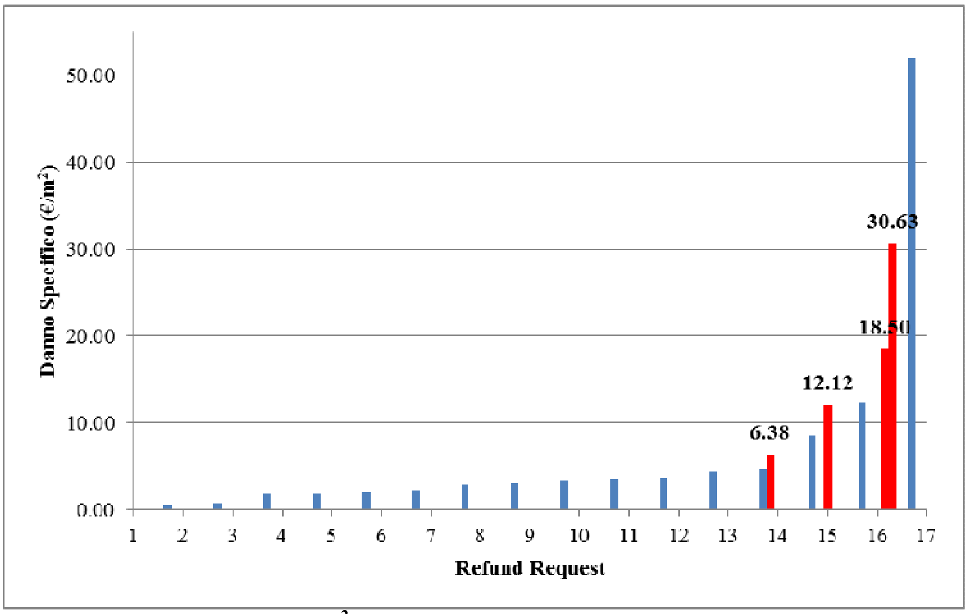


Figure 2-57.Refund Damage Value in €/m^2 histogram with damage based on the recalculated areas. Agriculture category

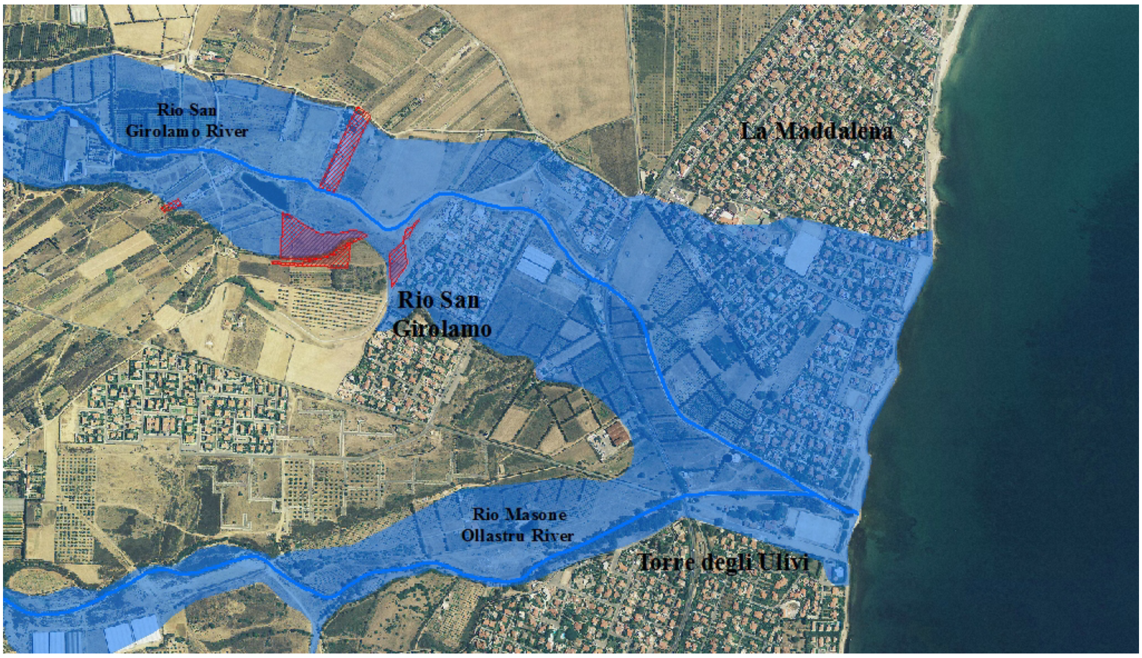


Figure 2-58.Claim associable in the flood plain map reconstruction. Agriculture category

2.2.2.2. Flood event of the 18th November 2013 in Olbia council area

The recent relevant flood occurred in Sardinia is registered between 18th and 19th November 2013 and hit mainly the eastern coast of the territory and south-west areas. 17 victims were registered and huge damages on 82 Sardinian towns were appraised due to the actions of flood, landslide and wind.

The analysis of the flood event, named Cleopatra cyclone, showed many river flood associated with flash flood characteristics of the Mediterranean basin during usually the months of October and November when temperature gradients occurs determined by the interaction of warm air mass from Africa Region and cold air mass from the north of Europe. In the Flood Significant Event Report-Volume 3 the isohyets representation is reported and underlines the area mainly damaged, Figure 2-59 (RAS-Vol.3, 2015) (Civil Protection, 2013).

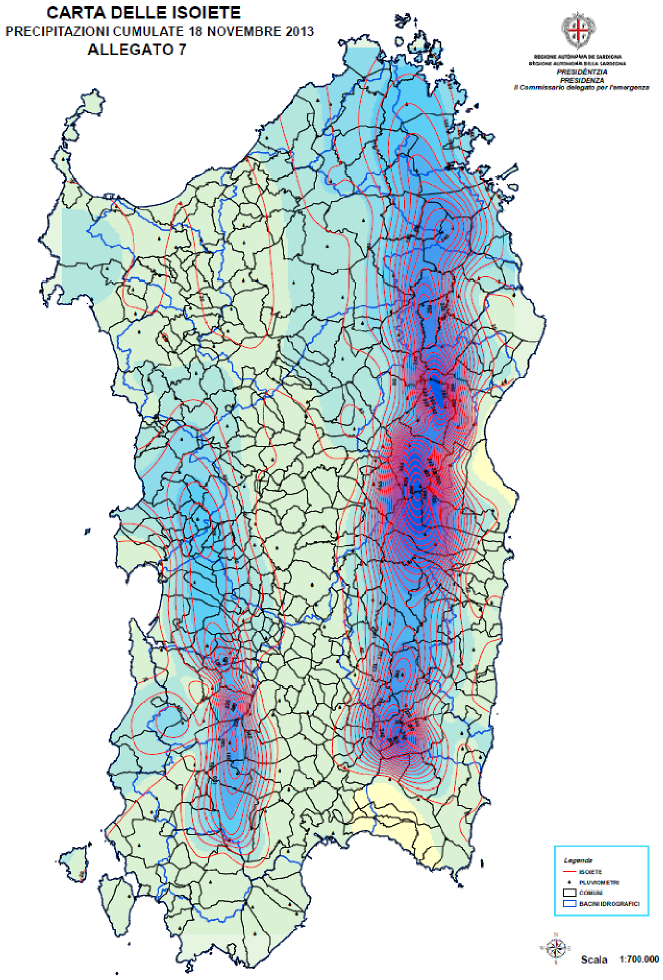


Figure 2-59.Isohyet of the 18th and 19th flood event (Civil Protection-RAS, 2013)

In the territory of Olbia town, North-East coast of Sardinia, the rain gauges registered a rainfall from 117.6 to 190 mm occurred between 9 A.M. and 22 P.M.. The authorities acted to support the emergency funding assistance for the population and urgent mitigation measures.

The Sardinian Hydrographic District Authority analysed the territory of the all towns mainly damaged by the flood comparing the flooded areas with the studies previously developed in the PSFF. The comparison underlined that Olbia town was hit by a no expected event, Figure 2-60, mainly caused by a strong urbanisation of the territory during the recent years.

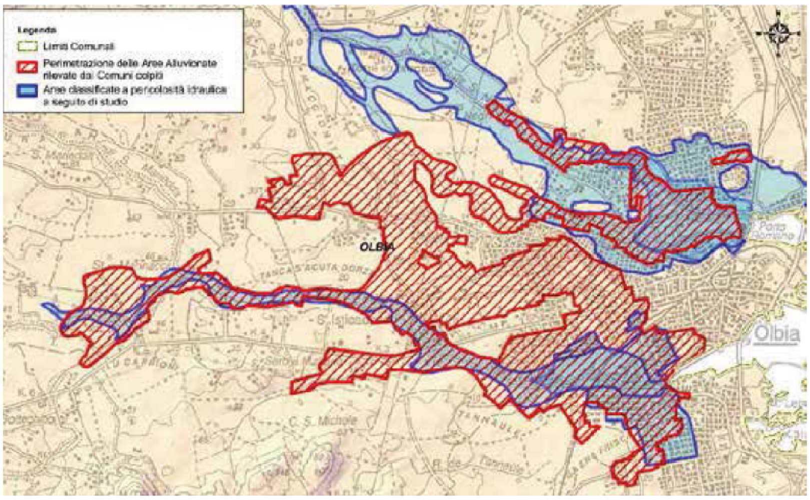


Figure 2-60.Comparison of the area flooded the 18th November 2013 (red) and the PSFF map (blue)(Mancini M. ,2014)

Olbia town is part of the Sardinia Liscia basin n°4. The territory around the town has been flooded by the six main rivers of Riu Paule Longa River, Riu Seligheddu, Riu Gadduresu, Zozò Canal, Riu San Nicola River and Riu Tilibas River that interested an area of 72.5 km^2 developed from a maximum ground level of 721.9 a.m.s.l. and a minimum level of 0.2 m a.m.s.l.. These rivers characterise the river network system of Olbia town as shown in Figure 2-61.

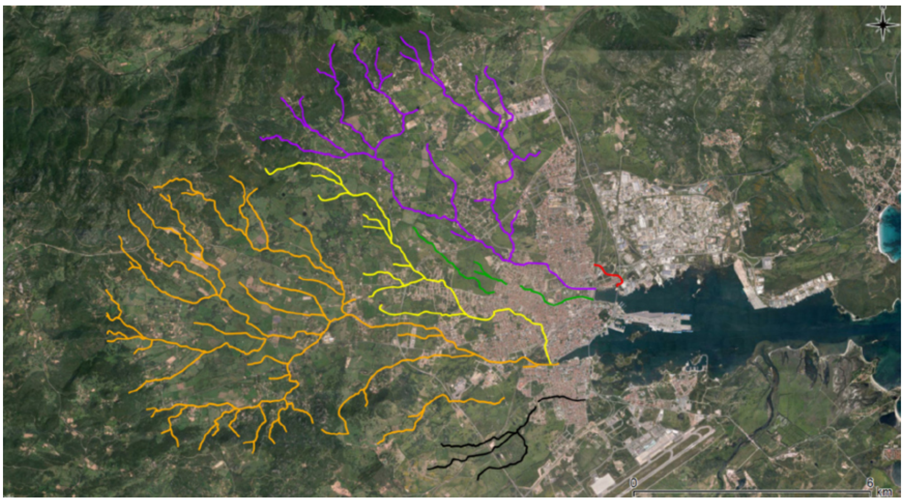


Figure 2-61.River system network of Olbia urban area(Mancini M. ,2014)

The flood in Olbia territory caused by Cleopatra Cyclone has been analysed and hydraulically remodelled taking in consideration water levels appraisal in the area observing the buildings, infrastructures and ground conditions. These data were compared with the water depth values obtained by the hydraulic reconstruction of the event with the distributed hydrologic-hydraulic model FEST-RS (Mancini M., 2014). The hydrologic analysis of the event was based on data rain gauged in the Olbia and Putzolu rain gauge stations and used to reconstruct the hydrograph of the event. The hydrograph shows high value of flow rate, the worst case was registered with peak of 200 m^3/s associated at a volume of 2'130'000 m^3 discharged around 12 hours on the Riu Seligheddu River. The analysis of the event defined a 25-30 years event for Riu Paule Longa River, Riu Gadduresu, Zozò Canal, Riu San Nicola River and Riu Tilibas River and 50 years event for Riu Seligheddu River.

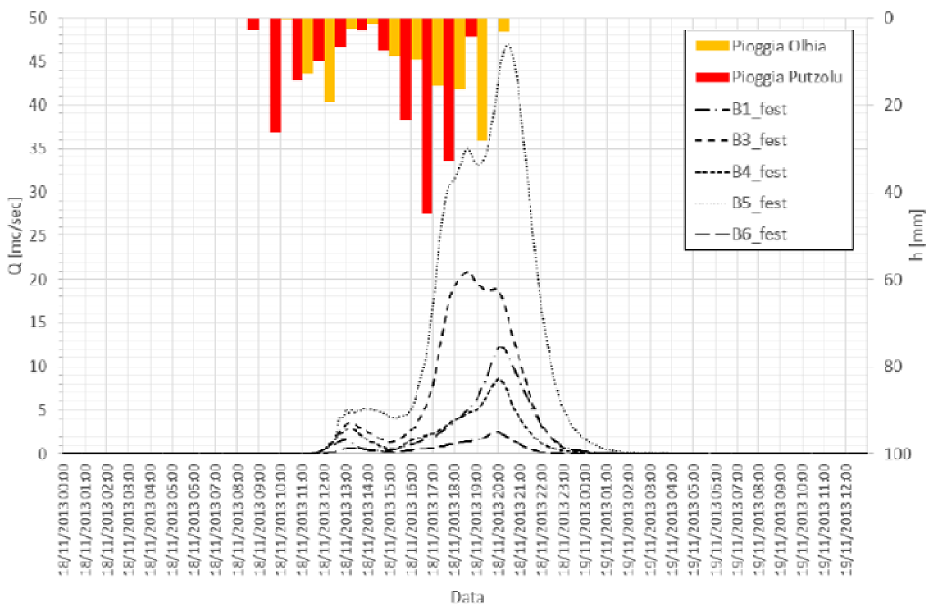


Figure 2-62.Simulated hydrograph of the 18th November 2013 event(Mancini M. ,2014)

The hydrograph defines the upstream boundary condition, while the downstream boundary condition consisted of a water level of 1 m.

The FEST-RS hydraulic model implemented the debris flood reducing the river sections and the obtained water depth map results very similar to the Cleopatra cyclone flood event boundaries, Figure 2-63.

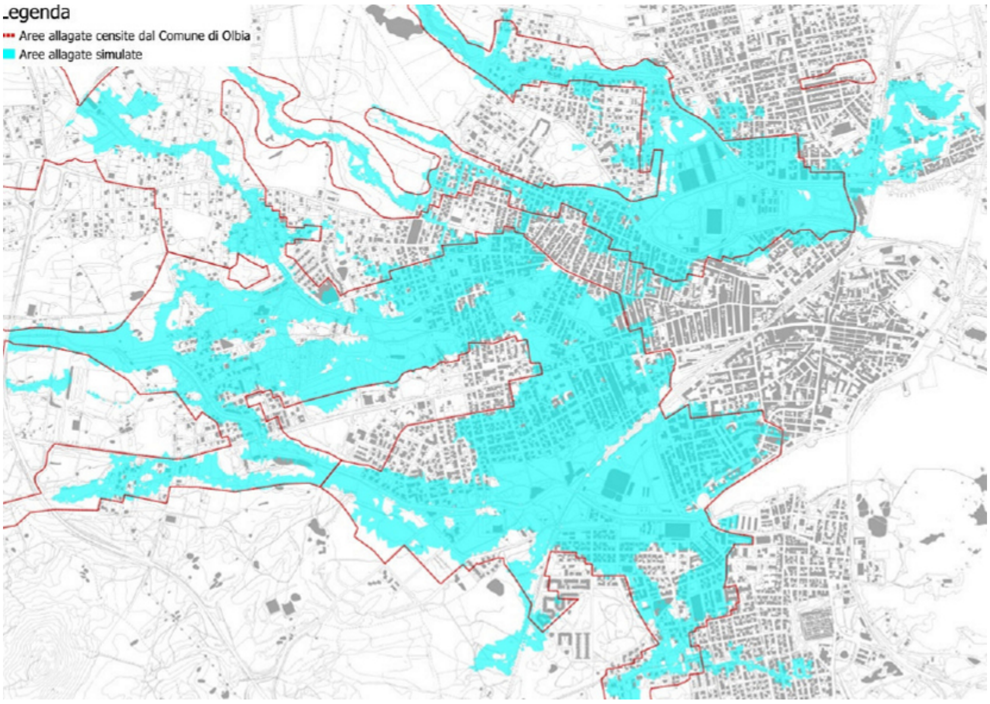


Figure 2-63.Comparison of the Cleopatra Cyclone event map and the FEST-RS model(Mancini M. ,2014)

The Sardinian Civil Protection agency supplied the database of required refunds that includes 82 damaged towns. The database consisted of damages caused to dwellings, commercial activity and public infrastructures. The post-flood event condition has been managed by the Regional Decree n.122 of the 20th November 2013 with which the Sardinian Civil Protection required the reconnaissance activity to identify urgent restore measures especially on road infrastructures and drainage networks in the urban centres (Civil Protection, 2013). In particular the Regional Decree 122/2013 collected the cost supported by each council and the associated emergency action are specified. For example Olbia town spent 705.442,75 € to support the population, rescuers and provide emergency goods as chemical baths and shelter points Table 2-47.

Safe Haven and chemical baths	239836.00
Laundry costs	196900.00
Food for rescuers and population	125000.00
Other costs	143706.75

Table 2-47.Emergency post-event costs supported by Olbia town for the event of the 18th-19th November 2013(Civil Protection-RAS, 2013)

The Civil Protection supplied three proper format file to require the refund for the flood damages considering the three categories of public structures, private properties and commercial activities. The total damage on public structures and properties is around 240 M € for 306 interventions among restore of road network, river path, canals, buildings, drainage network, waste water network all of them described in terms of location, level of the project, detailed description of the action and possible co-fund. The damages on private properties as dwellings should be described in terms of owner, address, use of the building (own building, rented, other owners), level of damage or building collapse, evacuated, type of building material (reinforced concrete, masonry, others), number of floors and number of populated floors, number of rooms and terraces, peopled area. In addition, the claim request has to define the cost to restore the damages on main structural elements, systems, internal and external building finishing and window fixtures. Olbia council receives 1573 claim requests for a total of 26.84 M € declared for a peopled area of 138280 m^2. 1054 of these building did not required the evacuation, while 519 of them were evacuated.

Commercial activity owners required the claim specifying the location of the activity, type of activity, level of damage or building collapse, evacuated, type of building material (reinforced concrete, masonry, others), number of floors and number of populated floors, number of rooms and terraces, covered and external area. The commercial claim format required to specify the cost to restore the damages on main structural elements, systems, internal and external building finishing and window fixtures, the cost to restore equipment and to rebuy raw material, semi-finished or finished products and damaged materials. The Civil Protection database identified in Olbia town area a total damage of 17.60 M € for an area of 62453 m^2 claimed by 362 businessman (Civil Protection, 2014).

The Demographic Office of Olbia town provided an analysis of the post-event situation to identify the damaged buildings. The database of Olbia council identified 17514 buildings in the urbanised area populated by 58759 habitants regularly registered as residents. 3791 buildings are located in the flooded zones probably peopled by around 8500 residents considering the people density distribution in the area close to a factor of 2.2 (Olbia Council-Statistic Office, 2013).

Olbia town supplied its residential and commercial database of requested claims georeferenced in the territory and provided of the economic damage and the declared built area damaged.

Residential and commerical refund data have been herein used to validate the JRC water depth-damage functions.

2.2.2.2.1. Residential refunds samples analysis

The residential claim sample consisted originally of 2848 data distributed in Olbia urbanised area and provided by address, economic damage, damaged area and information about the evacuation of the building. The sample has been crosschecked with Google Street to verify the reliability and avoid duplicates or incorrect localisation of the claim in the territory considering the difference of the sample size compared with sample supplied by the Civil Protection consisting of 1573 data. The crosschecked led the research to consider 1325 claim actually localised and allocated inside the proper built area identified using the cadastral map of Olbia supplied by the Sardinian Region Authority in "Sardegna Geoportale", Figure 2-64 and Figure 2-65. The appraisal total damage of 24.322 M € is associated at a declared damaged area of 106069.77 m^2 that has been reverified with the cadastral map that gives back a damaged area of 189534.09 m^2.

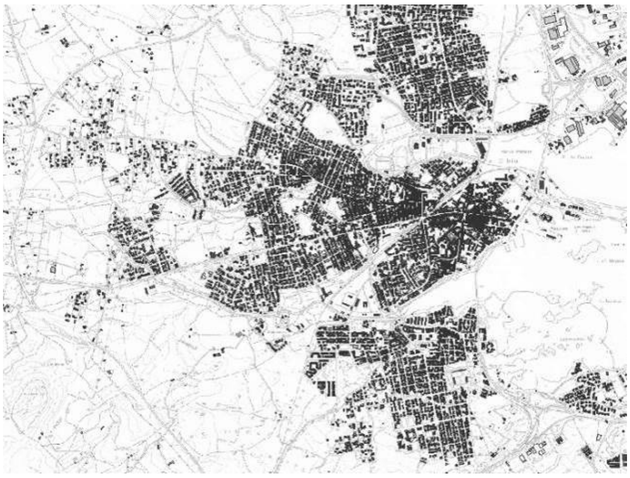


Figure 2-64.Olbia cadastral map

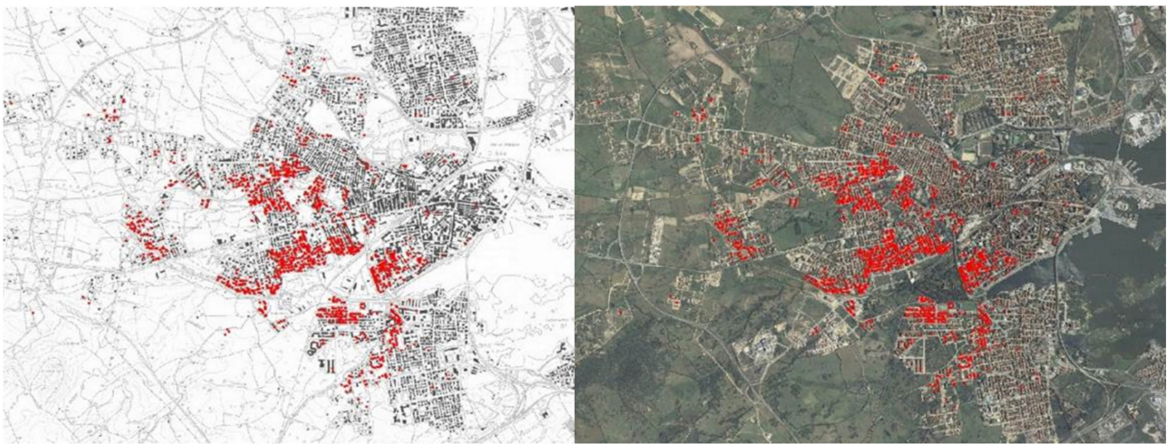


Figure 2-65.Distribution in the territory of Olbia residential sample of collected damages

The sample has been statistically analysed. It is characterised by an high asimmetry with index of 3.61, mean damage value of 162.85 €/m^2 and a maximum damage value of 1814.30 €/m^2, Table 2-48 and Figure 2-66. These values have been compared with the JRC residential water depth-damage function where the mean damage value of Olbia sample could be associated at a water depth of 0.53 m, while the maximum damage value is three times the maximum damage value of 618 €/m^2 defined in the JRC Model for Italian territory, Figure 2-67.

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2SD	Skewness Coefficient
162.85	194.34	0.77	1814.30	106.38	357.19	551.54	3.61

Table 2-48.Statistical parameters of the refund sample in €/m^2. Residential category

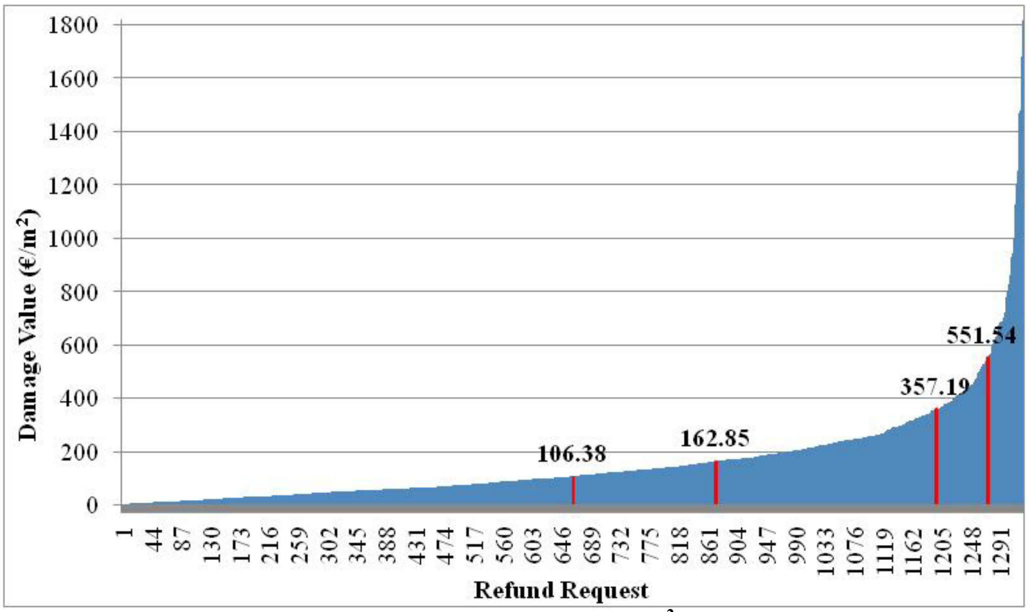


Figure 2-66.Histogram of the refund requests in €/m^2. Residential category

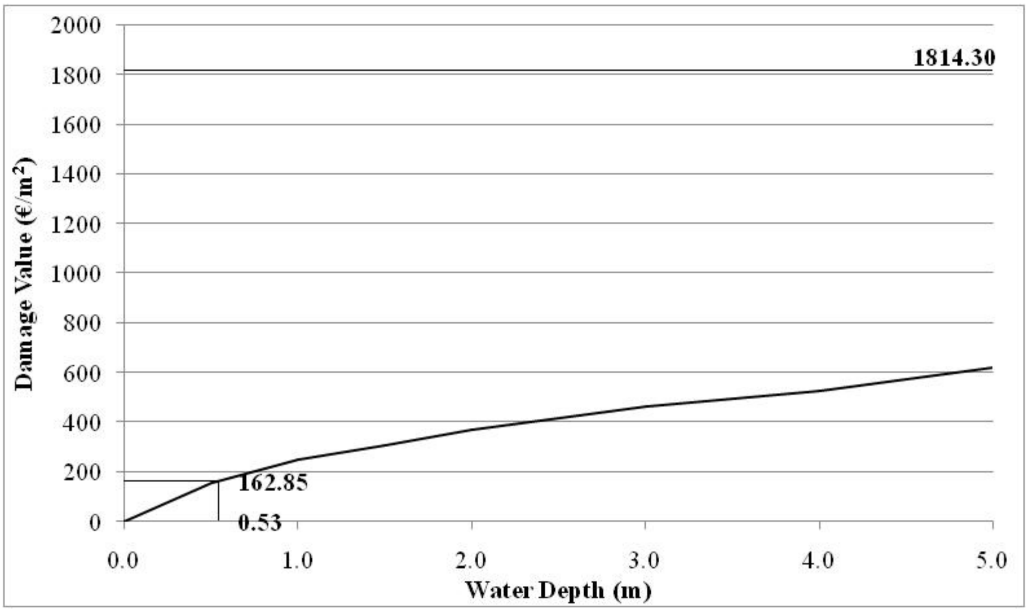


Figure 2-67.JRC water depth-damage curve and mean and maximum damage values of the sample. Residential category

The residential claims have been related with the flood map obtained by the reconstruction of the flood event in order to associate at each data the maximum water depth modelled for its area and validate the JRC residential water depth-damage function comparing the results. The flood map overlay with the georeferenced data decreased the sample size from 1325 to 1105 data, Figure 2-68.

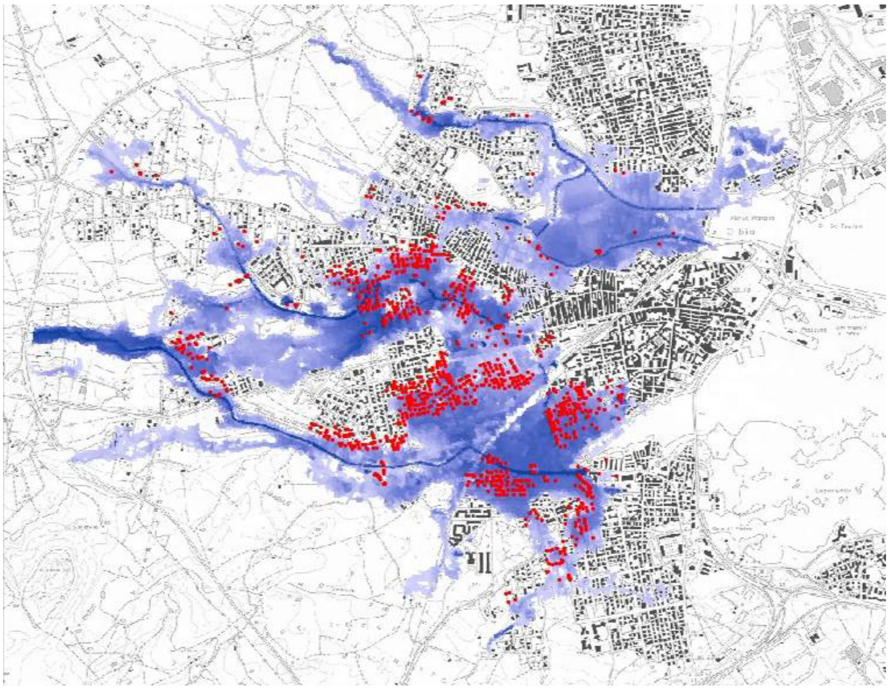


Figure 2-68.Olbia claim sample and flood map. Residential category

The distribution of the new sample still shows an asymmetry characterised by an index of 3.58, Table 2-49 and Figure 2-69. The sample is characterised by a mean damage value of 173.91 €/m^2 and a maximum damage value of 1814.30 €/m^2.

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2σ	Skewness Coefficient
173.91	67.81	0.77	1814.30	118.58	357.19	551.54	3.58

Table 2-49.Statistical parameters of the refund sample in €/m^2 and associated water depth. Residential category

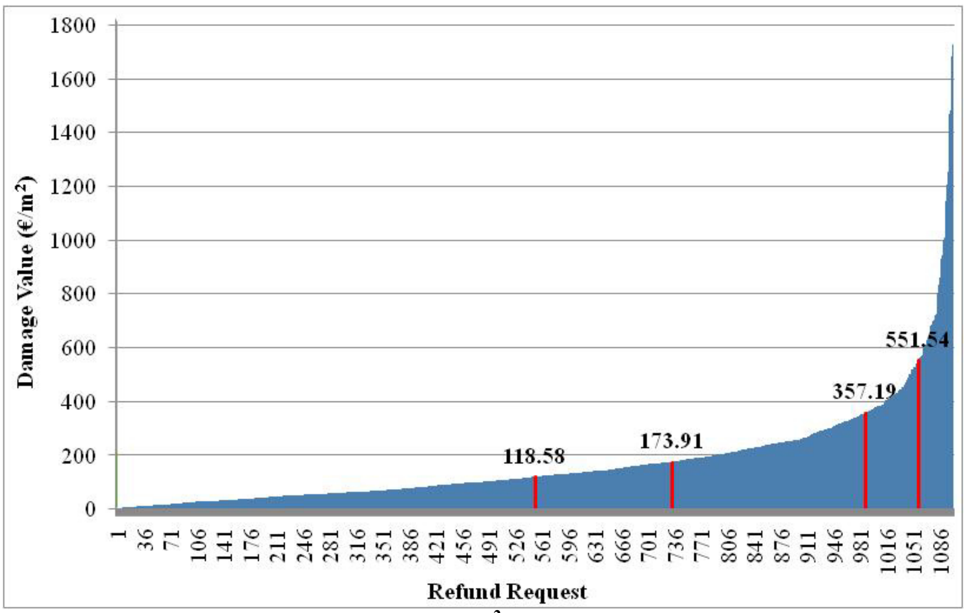


Figure 2-69.Histogram of the refund requests in €/m^2 and associated water depth. Residential category

The sample distribution has been analysed in relation with the JRC Residential water depth-damage curve for a comparison. Figure 2-70 shows the claims distribution close to the JRC residential curve trend for a step of water depth between 0 and 2.5 m considering the modelled maximum flood wave reaching a high of 2.13 m. The water depths associable at the mean damage value and maximum damage value of the sample in the JRC residential curve have been calculated. The mean damage value results associable at a water depth of 0.60 m, while the maximum damage value does not show changes with the first analysis and it is three times the maximum damage value defined for Italy in the JRC Model, Figure 2-70.

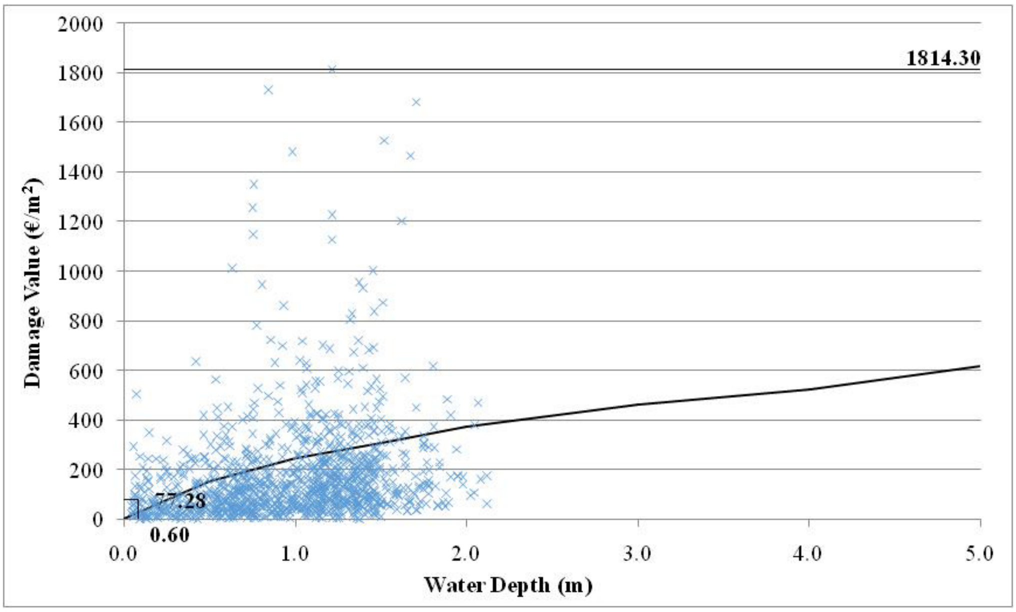


Figure 2-70.JRC water depth-damage curve and distribution, mean and maximum damage values of the sample. Residential category

The analysis has been focused on the water depth range between 0 and 2.50 m aiming to identify a representative curve for the residential sample of data, Figure 2-71. The sample is divided in 5 classes of water depth with steps of 0.5 m and for each subgroup the statistic parameters of mean water depth, mean damage value, standard deviation and size of the subgroup have been calculated, Table 2-50. Figure 2-71 shows the relation between JRC residential water depth-damage curve, the claim distribution, the curve obtained by the mean damage values of each subgroup and the curve obtained by the mean damage values of each subgroup summed with the relative standard deviation to include in the analysis the uncertainty of data.

Water Depth step	μ Water Depth (m)	Sample Size	Mean Value (μ)	Standard Deviation (SD)	μ+σ	Minimum Value	Maximum Value
0.0<h≤0.5	0.28	182	96.37	97.58	193.95	0.77	633.31
0.5<h≤1.0	0.75	353	157.16	209.21	366.37	2.16	1726.36
1.0<h≤1.5	1.25	463	201.96	193.42	395.38	1.70	1814.30
1.5<h≤2.0	1.69	100	241.93	291.96	533.89	30.28	1683.16
2.0<h≤2.5	2.08	7	206.81	157.23	364.04	60.37	471.58

Table 2-50.Statistical parameters for each water depth class with step of 0.5 m. Residential category

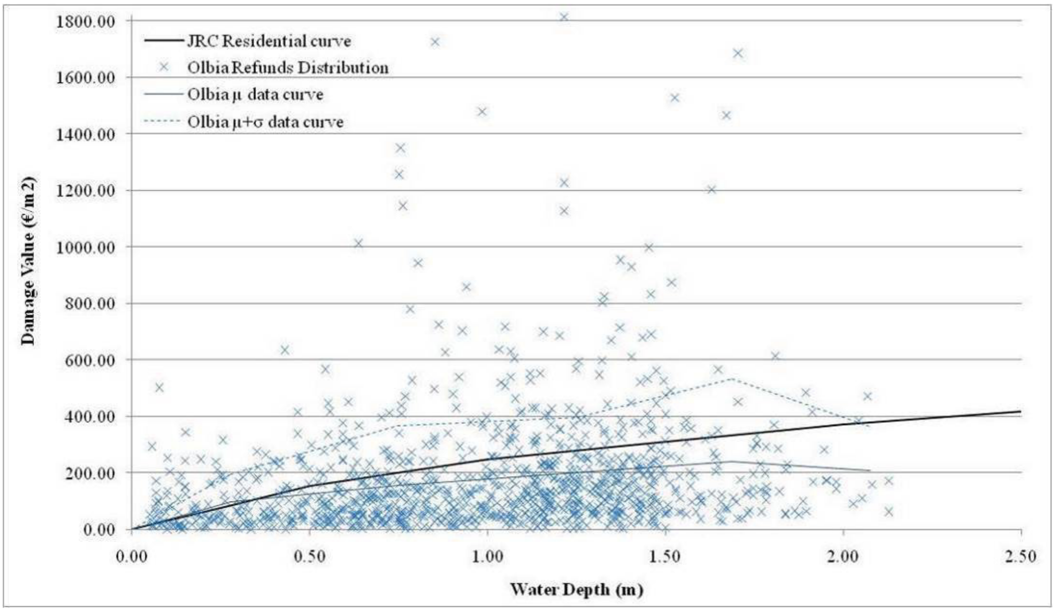


Figure 2-71.JRC water depth-damage curve, claim sample distribution, Olbia μ data curve and Olbia μ+σ curve. Residential sample

The sample distribution underlines a relevant scattering of data that led the analysis to refine the sample considering for each subgroup only data within the limits of μ-σ and μ+σ. Observing the Olbia curve obtained by the sum of mean and standard deviation values, its trend in the last step with water depth higher than 2 m tends to decreased. That aspect induced to join the last two subgroups of damage values with water depth between 1.5 and 2.25 m because the low size of the last subgroup characterised of 7 data.

The dimension of the refined sample decreased from 1105 to 989. The sample is characterised by a mean damage value of 125.32 €/m^2 and an observed maximum damage value equals to 492.05 €/m^2, lower than the maximum damage value identified by the JRC Model for Italian territory at 5 m of water depth, but slightly higher than the value at 3.46 m that is equals to 491.93 €/m^2.The sample has been reanalysed considering four classes of water depth and recalculating for each class the statistical parameters aiming to identify the curve obtained by the mean damage values of each subgroup (μ) and the curve obtained by the mean damage value plus the standard deviation of each subgroup (μ+σ) to include in the analysis the uncertainty of data information.

Water Depth step	μ Water Depth (m)	Sample Size	Mean Value (μ)	Standard Deviation (SD)	μ+σ	Minimum Value	Maximum Value
0.0<h≤0.5	0.25	155	64.45	51.62	116.07	0.77	192.62
0.5<h≤1.0	0.74	322	107.17	81.67	188.83	2.16	364.22
1.0<h≤1.5	1.25	412	149.86	96.71	246.56	1.70	387.13
1.5<h≤2.25	1.88	100	177.00	117.51	294.50	30.28	492.05

Table 2-51.Statistical parameters for each water depth class of the refined sample. Residential category

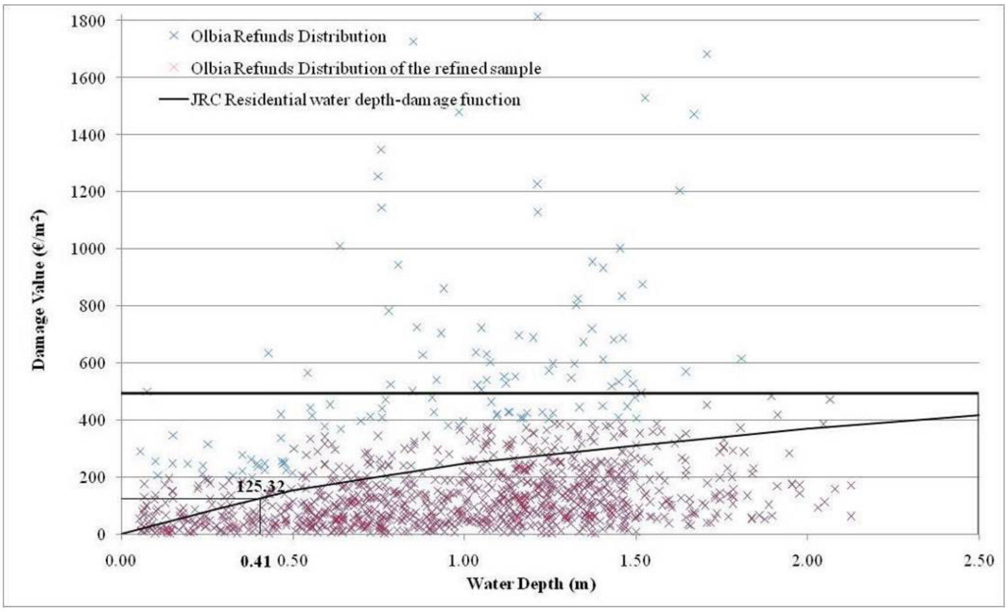


Figure 2-72.Comparison of the original and refined sample distribution, JRC water depth-damage curve and mean and maximum damage value of the refined sample. Residential category

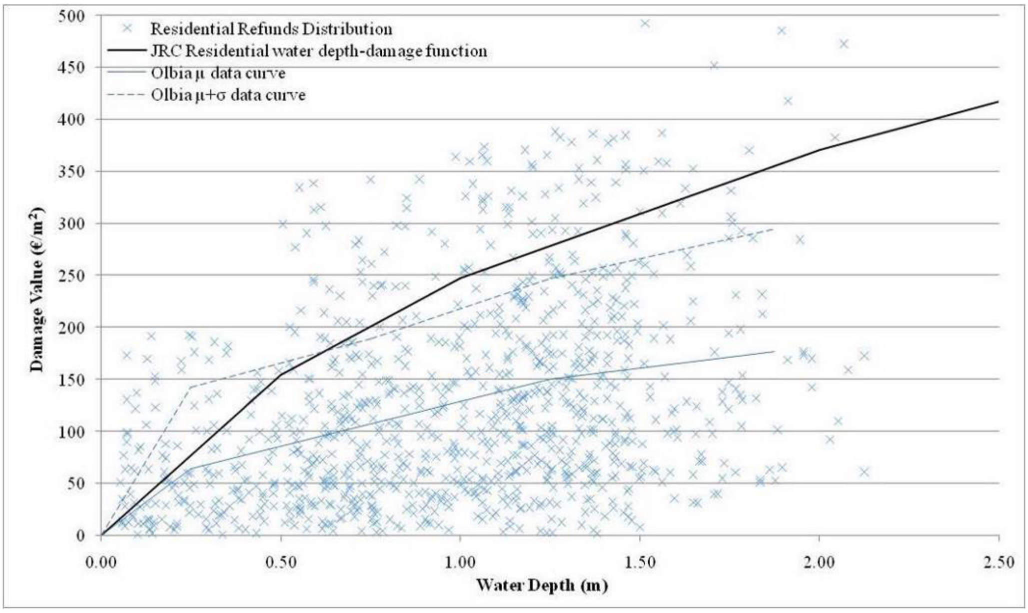


Figure 2-73.Comparison of JRC water depth-damage curve, Olbia μ curve and Olbia μ+σ curve. Residential category

The refined sample has been analysed in order to identify a representative curve for the residential flood damage registered in Olbia town and validate the JRC water depth-damage function for the event of the 18th November 2013. The trend of the residential μ+σ curve could be approximated in two parts. The first part of the curve, from 0 m to 0.27 m, is considered with a linear trend to take into account the gradual and fast increment of the damage with water depth within 0 m and 0.25 m. The second part of the curve is evaluated with an exponential form that at 5 m of water depth reaches the value of 408.20 €/m^2 lower than the value of 618 €/m^2 defined in the JRC Model for residential water depth-damage curve, Figure 2-74.

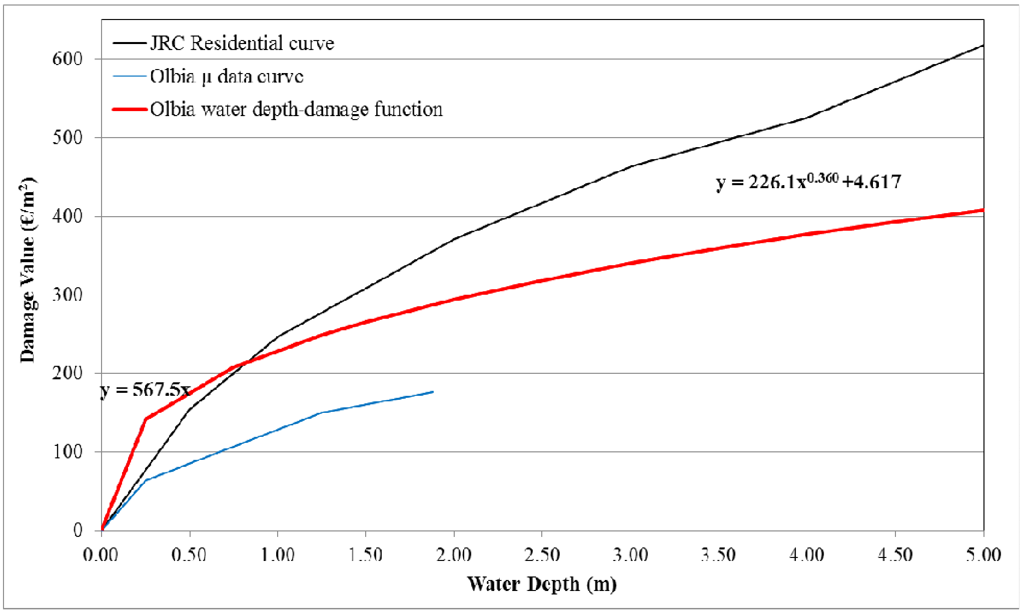


Figure 2-74.Comparison of the JRC water depth-damage curve, the Olbia µ data curve and Olbia µ+δ data curve. Residential category

The residential database provided of damage and water depth for each element has been studied to compare the total damage appreciated and declared in the refund requests with the potential damage evaluable with the JRC residential water depth-damage function and the Olbia water depth-damage function for residential land use category.

The comparison gives back a total damage evaluated with the JRC Model equals to 33.425 M € and higher than the total damage declared in the refund requests of 20.845 M € and close to the total damage of 31.918 M € evaluated with the Olbia residential water depth-damage curve, Table 2-52. This value is quite similar at the appreciated and declared total damage, but this result is justified because the refund requests are characterised by damages caused by water depth between 0 and 2.5 m. In fact, Olbia residential water depth-damage curve shows a trend with high damages at low water depth range, Figure 2-74.

Claimed Damage (M €)	JRC Model Olbia damage (M €)	Olbia curve damage (M €)
20.845	33.425	31.918

Table 2-52.Comparison of the total damage caused by the Cleopatra cyclone and the damage evaluated with the JRC Model and Olbia water depth-damage function. Residential category

2.2.2.2.2. Commercial refunds samples analysis

The commercial sample of refund data supplied by Olbia Council consisted of 426 data and for each data the address, economic damage for structures and equipment, damaged area and evacuation of the building have been provided. The sample analysis followed the same process applied for the residential sample of refund data in order to verify with Google Street the correct allocation of each data on the map confirming the address and verifying the association with the proper built area in the cadastral map, Figure 2-64. That process decreased the sample size from 426 to 306 data, Figure 2-75.

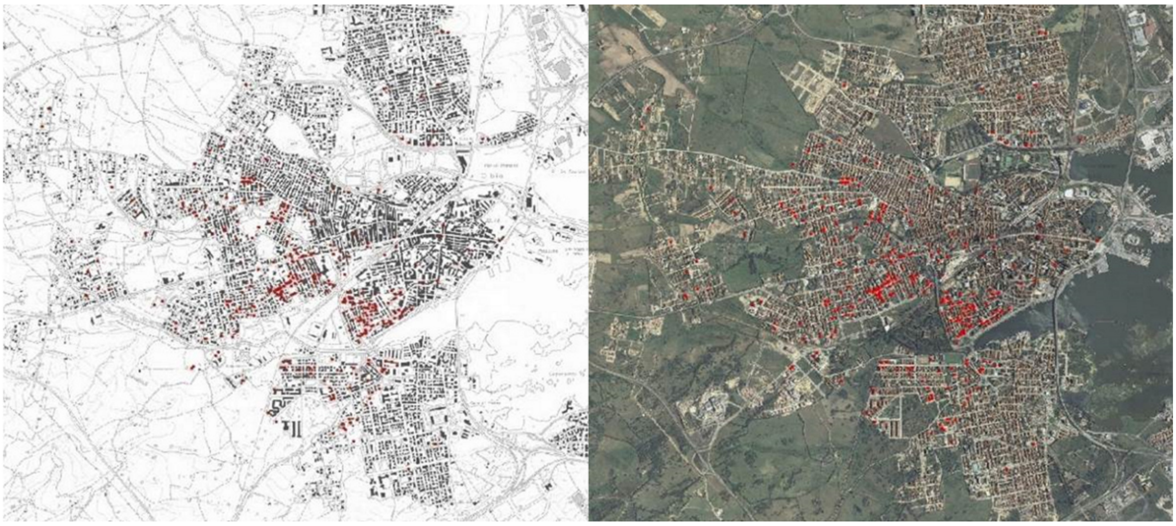


Figure 2-75.Distribution in the territory of Olbia sample of collected damages. Commercial category

The sample has been analysed to identified the total economic damage and damaged area caused by the flood event for the commercial activity. The analysis gives back a total damage of 794'000 € for a declared damaged area of 44361.70 m^2 that has been verified with the cadastral map and the second area analysis gives back a damaged area of 93322.40 m^2. A statistical analysis has been applied on the sample. The analysis gives back an high asimmetry with index of 2.75, mean damage value of 218.81 €/m^2 and a maximum damage value of 1979.98 €/m^2, Table 2-53 and Figure 2-76. These values have been compared with the JRC commercial water depth-damage function where the mean damage value of the commercial sample could be associated at a water depth of 1.43 m, while the maximum damage value is close to four times the maximum damage value of 511 €/m^2 defined in the JRC Model for Italian territory, Figure 2-67.

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2SD	Skewness Coefficient
218.81	315.07	1.22	1979.98	97.41	533.88	848.95	2.75

Table 2-53.Statistical parameters of the refund sample in €/m^2. Commercial category

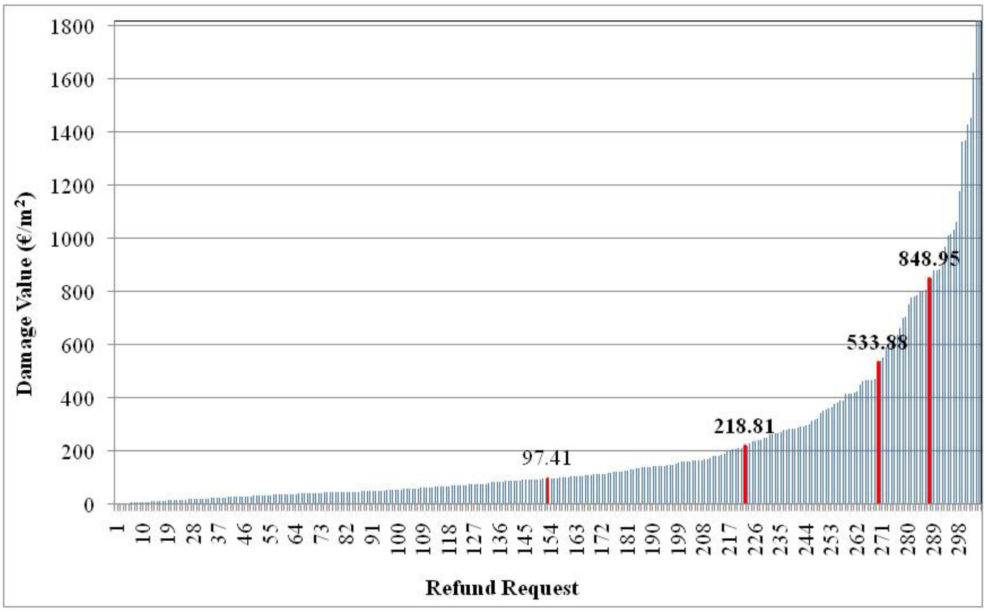


Figure 2-76.Histogram of the refund requests in €/m^2. Commercial category

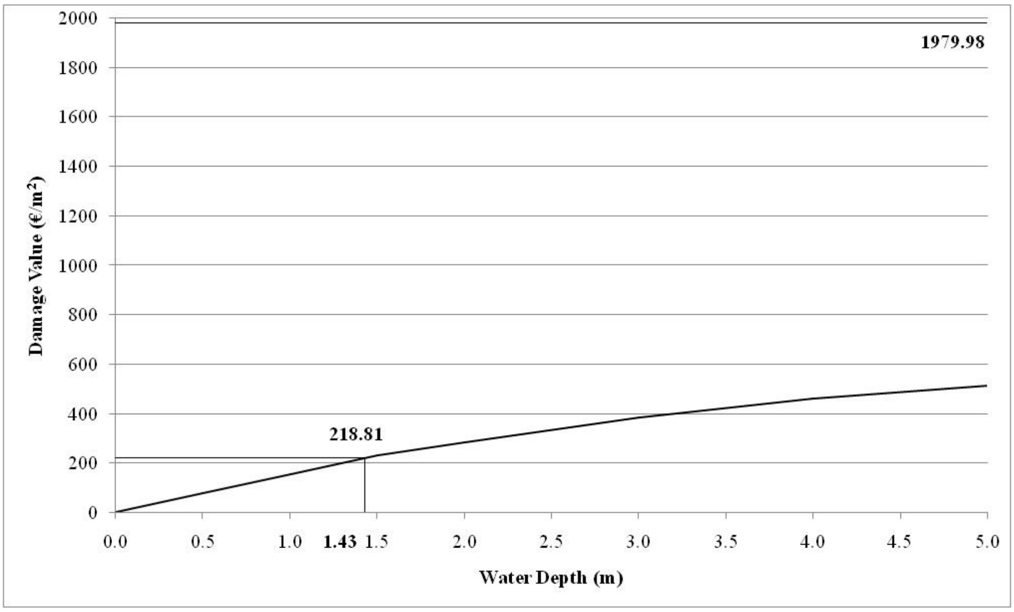


Figure 2-77.JRC water depth-damage curve and mean and maximum damage values of the sample. Commercial category

The commercial claims have been overlaid with the flood map obtained by the reconstruction of the flood event in order to associate at each data the maximum water depth modelled for its area and validate the JRC Commercial water depth-damage function comparing the results. The flood map overlay with the georeferenced data decreased the sample size from 306 to 222 data.

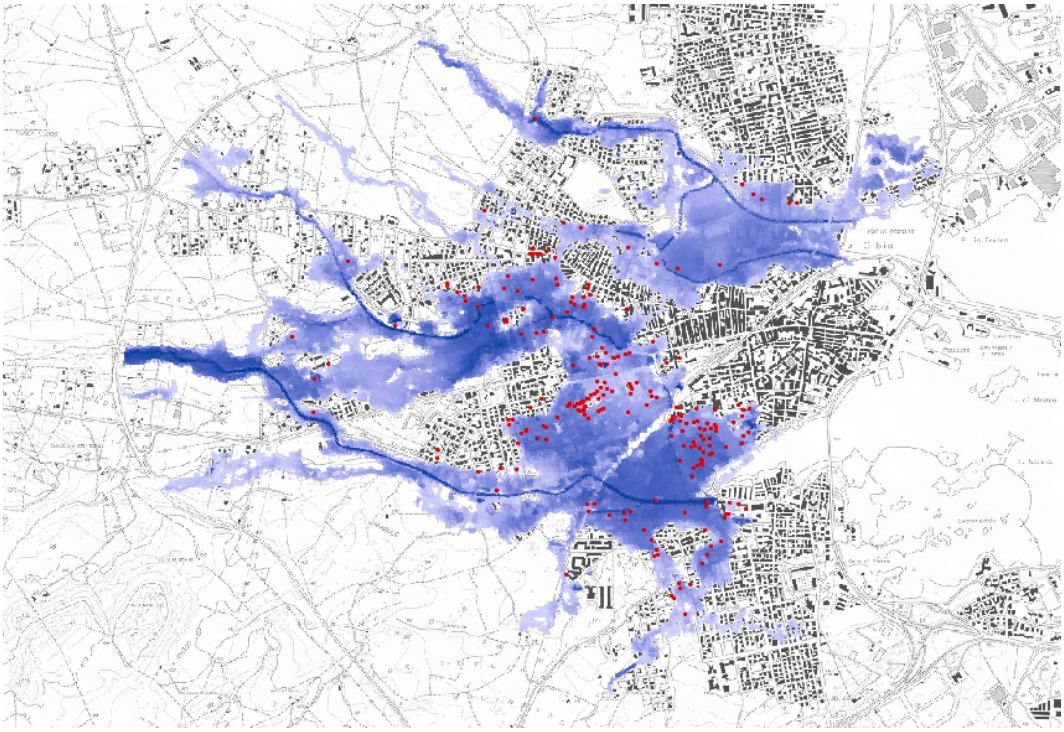


Figure 2-78.Olbia claim sample and flood map. Commercial category

The distribution of the sample with water depth information still shows an asymmetry characterised by an index of 2.46, Table 2-54 and Figure 2-79.

The sample is characterised by a mean damage value of 230.85 €/m^2 and a maximum damage value of 1901.24 €/m^2.

Mean Value (μ)	Standard Deviation (SD)	Minimum Value	Maximum Value	Median	μ + SD	μ + 2SD	Skewness Coefficient
230.85	295.97	1.22	1901.24	108.65	526.82	822.79	2.46

Table 2-54.Statistical parameters of the refund sample in €/m^2 and associated water depth. Commercial category

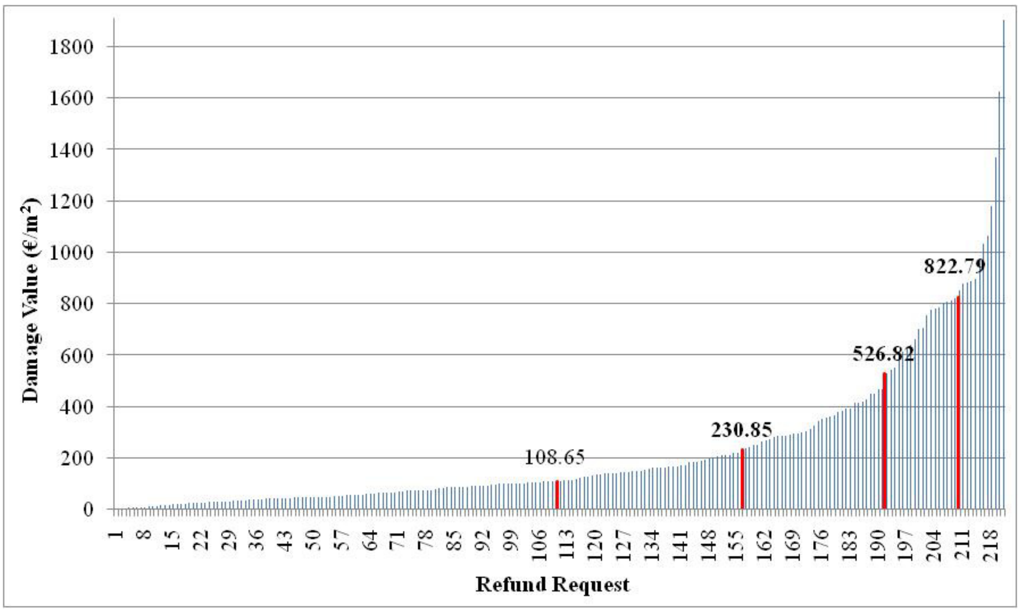


Figure 2-79.Histogram of the refund requests in €/m^2 and associated water depth. Commercial category

The sample distribution has been compared with the JRC commercial water depth-damage curve as shown in Figure 2-80 where the claims distribution is close to the JRC commercial curve trend for a step of water depth between 0 m and 2.5 m considering that the modelled maximum flood wave reached a high of 2.19 m. The analysis calculated the water depths associable at the mean damage value and at the maximum damage value of the sample in correspondence of the JRC commercial curve trend. The mean damage value results associated at a water depth of 1.51 m, while the maximum damage value does not show relevant changes with the first analysis and it is still close to a value four times the maximum damage value defined for Italy in the JRC Model, Figure 2-80.

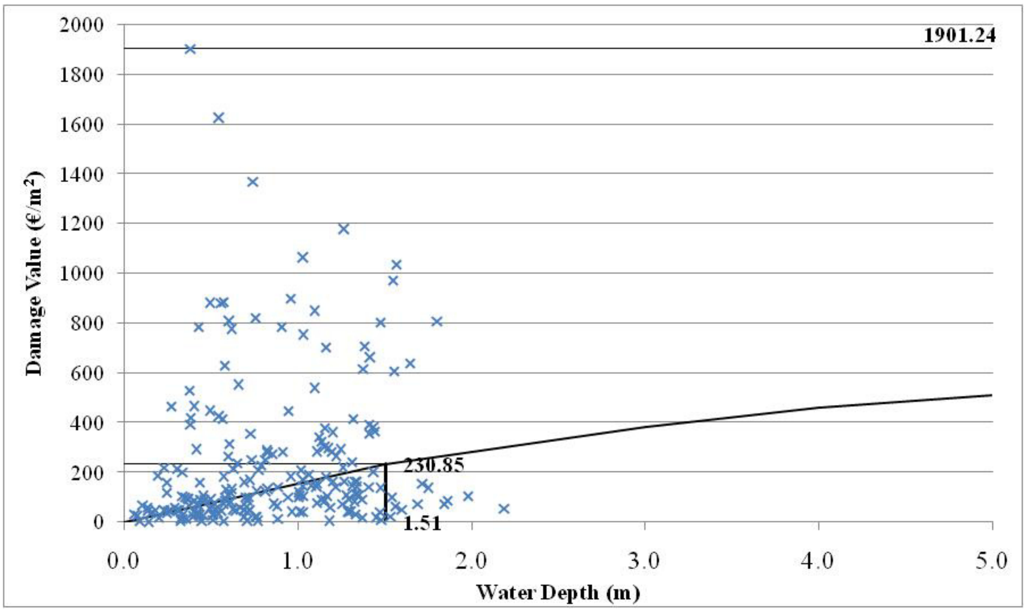


Figure 2-80.JRC water depth-damage curve and distribution, mean and maximum damage values of the sample. Commercial category

The analysis has been focused on the water depth range between 0 m and 2.50 m aiming to identify a representative curve for commercial sample of data, Figure 2-81. The sample is considered divided in 4 classes of water depth with steps of 0.5 m and for each subgroup the statistic parameters of mean water depth, mean damage value, standard deviation and size of the subgroup have been calculated. The class of water depth between 2 and 2.5 m consists of 1 data and for this reason it has been included in the class with water depth between 1.5 and 2.0 m as shown in Table 2-55. Figure 2-81 shows the relation between JRC Commercial water depth-damage curve, claim distribution, the curve obtained by the mean damage values of each subgroup (μ) and the curve obtained by the sum of the mean damage value plus the standard deviation of each subgroup (μ+σ) of refund data to consider the uncertainty of data.

Water Depth step	μ Water Depth (m)	Sample Size	Mean Value (μ)	Standard Deviation (σ)	μ+σ	Minimum Value	Maximum Value
0.0<h≤0.50	0.33	61	163.18	290.91	454.09	1.22	1901.24
0.5<h≤1.00	0.70	72	251.73	322.61	574.35	2.76	1625.44
1.0<h≤1.50	1.23	73	249.49	249.23	498.72	5.34	1177.32
1.5<h≤2.25	1.71	16	309.77	363.70	673.48	22.84	1033.68

Table 2-55.Statistical parameters for each water depth class with step of 0.5 m. Commercial category

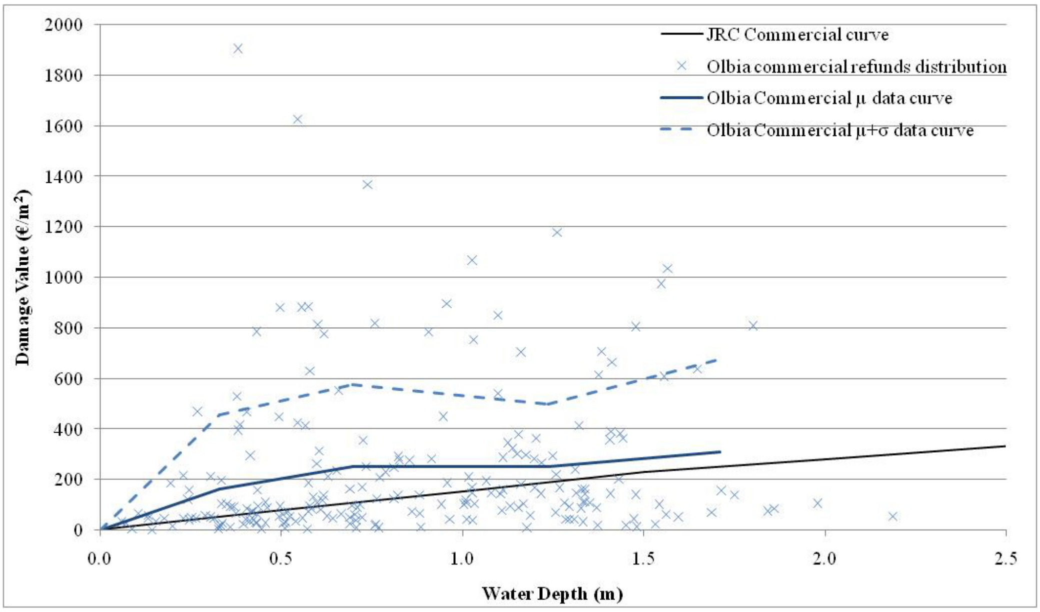


Figure 2-81.JRC water depth-damage curve, claim sample distribution, Olbia μ data curve and Olbia μ+σ curve. Commercial category

The sample distribution in Figure 2-81 underlines a scattering of data that led the analysis to refine the sample considering for each subgroup only data within the limits of μ-σ and μ+σ. The dimension of the refined sample decreased from 222 to 187 data. The sample is characterised by a mean damage value of 139.38 €/m^2 and a maximum damage value observed equals to 636.92 €/m^2, higher than the maximum damage value identified by the JRC Model for Italian territory at 5 m of water depth and equals to 511 €/m^2. The sample has been reanalysed and for each subclass the statistical parameters have been recalculated aiming to define the curve obtainable by the mean damage values of each subgroup (μ) and the curve obtainable by the mean damage value plus the standard deviation, (μ+σ). The commercial μ+σ curve is taken into consideration to include in the analysis the uncertainty of data. Figure 2-83 shows the commercial μ+σ curve with a trend higher but close to the JRC commercial curve than in the first analysis of the sample. The commercial μ+σ curve could be considered with a linear trend with water depth to 0.25 m and, then, the approximate curve follows with an exponential trend reaching a value of 464.91 €/m^2 at 5 m of water depth, Figure 2-83.

Water Depth step	μ Water Depth (m)	Sample Size	Mean Value (μ)	Standard Deviation (SD)	μ+σ	Minimum Value	Maximum Value
0.0<h≤0.50	0.25	55	89.63	100.43	190.05	1.22	448.27
0.5<h≤1.00	0.75	56	154.34	111.23	265.57	4.84	437.95
1.0<h≤1.50	1.25	63	164.20	111.56	275.76	5.34	414.15
1.5<h≤2.25	1.88	13	165.13	205.27	370.40	22.84	636.92

Table 2-56.Statistical parameters for each water depth class of the refined sample. Commercial category

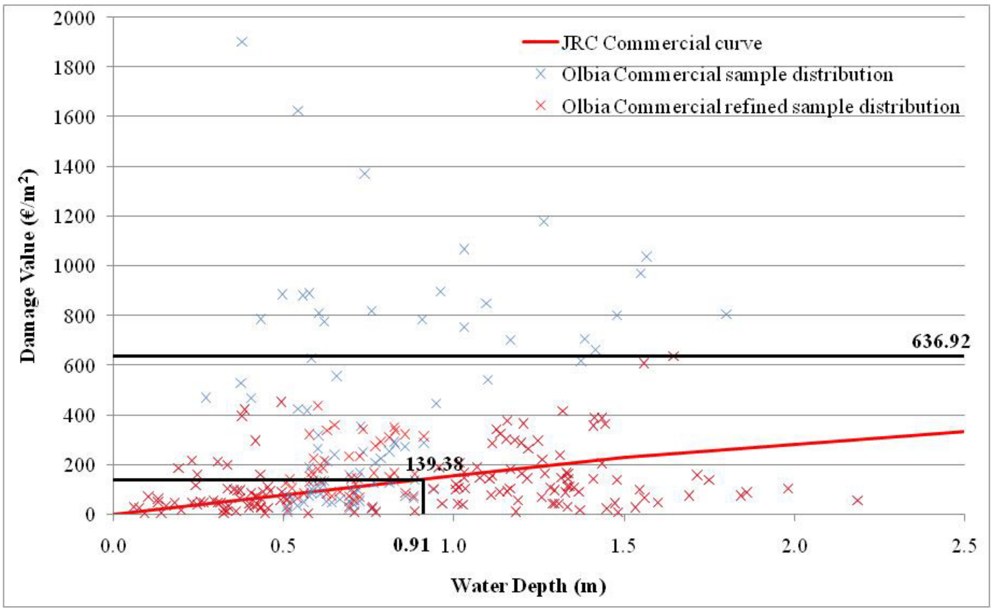


Figure 2-82.Comparison of the original and refined sample distribution, JRC water depth-damage curve and mean and maximum damage value of the refined sample. Commercial category

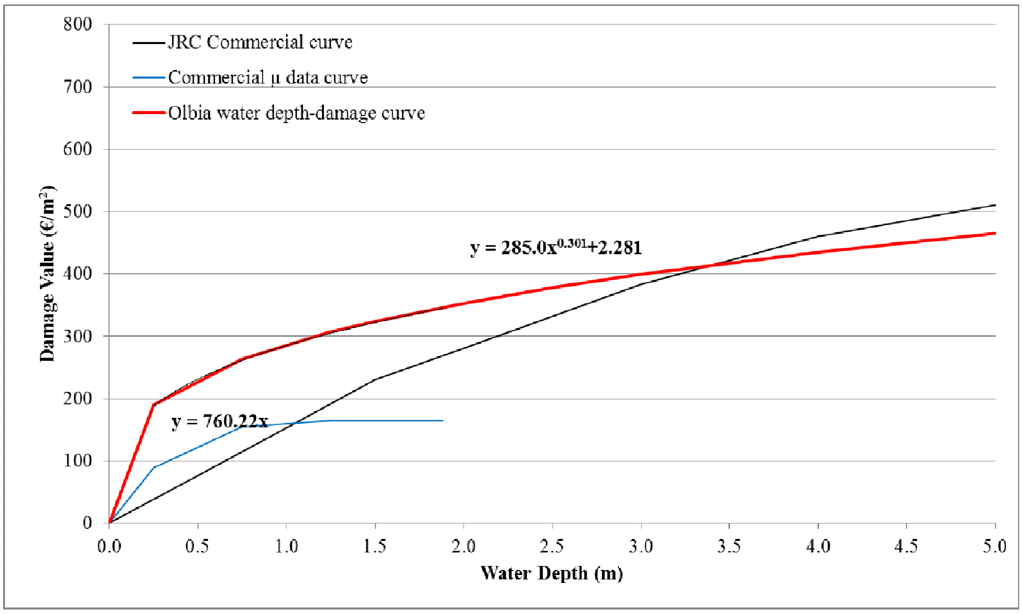


Figure 2-83.JRC water depth-damage curve, claim refined sample distribution, Olbia μ data curve and Olbia μ+σ curve. Commercial category

The commercial database provided of damage and water depth for each element has been analysed to compare the total damage appreciated and declared in the refund requests with the potential damage evaluable with the JRC commercial water depth-damage function and the Olbia water depth-damage function for commercial land use category.

The comparison gives back a JRC Model total damage of 6.03 M € lower than the total damage declared in the refund requests and equals to 9.34 M €, Table 2-57. The total damage evaluated with the Olbia commercial water depth-damage curve reaches 12.71 M €. This value is quite higher than the appreciated and declared total damage, but this result is justified because the refund requests are characterised by damages caused by water depth between 0 m and 2.5 m where the Olbia commercial water depth-damage curve is characterised by a high trend, Figure 2-83.

Claimed Damage (M €)	JRC Model Olbia damage (M €)	Olbia curve damage (M €)
9.34	6.03	12.71

Table 2-57.Comparison of the total damage caused by the Cleopatra cyclone and the damage evaluated with the JRC Model and Olbia water depth-damage function. Commercial category

2.2.2.3. Comparison of the Residential water depth-damage curve

The validation process of the JRC water depth-damage function for the residential land use category gives good results considering that the analysed damages in Sardinian territory have been collected from towns with different residential property types.

JRC water depth-damage function describes a study focused on different type of dwellings due to data coming from many European countries and adapted for the whole European territory. Residential properties on Capoterra coastal area consists in villa type of 1-floor dwelling, while Olbia residential area is characterised by 1-/3-floor houses. These types of residential building features are the consequence of different trend on the resulting curve that describe how the flood damage occurred due to the described flood.

In Figure 2-84 the JRC, Capoterra and Olbia water depth- damage functions are shown. As explained above, the curves are characterised by different trends. Capoterra and Olbia water depth-damage functions starts with a linear and slope trend till, respectively, 0.50 and 0.25 m of water depth, and after this points follow with two different trends.

Capoterra curve is characterised by a polynomial trend of third degree with a low damage increment between 0.50 m and 2.0 m following with a high increment till 3 m of water depth, Figure 2-44. While, Olbia curve is characterised by an exponential increment of the damage from 0.25 m of water depth till 3 m of water depth, Figure 2-74.

Capoterra and Olbia water depth-damage functions have been compared with the JRC function also in terms of potential maximum damage that could be registered at the maximum level of 3 m of water depth. This comparison gives back good results. In fact, the JRC maximum damage evaluated at 3 m of water depth is equal to 463.50 €/m^{2,} Capoterra curve reaches a maximum damage value of 476.22 €/m^2, while Olbia curve is characterised by a maximum potential damage of 340.40 €/m^2.

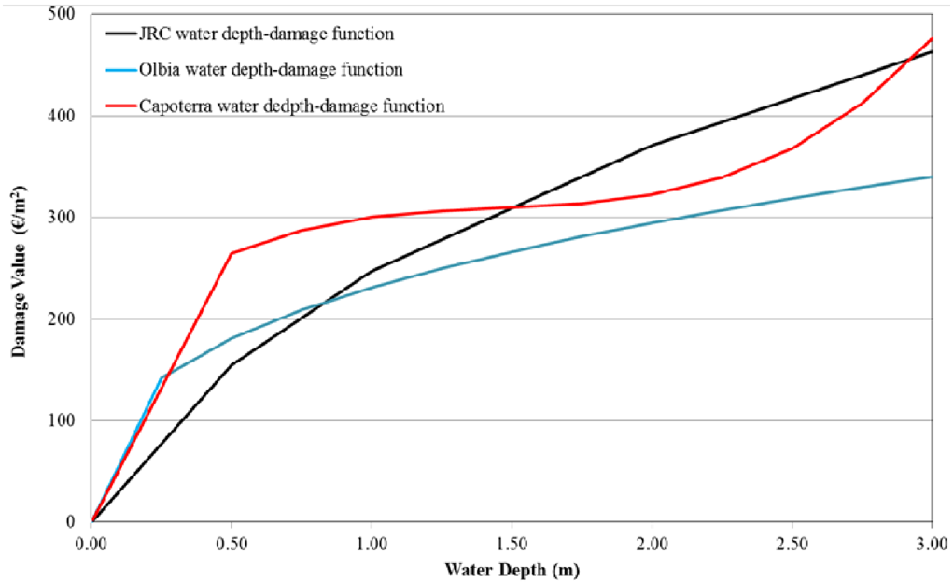


Figure 2-84.Residential water depth-damage functions comparison

2.3. Assessment of the intangible damage: The Life Safety Model

The Life Safety Model, LSM, developed originally by BC Hydro, aims to support analysts to determine the loss of life associated with flooding that could occur as the result of a hypothetical dam breach (BC Hydro, 2006), and later improved by HR Wallingford to determine the loss of life associated with flooding that could occur from any source which include dam breach or release, tsunami, river or sea flooding (HR Wallingford, 2014). LSM simulates the physical interaction of individuals to modelled flood inundation resulting from the range of flooding events mentioned above. The estimated loss of life incorporates a wider range of variables that influence loss of life (HR Wallingford, 2014).
and can be used to assess not only loss of life, but also to provide insight into the damage to structures, to specify areas of greater flood risk and to provide insight into the timing requirements of evacuation as a flood progresses. Since LSM simulates the movement of individuals, it can also be used to provide input into emergency planning, such as location of safe havens and evacuation routes (HR Wallingford, 2014) supporting authorities on flood risk management.

As assumed in the description of LSM Principles in the BC Hydro guidelines 2006 (BC Hydro, 2006), LSM supports the comprehension of how a flood event might unfold allowing also a comprehensive reviews of the consequent risks and providing a physically based model to simulate how a population might react to the flood event. In fact, LSM helps to understand what might happen to a population at risk in a flood hazard zone. BC Hydro report describes which elements should be defined to running the model and the necessary information (BC Hydro, 2006). These information consider how each person is distributed in the flood hazard zone prior to the flood event (which can be dependent on the time of day, week or year, site specific demographics, and location of services, workplaces, residences and schools), how each person moves within, into or out of the flood hazard zone while unaware of the flood, how everyone interact with each other during evacuation from a flood event incorporating behaviour as individuals, group dynamics and/or warning unaware persons. Moreover LSM is able to model how individuals interact with the flood (choosing to flee and method of evacuate, evacuation times dependent on individuals and/or toppling criteria and resistance to flooding dependent on individuals), how objects interact with the flood, how buildings withstand floods and provide protection to the persons within, how well vehicles resist toppling when inundated, how the timing for inundation of bridges/roads used as escape routes influences means of evacuation and how capacity limitations of an evacuation route can influence loss of life.

2.3.1. Life Safety Model Architecture

LSM incorporates input variables to define the characteristics of the territory under analysis and through which a flood wave would pass in order to simulate the “virtual world” in which the population exists. The model considers wide types of inputs to define the initial state of the world and specify the distribution of the persons for a given time to individual sites (BC Hydro, 2006). The LSM is designed to describe the virtual world using available GIS data sets with which topographic and natural environment are described using mapping sources. In addition, population statistics are collected on regular census periods in developed areas and general flood toppling characteristics can be ascertained from available research or modelling. Defining in LSM at what time the flood could occur it is possible to model how it can influence where a person might be located at the initiation of a flood, and thus influence their chance of survival during the flood event. The likelihood of each initial state of nature can be determined based on a temporal distribution of initiating events, or a probabilistic estimate of initial inflow conditions simulated in a range of different flood scenarios. Basically, LSM requires four key inputs: people’s world, natural environment, flood waves defined by hydraulic model and control parameters to manage the simulation of the evacuation and define characteristics of the people, buildings and vehicles.

LSM estimates loss of life and survival for a given flood event. The LSM includes a traffic flow model to simulate the movement and behaviour of individual or groups of people in space and time. The model includes an internal decision-making logic which defines the way individuals reacts to the flood (escape / no escape), chooses the method of escape (by foot, vehicle) and providing, also, a logic defining how vehicles and pedestrians interact. Other useful characteristics of LSM are the ability to use the concept of group dynamics (groups of individuals acting collectively as opposed to individually), and to simulate the building and vehicle behaviour in water.

The opportunity to link GIS-based information with LSM provides an effective tool for estimating loss of life, and determining a course of action for emergency response helped by the opportunity to observe the result animations of the flood event and reaction of the receptors of the virtual world. The animations provide graphic visual aids for portraying the impacts of a flood event identifying in detail how and where loss of life may occur, and indicating means of potentially reducing the loss of life risk.

2.3.2. Life Safety Model scope definition and statement of objectives

The definition of flood evacuation emergency plan could be useful for different aims. The evacuation model could be used to reach many scopes as pinpoint the communities under flood risk knowing the geographic extent of the floodplain. Moreover, a deep study of the community characteristics allows to be aware of the level of the receptor risk. In fact, the LSM implementation requires a description of the activities allocated in the area in order to define the group of people that could move in the road network. LSM has been implemented mainly to evaluate the intangible damage of loss of life identified in the number of fatalities.

The identification of LSM use should be associated at a description of the scope of the analysis to provide a complete framework to be implemented in LSM and, therefore, improve the study. One of the main scope of LSM use is the identification of flood consequences and this aspect has to be studied according with the definition of the baseline environmental scenario. The environment should be described including all of the possible risks and their geographic extents (seismic events, reservoir inflow, river flood stages, and local weather conditions), the communities under risk, the consequences depending upon the timing flood event and emergency actions together with the inundation modelling and the operations required to manage the event. All of these aspects description entails a definition of the virtual world and the modelling of various risk scenarios aiming to estimate potential losses of life and structures (BC Hydro, 2006).

Emergency plan LSM use requires an overview of available information and their acquisition should be provided by the Authorities and communities of the territory under analysis. The acquisition of good and complete data is essential to reach LSM aims (BC Hydro, 2006).

LSM implementation requires the definition of Initial Hydraulic Conditions that can be used in determining the likelihood of the various flood events to be simulated.

Analysis of the range of flood scenarios that could occur provides a more complete review of flood risks. Temporal considerations such as the time of year, week, or day will influence the number of persons at risk within a flood plain. People will move within, into, and out of flood prone areas throughout the course of a day. Seasonal changes may also influence the distribution of population in a flood area, or influence the local hydrologic and hydrodynamic conditions that can determine the size of the flood itself. Additional specific situations may also be considered and could change the possibility of loss of life in a flood, such as providing advanced warning. These events could be compiled to create an "event tree" defining the range of scenarios that might be considered when assessing loss of life. Each scenario would have a likelihood associated with it based on temporal considerations, and frequency of occurrence.

Data availability will determine the amount of effort required to set the project. Once data are collected, the datasets requires additional processing to reflect the most current information of the study area in order to generate at the end of the study a summary report as suggested in the BC Hydro 2006 report (BC Hydro, 2006), Table 2-58. In addition, photos of the area under analysis could be really useful to add accuracy at the study, confirm inundation frequency and extent and have a better overview of it. That step may be reached through field visit or, when the flood event dataset is opportunely update, using orthophotos of the area.

In particular, the study of the area aims to describe the people world in terms of population at risk, individual (PARU) or group (PARG), building infrastructure, road transportation network, time-varying location of people, awareness, and warning and evacuation people behaviour. The time delay before evacuation and/or the time to first awareness can have an important effect on losses. It is very important to use a range of values for building evacuation delays and the overall time to first awareness and compare them with the worst-case loss scenario usually considered as the scenario with no awareness.

The study case could be subjected at an analysis of uncertainty running the scenarios to consider different conditions as the time of the year when the event occurs, in relation to the location and elevation of the safe haven, to the first awareness water depth, emergency and evacuation issuance time, strength of people/building/vehicle, toppling and sweeping depth of people/vehicle, effect of building and vehicle losses and effect of simulation time step to be more realistic as possible.

Data Type	Examples
Local Data	Gather useful location information about: Local tourist maps, Published local road maps, Local trade association/business development information, Local planning information from the City, Any event info that might describe a large concentration of people at some time during the year (especially in low-lying areas)
Areas of Interest	Gather data describing each of the areas of interest including: Below dam site–both sides of river, Town site/core or downtown area, Town site/infrastructure along riverbank, Homes (including mobile homes) along the riverbanks, Parks or tourist areas proximal to rivers
Types of Areas- Building Stock- Occupied Areas	Residential, Farming, Recreational, Institutional, Commercial, Industrial, Transportation, Communication, Utility
Topography- River- Key Areas	Photographs of the topography/ground cover for the flood zone areas (e.g. steeply sloped, heavily tree or shrub covered embankments, open areas behind buildings near water, etc.), Photograph any key features close to the river's edge
Building-Building Use	Focus on major population concentrations: City Hall, Fire station, Police Station, Hospital, Retirement homes, Schools (day care, kindergarten, elementary, high school and post-secondary), Major shopping centres, Major Industrial & Commercial Sites, For all buildings surveyed/photographed, where possible gather: Name; Street address; Estimate number of people in the building; General observations on vacancy rates of office and residential buildings (e.g. for rent & for lease signs); Observations on building strength/method of construction Systematic gathering of information: • Gather pictures of each representative building type. • Specific sampling of the downtown office buildings to determine capacities & strengths
Usage-Occupancy:	General observation of the use of buildings (e.g. how full are the parking lots?), Assessment of how big of factor 'special use' buildings like retirement homes, nursing homes, etc. would play in a population model of LSM Study Area
Road & Rail Network &Footpath Network & Level of Use	Verify the road/rail network data in terms of attribution (e.g. type [highway, arterial, collector], speed limits), Note the number of people travelling by foot and in car at different times of day - commuter, work day, evening, gather facts on the local transit and school bus systems. Make any observations regarding how the road network would be affected by a major emergency (e.g. at key choke points) Make any observations regarding the existence / quantity of footpaths going uphill from the river's edge.
Key Infrastructure	Identify the location of key community lifelines (power, communications, transportation, water). Pictures of all bridges (road & rail) crossing rivers and tributaries
Preparedness-Escape Routes	Does the community have an emergency plan? (acquire a copy if possible). Is there any indication of a warning system in the community? Is there anything in the local phone book, etc. addressing preparedness and warning? Identify candidate escape routes / trails.

Table 2-58.Summary of the receptors of LSM (BC Hydro, 2006)

2.3.3. Life Safety Model virtual world description

Once the input parameters are identified, they have to be located in the area. The study area extent could be represented using the flood extent and dividing it into subareas via major population concentrations, classes of land use, and identifying the element in proximity to the risk area. The classes area could be describe in term of land use as residential, work, school, touristic, industrial, commercial and shopping areas and buildings have to be located and defined by their geographical location, use, ability to contain people and strength and more important if they could be considered as potential safe haven. There are special types of building stock that need to be checked as retirement homes, retail and commercial dwellings, emergency structures, civic or municipal structures, outdoor gatherings. At this point road network defines the paths people may use for evacuation specifying the type of them that could be highway, arterial, collector, local, lane, footpath, and additional attributes such associated speed limit need to be added. All of the road segment status attributes need to be set to “OPEN” and Z elevations added to any bridge segments that cross rivers.

The key LSM objects are defined in the BC Hydro report 2006 in terms of importance (BC Hydro, 2006). Each object is described by characteristics among physical (location), conceptual (flood awareness), static such as a name or a speed or dynamic characteristics such depth in water over time and “health”. The key object input could be summarised in groups as following:

- Flood Wave: the hydrodynamic flood wave (time-varying hydrodynamics) caused by an event such as a hypothetical dam breach, tsunami, dyke breach, or extreme rainfall.
- PARU: a PARU (Population at Risk – Unit) is an individual within or near the impact zone and identifies a virtual representation of a person who could be located within the inundation area. This is the most important object in the LSM because it represents individuals at risk and they might congregate in outdoor areas.
- PARG: a PARG (Population at Risk – Group) is one or more people that act together, will usually move together as a group, will be exposed to the same flood wave conditions, and will attempt to escape the flood wave together if the PARG is considered indivisible. This collection of PARU are defined by the same attributes such as location, direction, and transport mode. Their escape can be on foot or in vehicle. LSM is able to model PARG actions individually or separable as for example members of the same family.

- Building: structures such as houses, schools, shopping centres that could contain people. Buildings are assigned places which defined specific uses for that building as recreational, offices, school, residential, or shopping places and they are assigned to create PARU and PARG locations. Within this object Safe Haven are defined as location (perceived or real) where a PARG could be safe from the flood hazard. This could be a Building, an Outdoor Place, or a road/trail network Intersection above a predetermined Safe Elevation. If the safe haven is overcome by the flood wave with sufficient destructive or killing force, the haven would be destroyed and individuals killed.
- Road and trail network: the complete road and trail network incorporating and connecting all of the other objects that make up the road system (i.e. Intersection, Road Segment, Lane, Trail Segment, and Bridge). Multiple PARGs in vehicles on a road segment can cause congestion and reducing traffic of that segment, thus increasing the time required for evacuation creating bottleneck effects.
- Warning Centre: A warning centre represents a location within the impact zone from which a warning can be issued and sent to the local population. Warning centres can be networked to communicate warning to each other and can radially warn buildings, vehicles and pedestrians in an area, thus providing an ability to account for a local emergency plan in the simulation.
- Events: specifically-time events as the loss of bridges, closing of a road, collapse of a building could affect an emergency plan.

LSM uses Loss Functions (ODLF's) to simulate the interaction of PARU, building or vehicle with the flood wave. The system of equations expresses the limits to which a receptor can resist a flood without toppling or being destroyed.

The most important part of the attention is focused on the timing of the flood event that significantly influence the potential Loss of Life. A given time of analysis determine whether or not a site and the inundated area would be populated. LSM specifies time-based scenarios as Time Domains that could be considered in terms of time of years (specific periods in a year such seasons or months), time of week (separation of the days of the week such as by work days or weekends) or time of days (defining of periods in a day such as typical workday hours, off-work hours, morning, afternoon, commuting or night-time period). The definition of the Time Domain should be connected with the information where a PARU is located in the virtual world that will depend on their individual role (at

work, at home, recreating, at school, etc.), and their role can vary based on person type (senior, adult, child, etc.), and the Time Domain.
Following each LSM input is defined in details.

2.3.3.1. Flood Wave Modelling

The flood wave modelling is the definition of the flood wave development for the various flood scenarios. The hydrodynamic model gives a detailed summary of the inundation extents and characteristics of the flood itself. Flood wave arrival times, maximum depths, and peak flow rates / velocity all provide insight into the potential risks and consequences that might be associated with the simulated flood events. For these purposes LSM requires depth map, to provide an indication of the extent of floodplain and consequent damages that might occur during a flood event. In addition velocity maps are necessary to know the flow intensity values and identify toppling criteria for humans and vehicles, and for the destruction of buildings in the LSM virtual world. Other essential information as flood wave arrival time help determining emergency response requirements and it is possible taking advantage of 2D animation to provide a compelling visual tools for assessing and understanding which flood scenarios are critical.

2.3.3.2. Buildings

LSM requires the definition of places where people are located in terms of building considered as structure that will contain people in the study area and help in the distribution of population. Buildings are categorised by key parameters as ID, X and Y geographical coordinates (preferably UTM coordinate reference system), Use Type (to place properly people considering the Time Domain), person capacity (the maximum number of building that can occupy the building), strength index (to evaluate the capacity to withstanding at the flood risk), evacuation time (time required by PARU or PARG to escape from the building) and an index to identify the potential attitude to be a Safe Haven in case of emergency.
The Building use type depends on the economic and social nature of the area under analysis. A general framework identifies single family dwelling, multi-users dwelling, residential outbuilding, farm, school, assisted living, hospitals, religious, organised recreation, retail service, hospitality (hotels and restaurants), offices, outdoor place, industry, commercial.
LSM is implemented through international research study of the building behaviour when subjected at a flood event and focused to determine its capacity of standing or be destroyed. LSM Building sub model uses a Building Object Damage Loss Function

algorithm to vary the building condition of standing during the flood. The Figure 2-85 summarised the Building algorithm behaviour that is governed by the Equation 2-15, Equation 2-16 and Equation 2-17 as defined by the BC Hydro (BC Hydro, 2015) and later improved by HR Wallingford (HR Wallingford Ltd, 2015).

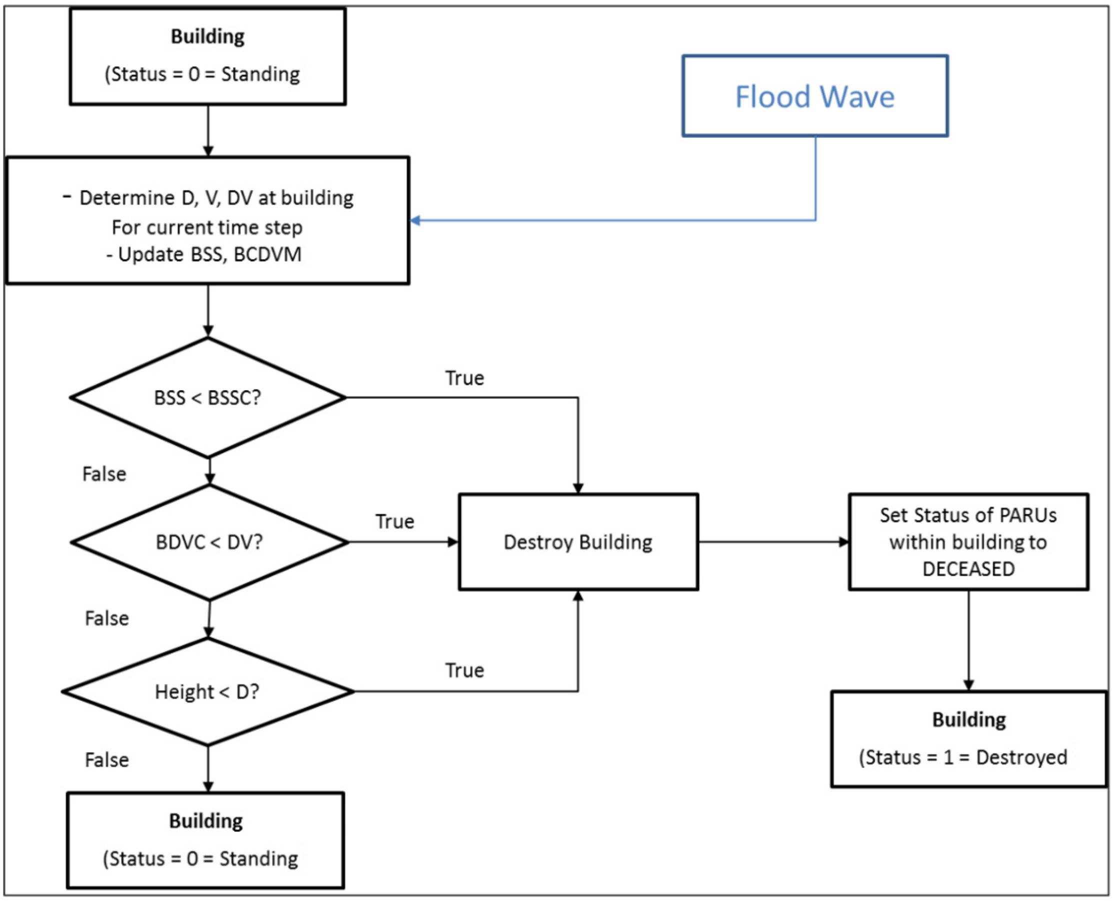


Figure 2-85.Algorithm for updating building status based on flood wave input (HR Wallingford 2015)

$$BSS(t+1) = BSS(t) * \left[1 - \frac{\frac{dv(t)+dv(t+1)}{2} * \Delta t}{BCDV(t)} \right]$$

Equation 2-15.Building Structural Strength(HR Wallingford 2015)

$$BCDVM\ (t+1) = BCVDM\ (t) - RBCVDM\ * (dv(t) * \Delta t)$$

Equation 2-16.Building dv Multiplier(HR Wallingford 2015)

$$BDVC\ (t) = BSS\ (t) * BDVCA$$

Equation 2-17.Building dv Criteria(HR Wallingford 2015)

Where BSS(t) is the Building Structural Strength parameter that varied with time, dv(t) is the flow intensity expressed in terms of the product of water depth and velocity, Δt is the time step, BCDVM(t) is the Building Critical dv Multiplier parameter, RBCDVM is the Building Critical dv Multiplier Reduction Factor, BDVC(t) is the Building dv Critical parameter, BDVCA is the Building dv Critical Actual parameter and BSSC is the Critical Building Structural State parameter.

Figure 2-85 shows that a building could be destroyed when the Structural Strength (BSS) is lower than the critical Building Structural State (BSSC), if the flow intensity, dv, is sufficiently high to exceeds the Building dv Critical parameter value (BDVC), or if the water depth reaches an high greater than the height of the building.

BSS parameter representing the building strength depends on building material characteristics. Three values have been assigned to BSS parameter: the value 1, that represents an average structural strength considering typical wood framed homes, BSS>1 for large masonry structures, and BSS<1 for weak or temporary structures. The default initial value is usually equals to 1.

BSSC parameter defines the threshold for building failure and the comparison with the BSS parameter means that a longer exposition of the building to the flood event could cause a gradual decrease of the BSS parameter till to became lower than the BSSC parameter and determine the building collapse.

BCDVM parameter defines the rate at which the Building Structural State (BSS) declines with exposure to the flood. In fact the flood event is characterised by hydrostatic forces, momentum of moving water and constant actions of debris that weaken the structure and the building capacity to standing and causing a gradually decrease with time and flood exposure, Equation 2-16. A positive value of BCDVM parameter means a decline rate in the BSS parameter. It could happen that structures are reinforced during the event and in this case a negative value has to be assigned at the BCVDM parameter to simulate an increment in the BSS parameter with time.

RBCDVM parameter considers that when a building is weakened with continued exposure to flood waters, the rate at which its strength declines could increase. The RBCDVM default value is usually equals to 1. Assigning at the RBCDVM parameter the value 0 the user considers constant the BCDVM parameter, a positive value increase the rate of strength decline, while a negative value decreases the rate of strength decline.

BDVC parameter is considered when the building is subjected at potential loss by a high intensity flow, dv criterion. The dv criterion implies the immediate destruction of the building because of the powerful flood wave, but could be used considering in addition debris transportation by the flood. The building limit to withstanding the flow intensity is represented by the BDVC parameter.

Building parameters are the results of accurate studies conducted through international researches and focused on the possible ways of buildings collapse when hit by a flood wave and usually these studies considers the building loss in function of the flow intensity, dv. LSM report (HR Wallingford Ltd., 2015) explains that LSM model is based on different studies, but in particular developed by Lorenzen et al. 1975, Sangrey et al. 1975, and the study developed by Clausen and Clark 1990 for the USACE on the Dale Dyke Flood event. Clausen and Clark proposed a set of dv envelope curves that define two threshold dv values of 3 m^2/s and 7 m^2/s for partial and total damage, respectively, and the results were supported by the RESCDAM study (Lorenzen et al., 1975) (Clausen and Clark, 1990) (RESCDAM, 2000). These two threshold values exclude a significant number of data points including those of minor damage as observed in Figure 2-86. An accurate analysis of Figure 2-86 shows different dv limits that could be considered due to a deeply analysis of data collected for building damages in the Dale Dyke Flood as presented in Clausen and Clark (1990) where dv curves for 10, 20, 30, 40 and 50 m^2/s are taken in consideration. According to this data, two buildings assessed as being exposed to a maximum dv of 25 m^2/s sustained only minor damage. Meanwhile, several buildings sustained major damages under maximum dv between 7 and 15 m^2/s. A different interpretation of this analysis might consider the effect of the time a structure is impacted by a varying flood depth and velocity (BC Hydro, 2006). A building that has been reported to be totally destroyed could have destroyed under lower dv conditions while another building reported to be destroyed by a seemingly lower dv may have been affected by the cumulative effect of lower, but more persistent dv conditions. This logic indicates that data pertaining to buildings which were reported to be partially or minimally damaged, especially under high dv values, provide more insight (as compared with buildings that were totally destroyed) into the structural reliability of buildings. The two buildings reported in the study to have been only partially damaged under high dv values of 25 m^2/s indicate that some buildings can survive higher than recommended dv conditions. This phenomenon could be attributed to several conditions which were unaccounted for such as structural design, shelter in the lee of larger upstream buildings, and flood proofing (BC Hydro, 2006).

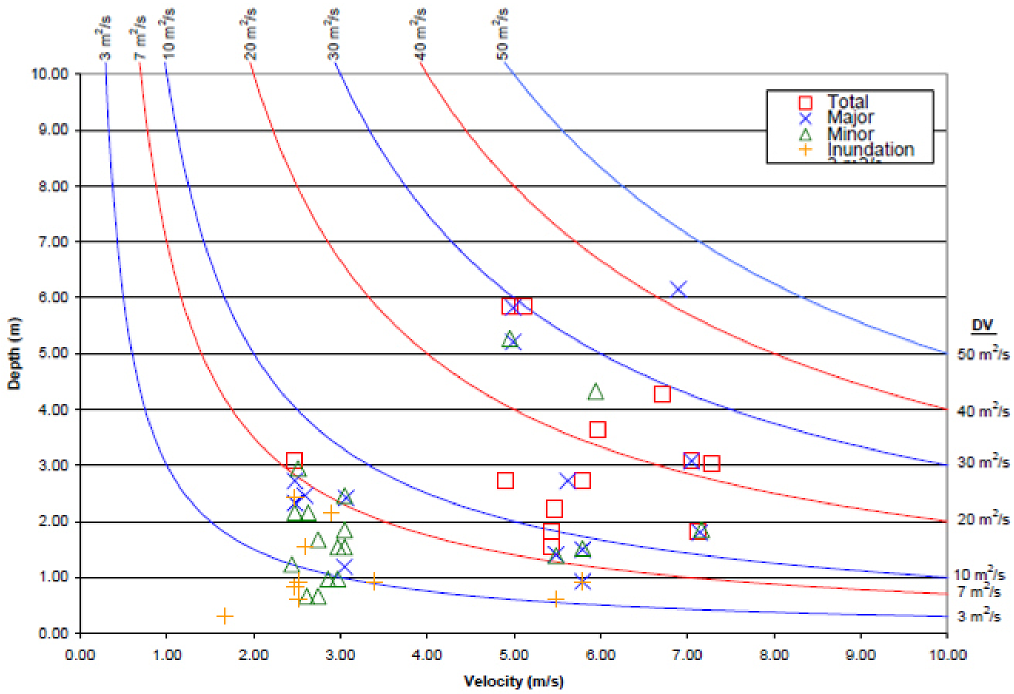


Figure 2-86.Building Damage in Dale Dike Flood (Adapted from Clausen & Clark 1990, BC Hydro report 2006)

The definition of Building parameters strength values derived by the studies mentioned above and their values changes considering which methods of building destruction the user decides to apply: building decline structural strength or dv criteria.

The decline of structural strength criteria simulates building degradation under a continuous exposure to the flood wave using the BSS value in the Equation 2-15. However, none of the currently available research describes the rate at which building strength decline with exposure to floods. Current research and analysis of building destruction in floods have been based on historic flood events that can only suggest possible ultimate threshold of dv causing total destruction of buildings. Given this lack of qualitative evidence on building structure strength decline, the use of the parameter BSS, BCDVM and RBCDVM is subjective. Further research is required to better ascertain suitable values for these parameters. However, as the understanding of building strength in flood grows, these parameters could be utilised in the LSM to simulate more accurately building loss.

That aspect leads the LSM user to consider the destruction of building based on dv criteria, taking apart that case when the building destruction happens for decline of its strength. In fact, the BC Hydro 2006 guidelines suggests to assign the value 1 at the BSS parameter, the value 0 at the RBCDVM parameter and setting a large value to the BCDVM parameter as 10^9. Using a large BCDVM value the algorithm considers that building structure does not show degradation during flood event and modelled the potential loss of building only in terms of the constant dv criteria.

If the user decides to consider the Building strength decline criteria, the BCDVM and BSS value should be set as following. BCDVM could be categories in three groups:

- < 1000 m^2 is representative of poorly structured or unanchored Buildings, (trailer houses, makeshift camps, neglected Buildings, or camper and pitches in case of camping areas);
- = 5000 m^2 is more indicative of the average detached houses;
- > over 10000 m^2 for well-built and anchored Buildings.

While the BSS parameter could be set with the following values:

- default of 1.0 for a typical Building;
- between 0.3-0.7 for poorly constructed Buildings;
- up of 1.2-1.3 for well-built Buildings.

BSSC can be subjectively determined based on estimated time a building would be able to stand, or some other criteria to denote building failure (such as 75% failure). Another approach would be to assign BSSC appropriate to the BCDVM to provide the expected time for building failure during a flood event.

Building dv criteria, represented by the BDVCA parameter, still retain some logical gaps in estimating dv that destroyed a structure in a flood wave and that may occurred instantly, or over a prolonged period. Additionally, the perceived "failure" of a structure could mean total collapse of Building or loss of protection due to only partial failure. Partial failure could entail a building still remaining standing but losing a portion of its structure to reduce the protection from the flood provided by a fully intact building. Failure of a lower floor wall of a multiple storey building could still provide sufficient protection to people on the upper floors. Therefore, BDVCA parameter depends by the LSM user definition of potential level of damage of failure of the building and depends by the building type construction and site conditions. Five different groups of BDVCA value are considered in LSM guidelines:

- 5 m^2/s for poorly constructed Buildings
- 10 m^2/s for well-built timber Buildings
- 15 m^2/s for well-built masonry Buildings
- 20 m^2/s for concrete Buildings
- 35 m^2/s for large concrete Buildings

Table 2-59 shows the mean building parameters value that could be used to set building strength limits.

Building Structural Strength Parameters	Building strength index (Mean Value)				
	1.No Strength	2.Low Strength	3.Medium Strength	4.High Strength	5.Extreme Strength
BSS - Structural State	0.05	1.00	1.00	1.00	1.00
BSSC - Critical Value	0.01	0.01	0.01	0.01	0.01
BCDVM - Critical DV – Continuous	0.10	1000	5000	10000	75000
BDVCA - Initial Critical DV	0.50	3.00	5.00	7.00	200

Table 2-59.Building Structural Strength Parameters (BC Hydro 2006)

HR Wallingford introduced in the version 3 of LSM the third building loss criteria due to a water depth higher than the building height. Building d criteria considers the study developed by the USACE and based in part by the use of a loss function with a quadratic form $aDV^2 + bDV + c$ and a second criterion, the maximum flood depth. This approach is used in the FEMA-HAZUS model for floods in the US (David S. A., 1985) (Scawthorn C. et al., 2006). Figure 2-87 shows the potential collapse of the building based on the water depth height related with the number of floor of the building.

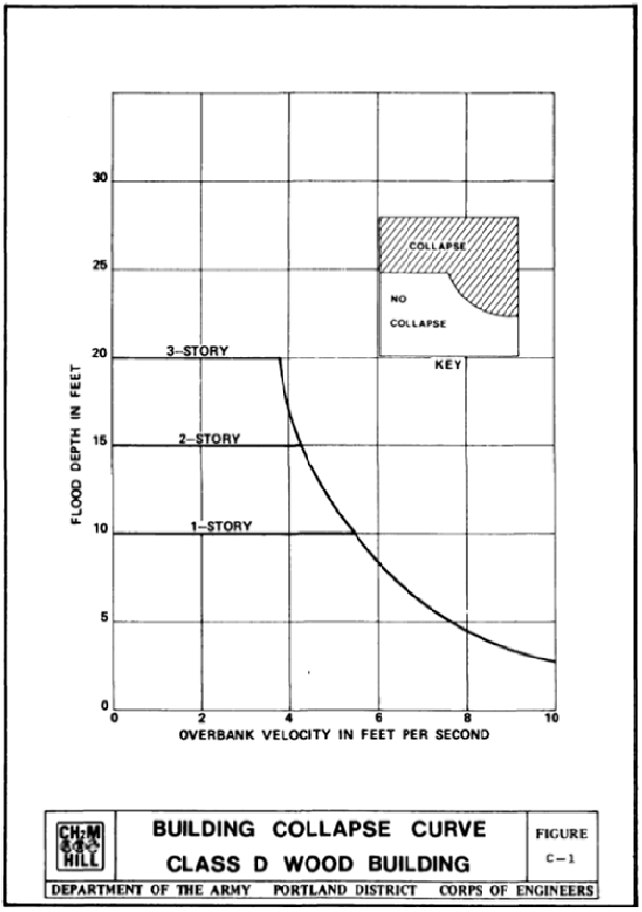


Figure 2-87.Flood Collapse curve for wood buildings developed by USACE (Davis 1985)

When a building collapses, it does not imply necessarily only the loss of the building, but also loss of people who could be drowned inside the building if the flood water rises high enough creating the Loss of Protection mechanisms as called in LSM. The loss of protection mechanism compared the water depth with the floor height if the building is a single storey building, or with the sum of the foundation height and the floor height per number of floor minus the value 0.3, Figure 2-88.

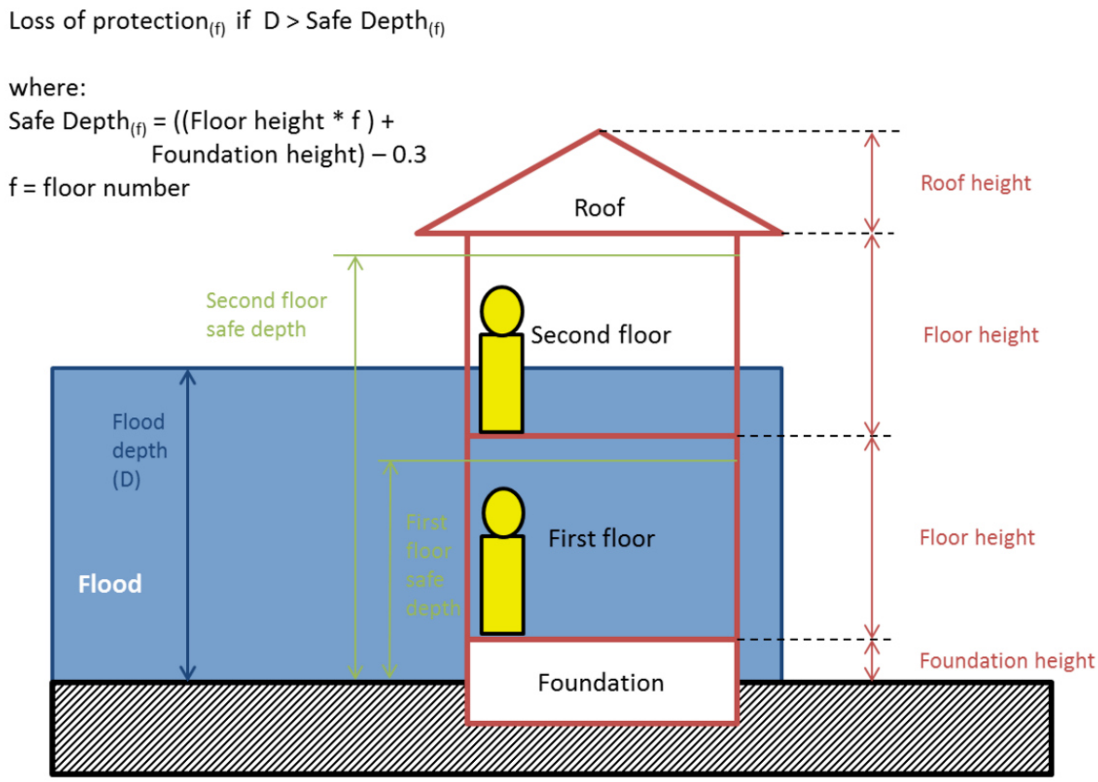


Figure 2-88.Loss of Protection with buildings (HR Wallingford 2015)

A second integration made by HR Wallingford is the introduction of multi-storey buildings allowing people to shelter in place rather than attempting to evacuate across flood water and considering to allocate people in each floor of the building. LSM requires to define the total building capacity considered as the number of floors multiplied by capacity, and the capacity of the floor is made by the maximum amount of people that the floor can hold.

LSM has been set considering three ways to evacuate the building:

0 – People behave leaving the building when they are made aware;

1 – People remain in the building;

2 – People exit the building if the water depth is below their safe depth.

The awareness depth is set for the 1^{st} /ground floor and this is applied above the invert of each additional floor minus the 1^{st} floor it is awareness depth plus floor size, for second floor it is awareness depth plus 2 times floor size.

2.3.3.3. PARU and PARG

The LSM object PARU is defined by different variables and the type of person is one of the most important aspect of single individual categorised by the age of each individual and by its physical characteristics. PARU object is defined as senior when the user considers a person over the age of 65, adult male or female when the person is over 18, children are divided by the age including male and female in the three groups of 12-18, 6-12 or 0-6. If the user is not conscious of the age of a single person, a generic PARU value could be used meaning any person with no distinction by age or sex.

The variable role is considered by the user to assign at each person a proper location, X and Y coordinates, as at work, shopping, recreation, at school, at home, out of the area, on road as pedestrian or in a vehicle, and to provide a linkage between person type and role. In addition the role of each PARU helps the user in the identification of the areas that characterised the studied domain.

LSM model is characterised by a branch that evaluates the state of a person, toppled or deceased, when subjected to flood waters. When a PARU is immobilised the individual is considered toppled. PARU strength may continue to decline until the individual becomes weak enough to be considered deceased or if the PARU is impacted by a significant dv it results into an immediate death. LSM considers also the case when the dv could decline and the PARU is again able to move, or the case of a person who is not toppled, aware of the flood and could decide where to hide or actively move toward a safe haven. The PARU behaviour is modelled through the PARU Object Damage Loss Function algorithm shown in Figure 2-89 and governed by the Equation 2-18, Equation 2-19, Equation 2-20 and Equation 2-21

$$PPC(t+1) = PPC(t) * \left[1 - \frac{\frac{dv(t) + dv(t+1)}{2} * \Delta t}{PCDVM(t)} \right]$$

Equation 2-18.PARU Physical Condition (HR Wallingford 2015)

$$PCDVM\ (t+1) = PCDVM\ (t) - RPCDVM\ * (dv(t) * \Delta t)$$

Equation 2-19.PARU Physical Condition dv Multiplier (HR Wallingford 2015)

$$PLTD\ (t) = PCC\ (t) * PLTDA$$

Equation 2-20.PARU Lowest Toppling Depth Decline (HR Wallingford 2015)

$$PDVTC\ (t) = PCC\ (t) * PDVTCA$$

Equation 2-21.PARU dv Toppling Criteria Decline (HR Wallingford 2015)

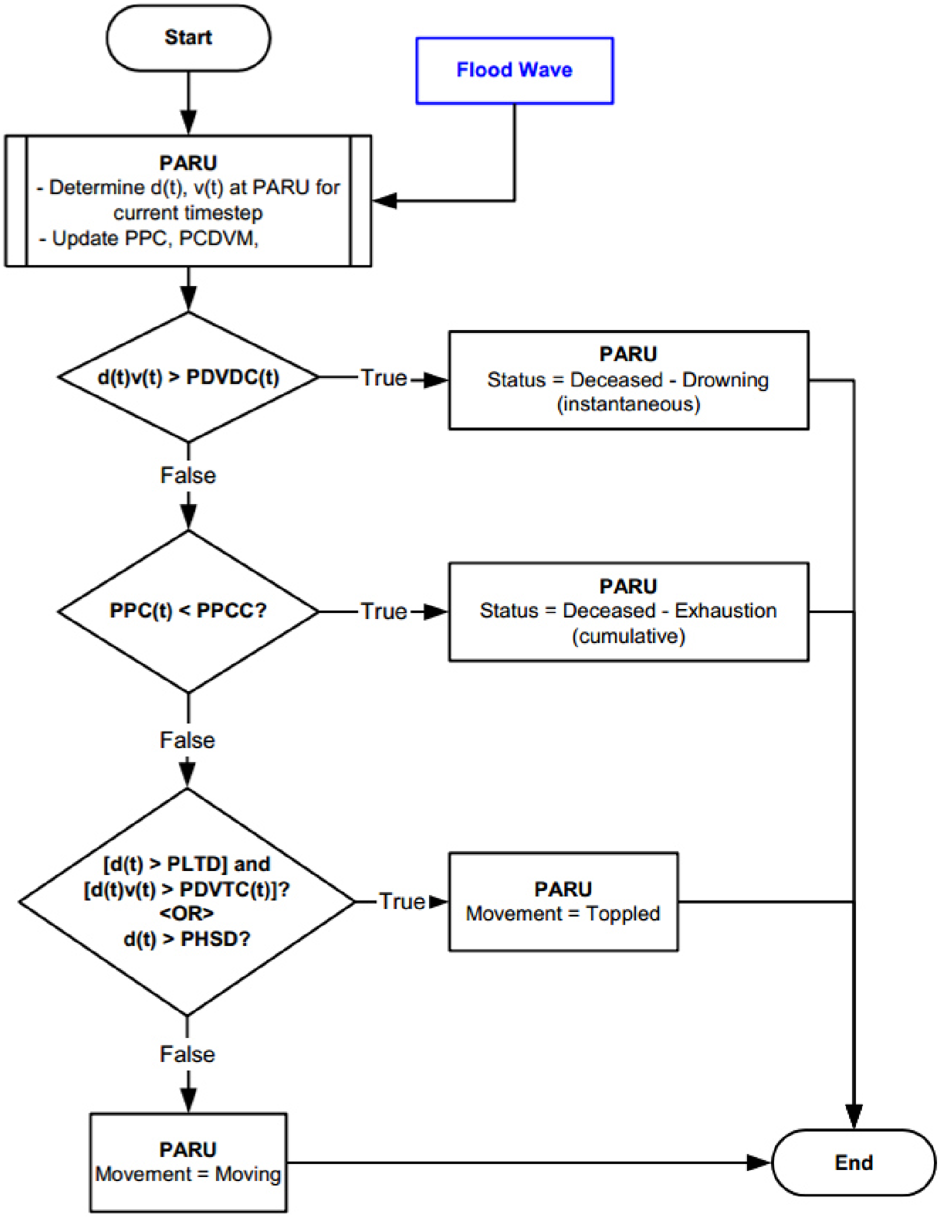


Figure 2-89.Algorithm for Updating PARU Status Based on Flood Wave Input (BC Hydro 2006 and HR Wallingford 2015)

Where PPC(t) indicates PARU Physical Condition, PCDVM(t) is the PARU Physical Condition dv Multiplier, RPCDVM is the Reduction Factor of the PCDVM parameter, PLTD(t) is the PARU Lowest Toppling Depth, PLTDA is the Initial Lowest Toppling Depth and PDVTC(t) represents the PARU Critical Toppling dv value. These parameters evaluates the state of the PARU following two criteria: toppled or deceased.

LSM PARU sub model considers a PARU deceased when hit by a flow intensity higher than the Drowning Critical value (PDVDC) resulting in an instantaneous death, or when the Physical Condition (PPC) declines gradually below the Physical Critical Condition value (PPCC) due to exhaustion caused for example by constant impact with debris or hypothermia. Instead, a PARU is considered toppled when experiences a flood water depth too great to walking and that limit is defined by the Highest Safe Depth value (PHSD), and when the dv value is sufficiently high to induce PARU instability and reaching the value of the DV Toppling Criteria parameter (PDVTC). In addition, LSM PARU sub model defines the Lowest Toppling Depth parameter (PLTD) to ensure that the PARU is not toppled in shallow and swift water.

PARU strength parameters assume different values due to type of person and environmental conditions.

PPC parameter represents the gradual decline of PARU physical condition when the person is continuously exposed to the flood. The PPC parameter value could be equal to 1 for a typical PARU with average physical condition, is higher than 1 when the PARU is extremely healthy or could lower than 1 in case of an unhealthy person. Considering the PARU person type categorisation in senior, adult and child the BC Hydro 2006 guidelines recommended to assign a PPC value into a range of 0.7 and 1.3 and a default value of 1 in case of generic PARU.

PPCC parameter is used to provide flexibility in the determination of loss of life of a PARU when the deceased criterion is defined by a gradual decrease PPC. The PPC parameter could decline to a level below PPCC parameter and the PARU will be considered deceased. For a healthy person the PPCC value is equal to 0, considered also default value, and it is higher than 0 for weaker persons as young, children, old or disable.

PCDVM parameter governed the decline rate of PPC that could accelerate with increased exposure to the flood water using the RPCDVM and due to particular condition as hypothermia. In fact the researches have been conducted on this field as the one made by Hayward, Eckerson and Collis (Hayward J. S. et al., 1975) who suggest that an adult might survive for about 1 hour immersed in water at 10°C. For an adult in healthy condition (PPC=1) subjected at a flow intensity of 0.5 m^2/s, the physical condition could decline to 0 in 1 hour due to a PCDVM=1850 m^2 and a RPCDVM=0.1, results could change if the flood is characterised by warm water or debris flood. BC Hydro guidelines suggest to consider only the dv criterion based on the PARU dv Drowning Criteria (PDVDC) assuming the RPCDVM parameter equals to 0 to provide no change in rate of PCDVM parameter, and set the last one with a high value, as 10^9, to assure that PPC parameter does not decline.

PHSDA parameter depends on physical characteristics of the individual. This variable defines the water depth limit between the possibility of the person to wade in deep water with low velocities and to be immobilised by the flood. The PHSDA value changes by age (adult or child) and by race of the person. A person is usually considered immobilised when the water depth reaches its chest and it is around the 0.7% of the PARU height.

PLTD parameter is based on a depth water in which a PARU could safely stand without being toppled regardless of the velocity. International studies have been conducted aiming to identify a proper PLTD parameter value. Abt, Wittler et al. study, later improvements by Lind and Hartford and in the RESCDAM project analysed the stability of a monolith and human subjected to moving water in a flume (Abt et al., 1989) (Lind and Hartford, 2000)(RESCDAM, 2000). The study showed that the monolith, at the same dv, is lower stable than the human due to the ability of the human to adjust its stance of balance. The results of this study has been shown in Figure 2-90, where the monolith stability limit is around the dv limit of 4 ft^2/s (0.37 m^2/s), with practical velocities, and the water depth along this dv curve would be in a range of 0.1 – 0.15 m.

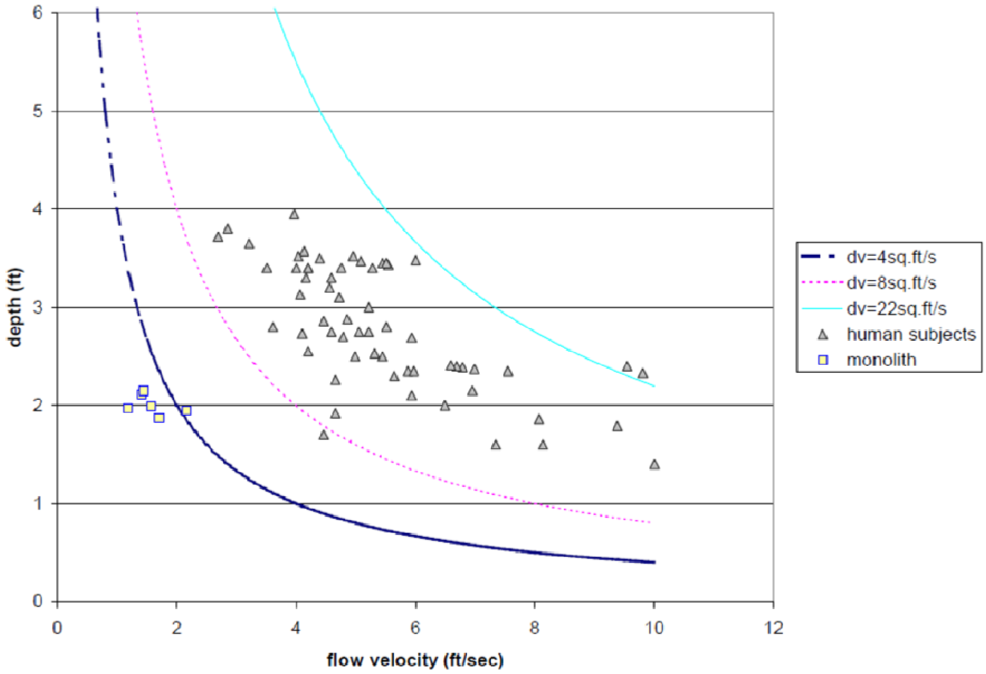


Figure 2-90.Human Stability Test Data (After Abt, Wittler et al. 1989, BC Hydro 2006)

PDVTCA parameter has been calculated using the same human stability tests explained above. The Figure 2-90 shows that an adult human stability is into a range of 8 ft^2/s (0.74 m^2/s) and 22 ft^2/s (2.04 m^2/s). Keller suggested to consider a toppling depth limit around 1.2-2 m^2/s for adult and 0.4-0.5 m^2/s for children (Keller R.J. and Mitsch B.F., 1992) (AR&R, 1997) (Engineers Australia, 2012).

In addition of the PARU physical condition parameters each person of the area under analysis is grouped to create the LSM object PARG, Population at Risk Group. As defined above, LSM works considering how people interact each other in order to identify the evacuation mode and related time to escape the risk have to be defined for each group of

PARU. LSM user could choose between two evacuation mode: by foot or by vehicle. Evacuation time is provided considering the building characteristics in terms of building size and number of floors, and it takes in consideration low values for slower moving individual, as elderly or young children.

All of the PARU parameters governed by LSM PARU algorithm are summarised in the Table 2-60.

PARU Strength Parameter	Person Type (Mean Value Index)					
	Senior	Adult (M/F)	Child 12-18	Child 6-12	Child 0-6	Generic
PPC-Physical Condition	1.0	1.0	1.0	1.0	1.0	1.0
PPCC-Critical Physical Condition	0.1	0.1	0.1	0.1	0.1	0.1
PLTDA-Lowest Toppling Depth (m)	0.1	0.1	0.1	0.1	0.1	0.1
PHSDA-Highest Safe Depth (m)	1.2	1.2	1.2	0.8	0.6	1.0
PDVTCA-Critical dv Topple (m^2/s)	1.2	2.0	2.0	1.0	0.5	1.5
PDVDCA-Critical dv Drowning(m^2/s)	2.4	4.0	4.0	2.0	1.0	3.0
PSA-Escape Speed on foot (km/h)	2.4	4.0	4.0	2.0	1.0	3.0
PDEUA-Building Evacuation Delay (s)	900	900	1200	1200	1500	1200
PDEVA-Vehicle Evacuation Delay (s)	30	30	30	60	60	40
PCDVM-Critical dv Multiplier	2000	2000	2000	1000	1000	1800

Table 2-60.PARU Strength Parameters (BC Hydro 2006)

Moreover, other studies have been conducted by Foster and Cox (1973), Abt. Wittler, Taylor and Love (1989), by the Engineers Australia for the development of the Australian Rainfall and Runoff Project, ARR Project 10 (AR&R, 1997) (Abt et al., 1989).

In particular, ARR Project evaluates the stability of people under flood risk according with scenarios run in laboratories testing people behaviour (adults and child) under flood conditions. Figure 2-91 shows the test considers conditions when rescue workers can operate: d= 0.4-1.1 m, v=0.6–2.6 m/s, dv=0.6–1.3 m^2/s, HM = 77 – 195 mKg (RESCDAM, 2000). Cox R.J., Yee M. and Ball J.E consider extension of Foster and Cox testing of smaller children defining as limited strength values d = 0.1 – 0.5 m, v = 0.9 – 2 m/s, dv = 0.3 – 0.6 m^2/s and HM = 21 – 33 mKg, Figure 2-92 (Cox et al. 2004).

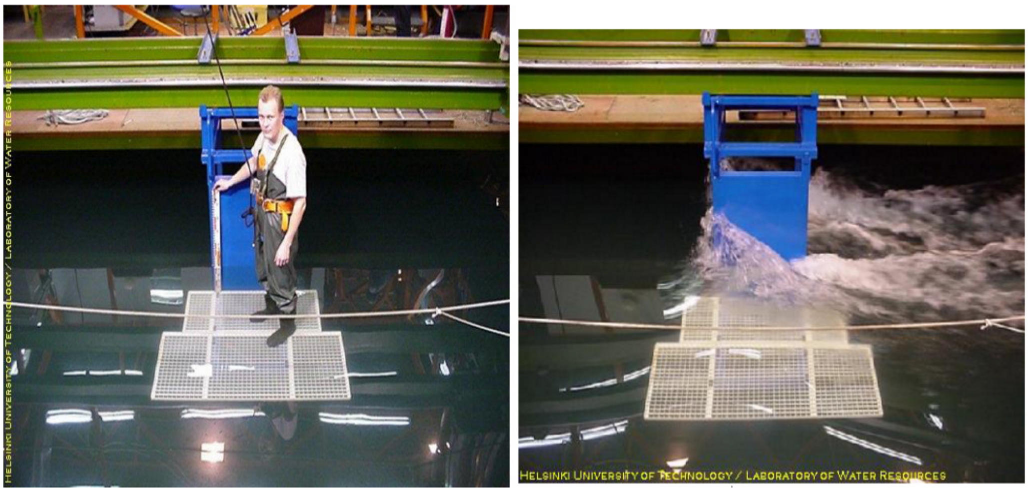
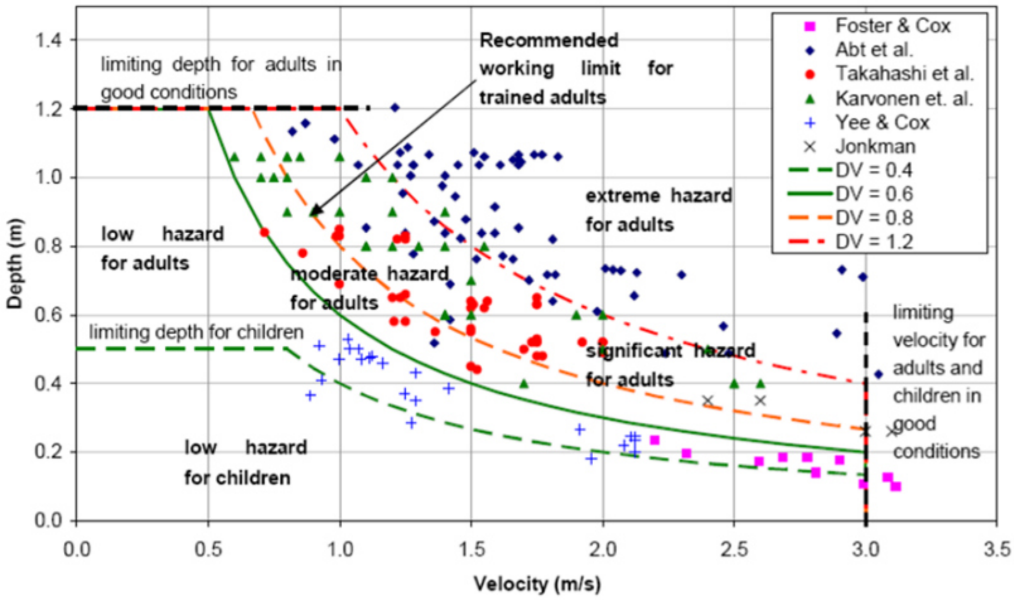


Figure 2-91.RESCDAM test on rescue workers (RESCDAM, 2000)

Figure 2-92.Small child test on flood conditions (Cox et al. 2004)

Figure 2-93 shows the resulted flood hazard regimes obtained by these studies and the obtained d, v and dv limits for different type of PARU, adult and children.



DV (m²s⁻¹)	Infants, small children (H.M ≤ 25) and frail/older persons	Children (H.M = 25 to 50)	Adults (H.M > 50)
0	Safe	Safe	Safe
0 – 0.4	Extreme Hazard; Dangerous to all	Low Hazard[1]	Low Hazard[1]
0.4 – 0.6		Significant Hazard; Dangerous to most	
0.6 – 0.8		Extreme Hazard; Dangerous to all	Moderate Hazard; Dangerous to some[2]
0.8 – 1.2			Significant Hazard; Dangerous to most[3]
> 1.2			Extreme Hazard; Dangerous to all

Figure 2-93.Proposed Hazard Regimes (ARR, 2001)

In AR&R Project it asserted that the most important factors of flood affecting human stability are firstly water depth and secondly velocity. Water depth dictates what type of failure is to occur, either sliding (friction) or tumbling (moment) failure. Moreover, high water depths increase buoyancy and reduce friction underfoot, while low water depth-high velocity flows may cause instability but the chances of drowning are less than in the more dangerous deep water situations.

The current AR&R guideline of DV=0.4 m^2/s is suitable for children (HM 25 to 50 mKg) but conservative for healthy adults who if trained could be expected to work in conditions up to DV= 0.8 m^2/s. Extreme hazard is indicated for all adults at DV > 1.2 m^2/s, while small children with HM less than 25 mKg are not safe at DV as high as 0.4 m^2/s. It is most likely that many frail/older persons may also not be safe under this criteria. Small children and frail older persons are unlikely to be safe in any flow regimes and their location should be properly defined as in retirement villages, childcare centres and kindergartens.

The AR&R project underlines that should be noted that loss of stability could occur in lower flows when adverse conditions are encountered including: bottom conditions (uneven, slippery, obstacles), flow conditions (floating debris, low temperature, poor visibility, unsteady flow and flow aeration), human subject (standing or moving, experience and training, clothing and footwear, physical attributes additional to height and mass including muscular development and/or other disability, psychological factors) and others aspects as strong wind, poor lighting, definition of stability limit (i.e. feeling unsafe or complete loss of footing).

2.3.3.4. Vehicles

LSM Vehicle sub model allows the user to model the flood evacuation by vehicles in function of the type, the size and characteristics of the vehicle that influence also its stability into flood. In fact, vehicles those are heavy or have high clearance from the ground will be more stable than lower or lighter vehicles. LSM simulates the interaction of vehicles with the flood determining whether or not a vehicle could be toppled or floating due to the flood water depth and velocity local to the vehicle position. LSM Vehicle sub model describes the vehicle-flood interaction using the Vehicle Object Damage Loss Function algorithm shown in Figure 2-94 and governed by Equation 2-22, Equation 2-23 and Equation 2-24.

$$dv(t) > VDVTC$$

Equation 2-22.Vehicle dv Toppling Criteria (HR Wallingford 2015)

$$dv(t) > VDVFC$$

Equation 2-23.Vehicle dv Floating Criteria (HR Wallingford 2015)

$$d(t) > VSDC$$

Equation 2-24.Vehicle Safe Depth Criteria (HR Wallingford 2015)

The LSM Vehicle algorithm simulates vehicle – flood interaction with two criteria. The vehicle could float when the local depth exceeds the Vehicle Safe Depth Criteria (VSDC), Equation 2-24, or when the flow intensity, dv, exceeds the Vehicle DV Floating Criteria (VDVFC), Equation 2-23. In case of floating risk the PARU within the vehicle will attempt to escape and become pedestrians. The Equation 2-22 shows the case of toppling criteria when the flow intensity exceeds the Vehicle DV Toppling Criteria (VDVTC), but in this case the PARU within the vehicle does not have the possibility to escape and will be considered deceased.

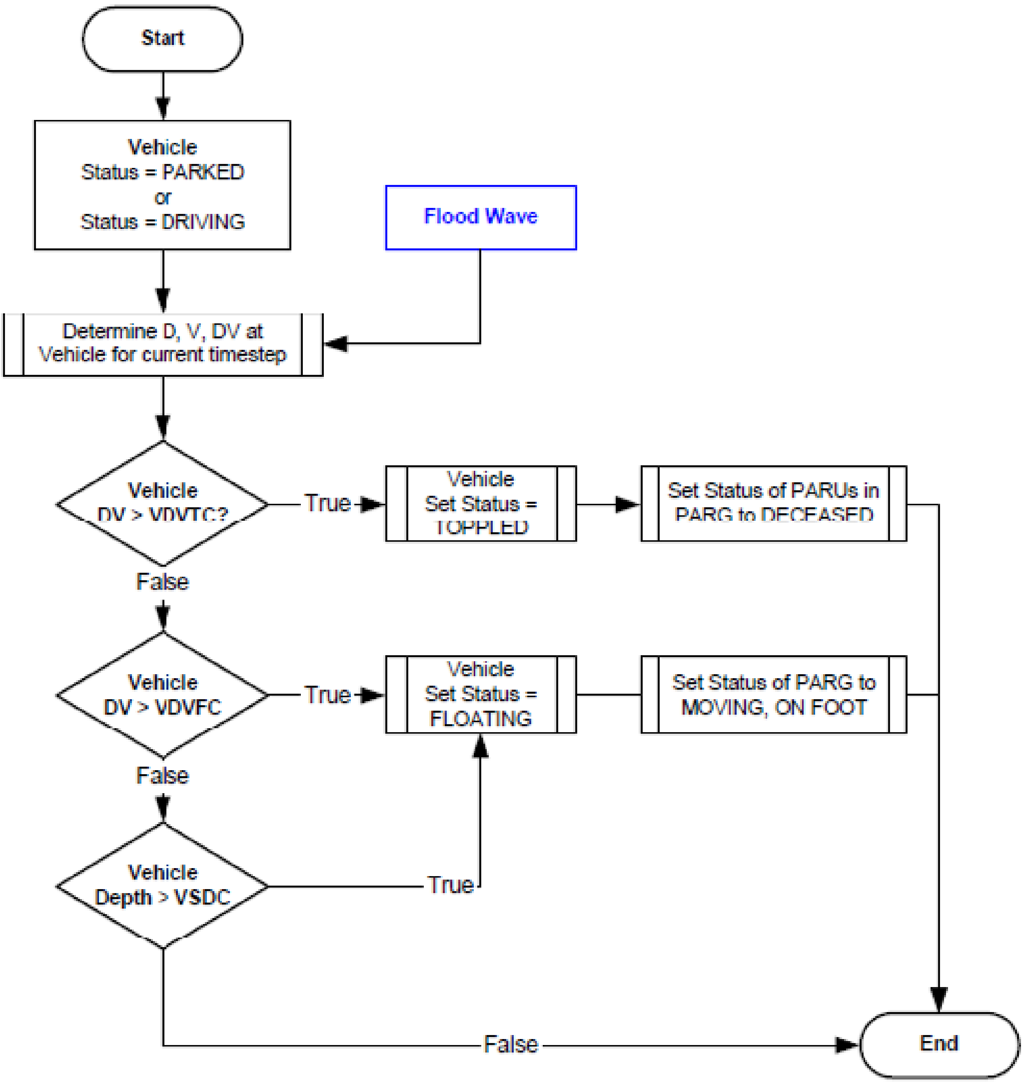


Figure 2-94.Algorithm for updating vehicle status based on flood wave input (HR Wallingford 2015)

The studies conducted on vehicle – flood interaction provide Vehicle Safe Depth Criteria considering the vehicle unstable or stall when the water depth makes unusable vehicle engine due to the inundation of the floor pan of the vehicle or because the pipe of the vehicle may be submerged. Vehicle Safe Depth Criteria value changes by type of vehicle. LSM Vehicle sub model considers five different groups of vehicles: car/wagon/van/SUV (1), Pickup Truck (2), Straight Truck (3), Tractor Trailer (4) and Bus (5). The first groups of vehicle type for typical passenger are subjected to lower Vehicle Safe Depth, around 0.3 m, than the value used for the bigger vehicle type, value that could be higher than 1 m. The vehicle floating condition has been evaluated using the depth and velocity criteria and based on the Vehicle DV Floating Criteria parameter (VDVFC). The instability vehicle point occurs when the drag force at an axle, due to the flowing water, is equal to the restoring force due to the axle load leading the VDVFC parameter into a range of 0.6 – 0.7 m^2/s (AR&R,1997)(BC Hydro 2006). These values could vary depending on the flood water depth (Keller R.J. and Mitsch B.F., 1992) and the vehicle instability could be caused also by high velocity and shallow water that do not reached the axle. Keller and Mitsch affirmed that a vehicle could be unstable in deep water and low flow intensity with dv value between 0.2 –0.3 m^2/s, and the three conditions are shown in Figure 2-96.

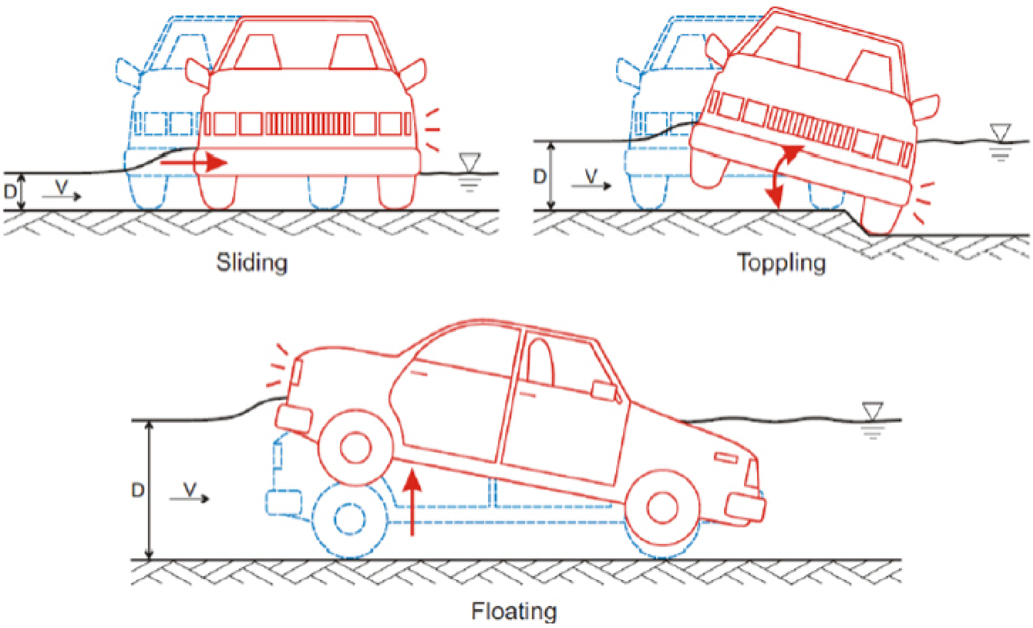


Figure 2-95.Vehicle conditions under flooding (AR&R 2001)

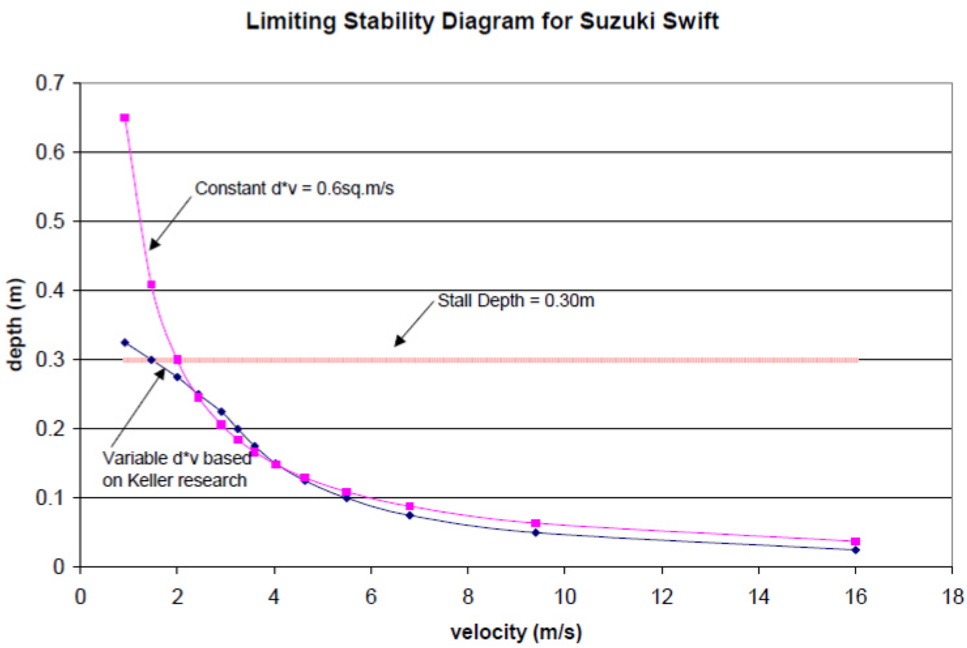


Figure 2-96.Vehicle Stability diagram (After Keller et Mitsch 1992- BC Hydro 2006)

LSM Vehicle sub model provides value for each parameter that governed the vehicle toppling, floating and water depth safe criteria, Table 2-61.

Vehicle Strength Parameters	Vehicle Type (Index Mean Value)				
	Car/Wagon/Van/SUV	Pickup Track	Straight Truck	Tractor Trailer	Bus
VEVT - Evacuation time (s)	15	15	15	15	300
VDVFC - Critical DV for Floating	0.50	0.60	0.60	1.00	1.20
VDVTC - Critical DV for Toppling	0.60	0.70	0.70	1.20	1.20
VSDC - Critical stall depth (m)	0.50	0.50	0.60	2.00	1.00
Capacity – Vehicle Capacity	/	3.00	3.00	3.00	/

Table 2-61.Vehicle Strength Parameters (BC Hydro, 2006)

2.3.3.5. Roads

Building, PARU, PARG and vehicles are linked and moved in the territory using the road network. LSM model requires the definition of the road network in terms of physical location and connectivity. Each road network is defined by a length, elevation, type (highway, arterial, collector, local, lane, footpath, bridge and footbridge), status (open or closed), number of lanes and available maximum speed. In addition, the LSM user could specify if the route is only by pedestrian or if it could be used by vehicles and pedestrian. All of these information are essential during the evacuation simulation to consider potential congestion in part of the road network and bottleneck effects due to limited road capacity, insufficient available escape routes, evacuation routes lost because of the flooding.

2.3.3.6. Events

Events file is used to provide a model about what could happen in the area under analysis if the initial state environmental conditions change. Specifically time events as the loss of bridges, closing of a road, collapse of a building could affect an emergency plan and these aspects could be predicted using LSM.

Many LSM scenarios may be modelled aiming to an efficient flood evacuation and emergency plan working on different aspects of the people virtual world and study environment as timing throughout the day, week, or year that influence the distribution and movement of the population at risk within the hazard zone. But other aspect could improve the model as climatic or seasonal changes (that influence dams management, cause potential dam breach or river floods), imposing open/closure of a road to simulate implementation of evacuation plan, simulate weakening from exposure to hazards prior to LSM simulation applying events as close a road, damage/destroy a building or reduce PARU strength variable PPC.

2.3.4. LSM Input summary

HR Wallingford LSM Users Guide provides for each receptor a list of parameters necessary to run the model (HR Wallingford Ltd, 2014).

Building characteristics are X and Y coordinates, Elevation (m), ID for each building, Building Strength parameters (BSS, BSSC, BCDVM, BDVCA), Perceived Safe Haven (PSH), number of floors, capacity, inflow people rate, in seconds, if the building is a safe haven, foundation (m).

PARU characteristics are X and Y coordinates, Elevation (m), ID for each person, PARG Index to identify at which group of person the PARU is assigned, PARU Strength parameters (PPC, PPCC, PLTDA, PHSDA, PDVTCA, PDVDCA, PSA, PDEUA, PDEVA, PCDVM) (HR Wallingford Ltd, 2014).

PARG file has to be set defining X and Y coordinates, Elevation (m), Group Type (Separable or Inseparable), Travel Mode (Stationary, Walking, Driving), Building Index, Road Index, Lane Index, Lane Position, TFAF (Time to first awareness), IUETA (Evacuation time from building), VEVT (Evacuation time from vehicle), VDVFC, VDVTC, VSDC and Evacuation Mode (evacuation from the building, shelter in the building, the PARG chose if evacuate or shelter in the building).

In addition, LSM models the evacuation plan using Warning Centres allocated in the analysed area to manage the emergency situation. Each Warning Centre is set in terms of location (X and Y coordinates), State (Inactive or Active), Initial Warning Time (Time at which the warning centre starts to disseminate the warning), Rate of Warning (m/s), Max Warning Radius (m), Delay (delay time in seconds between when the centre receives the alert and when it starts to warn people and other centres), Warning Centre Index.

2.3.5. LSM Output and potential simulation report summary

A broad variety of outputs are produced by LSM to describe PARU, PARG, Vehicle and Building objects conditions.

PARU information are defined by the X and Y coordinates of the location in the coordinate reference system, at each time step t of the simulation the water depth, velocity, flow intensity and PARU strength parameters are defined and more important is the definition of the PARU status. LSM in fact gives back the status of the PARU with 10 steps: unaware (0), aware (1), evacuating (2), safe (3), toppled (4), deceased – drowned (5), deceased – exhaustion (PPC<PPCC) (6), deceased – building collapse (7), deceased –building drowned (8), deceased – toppled vehicle (9).

PARG output file is characterised by the condition of the PARG at each time step t of LSM simulation. LSM gives the user the possibility to be aware of PARG location (X and Y coordinates and position in the road network), status conditions as defined for PARU and in addition a 10^{th} variable in case the PARG is empty. Moreover, it is possible to know the number of people for each PARG and at which water depth, velocity and dv the PARG is subjected. Each PARG is defined also by the parameters group type, travel mode, building where the PARG is allocated, evacuation parameters (TFAF, IUETA and VEVT), and critical dv in case the PARG is in a vehicle in terms of potential toppling or floating condition of the vehicle.

Vehicle output information defines the location of the vehicle, the water depth, velocity and the dv at which the vehicle is subjected. In addition, LSM allows to know the vehicle status in case it is parked (0), driving (1), safe (2), floating (3) or toppled (4).

LSM evaluates at each simulation time step also the building conditions repeating its location, defining the status (standing (0), destroyed by water depth (1), destroyed by dv (2), destroyed by cumulative effects (3)), and the water depth, velocity and dv that hit the building at each time step defining its status. LSM gives back building results in terms of building strength parameters, number of people in the queue to enter the safe haven in case the building is used as risk emergency shelter.

The road network file is rerun at each time step considering if the road is open or closed, and defining the minimum speed and maximum density on each road segment at the time step t.

2.4. Alert Operating Instructions pre- and post-emergency (AOICP)

Flood Risk Management should be supported in terms of no structural mitigation measures required in the Flood Directive 2007/60/EC by Flood Emergency Plans. The development of Flood Emergency Plans implements rules and tasks to be managed by Civil Protection Authorities when flood occurs supervising people behaviour and evacuation actions measures.

The 29th of September 2014 the Sardinian Regional Government approved the "Alert Operating Instructions for Civil Protection Agency" in case of Flood Risk with decision n° 53/52 and reconfirmed at June 2015 as integration and relevant element of the Sardinian Flood Risk Management Plan.

The "Alert Operating Instructions for Civil Protection Agency", AOICP Report, is the result of the synergy of Sardinian Authorities that compared their decisions with the National Italian Civil Protection and ISPRA stakeholders. This work consists in a Civil Protection guidelines containing alert procedures to be activated in regional scale when climatic, hydrologic and hydraulic risk occur defining a homogenous scheme of action for Regional Authorities involved in the flood risk emergency management for the pre-, during and post- flood event situation. This guideline has been developed conforming at the European, National and Regional Directives aiming to support emergency plan at council territory scale of detail. Councils with local civil protection groups should be the first authority acting to prevent the risk against population, residential, commercial and industry settlement and the council emergency plan should be update regularly about territory changes made by environmental and/or man-made alterations with accurate analysis of the land use.

The AOICP Report is a set of procedures and methods supported conveniently by tasks subdivided and entrusted at different authority considering their level of relevance on the management of the territory. This guideline supplies standardised code to prevent and manage the flood alert sustained by a monitoring system that takes in consideration climate changes that could give rise to Flash Floods, as in the last decades, or other natural disasters. In fact, flood events are characterised by difficult prevision and could determine relevant damages or even losses of life during people movement or collapse of structures leading the Civil Protection to frequently improved procedures and forecast systems in order to meet requirements provided in the Flood Directive 2007/60/EC in terms of people and urbanised areas protection.

The AOICP Report requires making available every information and supporting good at national and local scale aiming to support, preventing and managing the flood emergency.
The Civil Protection Department is provided by a Coordination Centre, named SISTEMA, that monitors emergency situations in the whole national territory and relative evolution in order to spread the risk alert, firstly, to the Regional Authority, and then to main authorities as:

- National Fire Department;
- National Armed Forces;
- Police Departments;
- Italian finance police;
- State Forestry Corps;
- Port Captaincy;
- Coast Guard;
- Italian Red Cross.

The AOICP Report defines every Directive and Authorities involved in the Emergency Plan. In particular, the Civil Protection Department is provided by a sector called "Centro Funzionale Decentrato", CFD. The CFD guarantees a correct execution of prevision, preparedness, monitoring and supervision phases interacting with Sardinian Regional Authorities involved to monitor climate changes and supervise hydrographic basins.
The CFD manages the prevision flood risk phase publishing updated bulletins in the Sardinian Regional Civil Protection website and spreading information about weather forecast, warns of potential critical weather conditions and warns of potential hydrogeological and flood risk. Moreover it provides to apprise authorities through text and emails when the risk conditions are not forecasted.
National Department of Civil Protection identifies in the territory "alert zones" meaning areas under potential homogeneous risk in case of critic hydraulic events. The subdivision of the territory should be coherent with homogeneous data obtained analysing the rain gauge hydrologic system information.
In particular, the AOICP Report describes the subdivision of the Sardinian Regional territory in seven uniform alert zones according with potential flood and meteorological events, achievement of floods during the last decades and their consequences acting in the territory.

The seven Sardinian alert zones are defined in the AOICP Report, Table 2-62, and described in Figure 2-97.

1	Iglesiente (Sard-A)
2	Campidano (Sard-B)
3	Bacini Montevecchio-Pischilappiu (Sard-C4)
4	Bacini Flumendosa - Flumineddu (Sard-D)
5	Bacino del Tirso (Sard-E)
6	Gallura (Sard-F)
7	Logudoro (Sard-G)

Table 2-62.Civil Protection Alert Zones for the Sardinian territory

Figure 2-97.Sardinian Alert Zones subdivision

The Flood Risk emergency Plan requires the definition of levels of criticality. The AOICP considers four classes of levels of criticality managing the potential flood and geological risks and defines for each one scenarios of hazard, effects on the territory and potential damages. This information is opportunely described in detail for hydrogeological and hydraulic risks meaning, respectively, landslide and flood in urban areas determined by river of no relevant importance and floods due to the main river network system. Table 2-63, Table 2-64, Table 2-65 and Table 2-66 define the four level of criticality assigning to each one proper colours and describing how the event could arise determining negative effects and damages on the territory.

Alert Colour	Criticality	Potential Scenario		Effects and Damages
Green	No Relevant		In case of storms: huge rainfall, local struck, hailstorm, important gust, difficulties on rainfall disposal and drop of rocks	Possible local damages

Table 2-63.Conditions, effects and damages in case of Green Alert

Alert Colour	Criticality	Potential Scenario		Effects and Damages
Yellow	Ordinary Level	Hydro geological	Erosion action, superficial landslides and debris floods on basins with limited expansion, drop of rocks, sediment transport. Increment of water levels and limited floods in areas adjacent of rivers with ground saturation and consequent landslide coupled with hydro geological hazards. In case of storms: relevant rainfall, local struck, huge hailstorms and gust, potential floods on road network, possible leakage of rain disposal interesting urban sections in low ground points, sudden increment of water levels in tributaries, canals and creeks determining limited floods of areas close to the rivers.	Local damages to infrastructures, buildings and activities interested by landslides, debris floods and superficial flood flows. Local floods of basements and ground levels of buildings. Local and temporary interruption of secondary road networks close to watershed, canals or underground areas and near areas interested by landslides. Local damages to structural mitigation measures as levees. In case of storms: Local damages to building roofs and temporary structures as losses of shingles due to strong gust and whirlwind. Falls of branch, trees, poles, vertical signage and scaffoldings causing interruption of road network, communication and supply services. Damages to agriculture areas, building industrial roofs and vehicles due to hailstorms. Localised fires and struck.
		Hydraulic	Increment of water levels in the riverbed and potential residual risks due to transport of sediment in the main rivers.	Local floods on basements or ground floor for buildings close to roads interested by outflow. Local and temporary interruption of secondary road networks close to watershed, canals or underground areas. Local damages to structural mitigation measures as levees. Potential injured and victims.

Table 2-64.Conditions, effects and damages in case of Yellow Alert

<table>
<tr><th>Alert Colour</th><th>Criticality</th><th colspan="2">Scenarios of the event</th><th>Effects and Damages</th></tr>
<tr><td rowspan="2">Orange</td><td rowspan="2">Medium Level</td><td>Hydro geological</td><td>Spreads out of landslides, debris flood and mudslides. Potential activation/reactivation and acceleration of instabilities of mountain/hill slopes.
Relevant falls of rocks.
Significant superficial flows and sediment transport.
Water levels increment and floods of areas adjacent at the river path with obstruction of bridges.
Ground saturation and consequent landslide coupled with hydro geological hazards of landslides and mudslides.
In case of storms:
relevant rainfall with high frequencies and persistent local actions, frequent and spread out struck, hailstorms and relevant gusts, relevant potential floods interesting road network, possible leakage of rain disposal interesting urban sections in low ground points.
Sudden increment of water levels in tributaries, canals and creeks determining limited floods of areas close to the rivers.</td><td>Damages identified for the Yellow Alert and:
Widespread damages and floods of buildings and small urbanised areas, infrastructure network possible interested by landslides and sudden debris floods.
Interruption of the road and service network.
Potential damages to the population and loss of lives.</td></tr>
<tr><td>Hydraulic</td><td>Relevant increment of water levels of main rivers, floods of adjacent areas, banks, areas protected by levees.
Potential erosion actions.
Sediment transport and changes in the river path.
Potential partial or completed obstruction of bridges.
High risk level of regular river flow.</td><td>Relevant and widespread damages to structural mitigation measures, to agricultural areas including inventory of farms, industries, building yards, residential settlements in flood hazard areas.
Widespread interruptions of road and services close to the river network.
Potential damages to the population and loss of lives.</td></tr>
</table>

Table 2-65.Conditions, effects and damages in case of Orange Alert

Alert Colour	Criticality		Scenarios of the event	Effects and Damages
Red	High Level	Hydrogeological	Numerous spreads out of landslides, debris flood and mudslides. Potential activation, reactivation and acceleration of instabilities of mountain/hill slopes at high deeps interesting extended areas. Potential falls of rocks in different points in the territory. Huge superficial water flows with sediment transport. Numerous and relevant increments of water depth coupled with floods that could occur in frequent obstructions of bridges.	Damages identified for the Orange Alert and: Huge and extended damages to buildings, agriculture, residential and industry areas due to landslides and debris floods. Huge and extended damages or destruction of road and services infrastructures. High hazards to population and potential loss of lives.
		Hydraulic	Floods of the main rivers and areas far from the riverbed coupled with damages to structural mitigation measures, levees erosion, sediment transport and changes in the river regular path. Possible overflows and break of levees with no regular flow of meanders. Potential numerous partial and completed obstructions of bridges. High risk level of regular river flow.	Relevant and widespread damages to structural mitigation measures, to agricultural areas including inventory of farms, industries, building yards, residential settlements in flood hazard areas close and far to the river path. Widespread interruptions of road and services close to the river network. Potential damages to the population and loss of lives.

Table 2-66.Conditions, effects and damages in case of Red Alert

At each risk level of criticality corresponds an operative phase that consists in the activation of proper mitigation measures, Table 2-67, and consequent tasks assigned to Authorities defined by the Civil Protection.

Alert	Warn of Criticality	Operative Phase
Yellow	Issuance of ordinary criticality	Attention
Orange	Issuance of medium criticality	Pre-alert
Red	Issuance of high criticality	Alert/Emergency

Table 2-67.Warning level and relative operative phase in case of potential flood risk

The three operative phases in Table 2-67 are followed by a fourth level considering the activation of the mitigation measures and restoration of regular conditions. In case potential flood emergency turned to negative consequences the Authorities have to active the scheme defined by the Flood Risk Emergency Plan of each council aiming to reduce locally potential damages to people, activities, inventories and environment.

In particular, during the Yellow and Orange Alerts all Authorities are warned about a potential floods, the Civil Protection Department and the CFD take under control the weather forecast system checking and updating regularly through texts and emails the other delegated authorities in order to be ready to act in case of worsening in the flood situation. The territory is under control mainly by the State Forestry Corps and council operators appointed to verify regular conditions or critical points especially in the river paths and designated on the warning of the population located in the flood hazard areas, while other proper authorities are appointed to check dams and verify the maximum water level avoiding risk of dam failure. In case the water level increases reaching dangerous levels a water discharge could be necessary and a prompt warn has to be sent to the authorities involved in the management of the area.

The Red, or Emergency, Alert requires to follows on the update of all authorities about the risk situation as in the preceding alert levels, and to organise monitoring action at the critical points in the territory as road intersections and bridges, avoiding vehicle traffic, and the river network particularly in correspondence of critical points to check possible levees failure.

The present research focuses the attention on the last phase of the Flood Risk Emergency Plan working towards to organise an efficient management emergency plan when floods is developing. In particular, the scale of emergency management used herein is concentrated upon the council level of management. If the flood emergency reaches high level of risk for the population and goods in the territory, the Major informs promptly the Prefecture, the Civil Protection Department and active effectively the Council Operative Centre involving the Local Civil Protection Volunteers. The Major should require an intensification of resources and vehicles by the Civil Protection Agency, warn and update the population through a proper centre and security forces, predispose closure of critical points in the road network paying attention on points of evacuation and rescue interest identifying also alternative paths. The evacuation action should be improved with the management of structure chosen as potential safe havens (hotels, tourist buildings, or even dwelling of relevant dimension and location to shelter people). Moreover a population census has to be active guaranteeing continuously the necessary goods, sanitary and health support to the population. At the same time Major, Civil Protection operators, security forces and experts has to work to restore the risk situation checking the structure conditions and identifying critical points on the road network. These information have been analysed to be implemented in LSM to provide evacuation plan rules.

3. Study case: Coghinas River Lowland Valley Basin pilot basin

The region of Sardinia is an Italian island located in the Western part of the Mediterranean Sea. The Sardinian territory consists of 24100 km^2 of area that Sardinian Hydrographic District Authority defined by seven hydrographic basins showed in the Figure 3-1 and list below:

1. Sulcis
2. Tirso
3. Coghinas, Mannu di Porto Torres, Temo
4. Liscia
5. Posada, Cedrino
6. Sud Orientale
7. Flumendosa, Campidano, Cixerri

Figure 3-1.Sardinian Hydrographic Basins subdivision

The hydro-geological study of the Sardinian basin shows a river system defined by 58 main water streams, for a total length of 1120 km, and 226 secondary streams of 2030 km (RAS-PSFF, 2015). The Sardinian Regional Hydrographic Authority studied the river hydrographic network several times in the recent decades in order to identify which part of the territory could be under a potential hydro-geological risk. The results of these studies improved the Sardinian regional flood protection policy characterised so far by two important flood plans, the Hydro-geological Settling Plan (PAI) and the Fluvial-Zones Definition Plan (PSFF), and more recently by the Flood Risk Management Plan (FRMP, 2015) according with the Flood Directive 2007/60/EC as explained in the Introduction chapter.

The flood protection regional plans identify potential flood damaged areas and damaged elements in the territory for four return-time period of 200, 100, 50 and 2 years, but they need to be completed defining structural and non-structural actions necessary to mitigate the risk in flood prone areas and for this aim the FRMP intervenes defining potential mitigation measures.

In particular, the PAI plan defined four levels of flood risk with values between one to four in respect of the risk increment based on the potential hydraulic or geological (for 500 years of return-time period) risks and pinpointed on the related flood maps.

Subsequently the PSFF plan, as improvement and integration of the PAI plan, outlines the pertinence of river flows with the aim to protect the natural streams capacity, the safety and protection of the adjacent areas. The PSFF plan consists also in flood hazard maps meant as basis to underline the area under flood risk and start the analysis of the river system situation as required by the Flood Directive 2007/60/EC in the Flood Risk Management Plan to identify the best mitigation measures and reduce the flood risk in the areas shown in Figure 3-2.

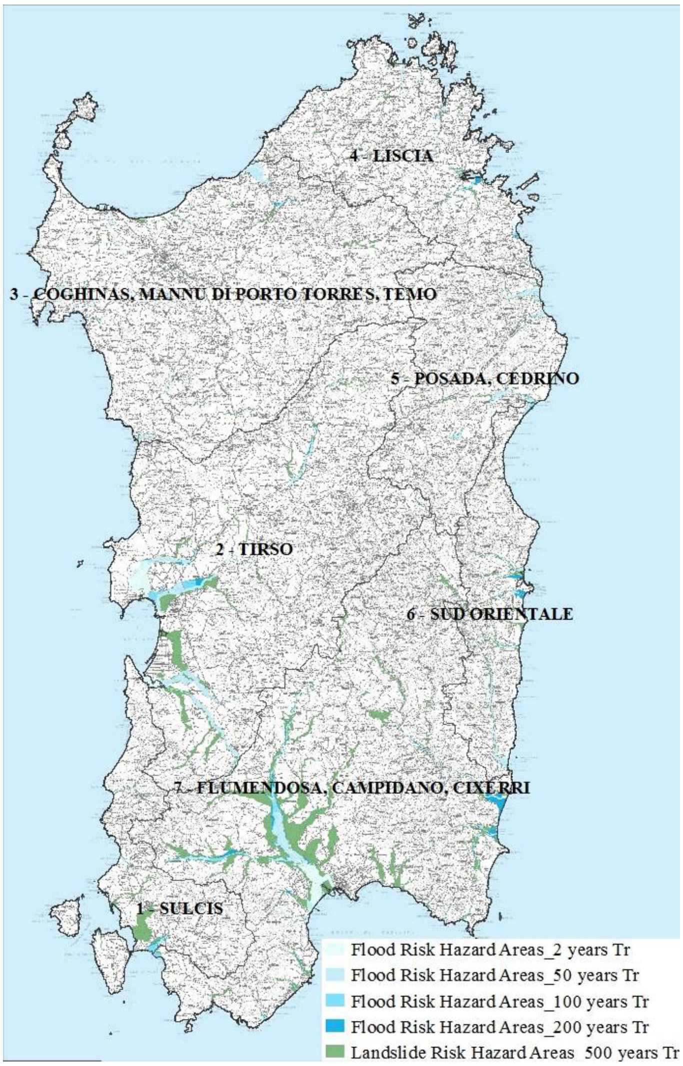


Figure 3-2.Sardinian Hydrographic Basins subdivision and PSFF Hazard Maps

The attention of the Flood Risk Management Plan (FRMP), and of the present research, is focused on the Coghinas River lowland valley basin, as part of the basin number 3 of the Sardinian region hydrographic scheme.

The Coghinas River lowland valley basin is located in the North-Eastern coast of the territory where the main river stream path is extended over 115 km and the catchment area is about 2473 km^2, Figure 3-3a. The flow rate discharged in the Coghinas River is controlled by two important dams currently under flood control management through the “Flood Lamination Plans”, the Muzzone dam on the upstream of the river and the Casteldoria dam around the middle path of the Coghinas River. The Coghinas River path under analysis is the sub basin in the lowland valley that starts from the Casteldoria dam and, after 15.9 km, reaches the Gulf of Asinara near Valledoria town where the territory is characterised by a partially stable dune of 15-20 m of height that run parallel at the coast.

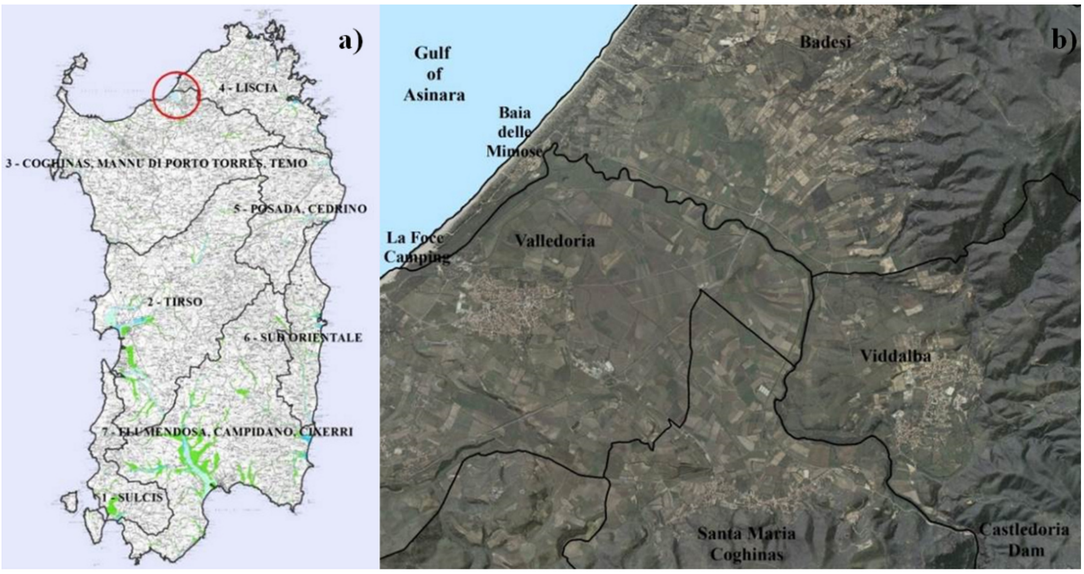


Figure 3-3.Coghinas River lowland valley basin placement on the Sardinian territory (a); Coghinas lowland valley basin urbanisation (b)

Four main urban centres regulate the area: Viddalba, Santa Maria Coghinas, Valledoria and Badesi. Figure 3-3b shows the characterisation of the area from the upstream to the downstream, from a narrow valley area to a plain area, where after less than 1.5 km from the Casteldoria dam the tourist structure of Casteldoria thermal bath are located and its pedestrian walkway crosses the river. After around 1.5 km from the Casteldoria Thermal Bath along the river path the Rio Badu Crabile tributary flows into the Coghinas River nearby the Viddalba town located in the right bank of the river and connected by two bridges with the territory of Santa Maria Coghinas town, located in the left bank of the river. The first bridge is part of the Provincial Road 146 (SP146), while the second one is around 10 m far and the oldest between the two. The second bridge avoids the regular flow of the river because of its height creating potential flow blockage and should be demolished to guarantee the regular flow of the Coghinas River.

Following the river path, the infrastructure Coghinas viaduct, the Provincial Road 90 Bridge (SP90), crosses the Coghinas River lowland valley basin with a length of 3.5 km that should be subdivided in two main parts. The first part of 2.2 km passes through the plain territory on the left side of the river until reaches the “Monte di Campo” hill. The second part of the Coghinas viaduct starts in “Monte di Campo” hill and crosses the Coghinas River with a span of the doorway of 9 m allowing a regular flow.

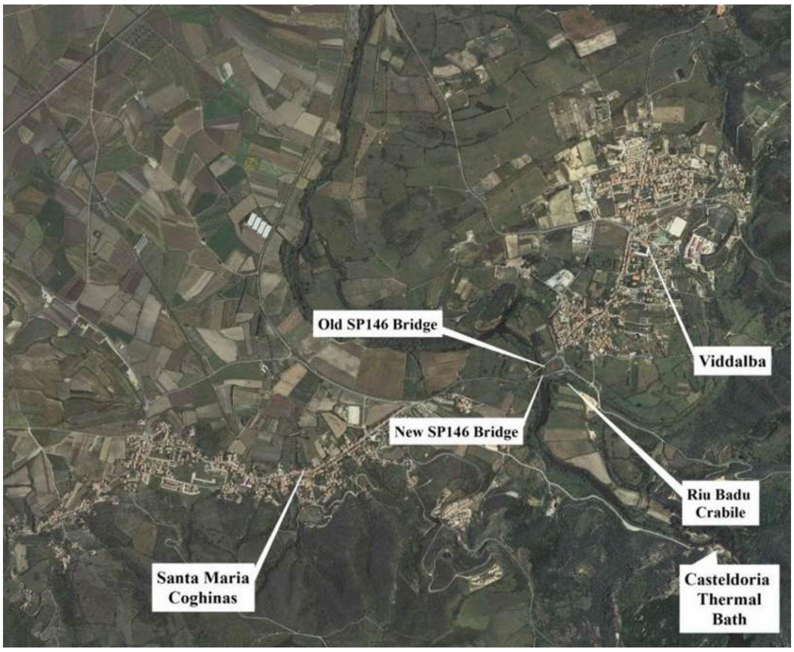


Figure 3-4.Coghinas River lowland valley basin upstream urbanisation: Casteldoria thermal bath, Viddalba and Santa Maria Coghinas towns

Near the outlet of the river, the Coghinas River lowland valley basin is characterised by the tourist and resort area called Baia delle Mimose, located in the right side of the Coghinas River, and built above and along the dune in the territory managed by Badesi town. Moreover, the left bank of the river, is interested by the Valledoria town and its expansion shows an urbanisation close to the mouth of the river where the camping area, known as La Foce Camping, has been built in an area of 4 hectares, Figure 3-5.

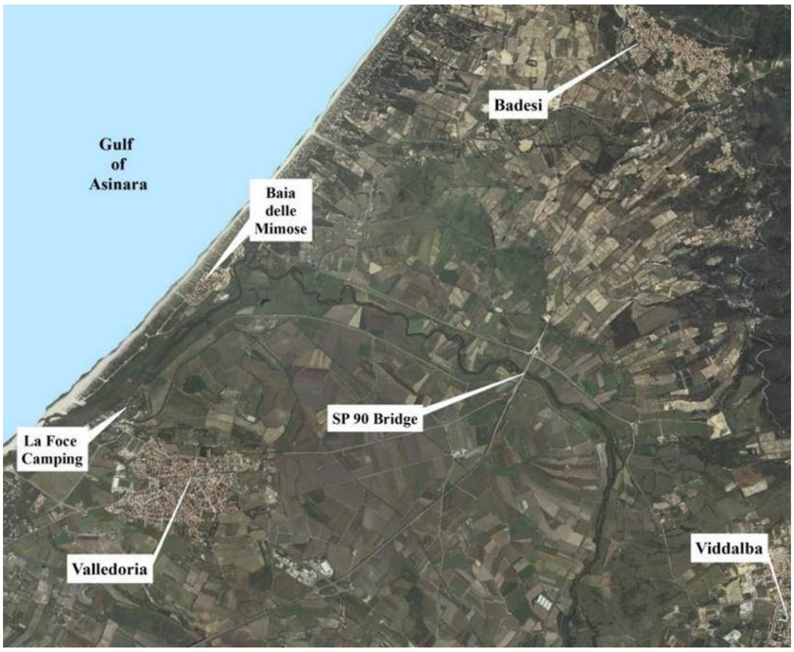


Figure 3-5.Coghinas River lowland valley basin downstream urbanisation: Baia delle Mimose resort, Valledoria and La Foce Camping

The pilot basin has been studied also in terms of urbanisation. The four residential areas are characterised by a potential number of residents and tourists that could be damaged by flood events. That aspect lead the project to analysis the potential development of the emergency situation in order to set a proper flood evacuation plan.
The inhabitants of the potential flooded area are mainly distributed in the three towns of Viddalba, Santa Maria Coghinas, Valledoria and in the resort Baia delle Mimose managed by Badesi council territory.
Two sources are available to achieve data of the population distributed in the study area. One document is the Piano Tutela delle Acque (PTA), where the characteristics of the Sardinian towns are defined to identify the potential number of people in the urbanised areas, and the second source is the National Institute of Statistics survey, ISTAT, collected in 2015. The present research has been improved also collecting data straight to the council offices aiming to work on more stable information, and contacting the offices of La Foce Camping and Baia delle Mimose resort.
The achieved samples allow to appraised the total amount of resident people, around 6406 persons, that could increase to 9450 considering the entity of tourists during the touristic period of the year especially in the La Foce Camping and Baia delle Mimose resort territories and considering a potential demographic increment of the residents.
PTA data have been used to start the analysis, while for a more accurate study ISTAT data gives also a description of the population in terms of age of the inhabitants.
The Valledoria council informed that 4210 residents live in the council area and 987 of them in the areas called La Muddizza and La Ciaccia, that should not be affected by the flood. The total amount of resident people that could be affected by the flood is equals to 3223 inhabitants. That information have been used to distribute the people in the buildings of Valledoria council area. Valledoria building sample consists in 1501 buildings among dwelling, commercial, agricultural, industrial and church building, Figure 3-6.

Figure 3-6.Valledoria area from Google earth

La Foce Camping offices made available information about the capacity of the tourist structure and the map of the camping area with the fan of the tourist structures in order to know how many tourists could host and in which structure they could sojourn. The La Foce Camping tourist sample has been evaluated equals to 1204 tourists, as shown in Table 3-1 and distributed in the structures or pitches shown in the Figure 3-7 and Figure 3-8.

Structure Type	N° of structures	Structure Capacity	Total
Mobile Home XL	16	6	96
Mobile Home Deluxe	10	6	60
Mobile Home Elegant	10	5	50
Mobile Home Comfort	10	5	50
Bungalow	44	5	220
Pitches	300	2	600
Camper	32	4	128

Table 3-1.La Foce Camping tourist area information: type of structures and their capacity

Figure 3-7.Maps of the La Foce Camping

Figure 3-8.La Foce Camping area from Google earth

The Badesi council apprised that 21 residents live in the tourist area of Baia delle Mimose, and the office of the resort gave information about the maximum capacity of the tourist centre. Baia delle Mimose people sample is close to 1500 tourists that could sojourn in the buildings. During field works it had been possible to observe an urbanised expansion in the Baia delle Mimose resort area, therefore, the area has been considered populated during the holiday period by a total amount of people around 1600 between residents and tourists distributed in 317 buildings, Figure 3-9.

Figure 3-9.Baia delle Mimose resort area from Google earth

More difficult was to collect reliable data from Viddalba and Santa Maria Coghinas towns. The area has been studied considering information collected by PTA plan and ISTAT samples and comparing them to apply the maximum number of people that could stay in the council areas.

The samples comparison leads to consider 1742 people on the Viddalba town territory, divided in 1726 residents and a tourist component of 16 people staying distributed in 822 buildings. The Santa Maria Coghinas town hosts 1618 people split in 1436 residents and 245 potential tourist people in 700 dwellings.

A summary of the PARU samples distributed in the Coghinas River lowland valley basin is shown in Table 3-2 with the division of the population between residents and tourists.

Town	Residents	Tourists
Valledoria	3223	/
La Foce Camping (Valledoria)	/	1204
Viddalba	1726	16
Santa Maria Coghinas	1436	245
Baia delle Mimose (Badesi)	21	1500

Table 3-2.PARU samples in the Coghinas River lowland valley area

3.1. Overview of the Sardinian hydraulic management plan: PSFF and FRMP

The Coghinas River, as the third main Sardinian river, has been studied accurately in the PSFF plan through field works and detailed data available as DTM and Corine Land Cover maps aiming to know the topography and the man-land use (RAS-PSFF, 2015).

The area under analysis is characterised in the first part by a valley followed by plain area mainly used for agriculture where the Coghinas River occupies the territory with a bed river width around 25 meters and reaches the downstream area characterised by many meanders. The last 4 km of the Coghinas River run parallel to the coast along the dune after turning on the left side and reaching the Mediterranean Sea in the Gulf of Asinara, Figure 3-10.

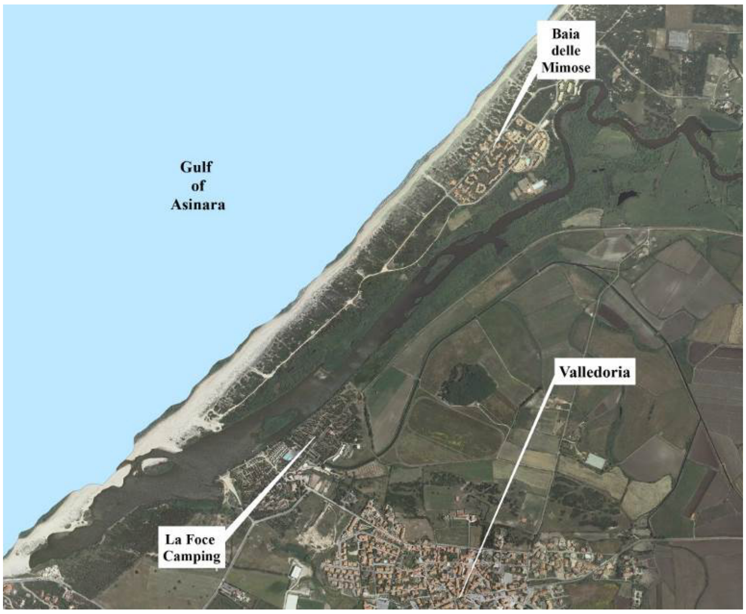


Figure 3-10.Coghinas River lowland valley basin downstream dune

The Coghinas lowland valley river area, and in particular the urban areas, are protected by four levees around 3-4 m height with a top width of 3 m used occasionally as service roads. Field works and detailed photos show that the area is characterised by low vegetation that does not obstacle the regular flow because of the low roughness values, Figure 3-11.

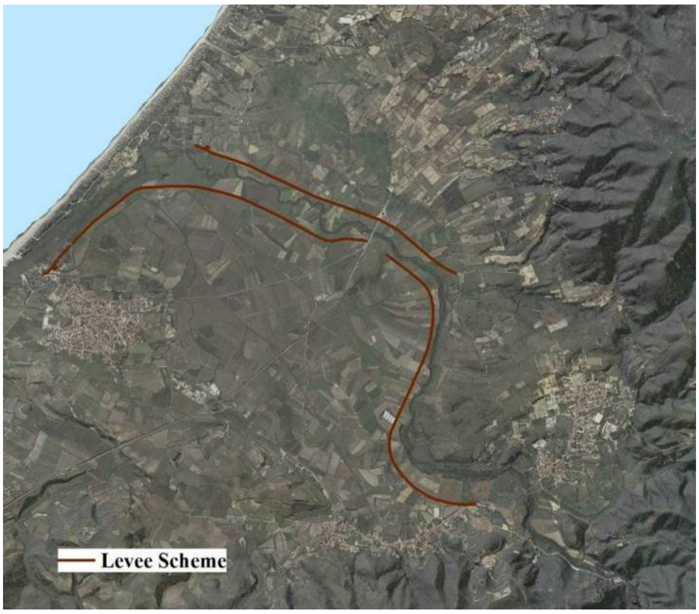


Figure 3-11.Coghinas River lowland valley basin levees scheme

Hydrological analysis of the area has been conducted for the PSFF plan allowing to know the potential flow rate for return-time period event of 2, 5, 100, and 200 years in term of hydraulic risk. As shown in Figure 3-12, the Coghinas River basin consists in 5 sub-basins and the sub-basin between the Casteldoria dam, sections D, and the Coghinas River mouth, section E, is the area under analysis.

The Casteldoria dam was built in the 1963 and currently under Enel S.p.A. management. It is a concrete gravity dam with a crest 35.50 m height and with a length of 97 m. The Casteldoria dam capacity is around $8x10^6$ m^3, but regulated for a capacity of $4.5x10^6$ m^3 mainly used for purposes as irrigation, hydropower and water-supply. The limited capacity of the Casteldoria dam lead the researchers to no consider it in the Coghinas River hydrologic analysis and the flow rate has been evaluated basing the study on the Muzzone Dam characterised by a capacity of $296.77x10^6$ m^3, that is limited at $242.00x10^6$ m^3 considering the maximum level of regulation.

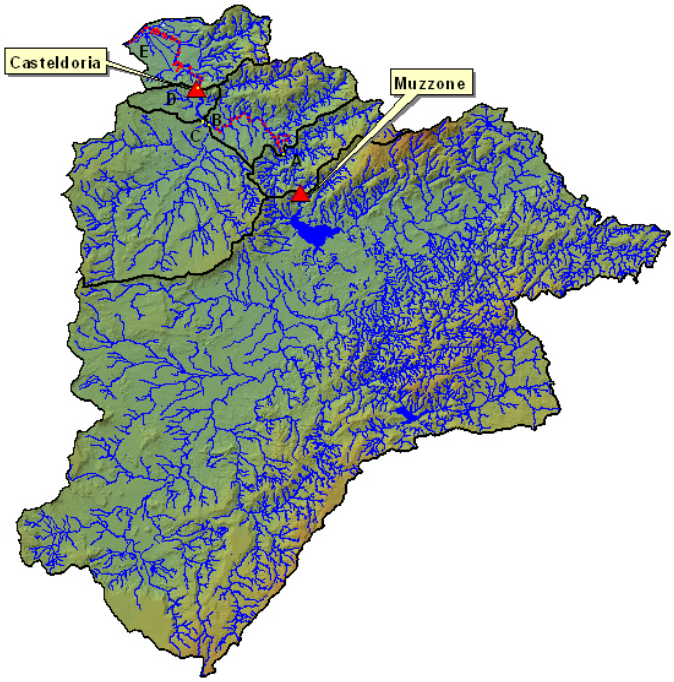


Figure 3-12.Coghinas basin subdivision in 5 sub-basins (RAS-PSFF, 2015)

The flow rate described in the PSFF plan was calculated using the direct method with a TCEV model distribution taking in consideration that the Coghinas River lowland valley basin is on the North-East Sardinian coast, in other words it is part of the subzone 1 and part in the subzone 2. The flow rate is considered discharged by the Muzzone dam and gradually adapted along the river path considering the dam flow rate lamination using the Marone expression.

The analysis made available the hydrographs of 2, 50, 100 and 200 years return-time period as required by the PSFF plan. The considered hydrographs are characterised by a triangular trend with base flow and peak flow, at which corresponds a maximum flow rate for each return-time period, shown in the Table 3-3 and Figure 3-13.

Tr (years)	2	50	100	200
Flow Rate (m^3/s)	433	2950	3745	4460
Max Level (m)	159.7	159.7	159.7	159.7
Peak Flow (h)	18.9	10.3	10	9.9
Base Flow (h)	50.6	27.4	26.7	26.3

Table 3-3.Casteldoria dam hydrographs

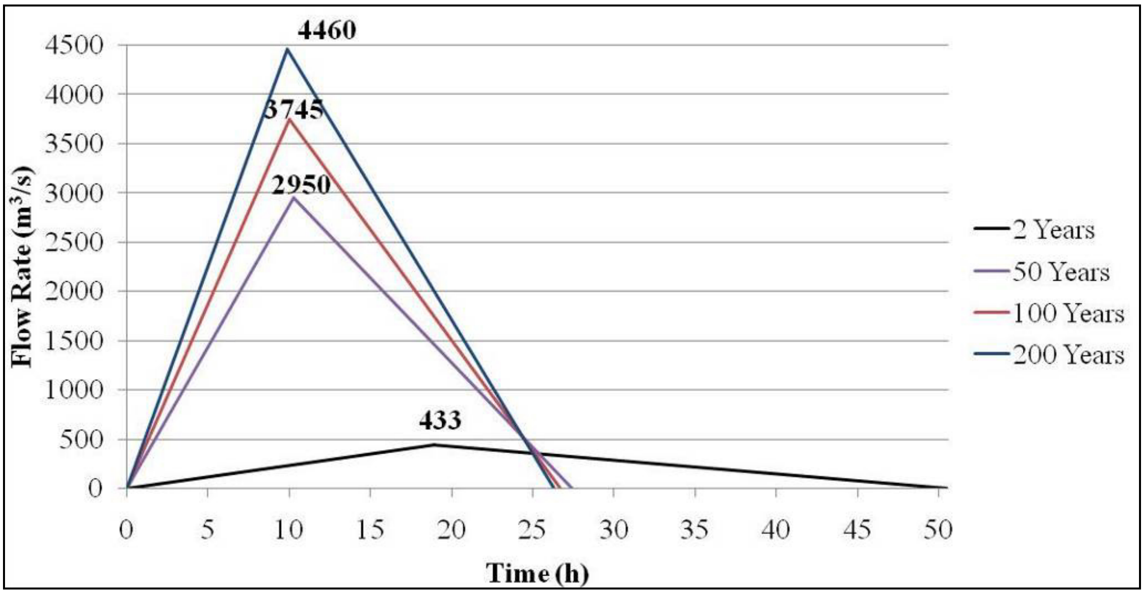


Figure 3-13.Coghinas basin hydrographs for return-time period of 2, 20, 100 and 200 years (RAS-PSFF, 2015)

3.1.1. PSFF 1D hydraulic analysis

In the PSFF plan the mono-dimensional hydraulic model was developed using the US Army Corps of Engineering software HEC-RAS considering steady flow conditions for the Coghinas River path of 37.5 km starting from the Muzzone dam. The Coghinas River was divided in 62 cross sections, but only the last 29 cross sections are considered in the present research, in other words the Coghinas River path after the Casteldoria dam, as mentioned above. The hydraulic analysis was developed taking in consideration critical points as the pedestrian walkway of the Casteldoria thermal bath and the three bridges on the SP146, new and old, and on the SP90. Moreover the levees built to protect the areas along the Coghinas River have been set in HEC-RAS model.

The roughness parameters was defined for each cross section dividing it in few parts (bed river, right and left banks) characterised by homogeneous roughness based on the study of the granular material, (RAS-PSFF, 2015).

The boundary conditions consider a uniform flow rate discharged from the Casteldoria dam in the upstream defined for each flood event in Table 3-3 and a maximum level of regulation of the Casteldoria dam equals to 26 m, information based on the data collected by the dam managing authority.

The downstream boundary condition, at the sea level, has been evaluated equals to 1.80 m considering the contribution of the tide, storm surge and wave set-up.

The collected data in 2005 shows a tide of 0.44 m approximated at 0.45 m. The storm surge is considered equals to 0.35 m by the sum of the wind set-up, around 0.10 m, and the evaluation of the pressure by the inverse barometer equals to 0.25. The wave set-up is assumed equals to 1.00 m, Table 3-4.

Tide (m)	Storm Surge + Wind Setup (m)	Wave Setup (m)	Sea Level (m)
0.45	0.35	1.00	1.80

Table 3-4.Coghinas River downstream boundary conditions

The PSFF plan analysed the Coghinas River path under the Casteldoria dam considering two different scenarios based on the potential overflow or not of the levees and comparing the two results.

The first scenario considers the levees not overflowed and analyses the Coghinas River path in three sections.

- The first section evaluates the Coghinas River situation for the first 2 km after the Casteldoria dam to 1 km after the Casteldoria thermal bath where the river runs inside the narrow valley with a width around 60 m, a bed river slope of 0.2 % and the territory is characterised by thick vegetation. In that part of the Coghinas River a structural mitigation measure is located, a masonry, to protect the Casteldoria thermal bath. The Coghinas River is there crossed by a pedestrian footpath of the thermal bath that could be overcome for return-time period of 200 and 500 years, while for the return-time period of 2, 50 and 100 years the flow does not overcome the pedestrian walkway. The water levels reach value between 6 and 12 m for return-time period, respectively, of 2 and 500 years, and the river width is contained between 60 and 100 m with related average velocities of 2.7 m/s and 8 m/s.
- The second section shows the Coghinas River behaviour from Viddalba and Santa Maria Coghinas urban areas to the area of Baia delle Mimose near the coast after to have crossed the plain area of 10 km length. The Coghinas River is characterised by levees along all of its length in the left bank, while the levee in the right bank starts around the half of the path. Where the levees are in both sides of the Coghinas River their distance is around 250 m in the upstream and enlarges gradually to 400 m reaching near Baia delle Mimose area. Coghinas River between the levees is characterised by a width around 30 m with a sinuous trend defined by many meanders. The territory in the banks and out of the levees is mainly cultivated and is interested by a residential area at the beginning in the suburban areas of Viddalba and Santa Maria Coghinas. The HEC-RAS hydraulic model shows that the levees contain the flood only for return-time period of 2 years when the flow occupies the whole bed river and some segments overflow. The water levels in that part of the river are around 5.5 m with velocities from 2 m/s to 4 m/s. That flood underlines the inadequacy of the old SP146 Bridge, while the new SP146 Bridge works well only for return-time period of 2 years resulting inadequate from return-time period of 50 years, probably because of the blockage caused by the old bridge in the immediate downstream that, therefore, should be

demolished. In addition, the analysis at the level of the SP90 Bridge shows a regular flow and inadequacy only for return-time period of 500 years.

- The third section evolves along the coast from Baia delle Mimose to the end of the river and the area is protected on the right side by stable dune of 15-20 height, and in the left side by levees. In this segment, the Coghinas River is wider than in the previous paths and no vegetation interests the bed river avoiding the regular flow. The levee is able to contain the flood of 2 years of return-time period in the upstream of the analysed section and the flood occupies the whole area with a width of 250 m, water levels around 5 m and flow velocities lower than 1 m/s.

The second scenario considers the potential overflow of the levees in order to evaluate the inadequacy of them and evaluate the flood over the banks. The area is divided in two main sections.

- The first section analyses the area of the Coghinas River lowland valley basin from the Casteldoria dam to Baia delle Mimose area and the suburban area of Valledoria. In this section the floodplain interests the suburban area of Viddalba and Santa Maria Coghinas, hits with a large expansion the left side of the river, getting close toward the downstream the suburban area of Valledoria town and partially the right side over the bank is flooded. The flow velocities are estimated around 3.5 m/s and decrease to 1 m/s in the areas out of the levees.
- The second section considers the coastal area from Baia delle Mimose and the coastal area of Valledoria town. The HEC-RAS hydraulic analysis shows a large floodplain for high return-time period that hit the suburban area of Valledoria. The average water levels are around 8 m for the 50 years return-time period and reach 9.5 m for the flood of 500 years with important values also in the floodplain area over the left bank before the end of the Coghinas River. The average flow velocities are evaluated around 3.5 m/s, but they do not increase more than 1 m/s overflowing the left bank and reaching the suburban area of Valledoria town. The downstream area shows average water levels variable from 6.5 m and 8.2 m for return-time period from 50 years, and associated velocities that could reach values of 2.5 m/s and usually stable around less than 1 m/s.

The two scenarios are not characterised by important differences as shown comparing the hydraulic profile of the first scenario, Figure 3-14 and the second scenario Figure 3-15.

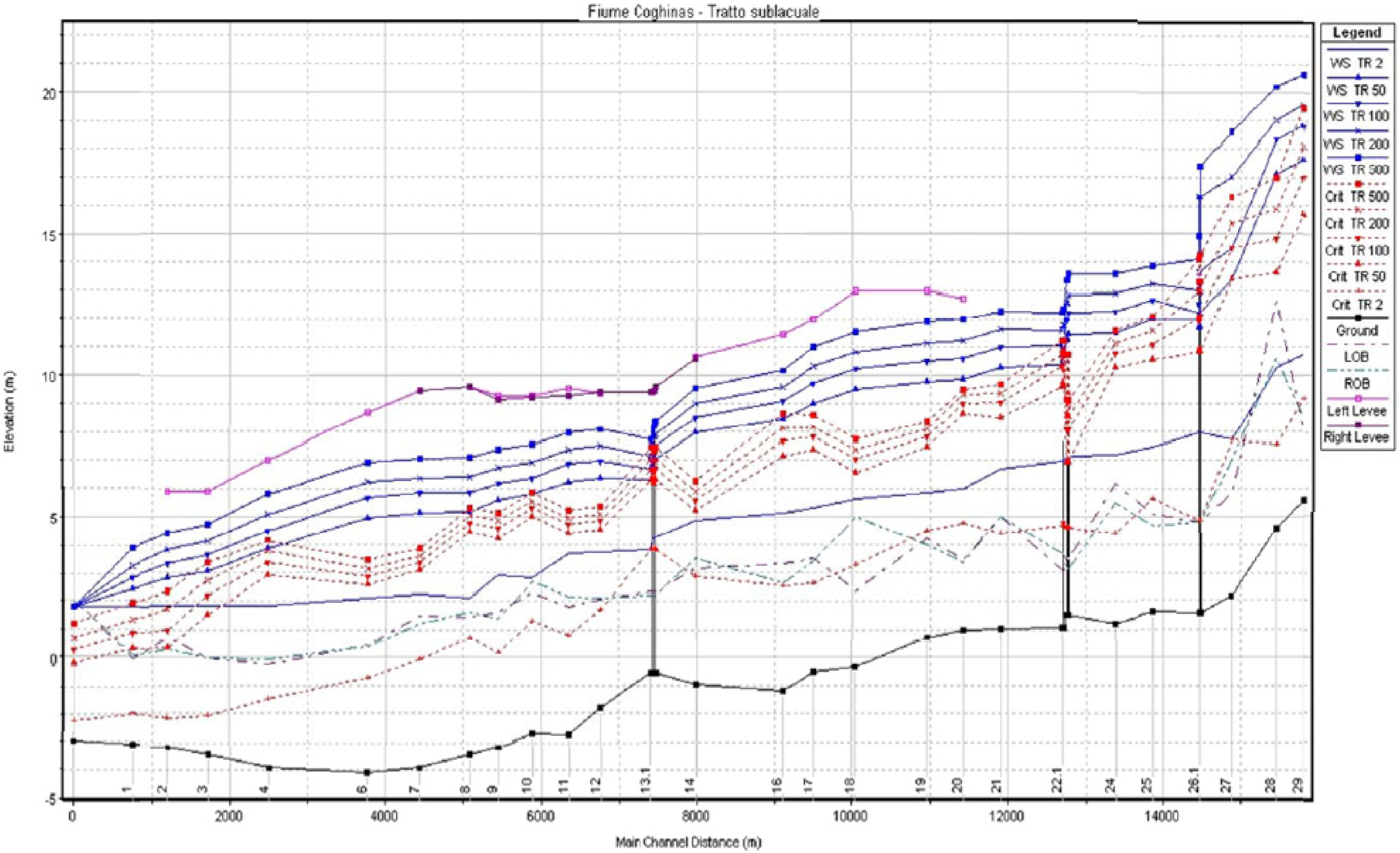


Figure 3-14.Longitudinal profile of the Coghinas River for event of return-time period of 2, 50, 100 and 200 years in the first scenario: no overflowed levees (RAS-PSFF,2013)

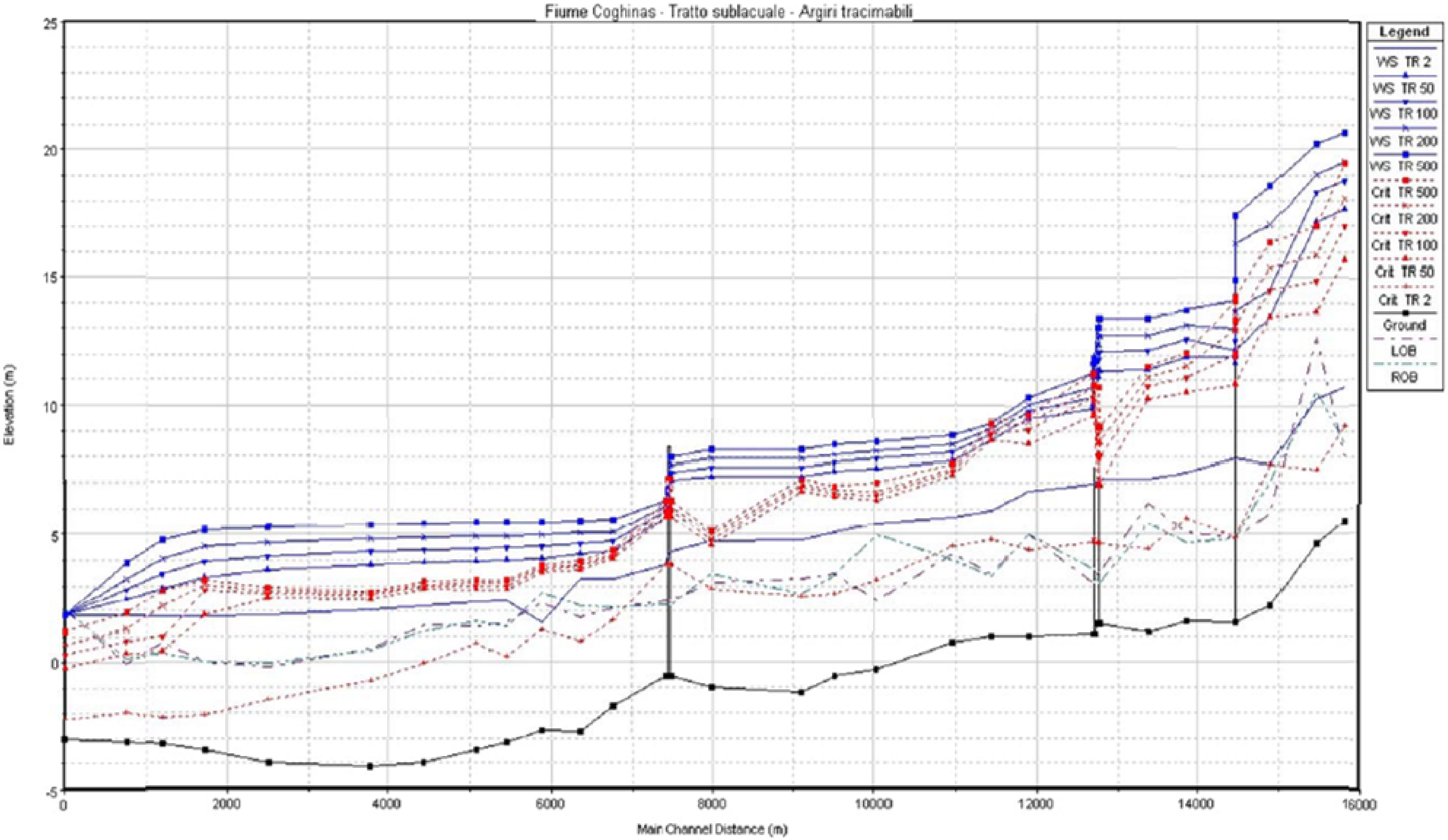


Figure 3-15.Longitudinal profile of the Coghinas River for event of return-time period of 2, 50, 100 and 200 years in the second scenario: overflowed levees (RAS-PSFF,2013)

The final step of the PSFF analysis of the Coghinas River lowland valley basin considers 5 floodplain risk areas that, as mentioned above, are studied under conditions of event of 2, 50, 100, 200 and 500 years of return-time period. The last scenario of 500 years has been taken apart considering its nature of geological risk and because the present research is mainly focused on the flood risk of the area. Moreover the analysis excludes the first part of the Coghinas River, from Muzzone dam to the Casteldoria dam, focusing the attention on the Coghinas River lowland valley basin area after the Casteldoria dam. Following these considerations the PSFF plan results have been considered for three main sections and merging the results obtained by the two scenarios defined by the levee possibility to be over flow or no:

- The first section, from the Casteldoria dam to before Viddalba urban area, is characterised by a narrow valley where the hydraulic analysis gives back floodplain of 60 – 80 m of width for each return-time period because of the topography. On the left bank of the river, the tourist structure of Casteldoria thermal bath is protected inadequately for return-time period higher than 50 years by the masonry protection measure.
- The second section interests 10 km of Coghinas River path from Viddalba and Santa Maria Coghinas towns to Baia delle Mimose resort area. The area is protected by ample levees for all of the river length on the left side of the river, interrupted only in correspondence of the "Monte di Campu" hill, while the right side of the river is protected only for the second half of the Coghinas River length till reach the area nearby Baia delle Mimose. In the area above Viddalba town, and before where the Rio Badu Crabili tributary flows into the Coghinas River, the floodplain shows a homogeneous behaviour with width between 80 to 300 m. After this area the floodplain is characterised by an enlargement that interests the suburban area of Viddalba and Santa Maria Coghinas not only because of the Rio Badu Crabili tributary, but also because of the presence of the two SP146 Bridges, the new and the old bridge. Analysing beyond the urban area of Viddalba and Santa Maria Coghinas, the territory is mainly subjected at agriculture works with extended plain lands surrounded by bordering hills that reach the urban area of Valledoria. The hydraulic models show levee inadequacy containing the flood caused by return-time period of 50, 100 and 200 years that have shown similar expansion among them with small differences and in all cases the suburban

residential and commercial area of Valledoria has been hit. The levee system is able to contain only the flood caused by the event of 2 years of return-time period characterised by a width around 200 m that interests the whole area between the levees.

- The third section interests the Coghinas River path along the coast from Baia delle Mimose area between the dune, in the right side, and the levee, in the left side of the river. The Coghinas River is characterised by a width around 250 m for event of return-time period of 2 years and the flood overflows the levee for higher return-time period event hitting the camping area La Foce and reaching the suburban area of Valledoria.

The hydraulic analysis of the Coghinas River lowland valley basin underlines few critical points in the area. In particular, the suburban area of Viddalba could be hit because of the water level raising due to the Rio Badu Crabili tributary and the blockage caused by the two bridges of the Provincial Road 146. Santa Maria Coghinas and Valledoria tows could be hit because of the dimensional inadequacy of the levee system, that does not show structural inefficiency, but their height allows the overflow of them for event of return-time period from 50 years. In addition, the Baia delle Mimose resort area has been built above the dune that, unless defined as stable dune, is continuously changing because of the erosion action of the Coghinas River. Finally the camping area La Foce, in the Valledoria town urban area, has been built inside the hazard area and could be subjected at huge damage also for event of 2 years and, therefore, should be moved. Figure 3-16 shows the PSFF flood hazard maps obtained in the last step of the hydraulic analysis

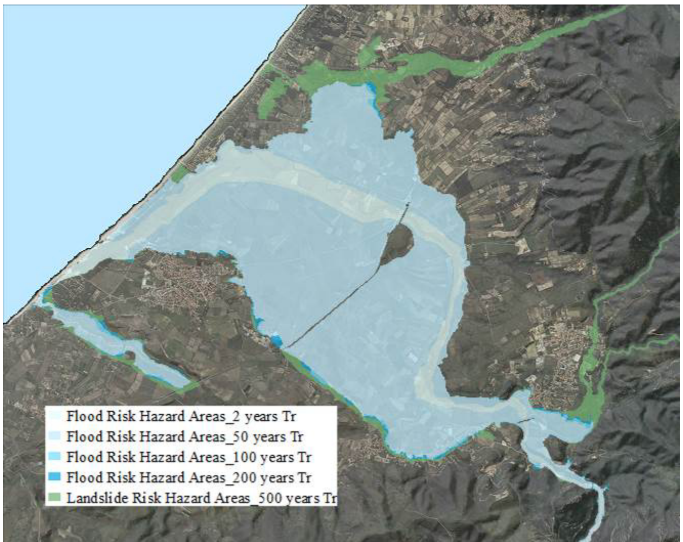


Figure 3-16.PSFF hazard maps of the Coghinas River lowland valley basin

3.1.2. FRMP 1D hydraulic analysis

The Flood Risk Management Plan (FRMP) analysed the Coghinas River lowland valley basin according with the Flood Directive 2007/60/EC that requires an update of the hazard maps of each European hydrographic basin when available and it has been chosen as pilot basin of the FRMP because of its features (topography, man-land use, location). The available photos of the area describe the territory with high resolution, in particular, along the Coghinas River, but also along the coast of the Gulf of Asinara. This information has been coupled with field works and the description of the topography through a digital terrain model of 1 m resolution.

The PSFF model of the Coghinas River lowland valley basin is the base to support the new HEC-RAS mono-dimensional hydraulic analysis using data about land roughness description, information of bridges size and structural type along the river path and levees scheme. The FRMP model follows the instructions of the PSFF plan and models the pilot basin for return-time period event of 2, 50, 100 and 200 years, using the same boundary conditions and hydraulic input gave by the PSFF plan aiming to confirm or integrate the previous studies.

The pilot basin has been studied few times, but below the FRMP HEC-RAS model is described, coherently, with the paper “Flood Risk Management Plan for the Sardinia Hydrographic District”, (Frongia et al., 2015b), where the FRMP mono-dimensional model was used to assess the flood risk conditions of the pilot basin and for consecutive studies focused on the economic evaluation of the flood damage.

3.1.2.1. HEC–RAS mono-dimensional hydraulic analysis

Recent analysis of the Coghinas River lowland valley basin does not show relevant changes on the man-made structures and on the territory, so the mono-dimensional HEC-RAS analysis has been developed based on information obtained by the PSFF model and studying three main segments of the Coghinas River starting from the Casteldoria dam and reaching its end when the river flows into the Gulf of Asinara, as shown in Figure 3-17.

The FRMP HEC-RAS model has been developed using a more detail DTM of 1 m resolution that led to the definition of a new model with new cross sections.

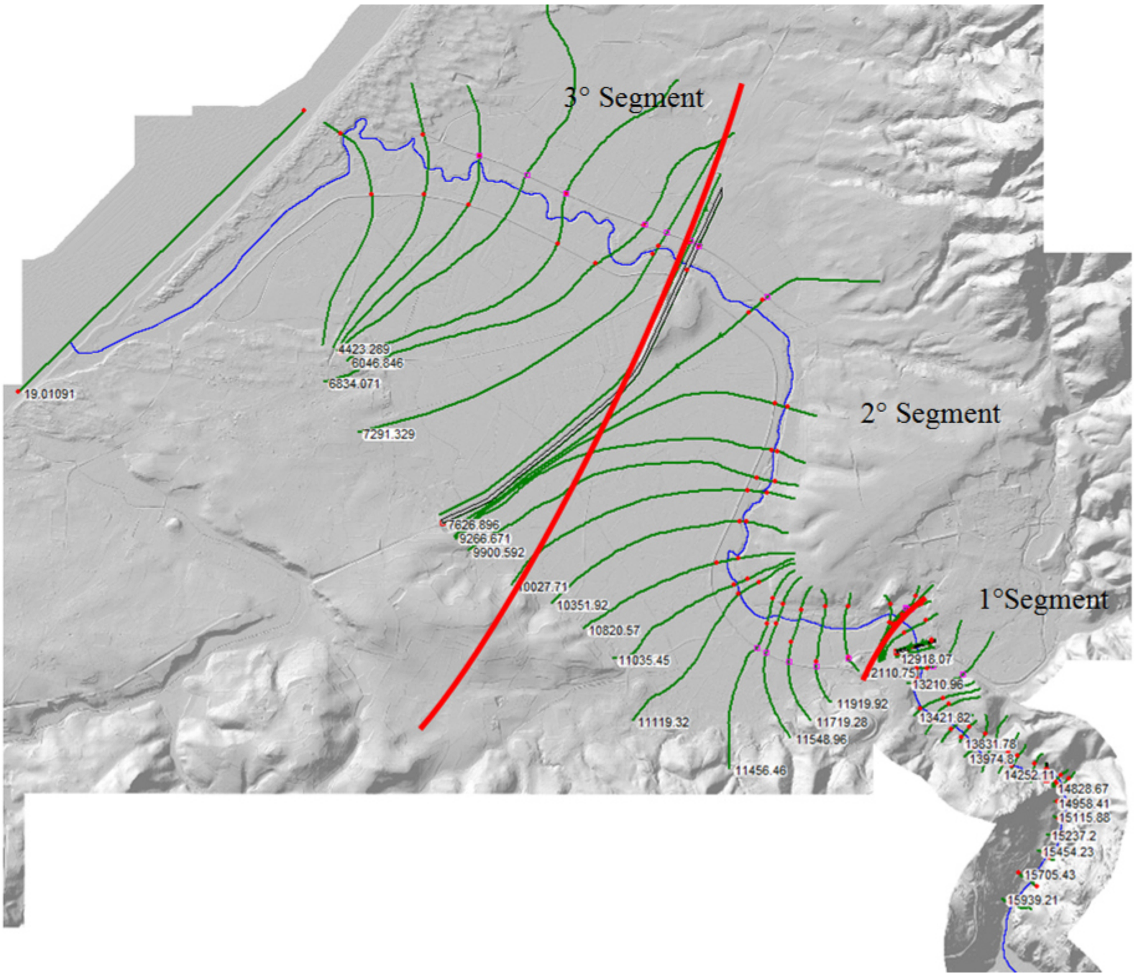


Figure 3-17.Coghinas River lowland valley basin scheme of the HEC-RAS hydraulic model (FRMP, 2015)

The first part of the Coghinas River interests the narrow valley from the Casteldoria dam to the cross-section 12110 after the urban area of Viddalba where the plain area starts, Figure 3-17. In this section, the model analyses the two main critical points where bridges create flood flow instabilities because of the insufficient bridges opening. The flow is characterised by a slow regime with average flow velocities around 4-5 m/s and a peak of 9 m/s before the footbridge of the Casteldoria thermal bath determined by the worst event of 200 years return-time period. The river flows regularly under the Casteldoria footbridge until the event of 50 years, while the event of 200 years shows the inadequacy of the footbridge height. In fact, Figure 3-18 and Figure 3-19 the flood interests the thermal bath structure and partially covers the road on the left side used to reach the tourist structure for the event of 200 years of return-time period.

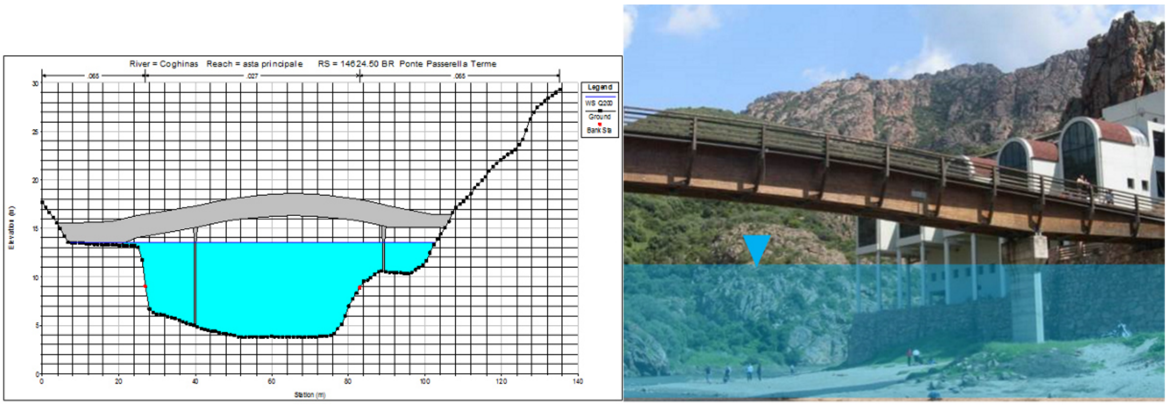


Figure 3-18.Casteldoria footbridge conditions under an event of 200 years of return-time period (FRMP, 2015)

Figure 3-19.200 Years flood in the area of Casteldoria thermal bath(FRMP, 2015)

Reaching the urban area of Viddalba town, the hydraulic model shows water levels of 11.4 m for the event of 50 years and 13.3 m for the event of 200 years. Moreover, the water levels overflow the new SP146 Bridge with 30 cm, the flow emerges unstable and with higher velocities because of the low height of the old SP146 Bridge that is located 10 m far from the new SP146 Bridge, Figure 3-20 and Figure 3-21.

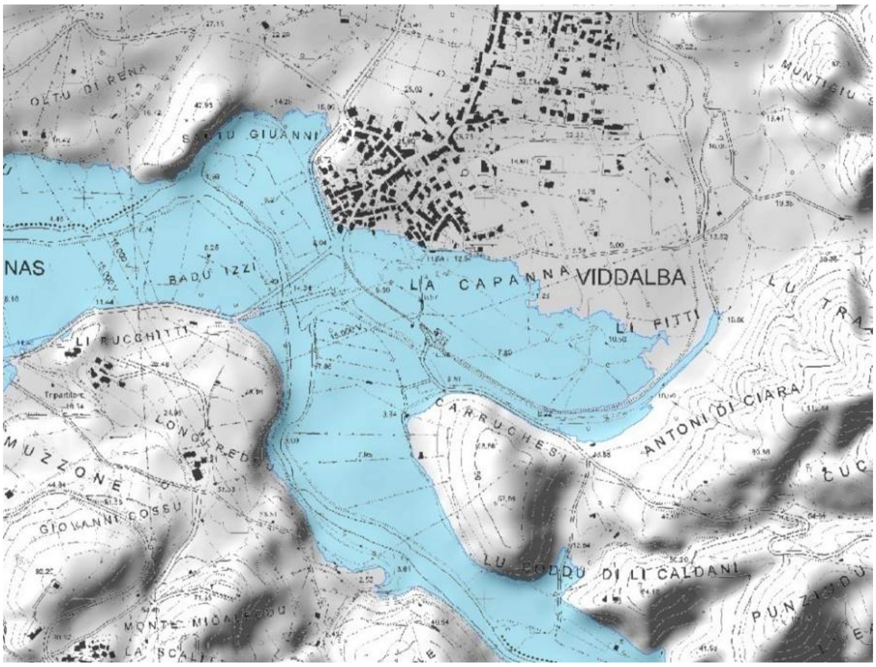


Figure 3-20.50 Years flood in the area of Viddalba town when the residential area starts to be hit (FRMP, 2015)

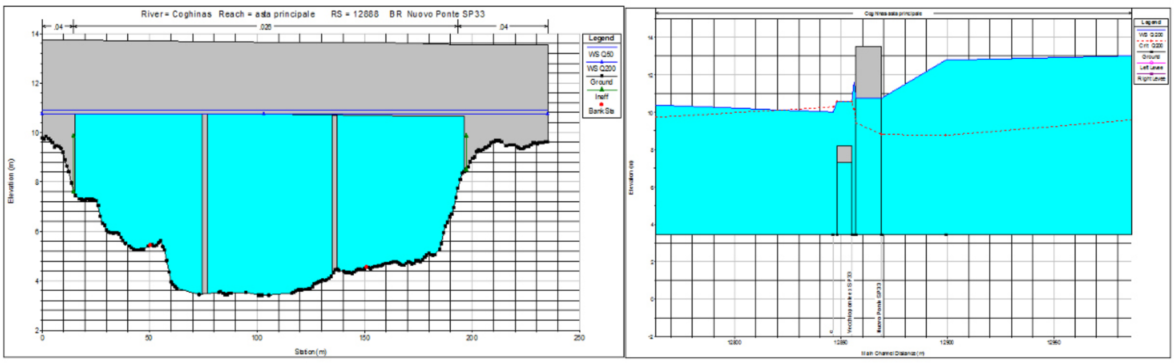


Figure 3-21.SP146 Bridge critical conditions (FRMP, 2015)

The second part of the Coghinas River, from after less than 1 km from the oldest SP146 Bridge, shows a flow with a slow regime and critical segments characterised by 2-3 m/s of velocities where the river width is small and velocities reach peaks of 5 m/s for a long tract where the bed river slope is equals to 1 ‰. In the last segment, the velocities are the main cause of the levee overflow where the water depth is evaluated around 1.40 m above the levee crowns and the overflow is due also to critical points in the levees scheme along their whole length. Following the Coghinas River path, the flow shows stable conditions until to reach the SP90 Bridge with velocities lower than 2 m/s and flooding width bigger than 1.5 km. At this section, the Coghinas River, reaching the "Monte di Campo" hill, is characterised by a flood that splits between the right side, defining a floodplain around 250 m, while in the left side of the river the floodplain reaches a width about 2 km, Figure 3-23.

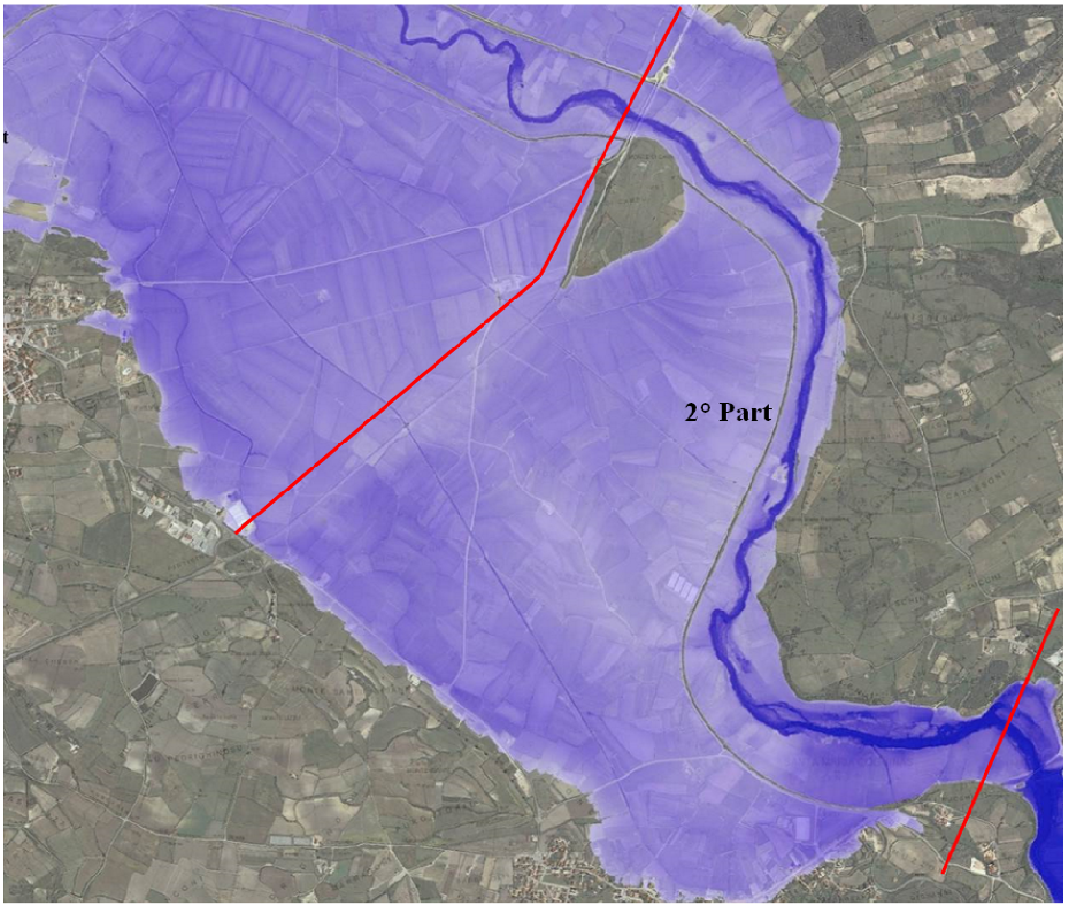


Figure 3-22.Coghinas River lowland valley basin analysis of the intermediate section for the event of 200 years of return-time period(FRMP, 2015)

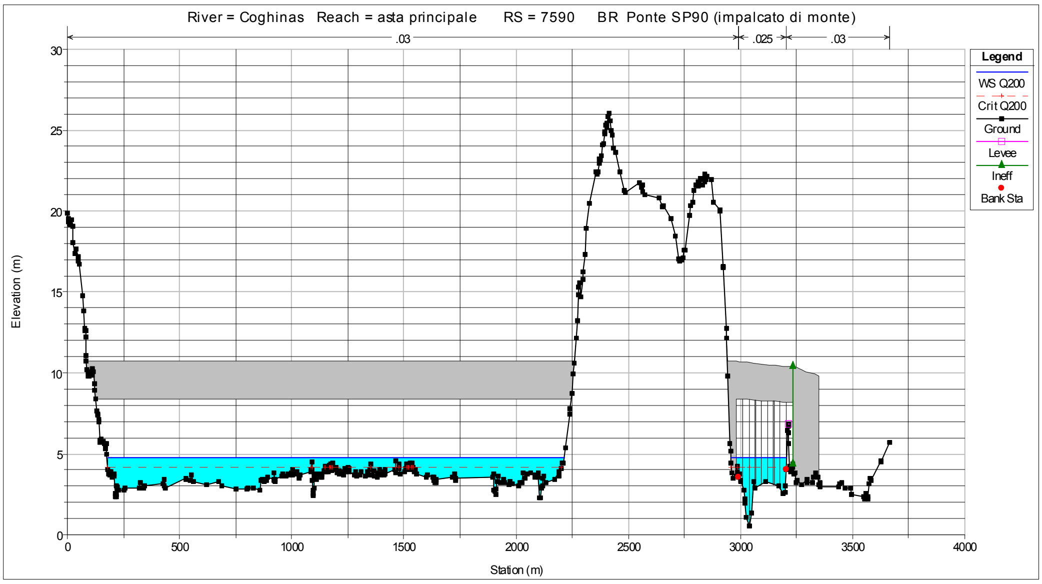


Figure 3-23.SP90 Bridge hydraulic conditions under the event of 200 years of return-time period (FRMP, 2015)

The third part of the Coghinas River, starting from the cross section of the SP90 Bridge whit a regular flow (Figure 3-23) and it is characterised by a widespread flooding due to the inundation of the analysed second part of the Coghinas River and to the inadequacy of the levees scheme. The flood is not characterised by relevant critical point and reaches the suburban area of Valledoria with a gradual reduction of the width hitting commercial and residential structures with registered water levels lower than 200 cm due to the event of 200 years of return-time period, Figure 3-24.

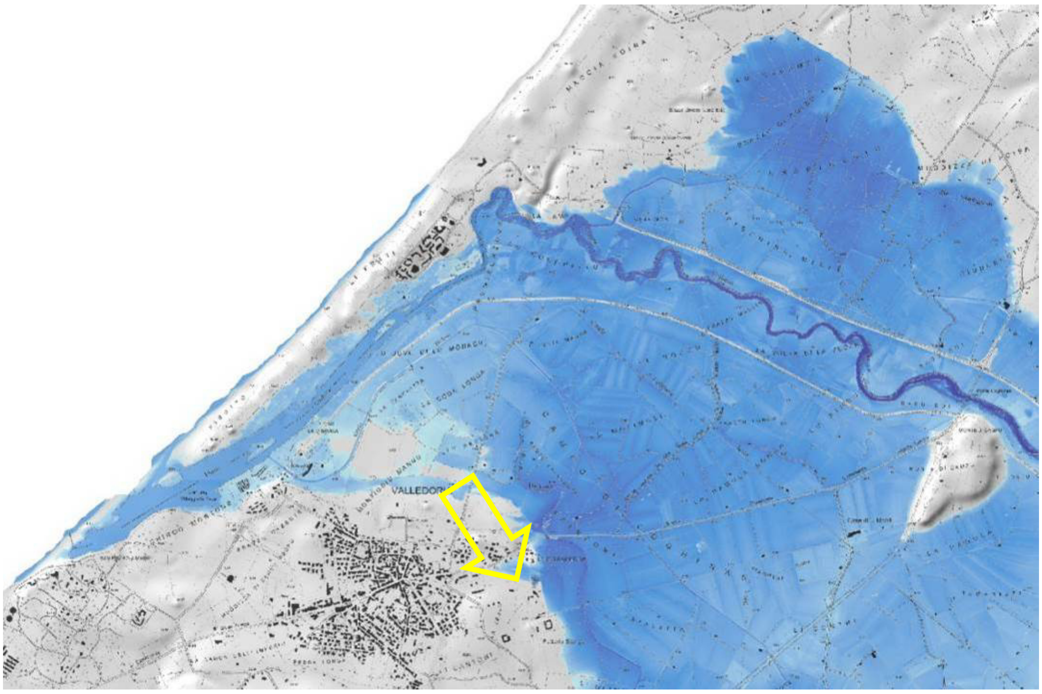


Figure 3-24.200 years flood extension on the Coghinas River downstream (FRMP, 2015)

The left side of the Coghinas River, near its end, is hit by the flood with water levels between 30 and 100 cm causing dangerous conditions in the camping area La Foce, Figure 3-25.

Figure 3-25.Flooding on the La Foce Camping area (FRMP, 2015)

The condition of the resort area Baia delle Mimose, on the right side of the bank river shown in Figure 3-26, appears under relevant danger. Baia delle Mimose resort is partially built above the dune that is gradually subjected at the erosion action of the Coghinas River flow. The water levels in the right side of the Coghinas River from the SP90 Bridge reach levels between 120 – 310 cm and velocities of 1.8 m/s inside the levees decreasing to 0.5 m/s out of the levees.

Figure 3-26.Flooding and erosion actions on the Baia delle Mimose area(FRMP, 2015)

In this level of analysis of the pilot basin the FRMP HEC-RAS model analysed the flood volume for the three return-time period of 50, 100 and 200 years and shown in the Table 3-5.

Tr (Years)	Volume (m^3)
50	28'222'500
100	32'859'200
200	36'831'100

Table 3-5.Flood Volumes discharged on the Coghinas pilot basin by the three return-time period event (FRMP, 2015)

3.1.3. RFSM-EDA 2D hydraulic analysis

3.1.3.1. RFSM-EDA model

Two-dimensional hydraulic model is particularly important for the analysis of the flood development. In particular, the research and LSM implementation require to analysis water depth and velocities values step by step during the flood development. That requirement leads to identify proper software for a two-dimensional hydraulic analysis of the study case. Many companies developed 2D hydraulic model software as MIKE of DHI, HEC-RAS 5.0 of USACE, TELEMAC 2D, FLOW-R2D, but the use of RFSM_EDA software, of the HR Wallingford company has been chosen considering the output extension required for LSM implementation (Zidarich M.P. and Petkovsek G., 2010) (Brunner G.W., 2014) (Bellos V. and Tsakiris G., 2015).

RFSM_EDA is a dynamic 2D flow inundation model that distributes water according to the floodplain topography defining water depth and velocity development during the hydraulic simulation (Goulby et al. (2012)) as necessary in the use of LSM.

RFSM_EDA, acronym of Explicit Diffusion wave with Acceleration term, is based on a Saint Venant equation where the advection term is considered negligible, but the acceleration term is included. It requires the use of a pre-processing, AccData, to analyse the floodplain topography and create a mesh grid where the diffusive equation is applied. AccData analyses the geometry of the studied domain that should be divided up into discrete and hydraulically consistent topographic depressions, called impact zones (IZs), and they are used for the flow calculations thanks to their connectivity.

The process steps has been described in detail by Jamieson et al. in the memory “A highly efficient 2D flood model with sub-element topography” in order to define step by step how the software works (Jamieson et al. (2012)) as reported following.

3.1.3.1.1. AccData: RFSM_EDA pre-processing tool

AccData, as explained above, is the pre-processing RFSM_EDA tool that creates the mesh grid with a detail analysis of the topographic domain under study. The domain topography and its representation are the key for a proper flood inundation model. AccData analyses the ground level described by a DEM and searches for the low point of each cell, called Impact Cell (IC). ICs characterise the studied domain and they are grouped considering that potentially they flow into the same topographic low point. That process could be interpreted as a subdivision of the domain in micro sub-basin called by the model Impact

Zone (IZ) and separated each other by interfaces characterised by high points and crests, that could imagined as watershed of the micro sub-basins (IZs).

The Impact Zones could be created in four different ways based on the user necessity for the floodplain analysis:

- Traditional RFSM
- Breakline grid
- Regular grid
- Mixed mesh (Regular and RFSM)

Except on particular circumstances the Traditional RFSM grid is usually applied, RFSM_EDA Guidance (HR Wallingford, 2013) defines how each type of mesh grid process works.

Traditional RFSM mesh grid creates Impact Zones assembling Impact Cells which flow to the same low topographic points and following the lines of greatest slope. Aiming to avoid undesirable shapes or sizes of Impact Zone, the model is forced with parameters that control three main aspects as the minimum crest between adjacent IZs (IZMinDepth), the IZs minimum size (IZMinSize), to avoid long-lasting runtime simulation, and the IZs maximum size (IZMaxSize) to avoid over-rapid propagation of water. Moreover AccData Traditional RFSM mesh grid could be controlled by a fourth parameter, the IZMaxZdiff, that avoid a creation of too large Impact Zones stretching from the top of the hill to the bottom and in this case the water will flux instantaneously down to the slope giving poor results, an example of a schematic Impact Zone is shown in Figure 3-28.

Breakline grid is useful when the user needs to change IZ shapes and describe minutely sites of particular interest as urban areas.

Regular grid creates IZ with rectangular or squares shape. The domain borders are usually not regular and in that case the cells could be cut by the boundaries creating smaller sections or merged in with their adjacent grid cells.

Mixed mesh considers the use of the Regular and Traditional RFSM mesh grid. This option creates firstly a regular mesh grid and, then, selecting which cell retain regular, the Traditional RFSM option is applied on the remaining cells. The regular cells could be chosen considering the difference between Impact Cell elevations, Z diff parameters, in order to maintain regular cells of areas where the topographic gradient is high. Otherwise, the user could define manually the region where the cells should be regular.

Figure 3-27 shows mesh grid when no parameters are selected (A),with IZMinSize = 10,000 m (B), with IZMinSize = 10,000 m and IZMaxSize = 200,000 m (C), with

IZMinSize= 10,000 m and IZMaxZDiff = 20 m (D),with regular grid cells of 10,000 m (G), and with a mixed mesh with regular cells of 10,000 m and a IZMinSize of 10,000 m (F) (HR Wallingford, 2013).

AccData mesh grid definition could be improved with parameters that underline the topographic elevation unit, the Coordinate Reference system, and a Log file reports in detailed IZ information. In addition AccData could be used setting advance options (usually left at their default values) to identify topographic specific points as, for example, downstream cells, embankment cells.

AccData working with an ascii file, describes the topography of the area under analysis, topography.asc, and a second ascii file is necessary to define the floodplain area. That ascii file, called floodareas.asc, is a mask layer that allows to separate the domain in hydraulically independent areas called Flood Areas, it contains the Flood Area ID in each cell (integer values). The two input files could be created with a GIS software and R software, paying attention that they are characterised by the same dimensions (number of rows and number of columns).

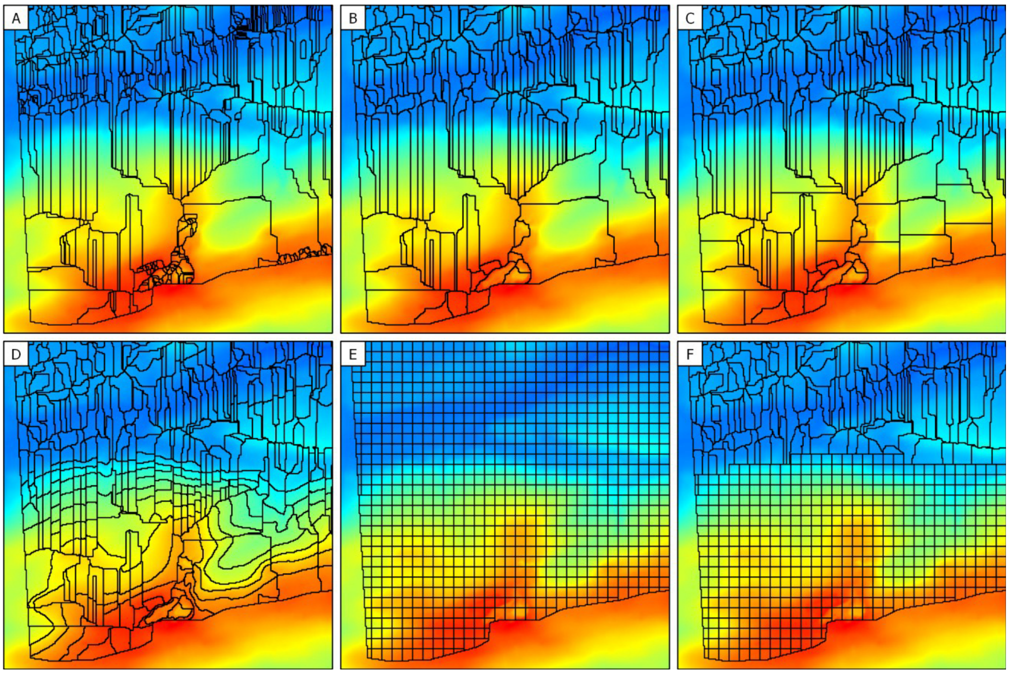


Figure 3-27.Comparison of grid types in high-gradient terrain. A) Default IZs (no parameters selected). B) With IZMinSize = 10,000m. Comparison of grid types in high-gradient terrain. A) Default IZs (no parameters selected). B) With IZMinSize = 10,000m. C) With IZMinSize = 10,000m and IZMaxSize = 200,000m. D) With IZMinSize = 10,000m and IZMaxZDiff = 20m. E) With regular grid cells of 10,000m (note how they merge at the boundary). F) With a mixed mesh with regular cells of 10,000m and a IZMinSize of 10,000m (HR Wallingford, 2013)

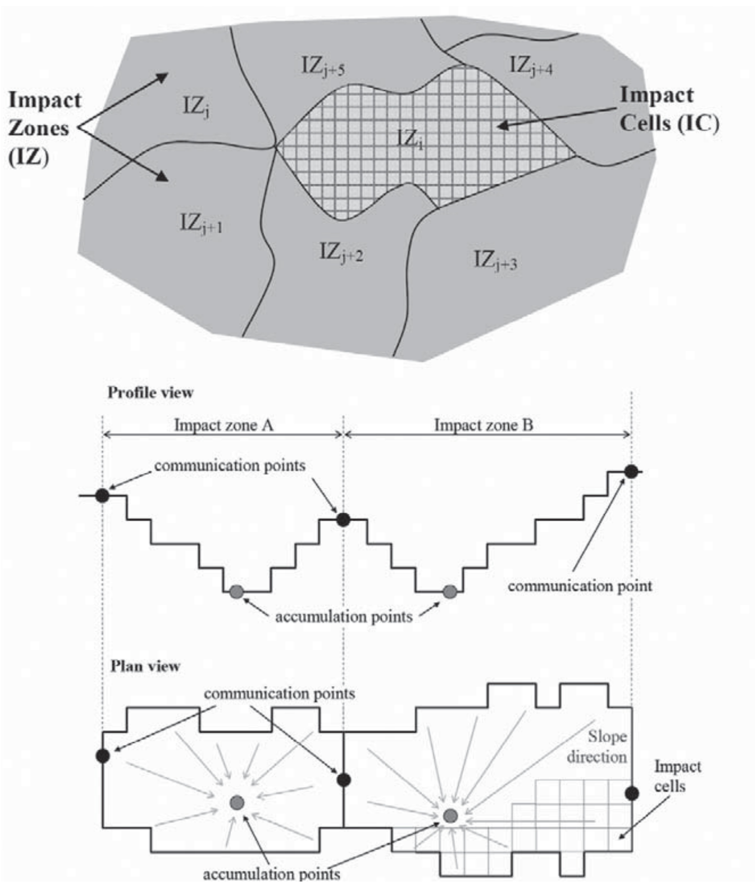


Figure 3-28.Idealised schematic Impact Zone created with a Traditional RFSM mesh grid (Jamieson et al.,2013)

3.1.3.1.2. RFSM_EDA Inundation model

RFSM_EDA requires that each Impact Zone respect main hydraulic aspects. The Impact Zones have been created pinpointing topographic depressions that in hydraulic terms should be characterised by constant water elevation, the relationship between water elevation and volume can be defined by a non-hysteretic relationship, the flow rate between neighbouring IZs are calculated linearly across interface between them ignoring the other IZ neighbours. In addition, the interface between IZs can be characterised by a level-width relationship where the width is assumed to increase gradually with level increment (Jamieson et al.,2012).

The 2D model is based on the study developed by Bates et al. and described in detail in the paper “A simple inertial formulation of the shallow water equations for efficient two-dimensional flood inundation modelling” about the derivation of an inertial formulation of the shallow water equations (Bates et al., 2010). The analysis considers the momentum equation from the quasi-linearized one-dimensional Saint-Venant equation, or Shallow Water equations, composed by the acceleration, advection, water slope and friction slope terms, respectively, as shown in the Equation 3-1.

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left[\frac{Q^2}{A}\right] + \frac{gA\partial(h+z)}{\partial x} + \frac{gn^2Q^2}{R^{4/3}A} = 0$$

Equation 3-1. Shallow Water equations (SWE)

where Q $[L^3/T]$ is the discharge, A is the flow cross section area $[L^2]$, z is the bed elevation [L], R is the hydraulic radius [L], g is the acceleration due to gravity $[L/T^2]$. Various flood flow models can then be constructed, depending on which of these terms is assumed negligible in comparison with the remaining terms (Hunter et al., 2007). In the studied case, the advection term for floodplain flows could be ignored because relatively unimportant due to low velocities determined considering large length scale of analysis and that lead the bed friction to dominate the flux. This assumption does not mean that the model will perform well if advection effects are important, but it means that an apparent improvement in model process representing will lead to little change in model results (Hunter et al., 2007). These considerations have been applied by Bates et al. (Bates P. D. et al., 2010) who obtained the Equation 3-2 in terms of flow per unit width, q $[L^2/T]$, assuming a rectangular channel and dividing Equation 3-1 through a constant flow width, w [L]:

$$\frac{\partial q}{\partial t}+\frac{gh\partial(h+z)}{\partial x}+\frac{gn^2q^2}{R^{4/3}h}=0$$

Equation 3-2. SWE in terms of flow per unit width for a a rectangular channel

where the hydraulic radius, R, for wide shallow flows can be approximated with the flow depth, h. Considering a simulation defined by a time step Δt, the Equation 3-2 could be expressed differentiating the first term and obtaining the Equation 3-3.

$$\left(\frac{q_{t+\Delta t}-q_t}{\Delta t}\right)+\frac{gh_t\partial(h_t+z)}{\partial x}+\frac{gn^2q_t^2}{h_t^{4/3}}=0$$

Equation 3-3. Approximation of the SWE (Equation 3-2)

The Equation 3-3 could be rearranged on an explicit equation to calculate q at the next time step, t+Δt, in function of q_t, h_t and z, and obtain the Equation 3-4 that includes the acceleration term and the water being modelled has some mass too.

$$q_{t+\Delta t}=q_t-gh_t\Delta t\left[\frac{\partial(h_t+z)}{\partial x}+\frac{n^2q_t^2}{h_t^{10/3}}\right]$$

Equation 3-4. Flow rate q in the approximated SWE of Equation 3-3

Instabilities may still arise at shallow depths and when the friction term becomes large the Equation 3-4 could be improved, firstly, replacing a q_t of the friction term by a q_t+Δt and, then, leading it to a linear equation in the unknown q_t+Δt, but which has some of the improved convergence properties of an implicit time stepping scheme.

$$q_{t+\Delta t}=q_t-gh_t\Delta t\left[\frac{\partial(h_t+z)}{\partial x}+\frac{n^2q_tq_{t+\Delta t}}{h_t^{10/3}}\right]$$

Equation 3-5. Approximation of Equation 3-4

Finally the Equation 3-5 could be rearranged to explicit the flow rate q at the next time step q_t+Δt obtaining the Equation 3-6.

$$q_{t+\Delta t}=\frac{q_t-gh_t\Delta t\dfrac{\partial(h_t+z)}{\partial x}}{(1+gh_t\Delta tn^2q_t/h_t^{10/3})}$$

Equation 3-6. Definition of the flow rate $q_{t+\Delta t}$

Bates et al. observed that the enhanced stability of Equation 3-6 stems from the increase in the denominator as the friction term increases, forcing the flow to zero, as would be expected for shallow depths.

Bates' study has been analysed later to simulate floodplain areas with RFSM_EDA (Jamieson et al., 2012). The model assumed to determine the flow for each IZ as the sum of flow calculations for each sub-element cell in the interface crest, f, applying the Equation 3-7, improvement of the Equation 3-6where the hydraulic radius, R, is calculated in full and not approximated at the water depth, h. The Equation 3-7 shows the approach called “compound-section” (CS) flow:

$$Q_f^{t+\Delta t} = \sum_p \frac{(Q_p^t - g\Delta t A_p^t S_f^t}{1 + g\Delta t n^2 \left|Q_p^t\right| / A_p^t \left(R_p^t\right)^{4/3}}$$

Equation 3-7. Compound-section approach equation

The terms in the Equation 3-7 are explained graphically in the Figure 3-29. Jamieson et al. represent with Q_f the interface flow, Q_p the panel flow (for one sub-element cell), g is gravity, Δt it the time-step, A_p is the panel area, R_p is the panel hydraulic radius (which includes vertical friction as well as horizontal), n is Manning’s friction and S_f is the water surface slope, calculated as the difference in neighbouring IZ water levels, divided by their centroid separation distance.

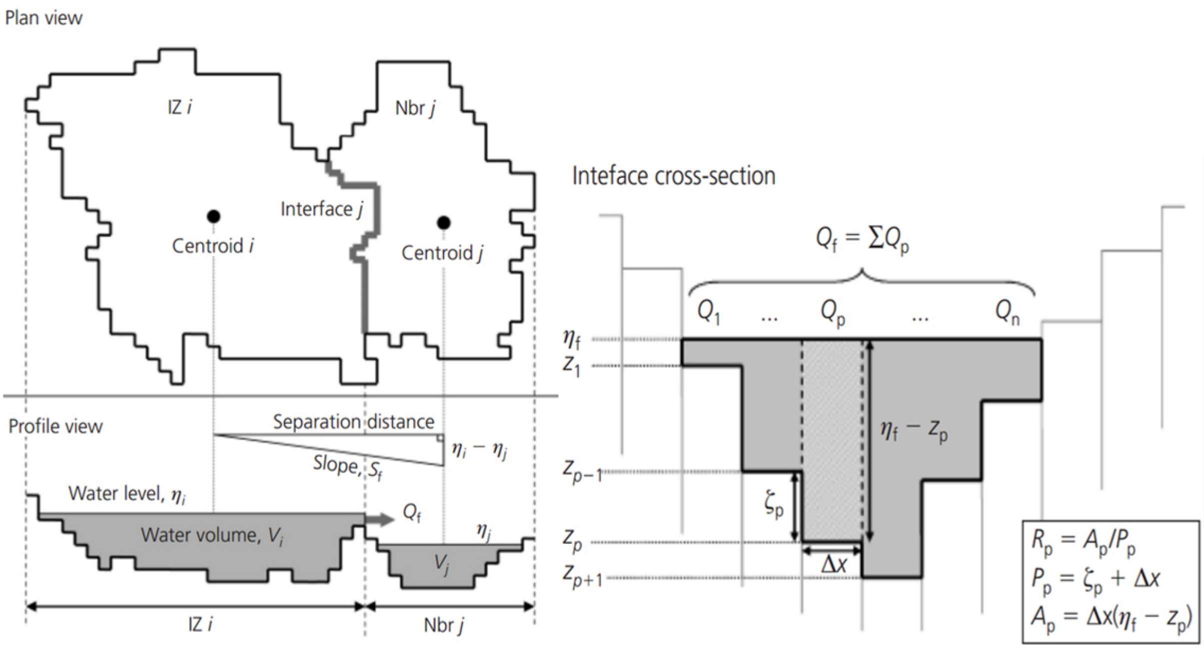


Figure 3-29.The Plan view (left side) represents a scheme of an IZ with a neighbour, in plan and profile. The irregular boundaries are shown and key variables are selected. The solid grey represents a volume of water. (Right side) The Interface cross-section schematizes an interface between two neighbouring IZs. The solid grey colouring represents water part sub-merging the interface, while the demarked rectangle represents a calculation panel corresponding with an individual sub-element cell (Jamieson et al.,2013)

Figure 3-29 shows the panel hydraulic radius, R_P, the panel wetted perimeter, P_P, and the panel area, A_P, equations. More attention is given on the interface flow level, η_f, because negative depths occur when the downstream level is below the interface crest. That aspect led the researchers to consider the maximum η_f value between the adjacent IZs, Equation 3-8. While the interface slope, S_f, is calculated by dividing the difference in neighbouring IZ water levels by the separation distance between their centroids.

$$\eta_f^{\,t} = \max(\eta_i^t, \eta_j^t)$$

Equation 3-8. Definition of the interface flow level

At a later stage, the flow calculation process has been improved introducing a new approach whereby only one flow calculation is undertaken for the whole interface (Jamieson et al., 2013). The new approach is called the 'total-section' (TS) flow and represented by Equation 3-9.

$$Q_f^{t+\Delta t} = \frac{(Q_f^t - g\Delta t A_f^t S_f^t)}{1 + g\Delta t n^2 \left|Q_f^t\right| / (R_f^t)^{4/3}}$$

Equation 3-9. Total-section approach equation

where A_f is the interface area, R_f is the interface hydraulic radius.

By this time the simulation is progressed by applying conservation of mass for each IZ, Equation 3-10.

$$V_i^{t+\Delta t} = V_i^t + \Delta t \sum_{j=1}^{n} Q_f^{t+\Delta t}$$

Equation 3-10. Conservation of the mass equation

where V_i is the volume in the IZ i, and n is the set of neighbouring IZs, j.

Water levels are then calculated using the pre-processed level-volume look-up tables once that the water volumes are evaluated.

The studies developed by Bates et al. (Bates et al.2000) (Bates et al., 2010) considered flow limiters to avoid the flow black of fluxes between two time steps, or wetting/drying problems as when IZs are assumed to have topographic barriers as crests between them, and, if IZ is initially wets, the water cannot leave until it fills the volume below the lowest interface level of its neighbours. In RFSM_EDA no flow limiters or special wetting or drying treatments are used. The model imposes that the stored volume below the minimum interface level will absorb gradually the excess flux. In fact, the topography depression of the IZs are assumed to provide a natural resistance to both over-rapid wetting (i.e. water must fill the depression before it can continue to flux) and mass balance errors whilst drying, (i.e. the 'dead' volume below the minimum interface level absorbs excess flux if inappropriately large flows occur in the drying phase).

The velocities on the IZs interfaces could be used as surrogate for the IZ average velocity in flat topography, but this is not appropriate when the IZs have a depression-like shape. In that case the interface velocities are expected to be relatively shallow and fast, compared with deeper and slower flow conditions at the IZ centre. The conversion of the interface velocities to an area-average velocity vector requires an additional step of analysis

(Jamieson et al., 2012). Assuming IZs of regular shape, the volume of water that has been fluxed out of the IZ (using the results of Equation 3-10) is divided by the area of a representative cross-section through the centre of the IZ, X_i, as shown in the Equation 3-11.

$$u_i^t = \frac{\Delta t \sum_j Q_j^t n_j}{X_i^t} \qquad \text{where } Q_j^t > 0$$

Equation 3-11. Velocity vector expression

where n_j is the unit vector between the IZ and neighbour centroids, used to provide the velocity as a vector. Whether the IZ shape is assumed cubic, cylindrical or as an inverted cone, the calculation for the IZ cross-sectional area can be written as in Equation 3-12.

$$X_i^t = \beta\sqrt{(h_i^t V_i^t)}$$

Equation 3-12. Centre of the cross-section

where β is a constant which for the aforementioned shapes takes on a value between 0.96 and 1.13. We assume IZs with variable shapes and sizes, for this reason β could be equal to 1 for simplicity. It is important to note that this velocity does not impact on the fluxes between IZs, which are calculated independently.

The model numerical stability is subjected at the Courant–Freidrichs–Lewy (CFL) condition, which is satisfied by ensuring that the domain of dependence of the interfaces of an IZ should not exceed the area of the IZ. The used version of CFL condition is described by Guinot V. and Soares-Frazao S. (Guinot V. and Soares Frazao S., 2006) and it is more appropriate for irregular shaped elements than the version used by Bates et al. (Bates et al., 2010), because it uses areas rather than lengths. The used CFL condition also differs by including velocity with celerity. The Equation 3-13 gives the maximum permissible time step, Δt_{max}:

$$\Delta t_{\max} = \alpha \min \frac{A_i^t}{\sum_i w_f \max\left(\left\|u_i^t\right\| + c_i^t, \left\|u_j^t\right\| + c_j^t\right)}$$

Equation 3-13. Maximum permissible time-step

where α is the 'alpha-parameter', used to scale the predicted time-step, A_i is the IZ area, w_f is the interface width, $||u_i||$ is the magnitude of the IZ velocity vector, and c_i is the celerity of a wave (characteristic velocity for the shallow water equation where the advection term is ignored), given by $\sqrt{gh_i^t}$, where h is the IZ water depth.

In particular, CFL condition has to predict and control simulation time steps to model the floodplain inundation during a given time of analysis. The simulation is defined by two time steps, minimum and maximum values, in order to avoid infinite calculation of it. CFL condition would calculate infinite time steps when there is no water in the domain and that lead to model RFSM_EDA to run limited by a maximum time step value equals to 20 seconds that will be used until water enters the domain. When instabilities arise, infinite water depths could be calculated and RFSM_EDA would calculate infinitely small time steps. That error stalls the simulation progression starting a loop that could be avoided by the model setting a minimum time step value (HR Wallingford, 2013).

3.1.3.2. RFSM_EDA 2D hydraulic analysis

Coghinas River lowland valley basin study has been improved developing a two-dimensional hydraulic analysis using the HR Wallingford software RFSM_EDA and obtaining water depth and velocity maps.

AccData, RFSM_EDA pre-processed tool, models the mesh grid of the Coghinas River lowland valley basin working with the topography ascii file of 10 m resolution DTM grid and, using the same characteristics of the topography file, creates the floodplain asci file with the software R Studio necessary for the hydraulic simulation as explained in the Paragraph 3.1.3.1.1 where AccData use is described. The pilot basin mesh grid has been set using the "Traditional RFSM" method to create a grid setting the parameters in IZMinDepth equals to 1 m, IZMinSize of 1000 m^2, IZMaxSize of 10000 m^2 and defining the mesh grid in UTM WGS84 Coordinate Reference System, Figure 3-30.

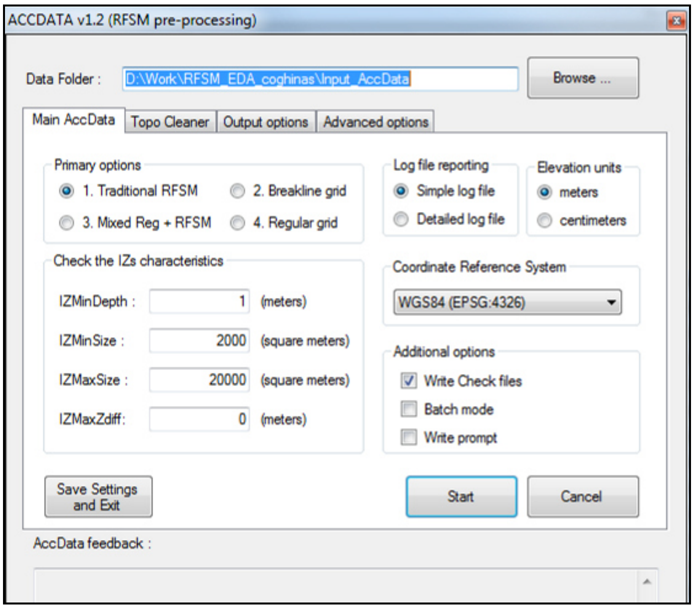


Figure 3-30.AccData parameters for the Coghinas River lowland valley basin mesh grid

AccData results has been modified to implement the hydraulic boundary conditions defined for HEC-RAS mono-dimensional model described at the beginning of Chapter 3.

RFSM_EDA models has been run 4 times for the return-time period of 2, 50, 100 and 200 years as required by the PSFF plan allowing a comparison between HEC-RAS results model.

Upstream boundary condition has been set checking in the mesh grid which IZ corresponds to the Casteldoria dam location in order to assign at that IZ the hydrograph of the chosen scenario event, in other words the base time, peak of time and related flow rate of each hydrograph have been implement in RFSM-EDA.

The roughness information has been added in the model using ArcGIS and intersecting the IZ distribution with a map characterised by Manning coefficient values of the study basin area after a deep observation of the roughness parameters described for the Coghinas River lowland valley basin in the PSFF. Finally, the downstream boundary condition of 1.8 m sea level has been set for all of the sea IZs as constant value for the whole simulation.

Once the mesh grid and the hydraulic boundary conditions were set, the RFSM hydrodynamic input file were coupled with the RFSM parameters to run the simulation.

Figure 3-31 shows the input required to run RFSM. Some input change for each simulation and are set specifying information as the folder where the topography and floodplain ascii files are saved, start and end time of the simulation, save time step, maximum and minimum time step of the simulation in order to avoid potential loop processes. All specified time values (EndTime, TimeStep, SaveTimeStep, etc) are in seconds by default, even though other permissible unit identifiers are possible: 's' = seconds, 'm' = minutes, 'h' = hours and 'd' = days and they could be set using the hash symbol followed by a unit identifier ("2.0#d" would signify two days (172,800s), and "75#m" would signify 75 minutes (4,500s))

input.xml - Notepad

File Edit Format View Help


```
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  <DbServer>none</DbServer>
  <DbName>C:/Users/sfr/Desktop/FRSM_EDA</DbName>
  <TestID>1</TestID>
  <BCSetID>1</BCSetID>
  <TestDesc>test coghinas</TestDesc>
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  <MaxTimeStep>5</MaxTimeStep>
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  <AlphaParameter>0.8</AlphaParameter>
  <SkipDryResults>0</SkipDryResults>
  <ManningGlobalValue>0.0315</ManningGlobalValue>
  <MinDepth>0.0005</MinDepth>
  <Equations>i</Equations>
  <SkipDryResults>2</SkipDryResults>
  <Results>1|2</Results>
  <LogVerbose>1</LogVerbose>
</settings>
```


Figure 3-31.Input.xml file example

At this level of the RFSM hydraulic analysis, bridges are not modelled in the simulation, but structural mitigation measures as levees are included in the model through the use of the DTM of the area.

At a first step RFSM models the 2 years return-time period scenario and the result shows a model that interests the area between the levees characterised by maximum water level of 6.49 m and levees overflowed near Baia delle Mimose, Figure 3-32.

More different is the situation for flood event with return-time period of 50, 100 and 200 years shown in Figure 3-33, Figure 3-34 and Figure 3-35. The flood maps of 50, 100 and 200 years return-time period scenarios show no relevant differences in flood maps extensions and the maximum water levels of each event is quite similar: 12.73 m for the event of 50 years, 13.93 m for the event of 100 years and 14.93 m for the event of 200 years return-time period as shown respectively in Figure 3-33, Figure 3-34 and Figure 3-35.

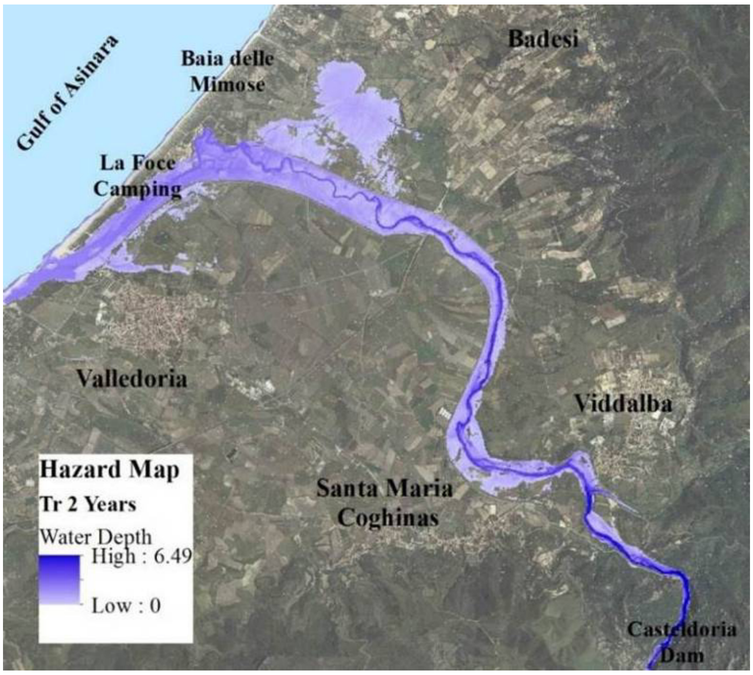

Figure 3-32.Flood hazard map due to the event of 2 Year of return-time period

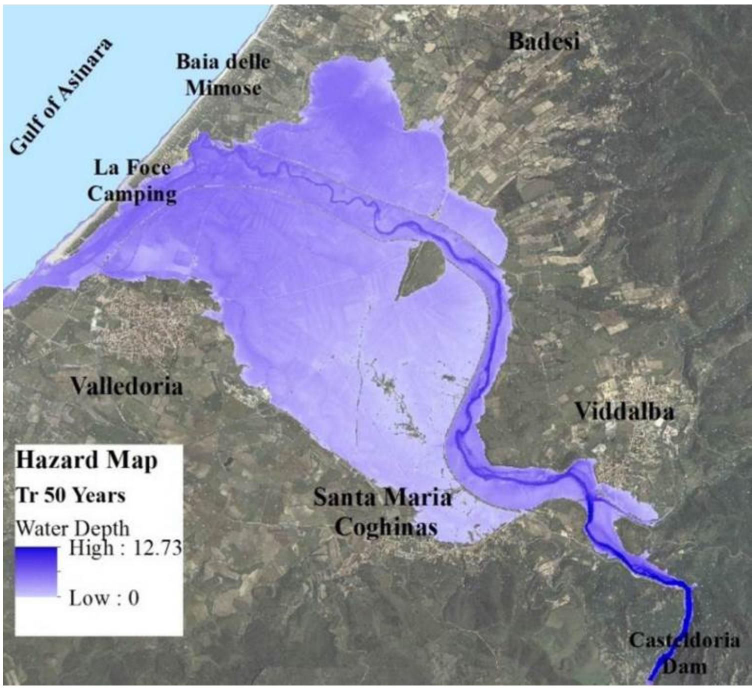

Figure 3-33.Flood hazard map due to the event of 50 Year of return-time period

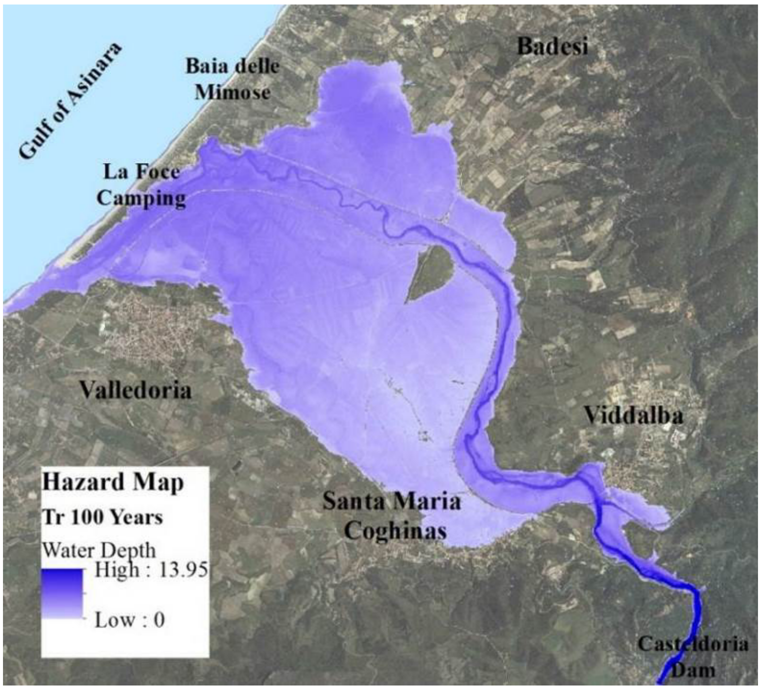

Figure 3-34.Flood hazard map due to the event of 100 Year of return-time period

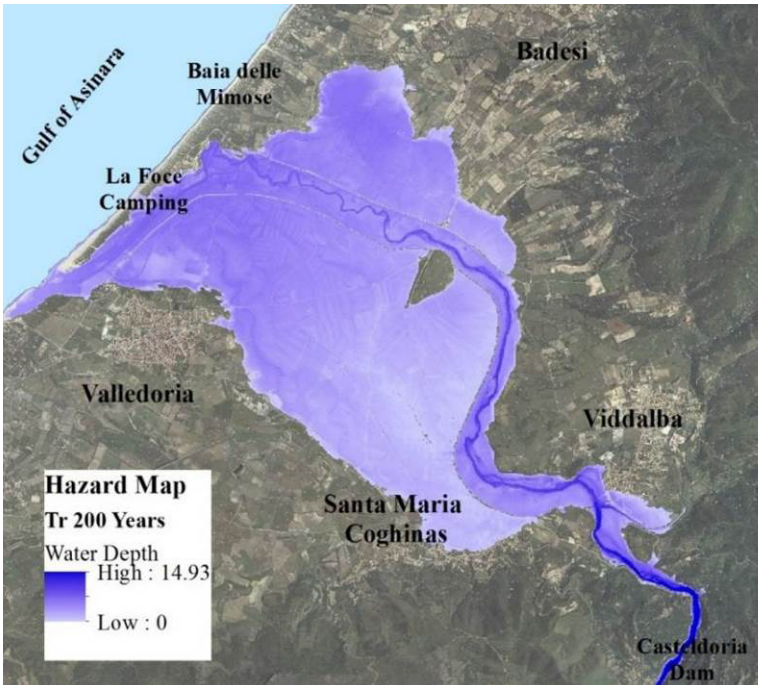

Figure 3-35.Flood hazard map due to the event of 200 Year of return-time period

The analysis of the Coghinas River lowland valley basin has been conducted accordingly with PSFF and FRMP HEC-RAS models in order to observe the affinities and the differences between the models.

In the first part of the Coghinas River after Casteldoria dam, the flooding could damage the area of Casteldoria Thermal Bath unless the valley nature of the river path. In fact, as shows in Figure 3-36, Casteldoria footbridge could be overflowed by the event of return time-period of 50 years, while the flow does not create huge damage for the 2 years event of return-time period. In detail, it is possible to identify maximum values of water levels from 0.39 m (2 years event) to 6.10 m (200 years event) in the right side of the footway, and from 2.81 m (2 years event) to 8.52 m (200 years event) in the left side of the Coghinas River hitting and overflowing the Casteldoria Thermal Bath masonry and the footway as described in Figure 3-37. The analysis of the water levels in the lowest point of the bed river shows that the river flows regularly with water depths of 5.53 m for the 2 years event, while the water levels increase from 9.79 m to 11.24 m for the 50 and 200 years event, respectively. In addition, it is possible to observe velocities from 2.86 m/s, for 2 years event, that increase till 11.57 m/s for the 200 years event.

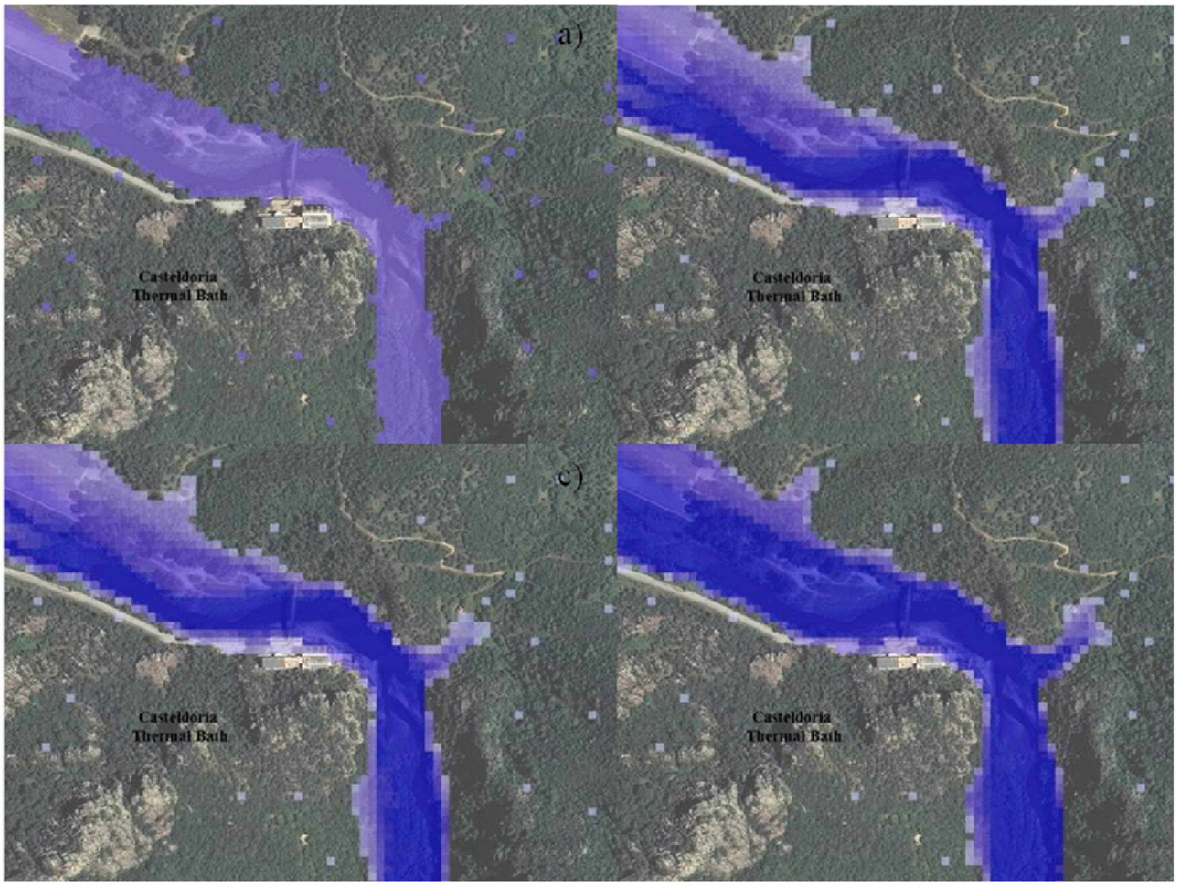

Figure 3-36.Flood conditions for the Casteldoria thermal bath area for event of return-time period of 2 years (a), 50 years (b), 100 years (c) and 200 years (d)

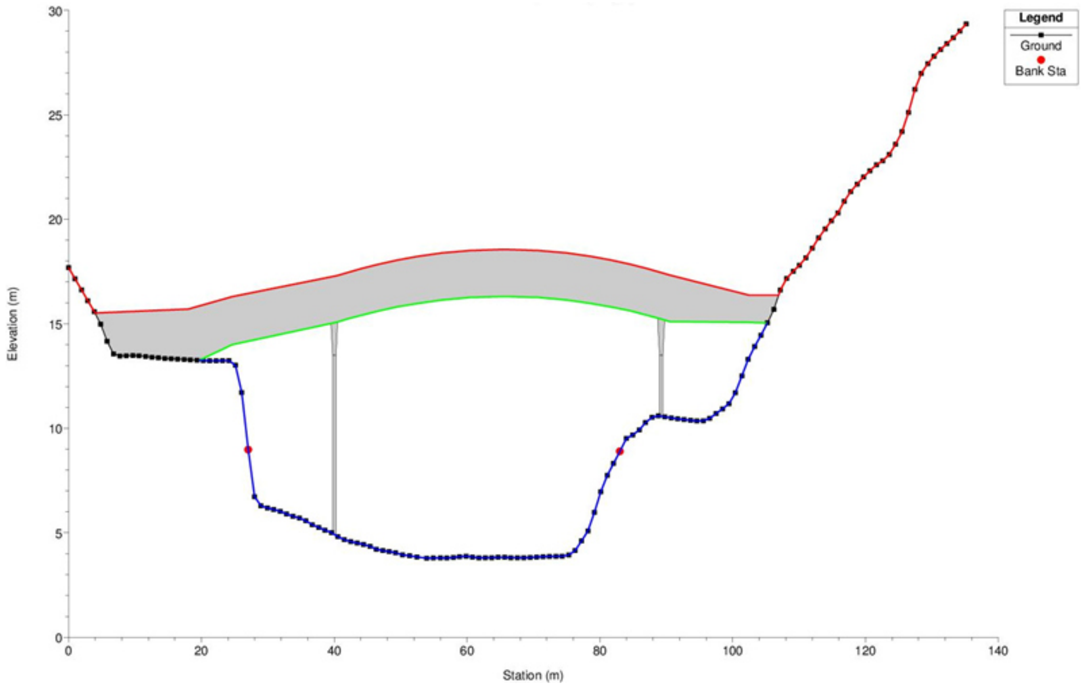

Figure 3-37.Casteldoria Thermal Bath Footway (FRMP, 2015)

Subsequently the Casteldoria thermal bath, the Coghinas River flows toward Viddalba and Santa Maria Coghinas towns. The two towns are linked each other by the new SP146 Bridge and the old SP146 Bridge. The new SP146 Bridge has been built with a high that allows regular flow of the river, while the high of the old SP146 bridge is not efficient and creates a blockage that increments the flood in the area. The floodplain of the area is shown in Figure 3-40 for the 4 return-time period of 2, 50, 100 and 200 years. The event of 2 years floods the area between the bridges abutment on the left side of the Coghinas River and the suburban area of Viddalba on the right side of the river without hit the residential area. The 50, 100 and 200 years event are characterised by significant water levels that determine the flooding of the area out of bridges abutment and hitting the suburban area of Viddalba flowing to the Rio Badu Crabile tributary.

The water levels increase on the left side of the Coghinas River from 1.59 m for of 2 years event to 5.05 m for the 200 years event. The right side of the river is interested by a range of water levels between 2.03 m to 5.44 m for return time-period respectively of 2 and 200 years respect to the new SP146 bridge, while the old SP146 bridge is hit by water levels between 1.65 m and 5.40 m for event, respectively, of 50 and 200 years of return-time period. The analysis of the water levels in the lowest point of the bed river for the new SP146 Bridge shows levels from 4.80 m to 8.19 m, while for the old SP146 Bridge the water levels reach values from 3.65 m to 7.05 m. These values compared with the bridge dimensions remarks the inefficiency of the new SP146 Bridge for the 200 years event, while the inadequacy of the old SP146 Bridge is defined for event from 50 years, Figure 3-38 and Figure 3-39. The model shows velocities from 4.33 m/s for the event of 2 years to 16 m/s for the event of 200 years in the Coghinas bed river, while in the right and left banks the velocity values do not exceed 8 m/s for the worst scenario and 2 m/s for the event of 2 years.

The Figure 3-40 allows to analyse the flooding in the suburban area of Santa Maria Coghinas that could happen from event of 50 years with water levels around 0.20 m and without become higher than 1 m for worst the higher flood event characterised by velocities around 1 m/s too.

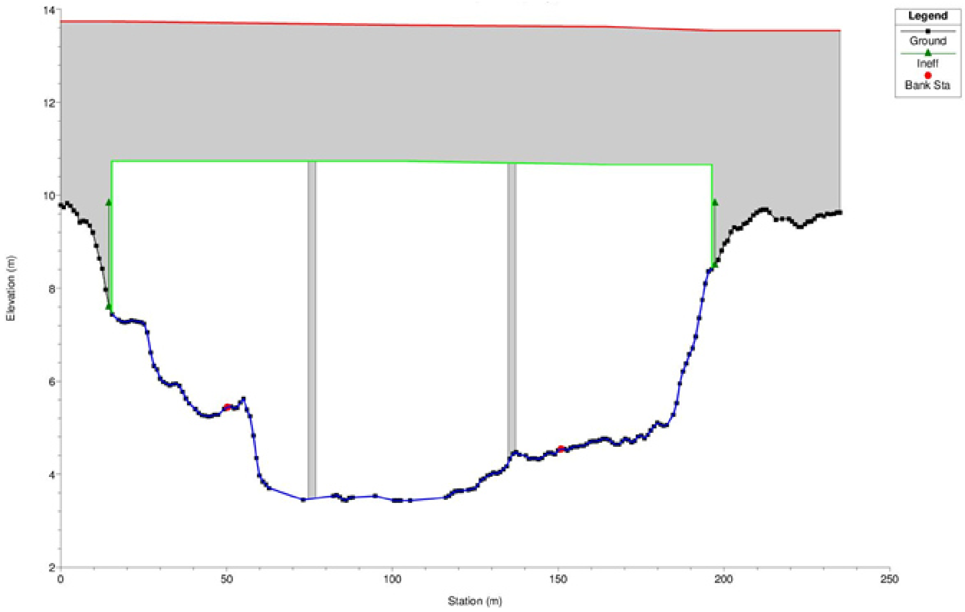

Figure 3-38.New SP146 Bridge (FRMP, 2015)

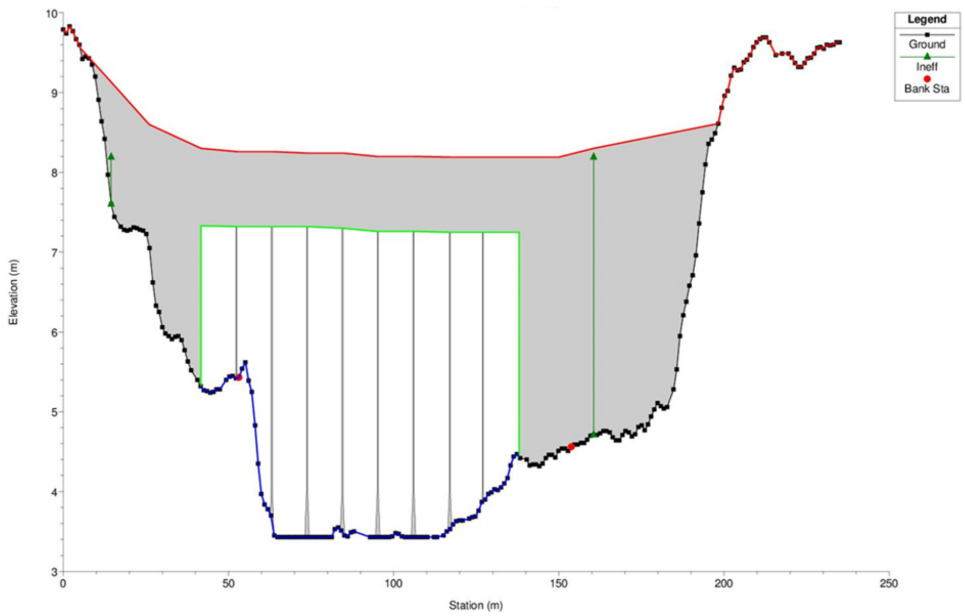

Figure 3-39.Old SP146 Bridge (FRMP, 2015)

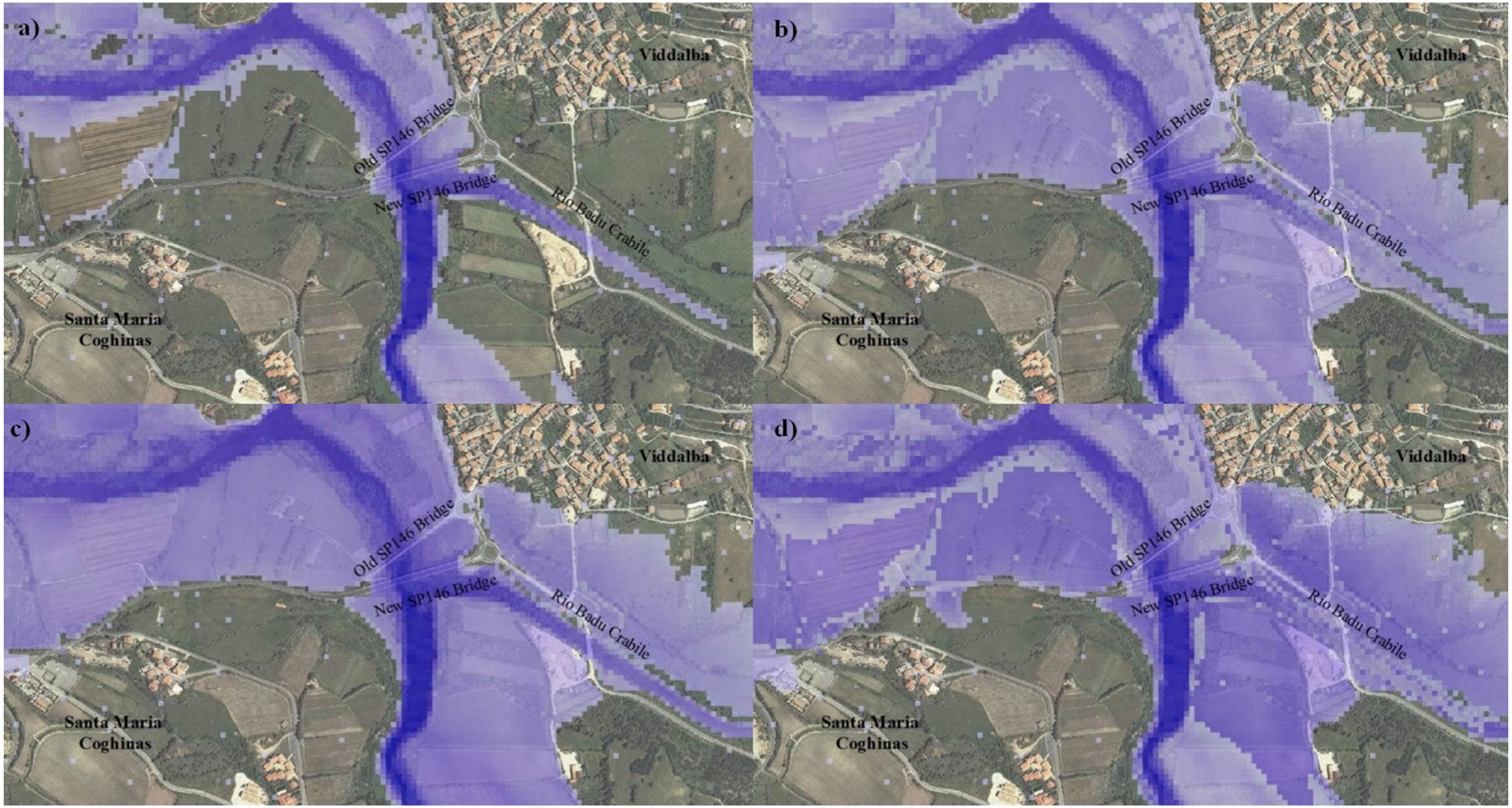

Figure 3-40.Flood conditions for the Viddalba - Santa Maria Coghinas area for event of return-time period of 2 years (a), 50 years (b), 100 years (c) and 200 years (d)

The Coghinas River turns to the right side of the area reaching the area of "Monte di Campo" hill where the river is crossed by the SP90 Bridge. In this section the river flows regularly for 2 years event with water levels around 3.5 m and velocities of 3.81 m/s, Figure 3-41, while for 200 years event the water level reaches 5.27 m and the velocities increase to 12.10 m/s. The hydraulic conditions changes gradually for event of higher return-time period when, from previous sections, the levees are overflowed and show height inadequacy containing the flood.

The comparison of Figure 3-42, Figure 3-43, Figure 3-44 and Figure 3-45 shows how the floodplain area has relevant changes from the 2 years event and the 50 years event. Figure 3-43, Figure 3-44 and Figure 3-45 are not characterised by significant differences in the extensions and water depth ranges because of the topography. For each of these events it is possible to observe the flood behaviour reaching the suburban area of Santa Maria Coghinas, toward the upstream, and Valledoria town toward the downstream. In both towns the flood hit residential and industrial structures containing the damages because of water depth levels no higher than 1 m and velocities registered around 0.5 m/s.

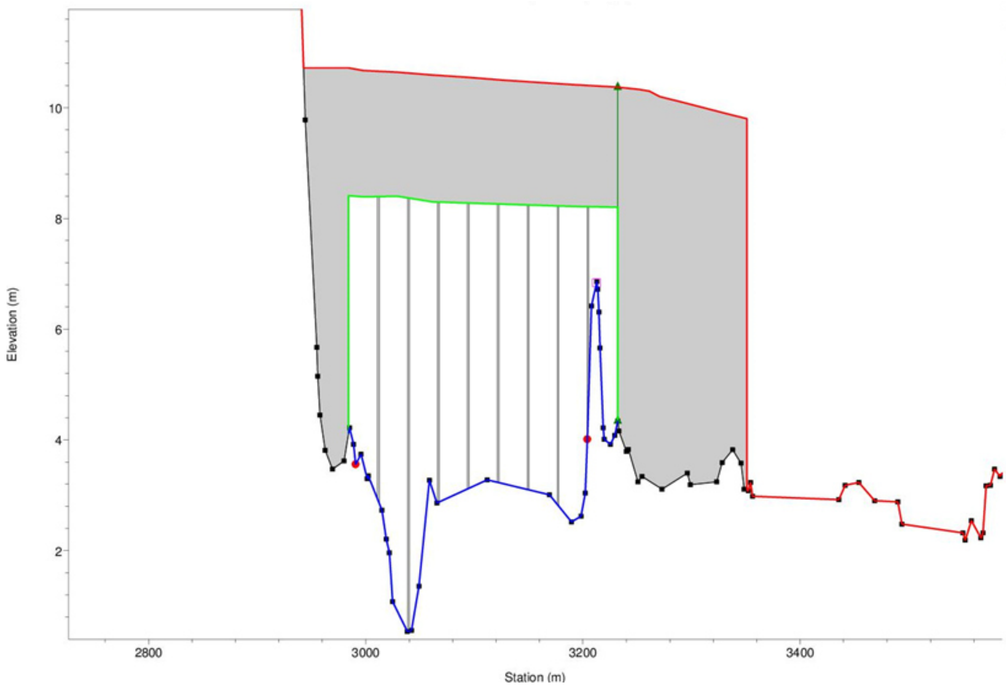

Figure 3-41.SP90 Bridge (FRMP, 2015)

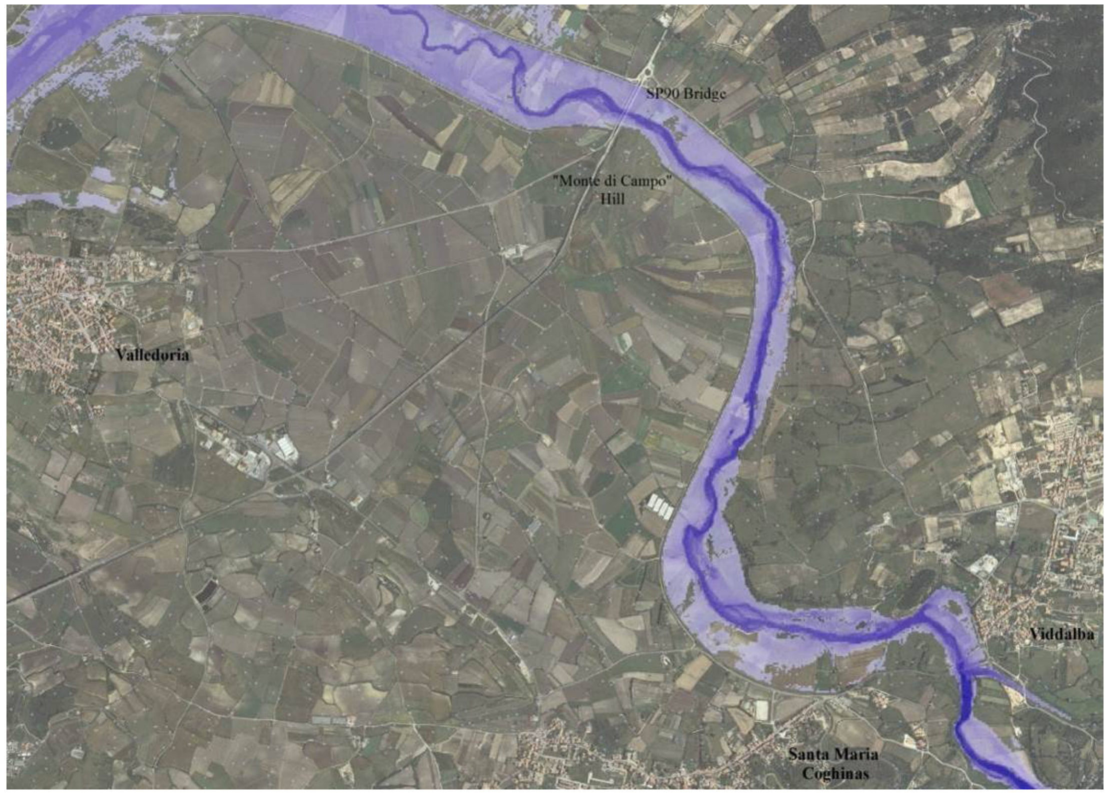

Figure 3-42.Flood behaviour for return-time period event of 2 years

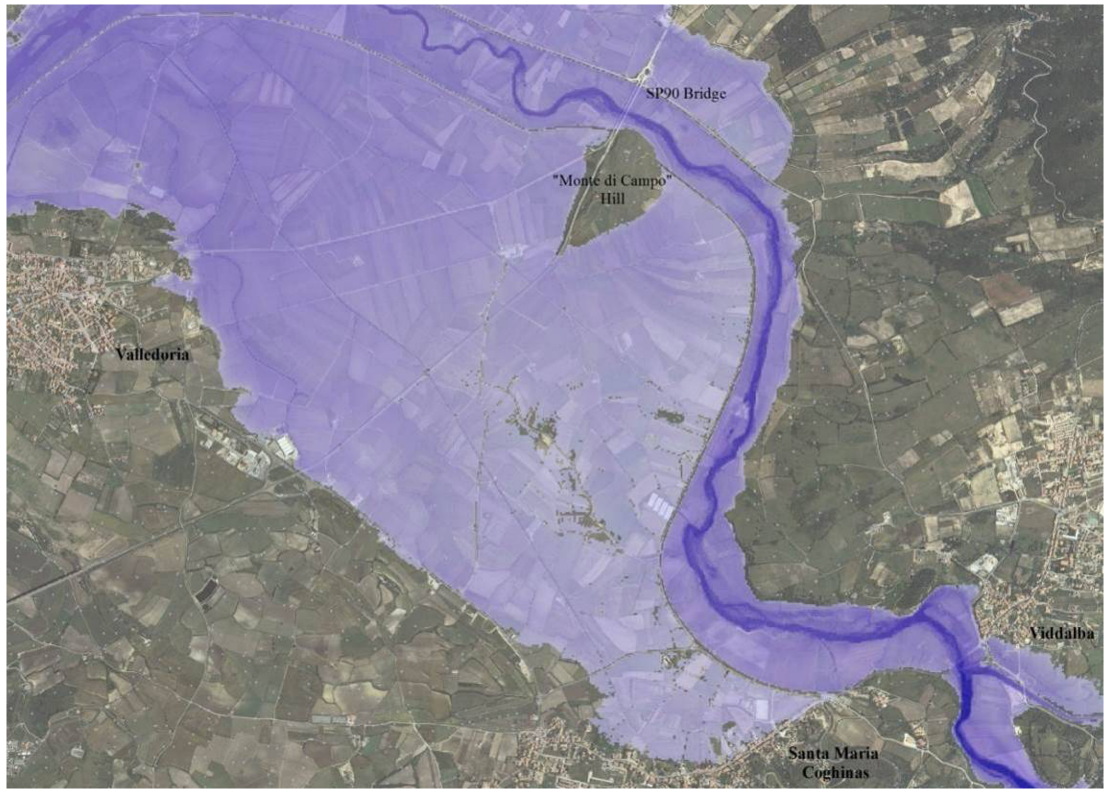

Figure 3-43.Flood behaviour for return-time period event of 50 years

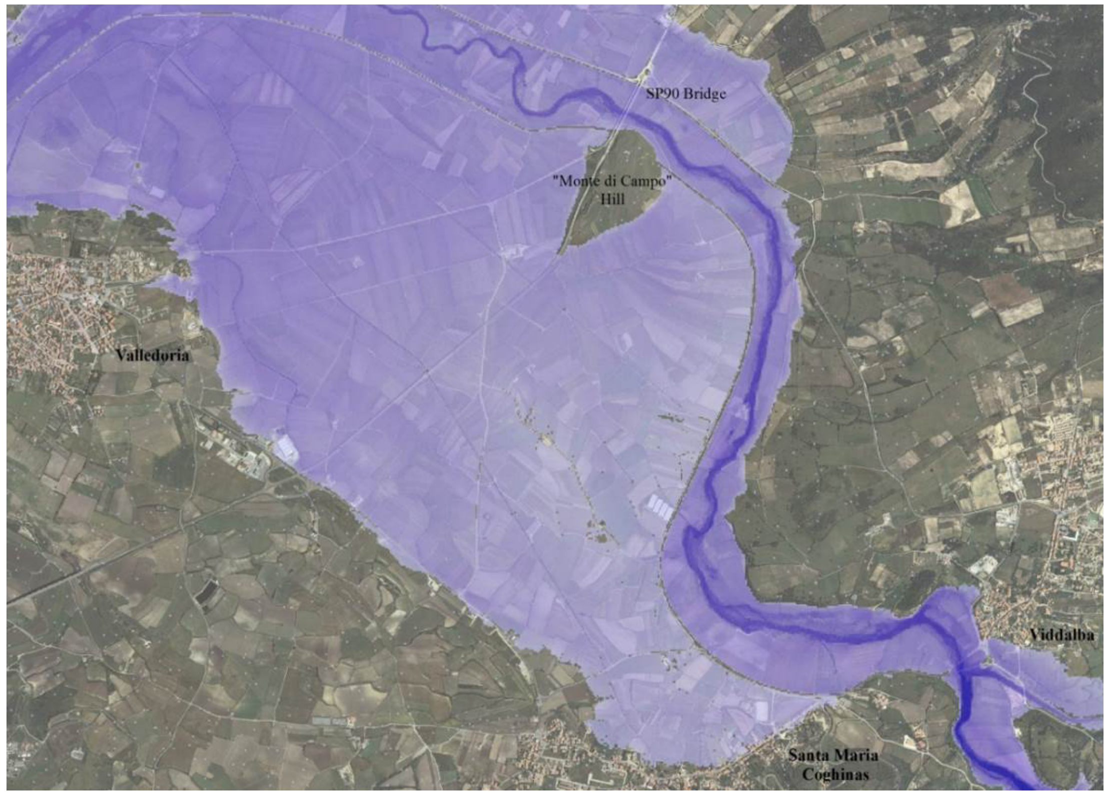

Figure 3-44.Flood behaviour for return-time period event of 100 years

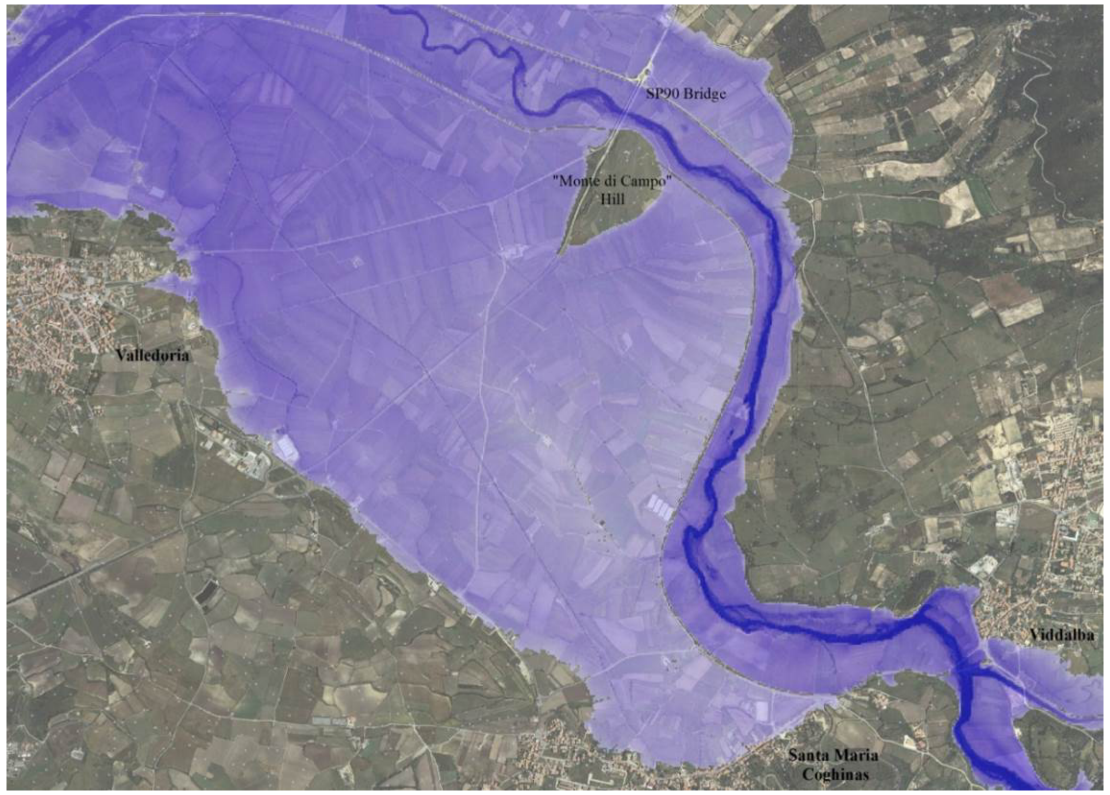

Figure 3-45.Flood behaviour for return-time period event of 200 years

More important is the situation on the downstream of the river characterised by the urbanised areas of Baia delle Mimose resort, La Foce camping and the suburban area of Valledoria town.

Baia delle Mimose resort area is built in the right side of the river path and, partially, above the dune between the Gulf of Asinara and Coghinas River. This location is particular dangerous considering the river shape. In fact, the river is characterised by many meanders reaching the downstream and near Baia delle Mimose resort changes direction turning to the left and flowing parallel to the Gulf of Asinara between it and the dune. The section where the Coghinas River changes direction is a critical point because of the erosion action that it develops on the right bank compromising the stability of the territory and, therefore, of the urbanised area. In Figure 3-46 Baia delle Mimose resort area is shown for flooding conditions under the 2, 50 100 and 200 years events. The area is flooded since the event of 2 years of return-time period with water levels that reach values around 1 m and velocities around 1.60 m/s interesting the playing fields and the swimming pool of Hotel & Residence Baia delle Mimose, Figure 3-46a. Since the event of return-time period of 50 years, Figure 3-46b, the tourist houses are interested by the flood that hit the structures with water levels and velocities, respectively, around 1.5 m and 0.5 m/s.

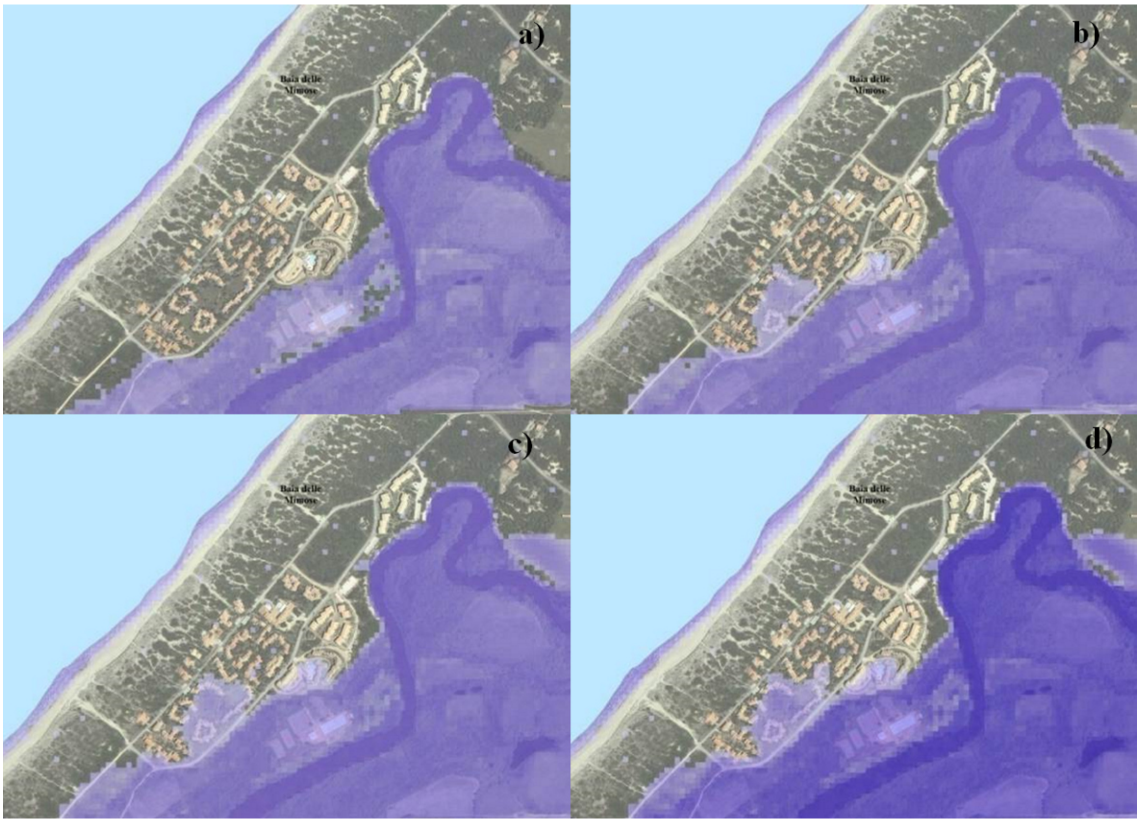

Figure 3-46.Flood conditions for Baia delle Mimose resort area for event of return-time period of 2 years (a), 50 years (b), 100 years (c) and 200 years (d)

After 1.5 km, Coghinas River reaches the Mediterranean Sea and flows near La Foce camping area, located in the Valledoria territory. The camping area has been realised above the river banks and this location lead the tourist area to a critical situation in case of floods. In Figure 3-47it is possible to observe the worsening of the camping area situation from the event of 2 years to 200 years of return-time period. The hydraulic model allows to identify the water levels in the area. The event of 2 years of return-time period hit the camping area with water levels around 0.5 m and velocities that could reach 2 m/s, while the hydraulic model gives back values around 2.5 m of water levels and from 7 m/s to 10 m/s for the event of 200 years of return-time period.

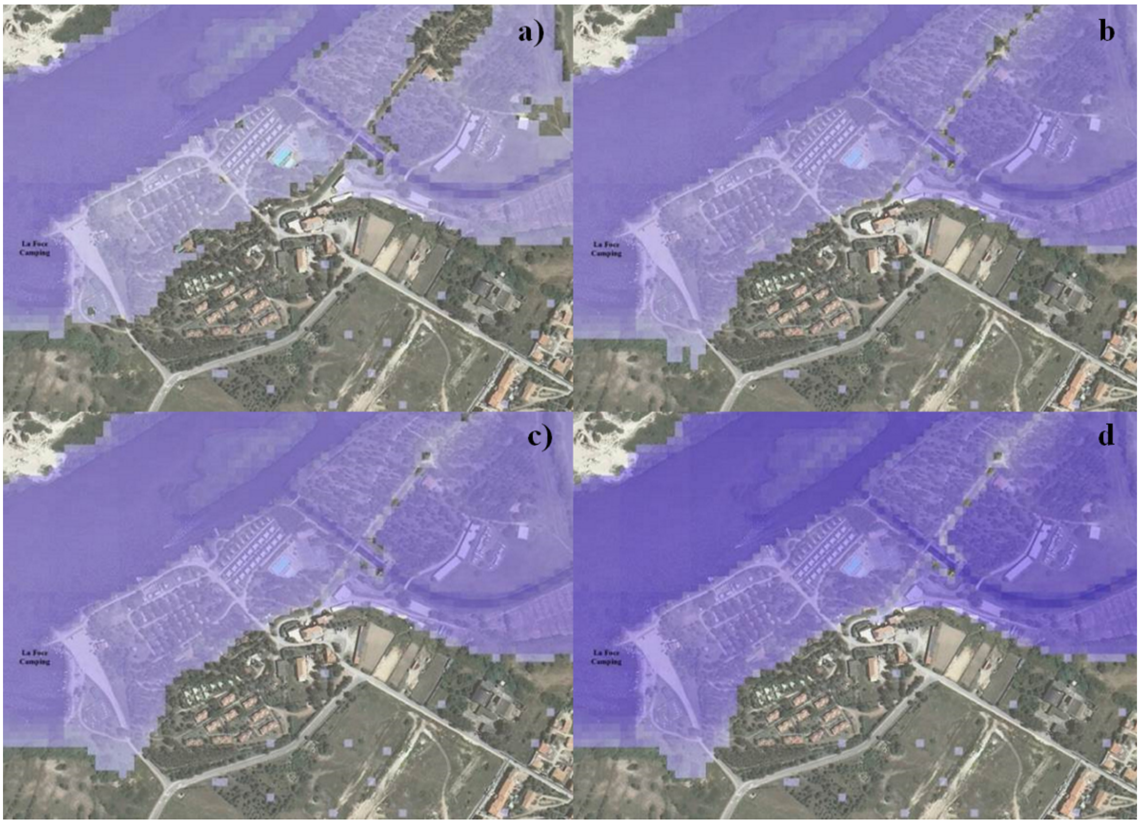

Figure 3-47.Flood conditions for La Foce camping area for event of return-time period of 2 years (a), 50 years (b), 100 years (c) and 200 years (d)

3.2. Flood damage Evaluation

3.2.1. Evaluation of the tangible damage: JRC Model

The direct tangible flood damage is evaluated considering the implementation of the JRC Model and, therefore, the application of the JRC water depth damage functions on the Coghinas River lowland valley basin. The JRC Model is applied with integration described in Chapter 2 and Paragraph 2.2.1 proper for Sardinian territory in terms of categorisation of the land use to describe more in detail the territory under analysis, Figure 3-48, and changes on water depth range of the JRC water depth-damage functions. The indirect part of the tangible damage has been appreciated with the MCM Model that considers to include emergency and rescue costs services in the indirect tangible damage category evaluating these damages as the 10.7 % of the direct tangible damages. The present research increased to 30 % the aliquot of the indirect tangible damage to include in the analysis economic losses due to disruptions of lifelines systems as telecommunication, road network, water and electricity systems.

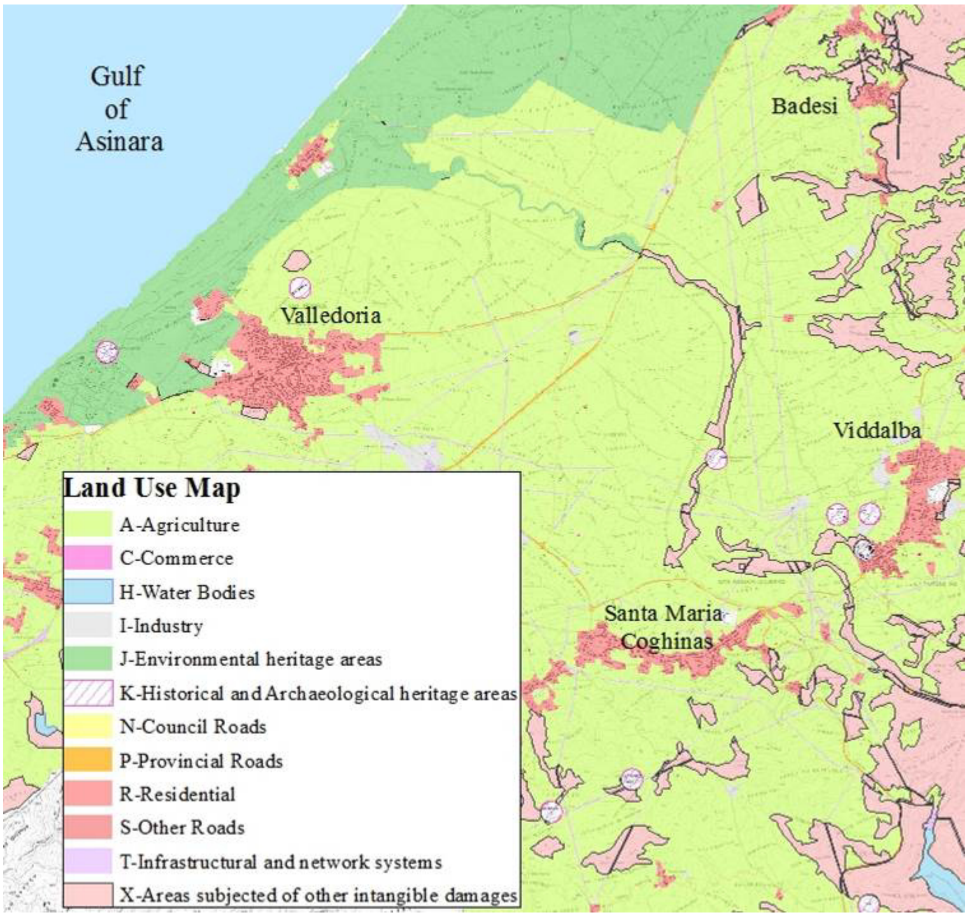

Figure 3-48.Land use map of the Coghinas River lowland valley basin

Figure 3-48 shows the land use map of the Coghinas River lowland valley basin territory with the categorisation in twelve classes of land use to evaluate potential flood direct tangible damage and the related damaged area. All of the nine of the twelve land use categories describes the territory and this first observation confirms the choice to consider the Coghinas River lowland valley basin as pilot basin of the present research for Sardinian territory.

The HEC-RAS flood hazard maps described in Paragraph 3.1.2 have been elaborated with ArcGIS to convert the grid flood maps into shape files. The shape files of the flood map were created with regular grid of 3 m cell size in order to describe in detail the territory and avoid slow elaboration process on the flood damage assessment. The analysis of the pilot basin has been conducted for event of 50 years, 100 years and 200 years and are shown respectively in Figure 3-49, Figure 3-50 and Figure 3-51 provided with the respectively water depth range.

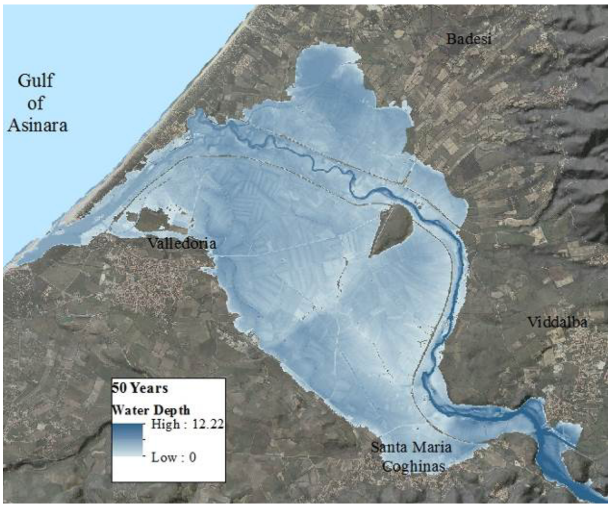

Figure 3-49.FRMP HEC-RAS flood map for the 50 years event

Figure 3-50.FRMP HEC-RAS flood map for the 100 years event

Figure 3-51.FRMP HEC-RAS flood map for the 200 years event

The intersection process between flood maps and the land use map of the territory allows to identify in the flood maps the land use categories potential damageable by the flood of 50, 100 and 200 years as shown in Figure 3-52, Figure 3-53 and Figure 3-54.

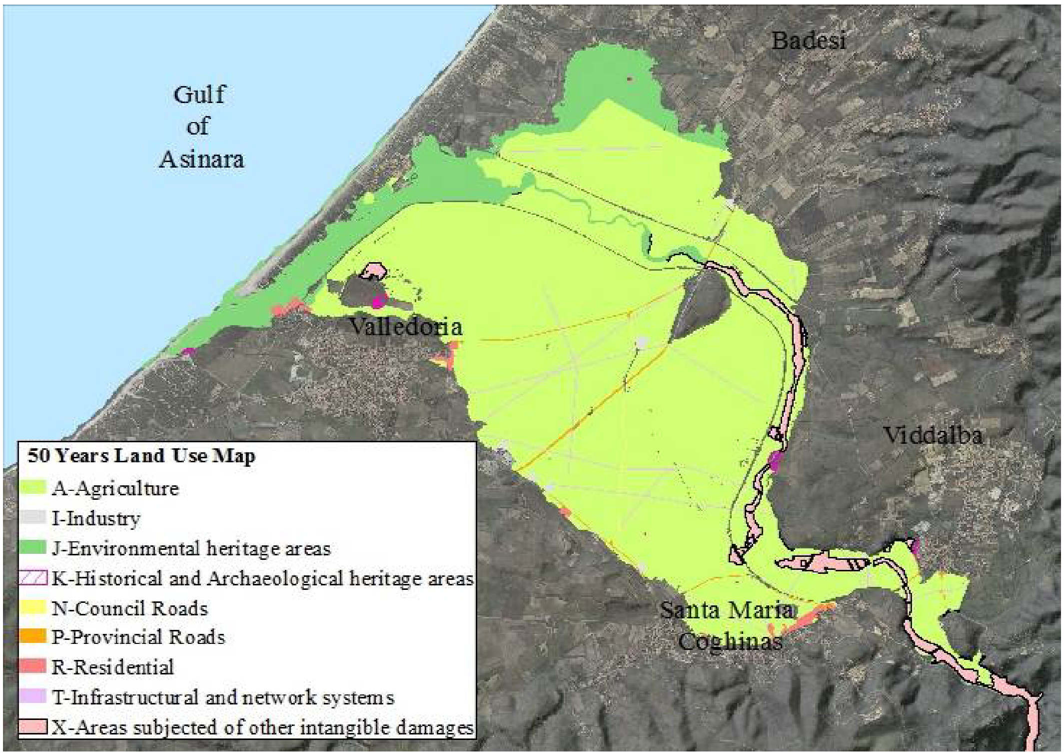

Figure 3-52.Land use map for the territory interested by the 50 years event

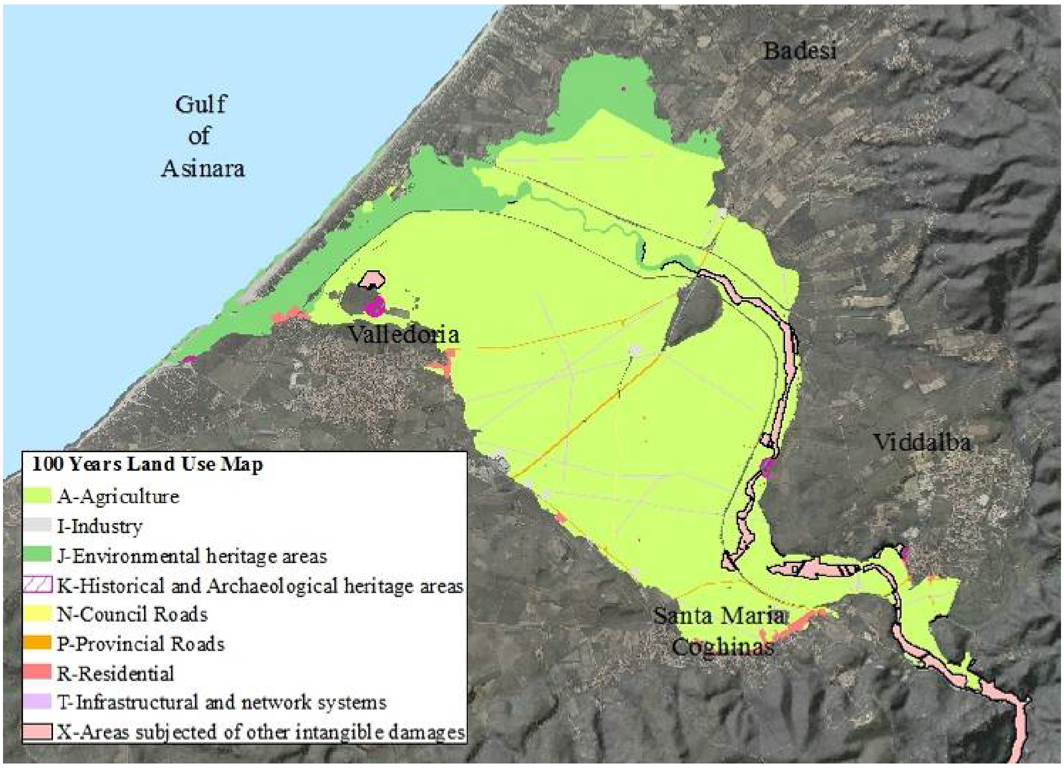

Figure 3-53.Land use map for the territory interested by the 100 years event

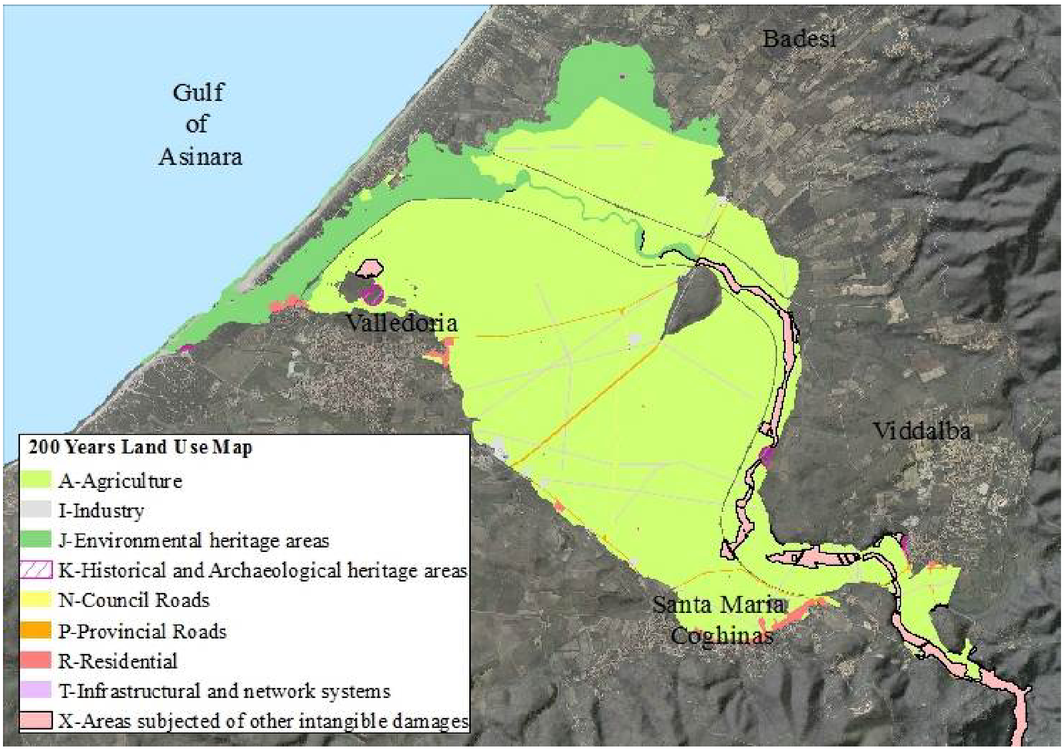

Figure 3-54.Land use map for the territory interested by the 200 years event

The described process associates water depth and land use category information at each cell of the shape file that have been created with 9 m^2 of area. The JRC Model requires to calculate the damage factor α with the Relative JRC water depth-damage functions associated at each cell in function of the land use category, Table 3-6.

α_R	$-0.0020646*h^4+0.029964*h^3-0.165641*h^2+0.526177*h+0.0082022$
α_C	$-0.0291056*h^2+0.345184*^h-0.014648$
$\alpha_{I,T}$	$-0.0011238*h^4+0.0120864*h^3-0.0601298*h^2+0.337384*h-0.0041365$
$\alpha_{N,P,S}$	$-0.00230344*h^4+0.0323194*h^3-0.178199*h^2+0.569831*h0.0012923$
α_A	$0.000314215*h^5-0.00812378*h^4+0.0747696*h^3-0.32839*h^2+0.793532*h-0.00496939$

Table 3-6.JRC water depth-damage functions considering a range of water depth of 5 m

The evaluation of the flood damage factor α for each cell of the flood damage map has been developed implementing in ArcGIS an algorithm that reads water depth and land use category information of each cell and associates the proper JRC water depth-damage function.

At this point, all of the necessary information to assess the direct tangible damage with the JRC Model are evaluated and the Equation 2-12 could be applied for the damage appreciation of each cell and the Equation 2-14 evaluates the total damage due to the flood.

The process implemented in ArcGIS for the evaluation of the direct tangible damage is summarised in the flow chart in Figure 3-55.

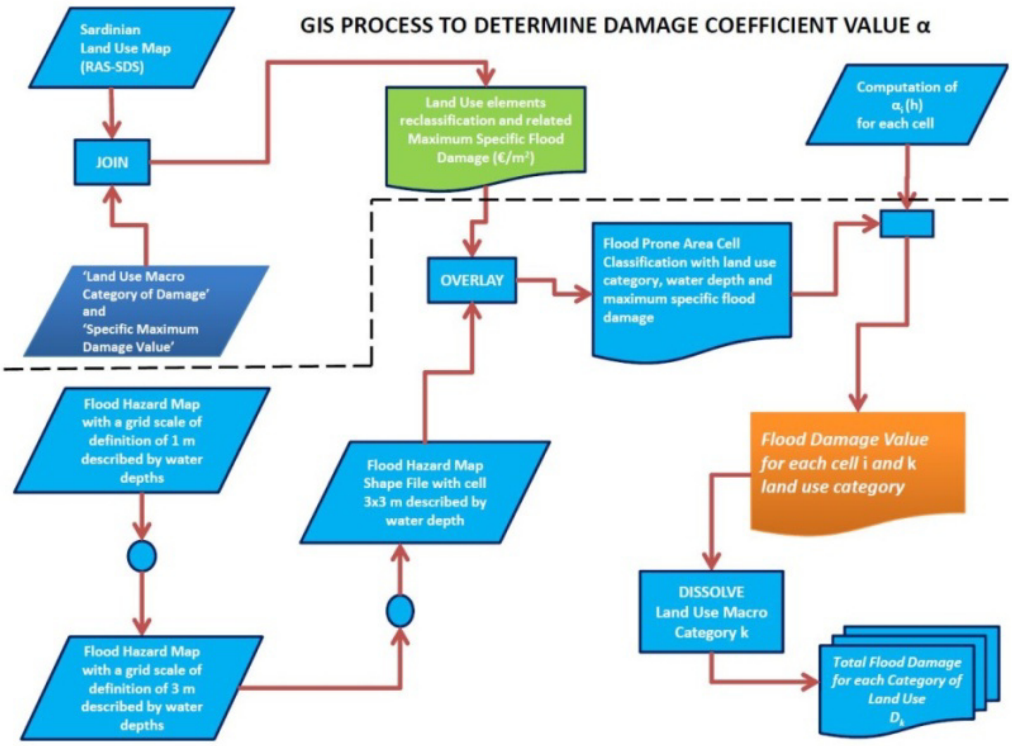

Figure 3-55.GIS Flow Chart to determine the flood damage coefficient and evaluate the flood direct tangible damage (Frongia et al., 2015b)

The analysis of the study case allows to define for each land use category the total damaged area and the economic total damage when the land use category is subjected at direct tangible flood damage.

The 50 years event could damage a total area of 16.35 km^2 determining an economic damage of 48.39 M €. The most part of the economic damage, 49.43 %, is caused on the residential area with a dimension of 0.15 km^2, while the rest of the damages interests mainly commercial, industry and agriculture activities, Table 3-7.

Label Land-Use Category	T_R 50	
	Area (m^2)	Damage (€)
A- Agriculture	13'055'381	5'221'925
C- Commerce	41'021	7'581'223
I- Industry	53'292	7'193'880
J- Environmental heritage areas	2'075'232	-
K- Historical and archaeological heritage areas	22'310	-
N- Council Roads	42'576	168'716
P- Provincial Roads	99'089	802'391
R- Residential	114'945	23'916'273
T- Infrastructural and network systems	213'333	3'497'885
X- Area subjected of other intangible damages	634'887	-
Total	16'352'066	48'382'292

Table 3-7.Evaluation of the direct tangible damage with the JRC Model. 50 years event

The 100 years event could cause a total economic damage of 60.37 M € interesting and area of 16.62 km^2 mainly interested by agriculture activity and environmental heritage areas. The comparison of the economic damage with the expected damage for the 50 years event underlines a difference of 11.27 M € between the two potential flood event mainly caused by damages on residential area for 7.27 M € and in commercial and industry area for a total of 3.49 M €, Table 3-8.

Label Land-Use Category	TR 100	
	Area (m^2)	Damage (€)
A- Agriculture	13'219'059	5'688'986
C- Commerce	41'969	9'107'924
I- Industry	70'330	9'150'344
J- Environmental heritage areas	2'099'058	-
K- Historical and archaeological heritage areas	26'687	-
N- Council Roads	45'321	204'835
P- Provincial Roads	104'138	979'904
R- Residential	135'434	31'182'354
T- Infrastructural and network systems	217'036	4'054'690
X- Area subjected of other intangible damages	656'570	-
Total	16'615'603	60'369'036

Table 3-8.Evaluation of the direct tangible damage with the JRC Model. 100 years event

The 200 years event analysis defines a potential economic damage of 71 M € for a total area of 16.79 km^2. The damaged area increment of 177843 m^2 determines an economic damage increment of 10.64 M € caused mainly on residential, commerce, industry and agriculture land use categories for an percentage of economic damage respectively of 53.31 %, 14.51 %, 15.42 % and 8.48 %, Table 3-9.

Label Land-Use Category	T_R 200	
	Area (m^2)	Damage (€)
A- Agriculture	13'319'222	6'019'251
C- Commerce	42'396	10'304'961
I- Industry	73'184	10'950'897
J- Environmental heritage areas	2'119'113	-
K- Historical and archaeological heritage areas	40'014	-
N- Council Roads	45'786	232'406
P- Provincial Roads	111'261	1'137'800
R- Residential	148'135	37'856'384
T- Infrastructural and network systems	220'499	4'504'593
X- Area subjected of other intangible damages	673'836	-
Total	16'793'446	71'006'292

Table 3-9.Evaluation of the direct tangible damage with the JRC Model. 200 years event

The JRC Model allowed the assessment of the direct tangible damage giving also the base for the evaluation of the indirect part of the tangible damage considered as the 10.7 % in the MCM Model as explained above for the emergency and rescue actions costs and implemented to 30 % in the present research to include other type of costs due to indirect damages as the disruption of relevant systems but also other type of indirect damages caused on the inadequacy of the services in the area during the post-event situation. Table 3-10, Table 3-11 and Table 3-12 show the value of indirect tangible damages caused for each land use category for the event of 50, 100 and 200 years. The indirect tangible damage reaches values of 14.51 M € for the 50 years event, 18.11 M € for the 100 years event and 21.30 M € for the event of 200 years.

Label Land-Use Category	Damage for the event of $T_{R=50}$			
	Area (m^2)	JRC Model Direct Tangible (€)	MCM Emergency (€)	Indirect Tangible (€)
A- Agriculture	13'055'381	5'221'925	558'746	1'566'578
C- Commerce	41'021	7'581'223	811'191	2'274'367
I- Industry	53'292	7'193'880	769'745	2'158'164
J- Environmental heritage areas	2'075'232	-	-	-
K- Historical and archaeological heritage areas	22'310	-	-	-
N- Council Roads	42'576	168'716	18'053	50'615
P- Provincial Roads	99'089	802'391	85'856	240'717
R- Residential	114'945	23'916'273	2'559'041	7'174'882
T- Infrastructural and network systems	213'333	3'497'885	374'274	1'049'366
X- Area subjected of other intangible damages	634'887	-	-	-
Total	16'352'066	48'382'292	5'176'905	14'514'688

Table 3-10.Evaluation of the tangible damage with the JRC Model. MCM Model. 50 years event

Label Land-Use Category	Damage for the event of $T_{R=100}$			
	Area (m^2)	JRC Model Direct Tangible (€)	MCM Emergency (€)	Indirect Tangible (€)
A- Agriculture	13'219'059	5'688'986	608'722	1'706'696
C- Commerce	41'969	9'107'924	974'548	2'732'377
I- Industry	70'330	9'150'344	979'087	2'745'103
J- Environmental heritage areas	2'099'058	-	-	-
K- Historical and archaeological heritage areas	26'687	-	-	-
N- Council Roads	45'321	204'835	21'917	61'451
P- Provincial Roads	104'138	979'904	104'850	293'971
R- Residential	135'434	31'182'354	3'336'512	9'354'706
T- Infrastructural and network systems	217'036	4'054'690	433'852	1'216'407
X- Area subjected of other intangible damages	656'570	-	-	-
Total	16'615'603	60'369'036	6'459'487	18'110'711

Table 3-11.Evaluation of the tangible damage with the JRC Model. MCM Model. 100 years event

Label Land-Use Category	Damage for the event of $T_{R=}200$			
	Area (m^2)	JRC Model Direct Tangible (€)	MCM Emergency (€)	Indirect Tangible (€)
A- Agriculture	13'319'222	6'019'251	644'060	1'805'775
C- Commerce	42'396	10'304'961	1'102'631	3'091'488
I- Industry	73'184	10'950'897	1'171'746	3'285'269
J- Environmental heritage areas	2'119'113	-	-	-
K- Historical and archaeological heritage areas	40'014	-	-	-
N- Council Roads	45'786	232'406	24'867	69'722
P- Provincial Roads	111'261	1'137'800	121'745	341'340
R- Residential	148'135	37'856'384	4'050'633	11'356'915
T- Infrastructural and network systems	220'499	4'504'593	481'991	1'351'378
X- Area subjected of other intangible damages	673'836	-	-	-
Total	16'793'446	71'006'292	7'597'673	21'301'888

Table 3-12.Evaluation of the tangible damage with the JRC Model. MCM Model. 200 years event

The overview of the tangible damage assessment on the pilot basin shows that an event of 50 years could determine a total damage of 62.90 M €, while an event of 100 years define a damage of 78.48 M € and finally the 200 years event could cause a total damage of 92.31 M € as summarised in Table 3-13.

Event	Direct Component JRC Model	Indirect Component 30 % of the direct damage including MCM Model	Total Damage
50 Years	48.38	14.51	62.90
100 Years	60.37	18.11	78.48
200 Years	71.01	21.30	92.31

Table 3-13.Tangible damages for 50, 100 and 200 years events in M of €

3.2.2. Evaluation of the intangible damage: Life Safety Model

LSM Model shows up as important tool for loss of life evaluation considered as one of the possible type of intangible damage.

The case study is described in terms of building and people distribution, how persons are grouped, road network and warning points according with LSM guidelines described in Chapter 2. The LSM assessment of loss of life requires the hydrodynamic model of potential floods described by water depth and velocities development through a two-dimensional model that has been obtained modelling the study case with RFSM_EDA, Chapter 3.1.3.1.

Building, PARU, PARG, Road Network and Warning Centres input files have been set considering generic values of their parameters and the database is described in the following paragraphs.

3.2.2.1.1. Building file

Building file is an update of the shape file available in the Geoportale Sardinian website created under the commission of the Sardinian Regional Authority to define building distribution in the Sardinian territory. The predisposition of the building file required to delete structures with small dimensions and, in particular, the cleaning-up considered buildings with very low area or ruins identifiable checking the structures with Google Maps.

The Paragraph 2.3.3.2 describes building parameters necessary to run LSM and their possible values. Table 3-14 shows which building parameters are necessary as defined by LSM guidelines and 2 new parameters have been added creating the building database: type name and town.

The first four parameters in the Table 3-14 (ID, X, Y and elevation) represent the unique identifier number and the location of the building in the territory, the Town parameter allows to know in which council area the building is located (Viddalba, Santa Maria Coghinas, Badesi, Valledoria). Following in the Table 3-14, Type parameter assigns a code to identify a type of building described in particular with the second parameter Type Name that defines the nature of the building, Table 3-15, Table 3-16 and Table 3-17. Structural state and strength of the building is defined with BSS, BSSC, BCDVM and BDVCA parameters that have been set considering generic values suggested in LSM guidelines (BC Hydro, 2006)(HR Wallingford Ltd., 2015).

LSM evaluates the building destruction based on the dv criteria setting BSS parameter with the default value 1, BSSC parameters equals to 0.01, BCDVM parameter equals to 109 meaning a structure that does not show degradation in Building Structural Strength, and finally the BDVCA parameter considers structures built with large concrete and, therefore, the assigned value is equal to 35 m2/s, Table 3-18. Every building is defined by height, area, number of floors and foundation height in order to know its structural characteristics. When a building is considered with structural characteristics to host people during flood emergency, it could be set as a Safe Haven, in that case the PSH parameter is set with the TRUE value, instead of FALSE, and the Inflow Rate parameter is set to define the number of people that could enter in the building per second. The Capacity parameter identifies the number of person that a building could accommodate. Considering needs and different situation during flood emergency and according with the Alert Operating Instructions for Civil Protection Agency, AOICP (Civil Protection-RAS, 2014), the Safe Havens are residential structures with high capacity of host people, hotels, resorts and public structures that could be managed to support people. The building distribution shown in Figure 3-56 has been defined using ArcGIS to identify each structure that could be populated or used during flood emergency as Safe Havens.

ID
X
Y
Elevation
Type
Type Name
Town
BSS
BSSC
BCDVM
BDVCA
PSH
N° of floors
Inflow Rate
Foundation
Capacity
Area
Height

Table 3-14.LSM Building parameters

Type	Type Name
1	Dwelling
2	Public or recreational
3	Commercial or Industrial
4	La Foce Camping structures
5	Baia delle Mimose resort and tourist structures
6	Religious building
7	Agricultural Building
8	Not Defined

Table 3-15.Type and Type Name parameters of the LSM Building file

Type	Type Name
2	Public
2	Council Office
2	Police Office
2	Post Office
2	Social Centre
2	School
2	Nursery School
2	Primary School
2	Secondary School
2	Football Building
2	Football Field
2	Bleachers
2	Pump House

Table 3-16.Public or recreational typology of building

Type	Type Name
4	Car Park / Chemical WC / Restaurant / Camper Service / Reception
4	4.1 Mobil Home XL
4	4.2 Mobil Home Deluxe
4	4.3 Mobil Home Elegant
4	4.4 Mobil Home Comfort
4	4.5 Bungalow
4	4.6 Pitch for 2 Persons
4	4.7 Camper

Table 3-17.La Foce Camping Type Name parameters

BSS	1
BSSC	0.01
BCDVM	10^9
BDVCA	35

Table 3-18.Building strength parameters BSS, BSSC, BCDVM and BCDVA

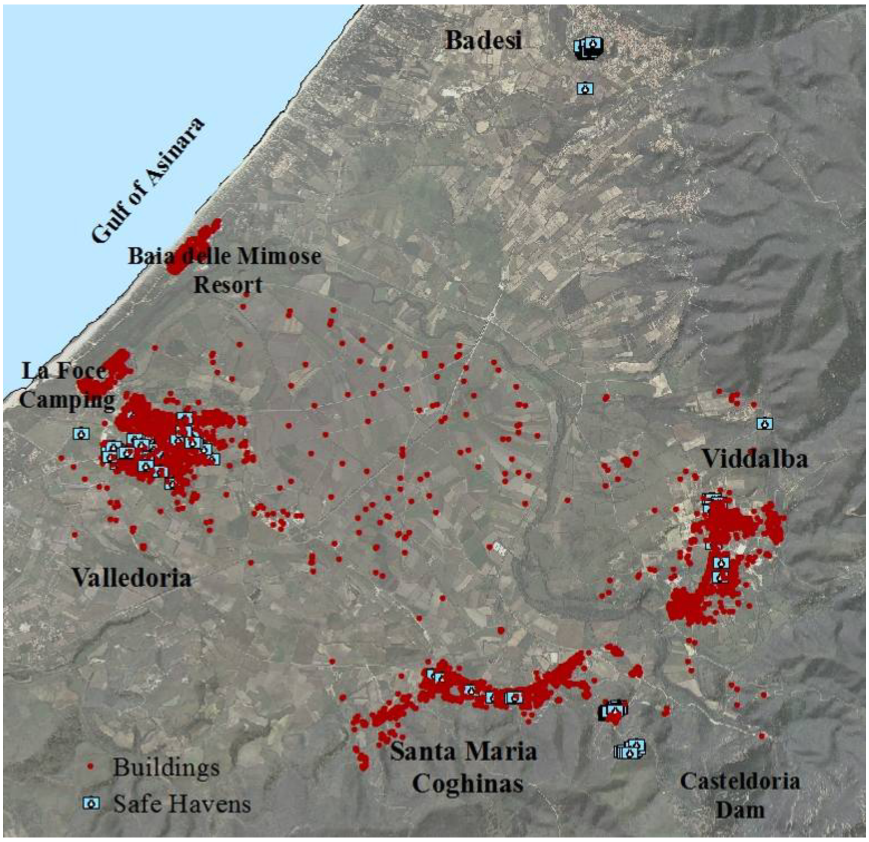

Figure 3-56.Building and Safe Havens distribution on the Coghinas River lowland valley basin

3.2.2.1.2. PARU file

PARU dataset consists of a collection of data from the Piano Tutela delle Acque (PTA), ISTAT survey of 2015 and information supplied by the demographic offices of Viddalba, Santa Maria Coghinas, Valledoria and Badesi towns as explained in Chapter 3.

The model considers people distributed in the study area in two main groups of residents and tourists and defines a scenario when people are in their home and tourist structures are fully booked. The first group, residents, has been allocated with a homogenous distribution in dwellings according with the urban instruction plan, PUC, of the towns, generally 1 person per 100 m^3 of dwelling volume. In the study area the population has been approximated at 9450 PARU and they are considered distributed in the area predicting a demographic increment.

Every PARU is defined by the parameters shown in Table 3-19. The first four parameters define unique PARU identifier, location and the PARG of the PARU belonging. LSM requires the definition of PARU strength parameters that are shown in Table 3-20. The PARU Physical Condition, PPC, is set equal to 1 indicating average physical condition for a typical PARU and the assigned PARU Physical Condition Criteria, PPCC, is set equal to 0.01 meaning that the PPC should decline to a level below PPCC to consider the PARU deceased. The PHSDA parameter is based on the height of the PARU and defining the water depth at which a PARU can wade through water, the value 1 is assigned considering low enough velocity. Toppling criteria considers the depth of water in which a PARU could safely stand without being toppled regardless of the velocity with the parameters PLTDA equals to 0.1, the parameter PDVTCA is set equal to 1.5 m^2/s meaning the highest flow intensity at which the PARU is stable without being toppled, while the value 3 m^2/s is assigned at the PDVDC parameter to set the PARU dv Drowning Criteria. The PARU capacity to withstand continuous exposure is defined by the PCDVM parameter set equal to 1800 m^2/s. Finally the PARU should be set defining the escape speed on foot and delay before evacuating by a building or by a vehicle. The PSA parameter is set with 3 km/hr and represents the escape speed on foot, while the PDEUA and the PDEVA represent, respectively, the delay in seconds before evacuating by a building, equals to 1200 s, and by a vehicle equals in this case to 40 s. Figure 3-57 shows PARU distribution in the study area.

ID
X
Y
Elevation
PARG INDEX
PPC
PPCC
PLTDA
PHSDA
PDVTCA
PDVDCA
PSA
PDEUA
PDEVA
PCDVM

Table 3-19.LSM PARU parameters

PPC	1
PPCC	0.01
PLTDA	0.1
PHSDA	1
PDVTCA	1.5
PDVDCA	3
PSA	3
PDEUA	1200
PDEVA	40
PCDVM	1800

Table 3-20.PARU strength and height parameters

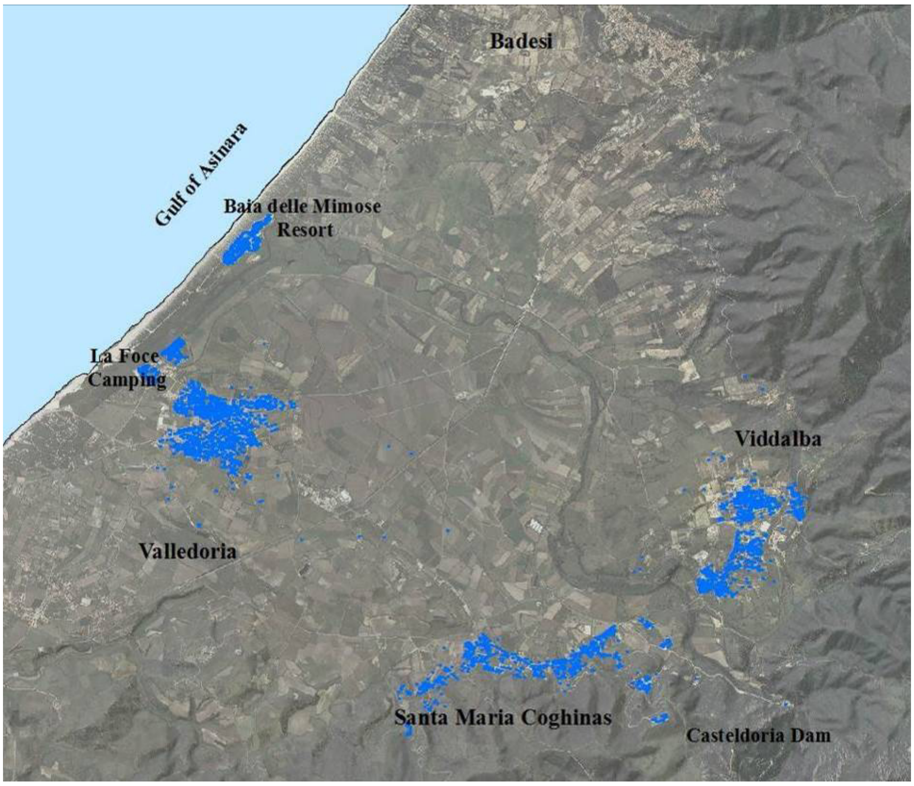

Figure 3-57.PARU distribution on the Coghinas River lowland valley basin

3.2.2.1.3. PARG and Vehicle file

LSM models the virtual world and, in particular, the PARUs are grouped to define their relation and evacuation mode, Table 3-21. PARG and Vehicle file requires to define the location of each PARG and assigned a proper unique identifier. The PARGs in the study area are group of persons located in the same building. LSM requires to define if the PARG is separable (0) or inseparable (1) with the Group Type parameter, how the PARG could evacuate in terms of travel mode by the Travel Mode parameter that could be set as stationary (0), walking (1) or driving (2). The Building Index, Road Index, Lane Index and Lane Position parameters assign each PARG at a proper building and road segment. The evacuation emergency is modelled by the TFAF parameters that with a high value, more the 1000000 seconds, allows to simulate a scenario when people are not aware of the flood. The scenario is even set with proper evacuation time assigned by the IUETA and VEVT parameters that represent, respectively, the evacuation time from a building and from a vehicle with values of 600 and 60 seconds, Table 3-22. In addition LSM models the emergency situation through the Evacuation Mode parameter that could be set with 0, when the PARG will evacuate the Safe Haven, with 1, if the PARG will shelter in the building, or with the value 2 if the PARG has the opportunity to choose if evacuate towards the Safe Haven or shelter in place defined in function of the water depth level outside the building, Table 3-22.

LSM models the vehicle conditions through three parameters: VDVFC, VDVTC and VSDC. The VDVFC parameter, set with the value 0.45 m^2/s, represents the limit when the vehicle is floating and the PARU has still the possibility to escape the vehicle and become pedestrian. Similarly, the VDVTC works for the toppling flood condition and it is set with the value 0.55 m^2/s. While the VSDC parameter represents the water depth that starts to immobilise the vehicle, Table 3-21 and Table 3-22.

ID
X
Y
Elevation
Group Type
Travel Mode
Building Index
Road Index
Lane Index
Lane Pos
TFAF
IUETA
VEVT
VDVFC
VDVTC
VSDC
Evac Mode

Table 3-21.LSM PARG and Vehicles parameters

TFAF	1E+09
IUETA	600
VEVT	60
VDVFC	0.45
VDVTC	0.55
VSDC	0.69

Table 3-22.Awareness PARG time, Building and vehicle evacuation time, vehicle critical parameters

3.2.2.1.4. Road Network file

LSM models the evacuation of the study area in case of flood emergency working with a road network optimization algorithm to identify step by the step the best path that PARG should follow to reach the safe haven in the virtual world. The Road Network file contains the physical location and connectivity of the roads and trails and attributes for each road segment. Figure 3-58 shows the road network in the Coghinas lowland valley area. An ID unique identifier is assigned at each road segment that is described by parameters shown in Table 3-23 and Table 3-24. The road segment is classified by the Type parameter that could be set in road, road bridge, foot path, foot bridge or foot path escape. Elevation parameter is usually set with the value -9999 except in case of bridge when its height by the ground is assigned. Additional parameters are the Status parameter that is defined in Open or Closed, the number of lanes that depends by the road segment characteristics, the speed limit in km/hr and the length information. In case the road segment is interested by a Monitoring Point it should be defined using its distance by the tail of the segment, otherwise the value -1 is assigned.

ID
Description
Elevation
Type
Status
Number Lanes
Speed Limit
Road Class
Length
Monitoring Point

Table 3-23.LSM Road Network parameters

Elevation	-9999
Type	ROAD
Status	OPEN
Number Lanes	2
Speed Limit	50
Road Class	Local Road
Monitoring Point	-1

Table 3-24.Road Network status and default parameters

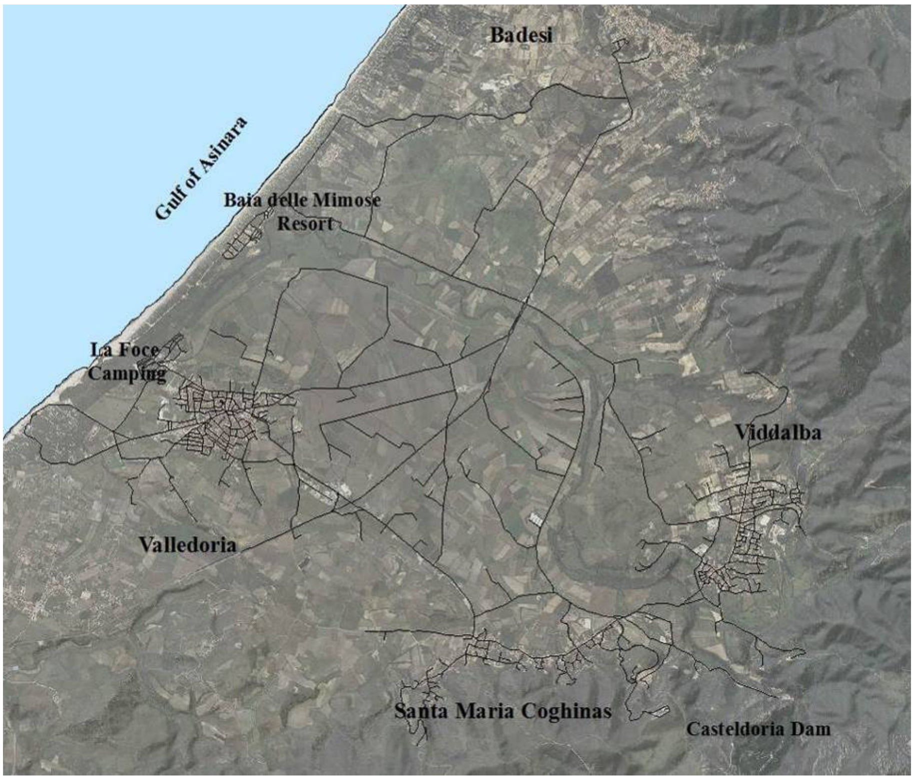

Figure 3-58.Road Network on the Coghinas River lowland valley basin

3.2.2.1.5. Warning Centre file

The flood evacuation is managed by the Authorities defining proper Warning Centres in the area under risk. The Warning Centre file contains the location of the warning centres distributed in the area and their attributes shown in Table 3-25.

The Coghinas River lowland valley basin virtual world is defined considering three warning points located in critical points: the Casteldoria dam control building, the council buildings of Viddalba and Valledoria, Figure 3-59. Each warning centre is described by its location in coordinate system, by the State parameter set in 0 or 1, respectively, if the warning centre is inactive or active. The LSM User defines the Initial Warning Time parameter in seconds to identify at which time the warning centre begins to disseminate the warning, the Rate of Warning parameter to know the velocity (in m/s) of the warning dissemination, but it is important to set the Maximum Warning Radius parameter and the Delay parameter to define the area covered by the warning centre and the delay time between when the centre receives the alert and when it starts to warn people and/or other centres.

X
Y
State
Initial Warning Time
Rate Of Warning
Max Warning Radius
Delay
Warning Centre Index

Table 3-25.LSM Warning Centres parameters

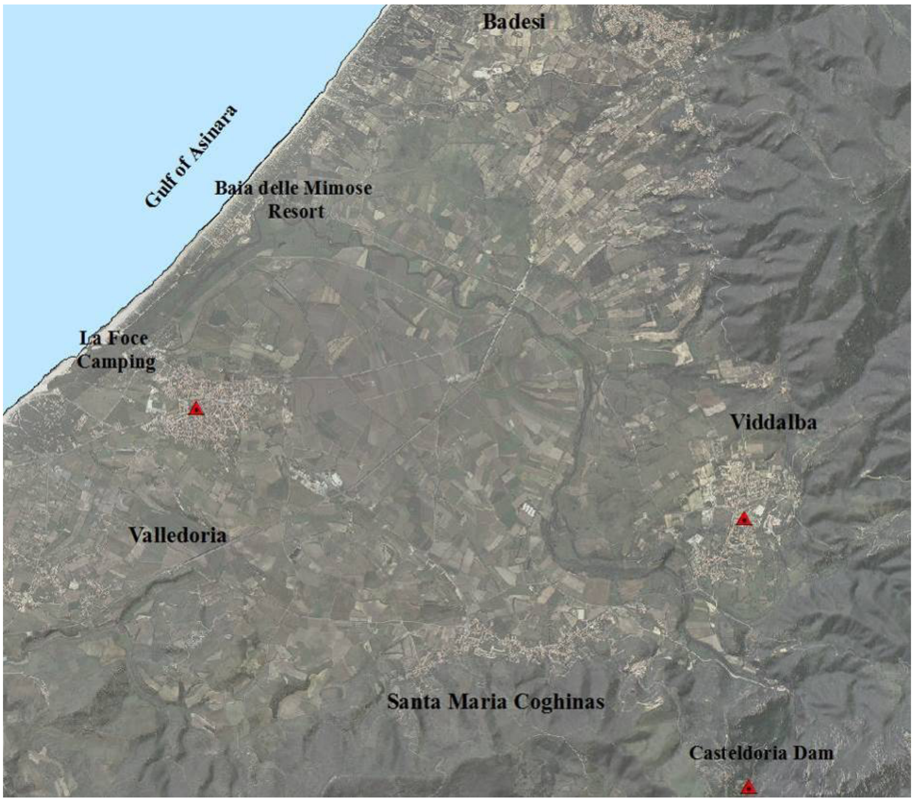

Figure 3-59.Warning Centres on the Coghinas River lowland valley basin

3.2.2.1.6. Events

LSM allows the management of flood emergency modelling mitigation and protection actions in the study area. The floods of the last decade in Sardinia damaged and compromised road segments as bridges. In particular, bridges showed up as critical points where floods caused loss of lives. Following these important consequences, the Coghinas River lowland valley basin has been modelled closing the bridges along the Coghinas River and road segment from which people could reach risk areas nearby the Coghinas River, Figure 3-60.

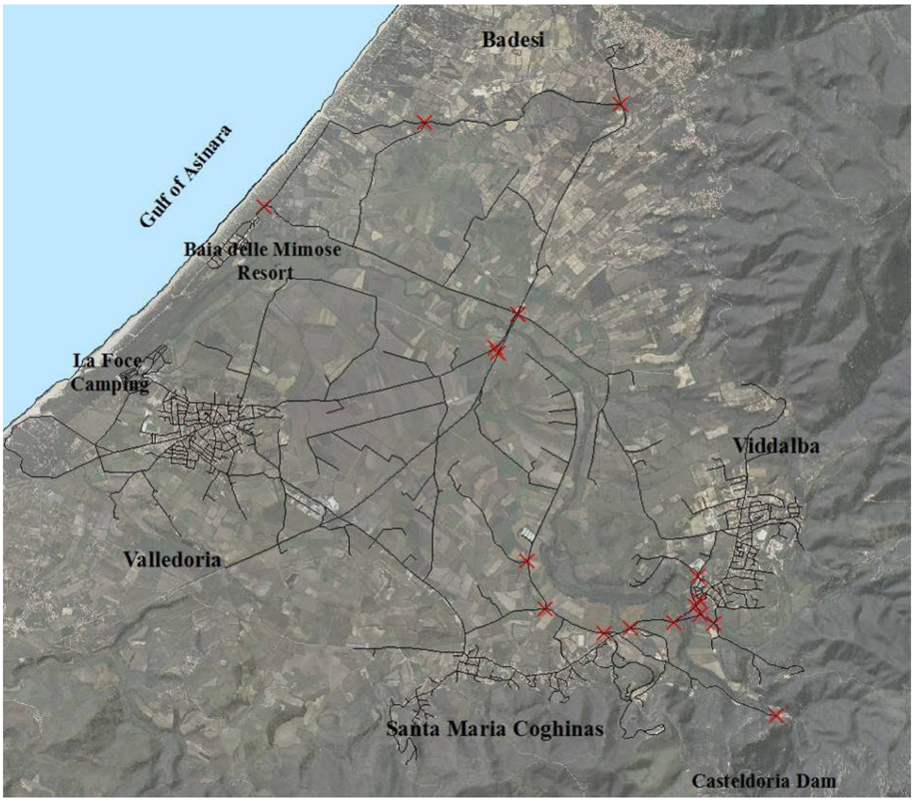

Figure 3-60.Events on the Coghinas River lowland valley basin

3.2.2.2. LSM application and flood evacuation plan

The analysis of the Coghinas River lowland valley basin has been developed considering, at a first step, three main scenarios: “No Warning”, “Warning” and a last scenario, “Warning and Event”, where the warning is sent to the population and the event actions are activated.

LSM scenarios models the case study considering people located in their houses or in the tourist location and modelling the situation as the floods happens during the night or generally when commercial, educational and tourist centres are closed and people would not imagine a possible flood. Moreover, the parameter “Evacuation Mode” of the PARG file is always set with the value 2 in order to leave every PARU to decide how to act during the flood emergency.

The “No Warning” scenario aims to reproduce a flood emergency situation when the population is unaware of the danger, became conscious of it by the increment of the water depth and, when it reaches the level of 0.20 m, PARGs are free to decide if to shelter in place or evacuate towards the Safe Haven.

The “Warning” scenario models an extreme flood situation that sees authorities manage the potential flood emergency sending the evacuation issuance to the population as soon as the emergency situation starts. The scenario considers people moving towards the Safe Haven.

The “Warning and Event” scenario replies the “Warning” scenario and the road network critical point are managed by the authorities in order to avoid people circulation where the flood could cause bridge collapse or near levees with high flow intensity.

The LSM Coghinas River lowland valley basin model has been run different times aiming, in particular, to reach the best Safe Haven configuration that would guarantee the best results protecting people by the flood risk. The “No Warning” scenario does not require any adjustment considering that it has to represent the baseline situation and how the virtual world receptors could be involved and damaged by the flood. Table 3-26, Table 3-27, Table 3-28 and Table 3-29 show the results at the end of each scenario.

Table 3-26 describes the conditions of the PARUs. LSM evaluates intangible damages in quantitative terms and as loss of life described by individual persons, PARU, and by group of persons, PARG. The 9450 PARUs of the virtual world are divided mainly in four groups: unaware, aware, safe and deceased. The subdivision of the deceased group appears of relevant importance considering the causes of death categorisation.

PARU result file shows that 274 loss of life of the 806 deceased are determined by drowned conditions, 235 of 806 by exhaustion, 196 of 806 dead after the building collapses, 95 of 806 PARU are dead because drowned in buildings and 6 of the dead PARU where inside a vehicle after that they are toppled.

Table 3-27 shows LSM results for the PARG identifying the PARG conditions at the end of the event as represented for PARUs. LSM represents also a description of damages meant as direct tangible damage and identified in the loss of buildings and vehicles described numerically in detail in the Table 3-28 and Table 3-29. Table 3-28 shows the vehicle conditions and the process that caused their loss, floating or toppled. In particular for the “No Warning” scenario 1836 vehicles of 1935 have been parked, 21 are safe, 76 floated and 2 are toppled.

Building condition results are shown in Table 3-29 where it is possible to observe that 305 buildings collapsed because of the water depth level, 43 buildings, and because of the DV flow intensity, 262.

SIMULATION	No Warning	Warning	Warning and Event
Population at Risk Unit – PARU			
N of Parus	9450	9450	9450
Unaware	8334	0	0
Aware	2	0	0
Aware & Evacuating:	0	0	0
Safe	308	9450	9450
Toppled	0	0	0
N° Deceased-Total	806	0	0
N° Deceased-Drowned	274	0	0
N° Deceased-Exhaustion (PPC<PPCC)	235	0	0
N° Deceased-BLDG Collapse	196	0	0
N° Deceased-Drowned in BLDG	95	0	0
N° Deceased-VHCL Toppled	6	0	0

Table 3-26.LSM PARU Results for the No Warning, Warning, Warning and Event Scenarios

SIMULATION	No Warning	Warning	Warning and Event
Population at Risk Group - PARG			
N° of PARGs	2910	2910	2910
Unaware	2502	0	0
Aware	1	0	0
Aware & Evacuating:	0	0	0
Safe	78	2910	2910
Toppled	0	0	0
N° Deceased-Total	297	0	0
N° Deceased-Drowned	84	0	0
N° Deceased-Exhaustion (PPC<PPCC)	69	0	0
N° Deceased-BLDG Collapse	98	0	0
N° Deceased-Drowned in BLDG	44	0	0
N° Deceased-VHCL Toppled	2	0	0
N° Empty	32	0	0

Table 3-27.LSM PARG Results for the No Warning, Warning, Warning and Event Scenarios

SIMULATION	No Warning	Warning	Warning and Event
Vehicles - VHLC			
N° of VHCLs	1935	1935	1935
N° Parked	1836	0	0
N° Driving	0	0	0
Safe	21	1935	1935
N° Floating	76	0	0
N° Toppled	2	0	0

Table 3-28.LSM Vehicles Results for the No Warning, Warning, Warning and Event Scenarios

SIMULATION	No Warning	Warning	Warning and Event
Buildings - BLDG			
N° of BLDGs	3372	3372	3372
N° Standing	3067	3067	3067
N° Destroyed-Depth	43	43	43
N° Destroyed-DV	262	262	262
N° Destroyed-Cumulative	0	0	0

Table 3-29.LSM Buildings Results for the No Warning, Warning, Warning and Event Scenarios

The "Warning" and "Warning and Event" scenarios show same results in every group of receptors. These results have been obtained after many LSM runs aiming to improve the model reaching the best results also in the case that any event are activated.

One of the main improvements required in the model, and that lead to important results working just on the warning system, has been made focusing the attention on the Safe

Haven distribution. The firsts LSM simulations showed many losses because of the insufficient availability of the Safe Haven, that problem induced people to move around the area in order to reach another shelter where to stay. The people and vehicles circulations in the road network caused many bottlenecks problems and many of the PARU deceased along the road segments or near the Safe Haven because of their inadequacy and because they were hit by the flood when trying to find a place where to shelter. According with the Alert Operation Plan in case of Flood Emergency of the Civil Protection Agency, tourist and hotels centres have been considered as Safe Haven and the model has been gradually improved till to obtained the results shown in Table 3-26, Table 3-27 and Table 3-28 that are determined by the people evacuation management.

The Building result file could not change working on evacuation mitigation measures because they depend by the building material characteristic and its interaction with water depth and velocity of the flood. In that case the results could be improved working with structural mitigation measures as levees, structural improvement of buildings or basically with additional protection as flood-resistance measure that reduce the amount of water entering a property, temporary flood barriers as interlocking barriers that can prevent water reaching the building, barriers fitted to exterior doorways or window openings that raise the threshold of the building against rising water, bagged barriers as sandbags that assure protection by minor flooding, (English Heritage Regional Offices, Flooding and Historic Buildings,2007), air-brick covers which are simply clip into place plastic or metal boards used to seal openings such as doors and windows (Information for Historic Building Owners-Flood Damage to Traditional Buildings, Historic Scotland Alba Aosmhor, 2014).

Subsequently, the LSM analysis of the study case has improved running new scenarios changing warning and event time parameters in the virtual world and defining a model that aims to avoid useless PARU movement during emergency and, therefore, potential bottlenecks or car traffic increment that could made worst the flood emergency management of the Civil Protection Agency and Authorities. The study case is modelled considering the baseline scenario under the risk of a flood event of 200 years and the PARU are under different and consecutive warning issuances to compare their behaviour.

In detail, PARUs are divided in two groups considering their distance from the flood hazard map boundaries. PARUs must stay shelter in their location if their distance from the flood hazard map boundaries is higher than 500 m, otherwise PARUs have to move towards the Safe Haven if their location is lower than 500 m from the flood hazard map boundaries or they could be hit by the flood, in other words only PARUs inside the red polygon in Figure 3-61 should move to reach the Safe Haven in case of flood emergency.

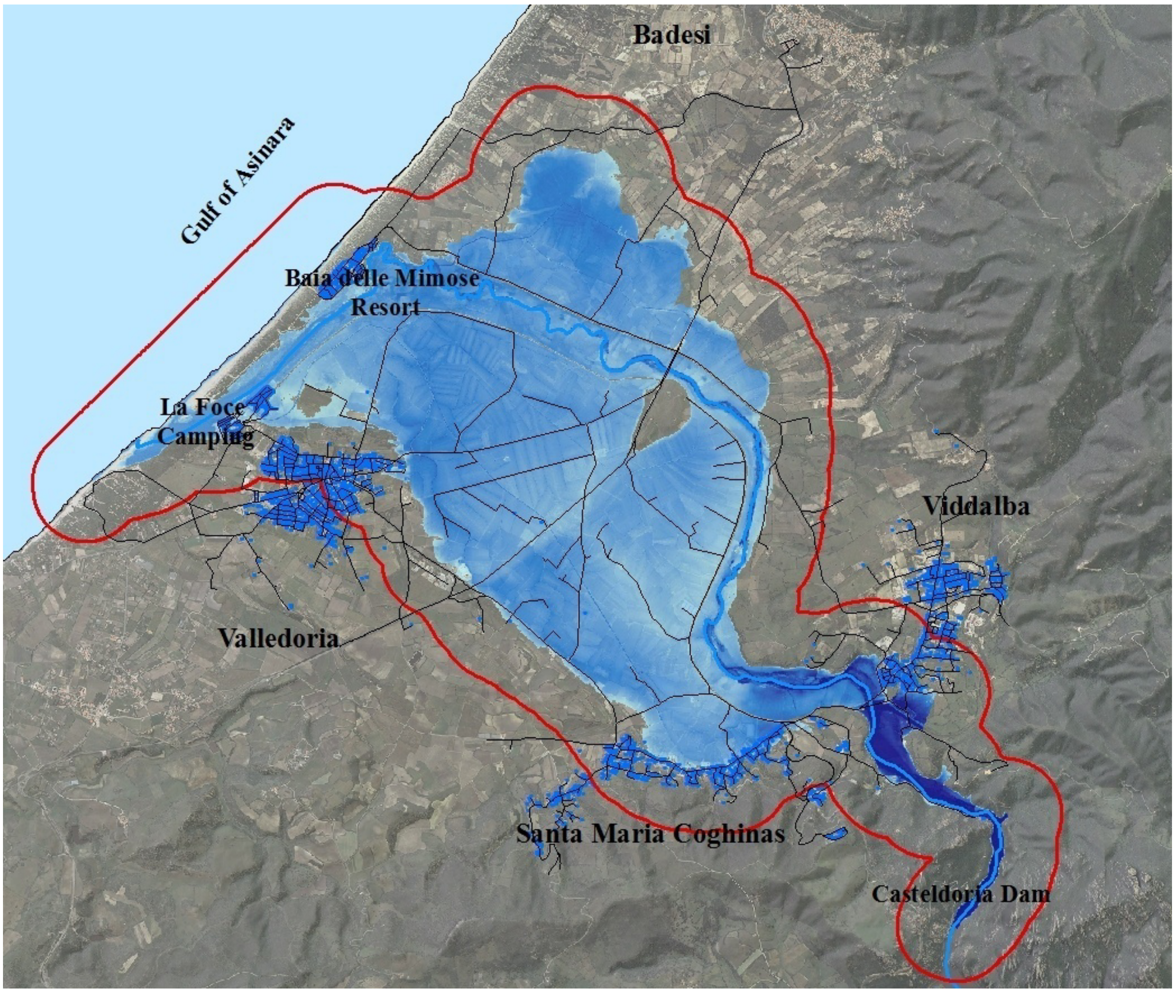

Figure 3-61.LSM boundary analysis on the loss of life evaluation

Firstly, the model run the "No Warning" simulation and people starts to egress when realise a critical water depth; the second simulation has been set sending the flood evacuation issuance when the flood event starts and PARUs receive the warning to move in one minute since when they receive the issuance. Finally, the last simulation has been rerun different times incrementing the flood evacuation issuance of 20 minutes each time from the beginning of the event till reach 10 hours. In fact the base time of the hydrograph reaches the peak of the flow at 9.9 hours and the rerun of the model allows to analyse how the results change under different evacuation issuance conditions.

Table 3-30 shows the results of the simulations making possible to observe how the situation of the virtual world changes gradually starting from the evacuation issuance simulation of 2 hours and 40 minutes when the no loss of life are expected. Since a warning issuance of 3 hours the emergency evacuation plan shows an increment on the death toll starting with a value of 34 and increasing gradually till exceeds at 6 h and 20 m the loss of life rate evaluated in the “No Warning” simulation. That results lead to consider the results useful to identify when should be better no send the evacuation issuance to the population in order to avoid damages higher than the baseline scenario when the Authorities activate any mitigation measures.

TTable 3-31 shows PARGs results under the evacuation condition during the different simulations. PARGs results follow the same behaviour analysed in PARUs results, as happen for the Vehicles behaviour shown in Table 3-32. PARG and Vehicle results change considering their interaction with the flood and, proportionally, they have the same increment shown analysing PARU behaviour because they depends by when the population starts to egress the buildings to reach Safe Haven and to occupy the road segments.

Table 3-33 shows LSM simulation results for Buildings behaviour under flood conditions. In this case the results do not change considering the stable location of the buildings and the same flood water depth and velocities development for every simulation. Buildings results could change only applying structural flood mitigation measures that are not considered at this step of the analysis.

SIMULATION	No Warning	0	20m	40m	1h	1h 20m	1h 40m	2h	2h 20m	2h 40m	3h	3h 20m	3h 40m
N of Parus	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450
Unaware	8334	0	0	0	0	0	0	0	0	0	0	0	0
Aware	4	2918	2918	2918	2918	2918	2918	2918	2918	2918	2918	2918	2918
Aware & Evacuating:	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	306	6532	6532	6532	6532	6532	6532	6532	6532	6532	6498	6200	6018
Toppled	0	0	0	0	0	0	0	0	0	0	0	0	0
N° Deceased-Total	806	0	0	0	0	0	0	0	0	0	34	332	514
N° Deceased-Drowned	274	0	0	0	0	0	0	0	0	0	0	6	24
N° Deceased-Exhaustion (PPC<PPCC)	235	0	0	0	0	0	0	0	0	0	34	118	258
N° Deceased-BLDG Collapse	196	0	0	0	0	0	0	0	0	0	0	138	160
N° Deceased-Drowned in BLDG	95	0	0	0	0	0	0	0	0	0	0	70	72
N° Deceased-VHCL Toppled	6	0	0	0	0	0	0	0	0	0	0	0	0

SIMULATION	4h	4h 20m	4h 40m	5h	5h 20m	5h 40m	6h	6h 20m	6h 40m	7h	7h 20m	7h 40m	8h
N° of Parus	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450
Unaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Aware	2918	2918	2918	2918	2918	2918	2918	2922	2922	2930	2939	2943	2943
Aware & Evacuating:	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	6010	6010	6010	5902	5895	5826	5790	5696	5651	5628	5641	5606	5594
Toppled	0	0	0	0	0	0	0	0	0	3	3	3	6
N° Deceased-Total	522	522	522	630	637	706	742	832	877	889	867	898	907
N° Deceased-Drowned	30	30	46	76	109	197	267	291	308	302	293	322	316
N° Deceased-Exhaustion (PPC<PPCC)	260	260	244	314	291	254	198	174	182	186	197	207	232
N° Deceased-BLDG Collapse	160	160	160	160	160	162	172	180	190	194	196	196	196
N° Deceased-Drowned in BLDG	72	72	72	72	72	88	95	95	95	95	95	95	95
N° Deceased-VHCL Toppled	0	0	0	8	5	5	10	92	102	112	86	78	68

Table 3-30.LSM PARU Results

SIMULATION	No Warning	0	20m	40m	1h	1h20m	1h40m	2h	2h20m	2h40m	3h	3h20m	3h40m
N° of PARGs	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910
Unaware	2502	0	0	0	0	0	0	0	0	0	0	0	0
Aware	3	944	944	944	944	944	944	944	944	944	944	944	944
Aware & Evacuating:	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	76	1966	1966	1966	1966	1966	1966	1966	1966	1966	17	1828	1761
Toppled	0	0	0	0	0	0	0	0	0	0	0	0	0
N° Deceased-Total	297	0	0	0	0	0	0	0	0	0	17	108	173
N° Deceased-Drowned	84	0	0	0	0	0	0	0	0	0	0	3	12
N° Deceased-Exhaustion (PPC<PPCC)	69	0	0	0	0	0	0	0	0	0	0	1	45
N° Deceased-BLDG Collapse	98	0	0	0	0	0	0	0	0	0	0	69	80
N° Deceased-Drowned in BLDG	44	0	0	0	0	0	0	0	0	0	0	35	36
N° Deceased-VHCL Toppled	2	0	0	0	0	0	0	0	0	0	0	0	0
N° Empty	32	0	0	0	0	0	0	0	0	0	0	30	32
SIMULATION	4h	4h20m	4h40m	5h	5h20m	5h40m	6h	6h20m	6h40m	7h	7h20m	7h40m	8h
N° of PARGs	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910
Unaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Aware	944	944	944	944	944	944	944	946	946	948	951	953	953
Aware & Evacuating:	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	1757	1757	1757	1704	1700	1666	1653	1625	1614	1604	1608	1608	1605
Toppled	0	0	0	0	0	0	0	0	0	1	1	1	2
N° Deceased-Total	177	177	177	230	234	267	281	307	318	325	318	316	318
N° Deceased-Drowned	15	15	15	18	18	59	86	94	101	98	95	90	87
N° Deceased-Exhaustion (PPC<PPCC)	46	46	46	93	98	85	61	53	51	54	56	61	69
N° Deceased-BLDG Collapse	80	80	80	80	80	81	86	90	95	97	98	98	98
N° Deceased-Drowned in BLDG	36	36	36	36	36	40	44	44	44	44	44	44	44
N° Deceased-VHCL Toppled	0	0	0	3	2	2	4	26	27	32	25	23	20
N° Empty	32	32	32	32	32	33	32	32	32	32	32	32	32

Table 3-31.LSM PARG Results

SIMULATION	No Warning	0	20m	40m	1h	1h20m	1h40m	2h	2h20m	2h40m	3h	3h20m	3h40m
N° of VHCLs	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935
N° Parked	1838	759	759	759	759	759	759	759	759	759	759	759	759
N° Driving	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	19	1176	1176	1176	1176	1176	1176	1176	1176	1176	1176	1171	1171
N° Floating	76	0	0	0	0	0	0	0	0	0	0	0	0
N° Toppled	2	0	0	0	0	0	0	0	0	0	0	5	5
SIMULATION	4h	4h20m	4h40m	5h	5h20m	5h40m	6h	6h20m	6h40m	7h	7h20m	7h40m	8h
N° of VHCLs	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935	1935
N° Parked	759	759	759	759	759	759	759	760	760	760	760	760	760
N° Driving	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe	1171	1171	1166	1166	1166	1141	1128	1127	1122	1119	1116	1111	1105
N° Floating	0	0	0	0	0	1	1	1	3	7	16	22	29
N° Toppled	5	5	10	10	10	34	47	47	50	49	13	42	41

Table 3-32.LSM Vehicles Results

SIMULATION	No Warning	0	20m	40m	1h	1h20m	1h40m	2h	2h20m	2h40m	3h	3h20m	3h40m
N° of BLDGs	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372
N° Standing	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067
N° Destroyed-Depth	43	43	43	43	43	43	43	43	43	43	43	43	43
N° Destroyed-DV	262	262	262	262	262	262	262	262	262	262	262	262	262
N° Destroyed-Cumulative	0	0	0	0	0	0	0	0	0	0	0	0	0
SIMULATION	4h	4h20m	4h40m	5h	5h20m	5h40m	6h	6h20m	6h40m	7h	7h20m	7h40m	8h
N° of BLDGs	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372	3372
N° Standing	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067	3067
N° Destroyed-Depth	43	43	43	43	43	43	43	43	43	43	43	43	43
N° Destroyed-DV	262	262	262	262	262	262	262	262	262	262	262	262	262
N° Destroyed-Cumulative	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3-33.LSM Buildings Results

The definition of the loss of life as the most important damage determinable by floods induced to focus the attention on PARU results to evaluate the changes in loss of life, or number of fatalities. The loss of life assessment shows up the relevance of the results use to obtain a proper curve that relate the intangible damage with the warning/evacuation time issuances.

Figure 3-62 represents the loss of life – warning time issuance curve where the evacuation alert is considered in a gap of time between the beginning of the flood and by the peak of the flood event of 200 years approximated at 10 h considering that the peak is reached at 9.9 h as mentioned above and shown in Figure 3-13.

The analysis of the number of fatalities associated at a warning issuance close to the peak of the event shows a rate of loss of life higher than the result obtained without to send warning issuance in the "No Warning" simulation. Figure 3-62 shows a useless of the warning issuance from 6 hours and 40 minutes from the peak with a loss of life rate of 832 compared with the loss of life rate of 806 gave back from the "No Warning" simulation. The loss of life – warning issuance curve shows an increment of the victims reducing the promptness sending the alert; in fact the number of fatalities at 0 hours (when the event reaches the maximum flow rate) is evaluated equals to 942.

These observations lead the research to consider the useless of the warning alert by the Authorities if they act too late because a not prepared action could lead to an amount of damage higher than to leave people the decision how to act during the flood emergency.

The LSM application in the study case results as relevant tool to help the Authorities on the flood emergency situation that, according with the Alert Operating Instructions of the Sardinian Civil Protection Agency, it would be supported by a flood alert management based on an accurate monitoring of the climate changes forecast.

Successively, in Figure 3-63 a second curve is plotted to show the impact of a 1 hour delay in the response of people to the evacuation warning on the number of fatalities. The trend does not change in that the number of fatalities reduce as the lead time of the warning increases. Although, as the response time increases the warning lead also needs to increase to reduce the potential number of fatalities.

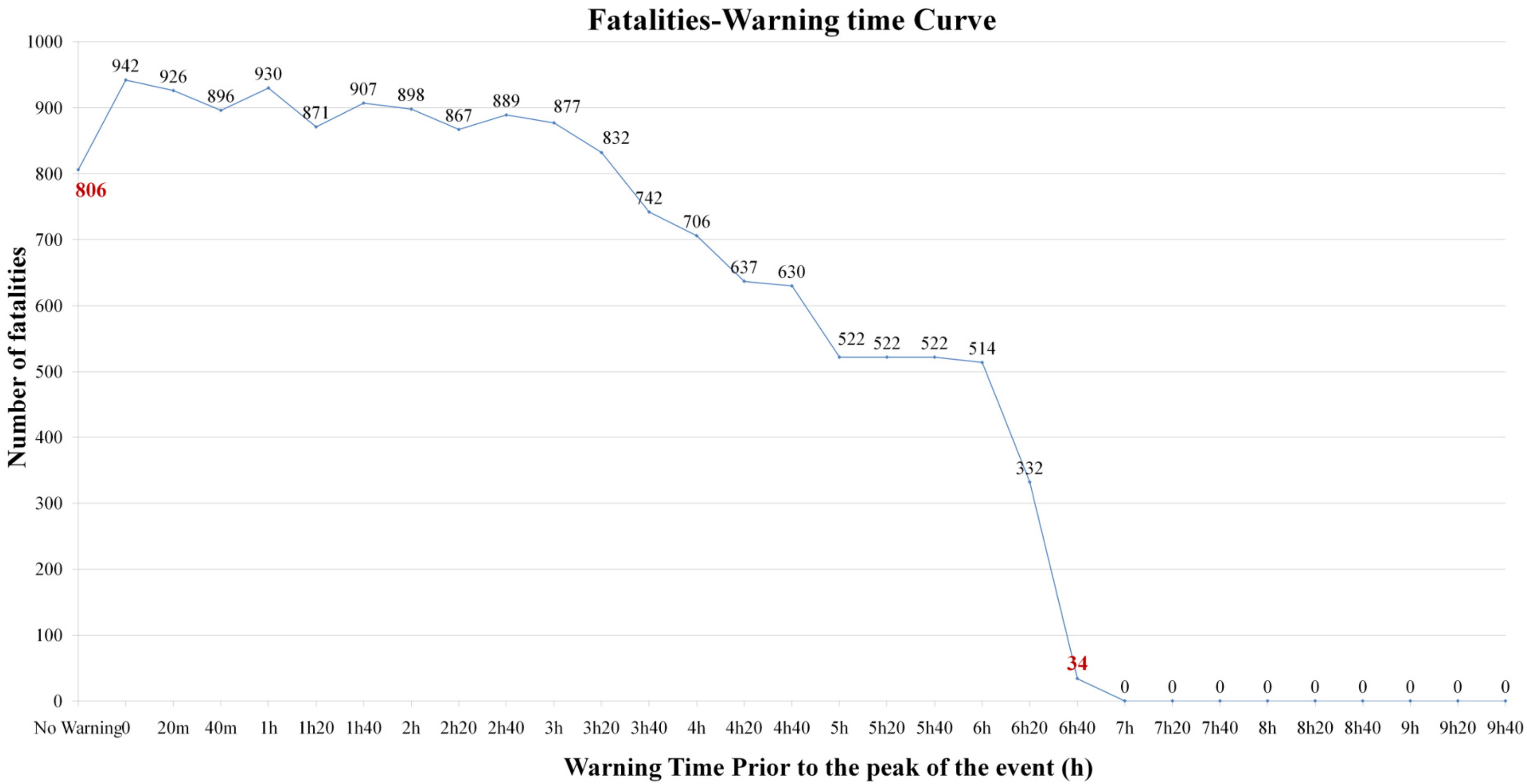

Figure 3-62.Loss of Life - Warning time Issuance curve of the Coghinas River lowland valley basin for different flood warning and response scenarios

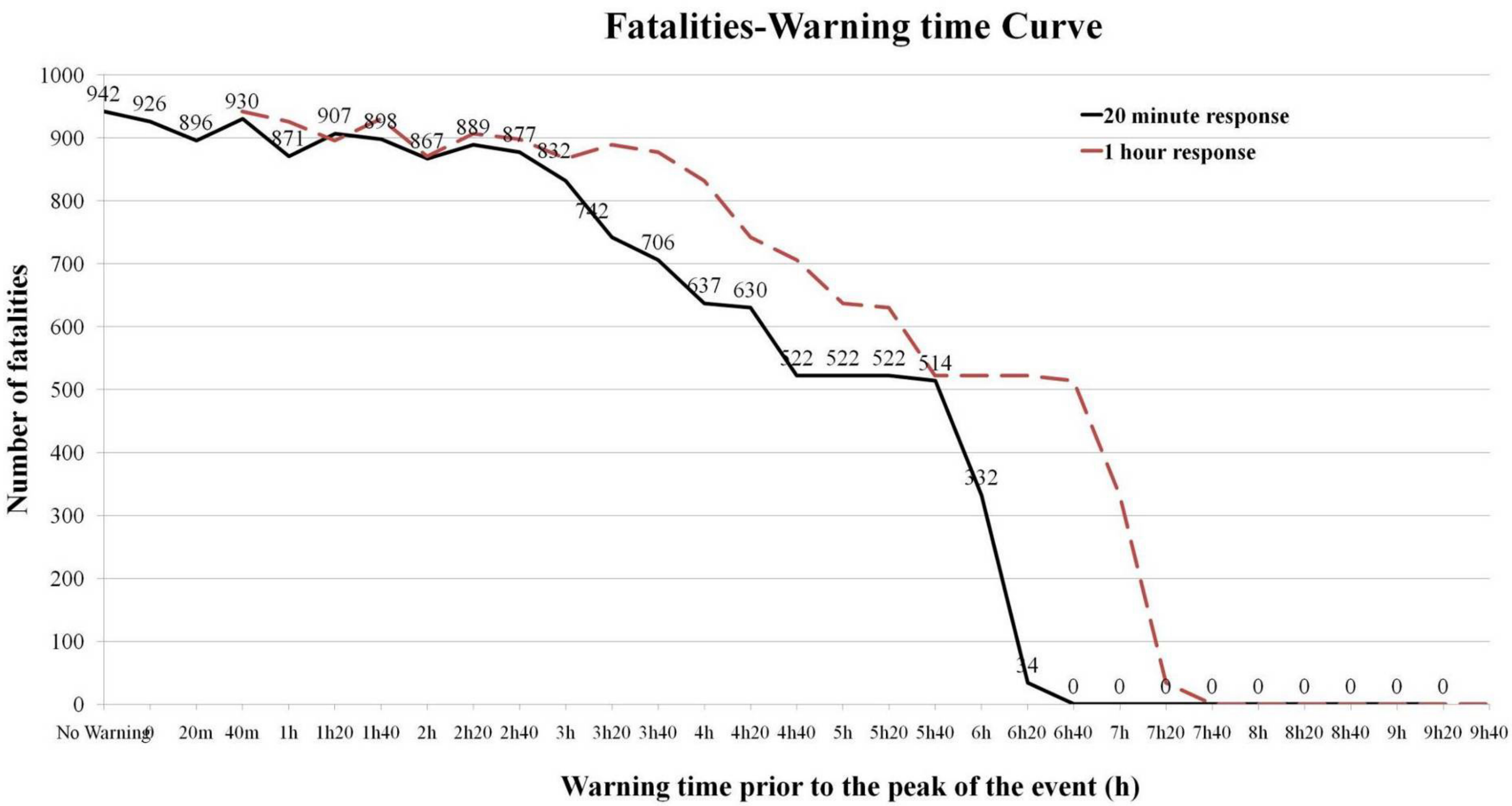

Figure 3-63.Loss of Life - Warning time Issuance curve of the Coghinas River lowland valley basin for different flood warning and response scenarios with 20 minutes and 1 hour of response

The curve Loss of life – Warning time Issuance obtainable studying LSM results consist in a significant support for the predisposition of emergency plan when flood occur.

Considering the Alert Operating Instruction scheme described in Chapter 2 Paragraph 4, the LSM emergency plan could be set to manage the evacuation of the virtual world receptors and model potential losses.

In particular, the predisposition of buildings as Safe Haven has been defined according with requirement specified in the AOICP. The emergency is considered at meso-scale of councils area managed in this case by the four council of Viddalba, Santa Maria Coghinas, Valledoria and Badesi. These four towns have been studied in terms of road network, building elevation and type in order to identify the best location of the Safe Haven that people should reach when the evacuation issuance is disseminated by local authorities. As explained above the three key point of the Casteldoria dam control building, Council Hall of Viddalba and Valledoria have been set to cover all of the territory when the alert dissemination action is activated and set properly in LSM warning file.

A relevant properties of LSM is defined by the possibility to observe how the evacuation may develop and how could change the status of the receptors defined in the virtual world.

Following the attention on the potential victims of the flood and on the representation of particular moment during the flood development have been shown from Figure 3-64 when the flood it is not still occurred to Figure 3-74 when the evacuation is completely managed and population stopped to move towards Safe Haven.

Each relevant moment shown in the mentioned figures has been explained.

Figure 3-65 describes the situation after 1 hour that the flood started and no changes on the people distribution are registered.

Figure 3-66 describes the situation at 3 hour and 5 minutes from the beginning of the event. Changes on PARU status could be observed and the population of Viddalba and Santa Maria Coghinas Tows are aware of the potential flood event.

Figure 3-68 describes the situation at 3 hours and 10 minutes from the beginning of the event when also part of the population located in Valledoria Town are aware of the potential flood event.

Figure 3-67 describes the situation at 3 hours and 16 minutes from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event.

Figure 3-69 describes the situation at 3 hours and 37 minutes from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event and part of the population in Viddalba, Santa Maria Coghinas and Valledoria starts to egress towards the Safe Haven.
Figure 3-70 describes the situation at 3 hours and 45 minutes from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event and evacuating towards the Safe Haven.
Figure 3-71 describes the situation at 3 hours and 56 minutes from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event and evacuating towards the Safe Haven. It is possible to observe the first victims of the flood located in the La Foce Camping close to the end of the Coghinas River.
Figure 3-72 describes the situation at 4 hours and 29 minutes from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event and evacuating towards the Safe Haven. More victims of the flood in the La Foce Camping area are registered and the survivors follow to move towards the Safe Haven.
Figure 3-73 describes the situation at 5 hours from the beginning of the event when all of the population located in the pilot basin are aware of the potential flood event, La Foce Camping area has been completely evacuated unless the 34 registered victims. It is possible to observe that survivors from the Baia delle Mimose Resort area are following to move towards the Safe Haven located for that area in the suburban area of Badesi Town.
Figure 3-74 describes the situation after that the emergency management is finished unless the flood does not reach its peak.

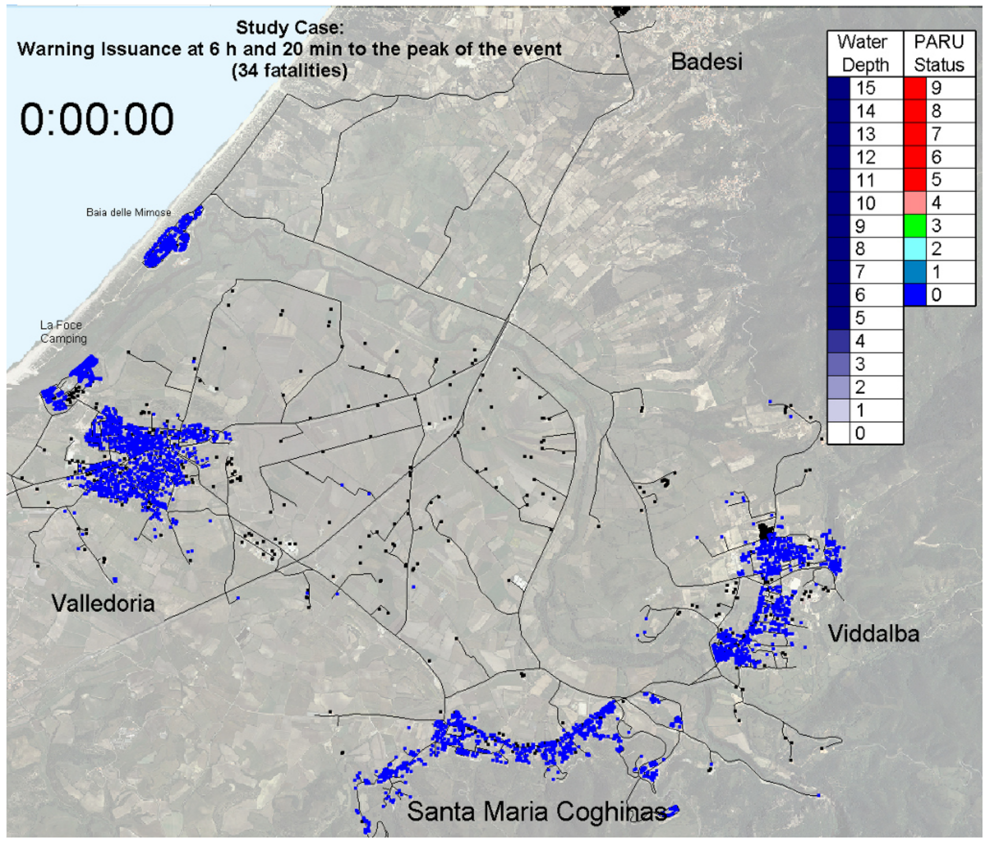

Figure 3-64.Study case condition without flood risk

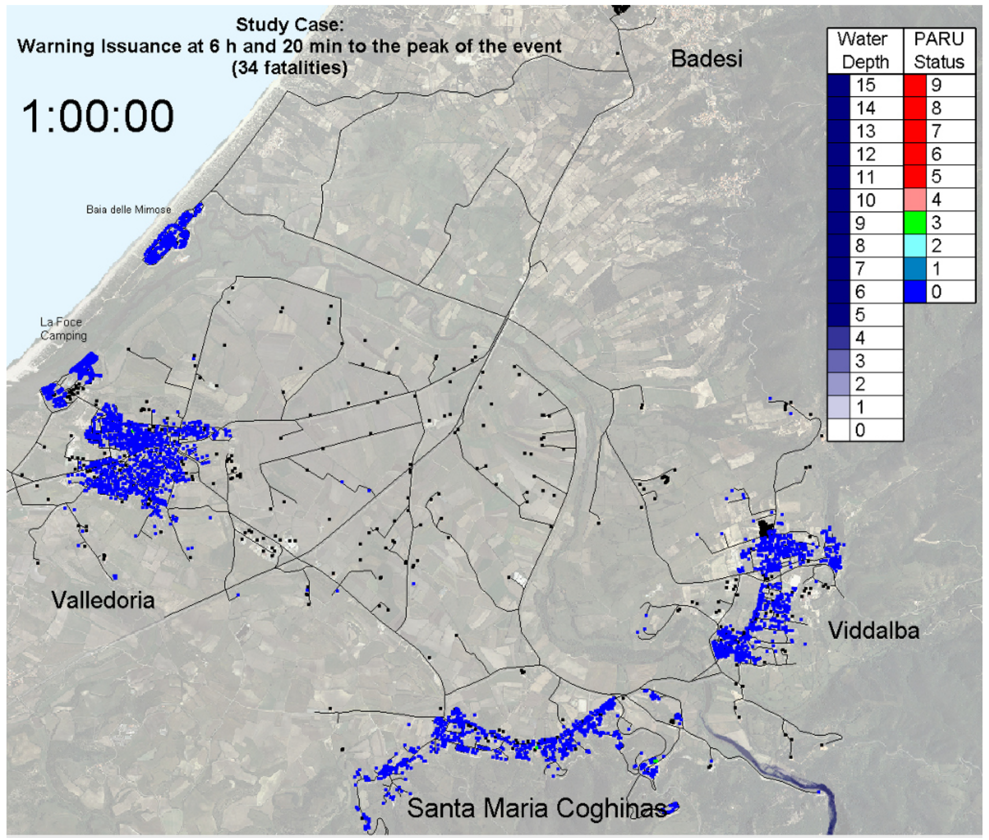

Figure 3-65.Study case condition at 1h since the beginning of the flood

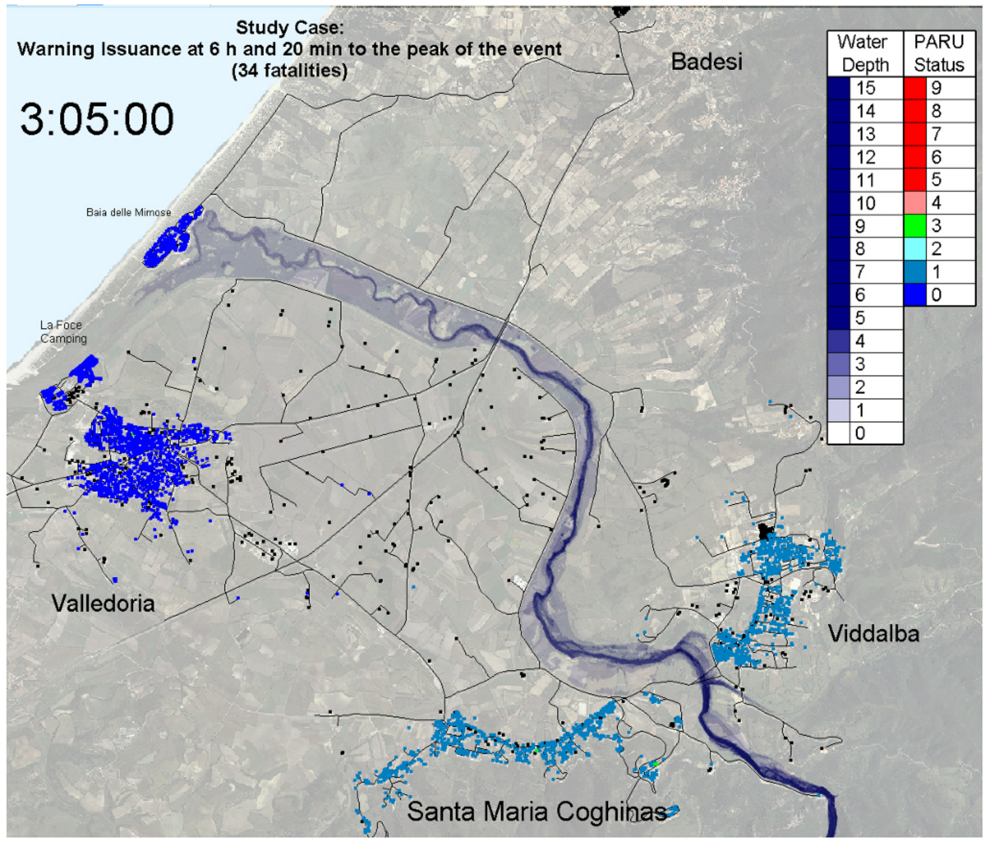

Figure 3-66.Study case condition at 3h5min since the beginning of the flood

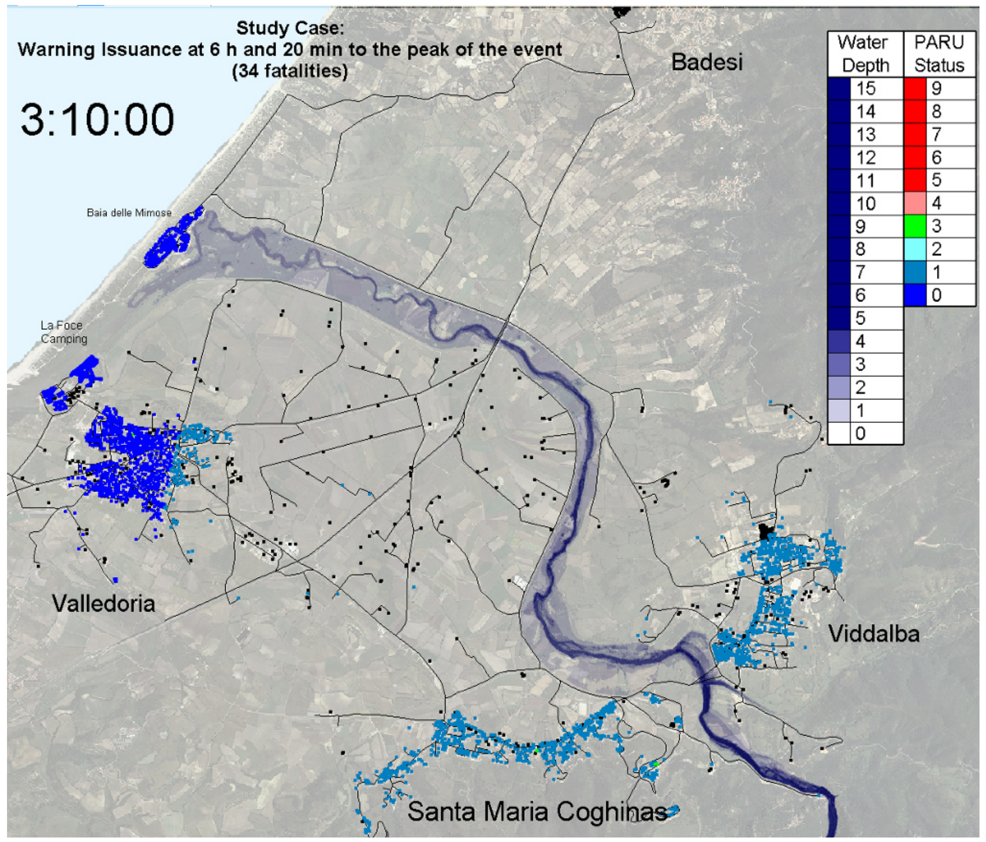

Figure 3-67.Study case condition at 3h10min since the beginning of the flood

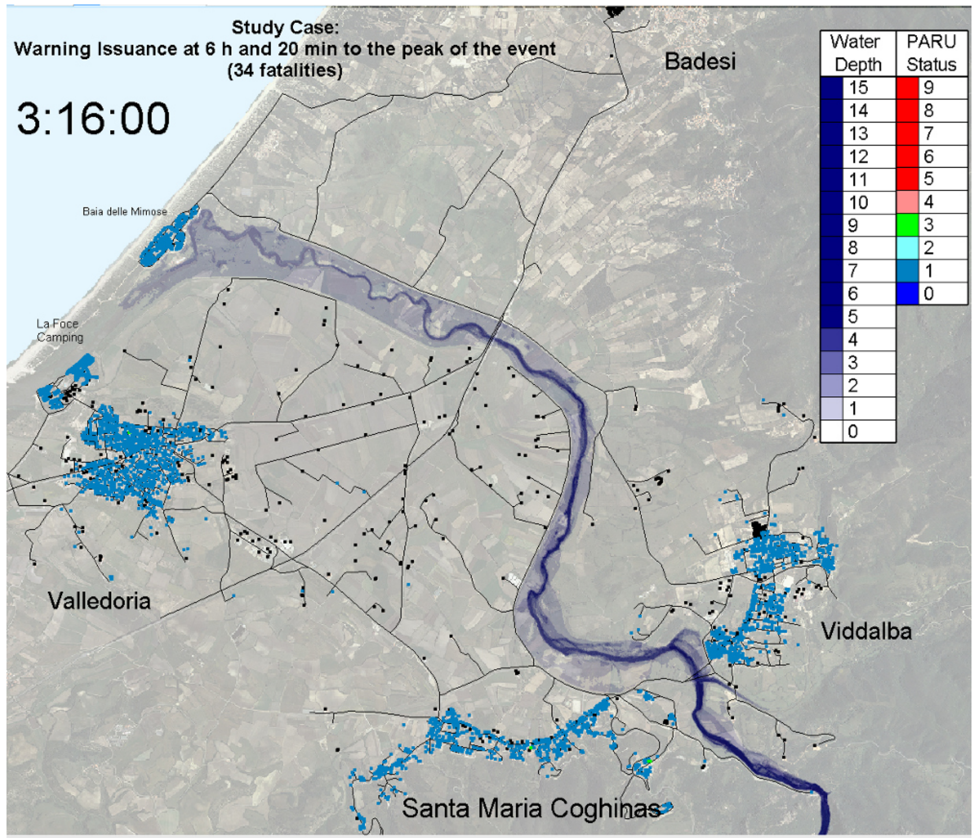

Figure 3-68.Study case condition at 3h5min since the beginning of the flood

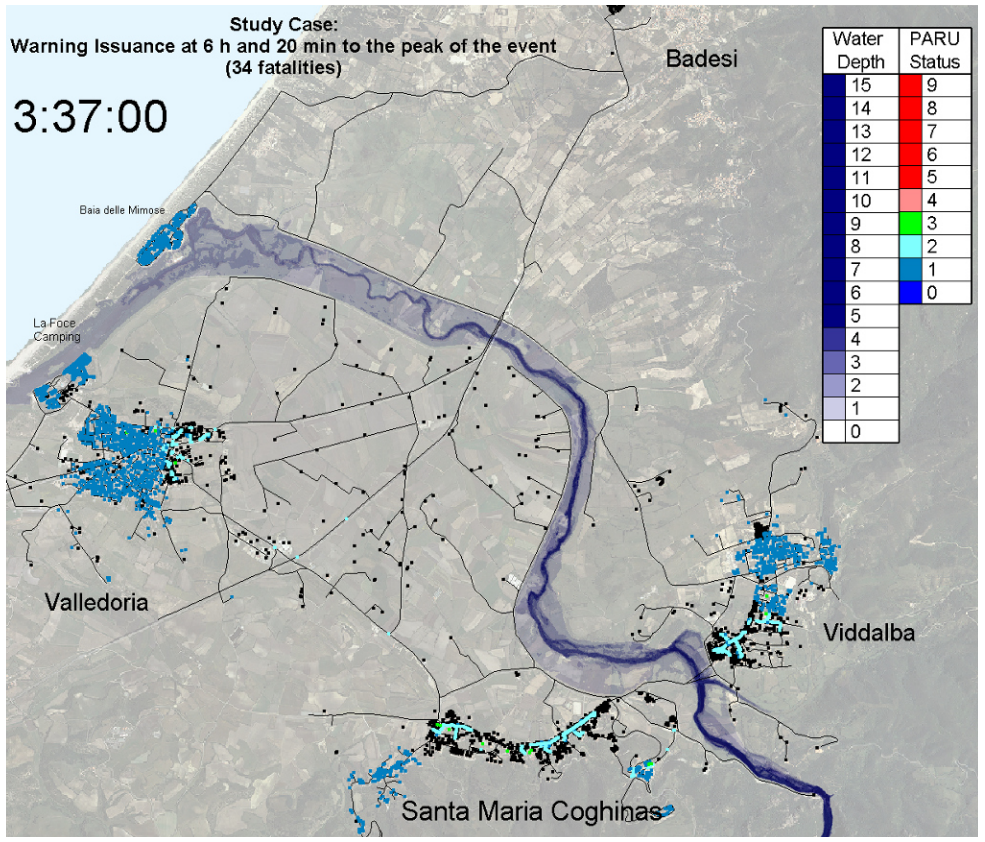

Figure 3-69.Study case condition at 3h37min since the beginning of the flood

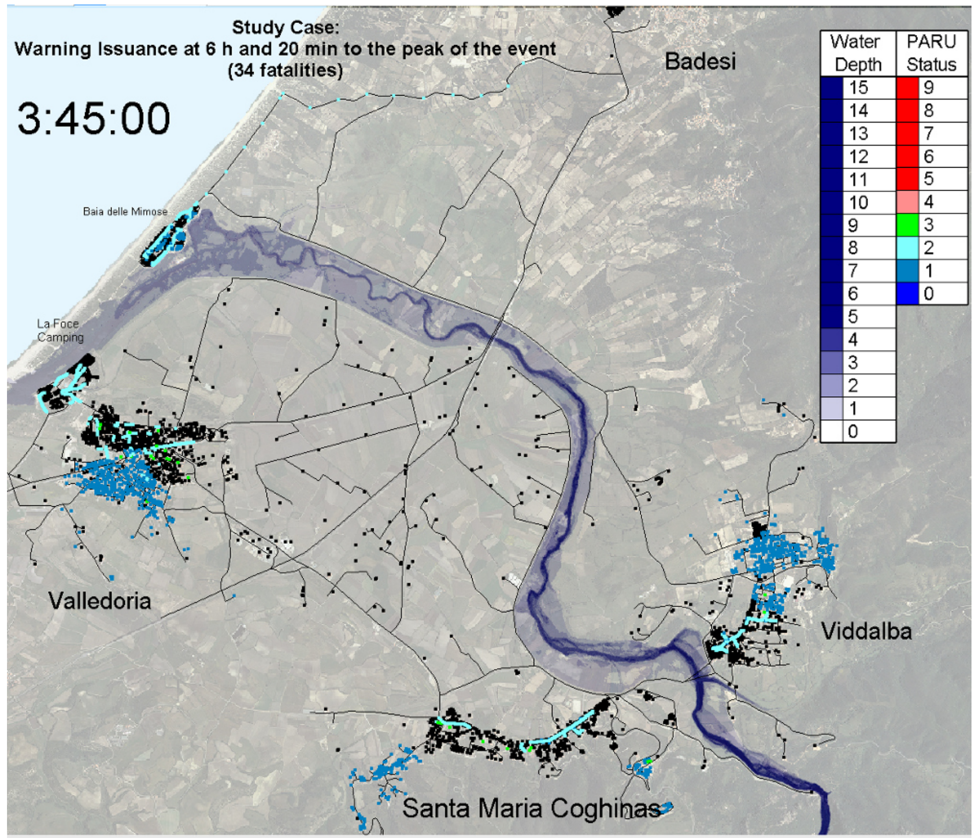

Figure 3-70.Study case condition at 3h45min since the beginning of the flood

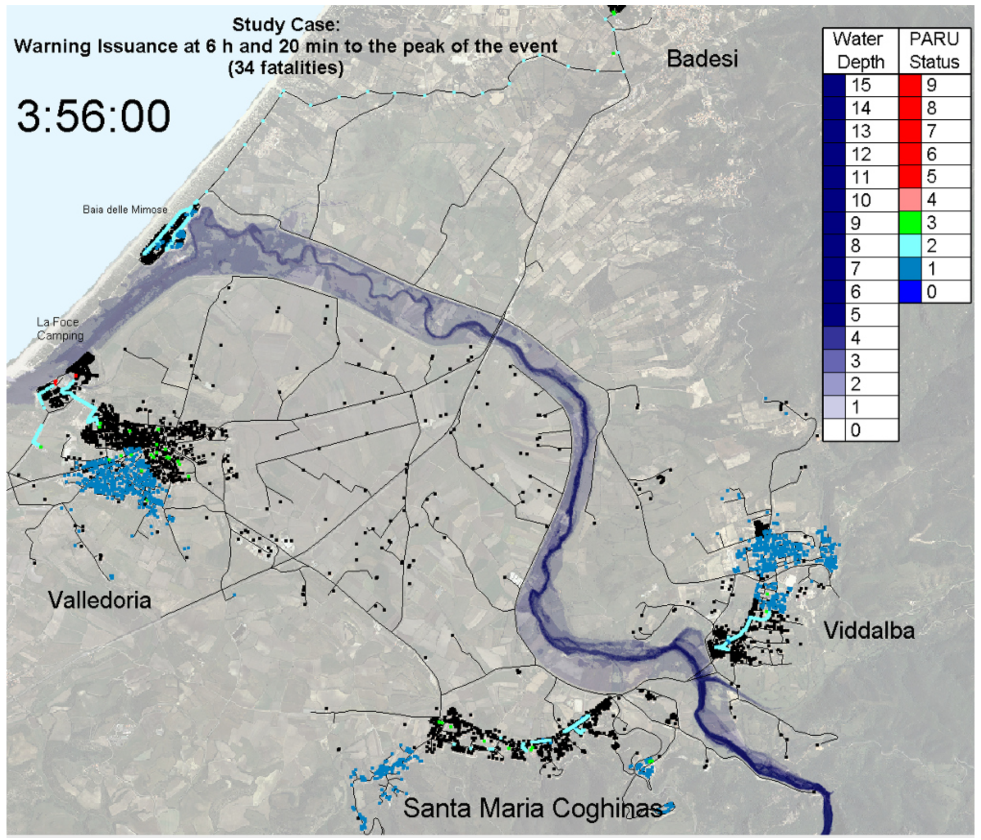

Figure 3-71.Study case condition at 3h56min since the beginning of the flood

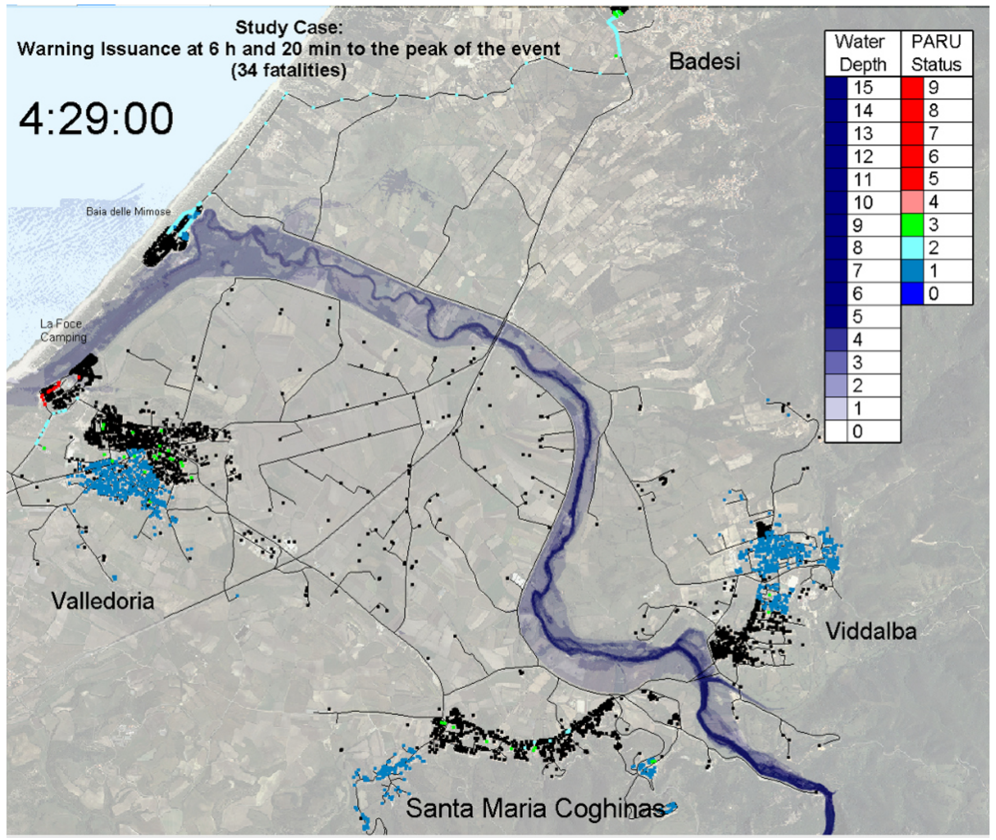

Figure 3-72.Study case condition at 4h29min since the beginning of the flood

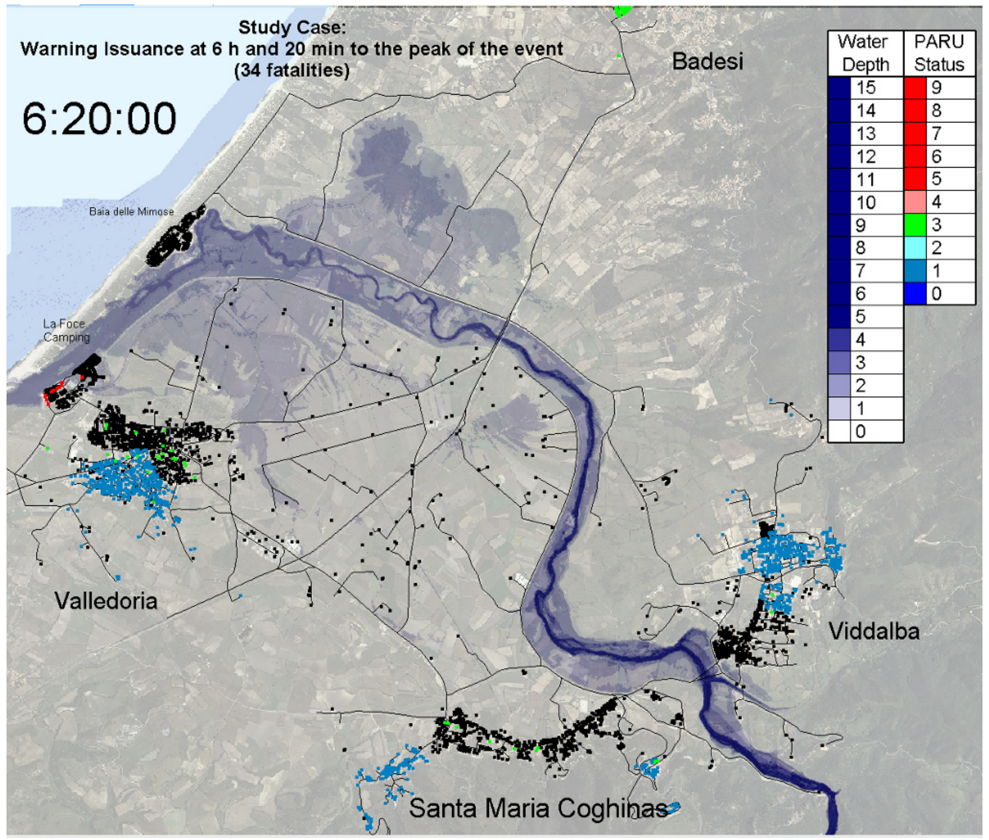

Figure 3-74.Study case condition at 6h20min since the beginning of the flood

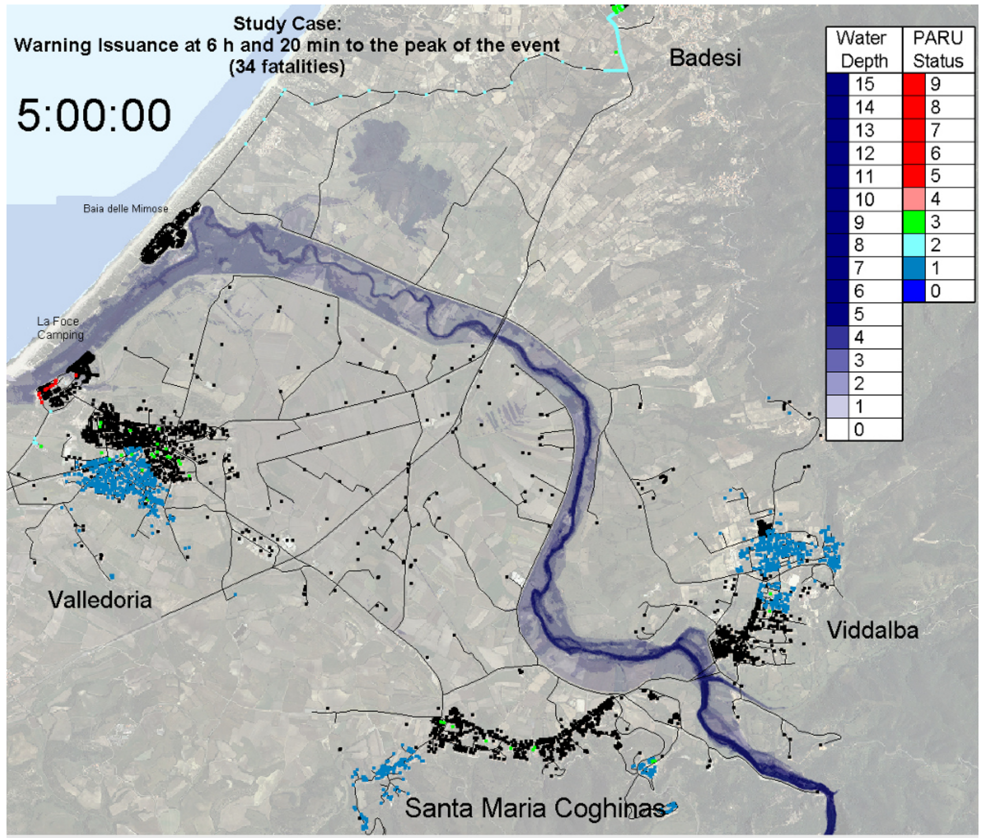

Figure 3-73.Study case condition at 5h since the beginning of the flood

4. Results and Conclusion

The project outline, defined in the Introduction chapter, focalised the attention on the methodologies chosen for the evaluation of the flood damage. In the first step of the PhD research the JRC Model has been chosen for the evaluation of the direct tangible damage after an accurate analysis of the methodology. In addition, the harmonised water depth-damage functions should be compared with collected data of occurred event to verify the compatibility of the model with the registered damages. One contribution of this research consists in the definition of water depth-damage functions for the Sardinian territory and their comparison with the JRC water depth-damage functions in order to validate the JRC Model for the study territory. The validation process consisted in the analysis of the water depth-damage functions for residential land use category obtained by the analysis of collected data from the flood events of the Capoterra 2008 and Olbia 2013 occurred in Sardinian. The Sardinian water depth- damage functions describe properly the flood damage increment with the increase of the water depth unless do not follow perfectly the JRC water depth-damage function trend. This is caused by the different type of residential properties characteristics of the analysed flooded territories. In addition, the two Sardinian curves are described by a linear high increment of the damage for water depth lower than 0.5 m. In this research the choice to accept the linear trend results from the observation that around 0.5 m of water depth dwellings are subjected at the most part of the losses due to damages on inventory and necessary goods. After 0.5 m of water depth, the two curves are described, respectively Capoterra and Olbia, by a polynomial and exponential trend that are justified by the observation that from 0.5 m to 2 m the flood has usually made the most part of the damages and at this range of water depth the damages should be determined by how long the waves acts to the structural part of the properties. Capoterra water depth-damage function describes better the damage increment from 2 m of water depth when the flood could reach the first floor incrementing the damages on inventory and worsening the stability of the structures. This conclusions are confirmed also with the study developed by the Natural Hazards Research Centre and shown in Figure 2-4 where the maximum damage to structure are registered for 3 m of water depth and an relevant part of the damages to inventory could be determined between 0.5 and 1 m of water depth.

The research took into account that JRC Model provides water depth-damage functions applicable for the whole European territory. This aspect is a significant contribution on the international research, but the application of the JRC Model at meso- or micro-scale of detail required integration. The integration should considers, for example, the categorisation of the land use, as suggested in the JRC Report. JRC Model has been, herein, subjected at the integration regarding the land use categorisation that from the five original land use categories increased to twelve to describe more in detail Sardinian territory as explained in Chapter 2 Paragraph 2.2.1 and shown in Table 2-27.
Moreover, the JRC Model study gave rise to the necessity to use mathematical expression to be implemented in GIS software for the flood damage factor α evaluation considering the process herein used for the damage evaluation shown in Figure 3-55. The extrapolation of the water depth-damage mathematical expression led to observe that the achievement of the maximum value of the flood damage factor happens, for four of the five JRC land use category, at 5 meters of water depth instead of 6 meters that as considered as the maximum level of water depth in the JRC Model. The JRC Model application has been applied in this research decreasing of one meter the range of water depth in the JRC functions and the mathematical expression have been obtained, Equation 2-7, Equation 2-8, Equation 2-9, Equation 2-10 and Equation 2-11.
JRC Model has been applied on the Sardinian territory choosing as pilot basin the Coghinas River lowland valley basin. The study case has been firstly modelled with HEC-RAS mono-dimensional model and the water depth map have been used for the appreciation of the direct tangible damage. Table 3-7, Table 3-8 and Table 3-9 show the economic magnitude of the damage determinable by flood event of 50, 100 and 200 years, respectively, and summarised in Table 4-1.

Event	50 Years	100 Years	200 Years
Total Damage (M €)	48.38	60.37	71.01

Table 4-1.Total Direct Tangible Damage for the study case. JRC Model

These results could allow to implement a costs-benefits analysis defining mitigation measures scenario for the pilot basin. Basically, the study turns out to be a useful tool to compare the flood damage between baseline scenario and mitigation measure scenario when flooding occurs supporting the costs-benefits analysis developed for the Sardinian

FRMP according with requirement of the Flood Directive 2007/60/EC, (Frongia et al., 2015b).

Unfortunately the JRC Model provides only the appreciation of the direct tangible damage. That lack induced the research to an improvement aiming to identify completely the tangible damage. The MCM Model showed up as useful methodology with its approach on the evaluation of the indirect component of the tangible damage unless the methodology developed for the direct tangible damage has not been conducted because it required data no still available to be applied in Sardinian territory. The MCM Model evaluates indirect damages as percentage of the direct aliquot of the tangible damage. In this project the indirect tangible damage considers the costs of emergency, health care and sanitary services at the post-event phase (identified as the 10.7 % of the direct tangible damage in the MCM Model) plus the aliquot that includes disruption of systems as road network, telecommunication, drinking water and waste water systems. Therefore, the indirect tangible damage has been appreciated as the 30 % of the direct tangible damage. Table 4-2 shows the total economic damage of the indirect tangible component divided for the MCM methodology and for the aliquot of 30 % of the direct damages for the flood scenarios of the pilot basin studied with the JRC Model.

Event	50 Years	100 Years	200 Years
Total Damage (M €)	48.38	60.37	71.01

Table 4-2.Total Indirect Tangible Damage for the study case. MCM Model with integration

The second main contribution of this research, and possible support for the update phase of the Sardinian FRMP, worked to identify methodologies for the evaluation of intangible damages, in particular losses of life, and improvement of the emergency situation during flooding with the use of Life Safety Model that resulted as potential methodology to accomplish these goals.

Life Safety Model supported this step of the research thanks to the possibility to model physically the receptors of the pilot basin virtual world (mainly structures and people) and studies their interaction with the water depth and velocity flood parameters during the disaster development. LSM gives the possibility to observe people movement, by foot or driving, and their state conditions during each step of the flood applying people, structure and vehicle Object Damage Loss Function algorithms described in detail in Chapter 2. It has been useful to model the behaviour of the receptors for the three scenarios of 50, 100 and 200 years studied also with the JRC Model and the MCM Model. The results of the study depend by the alert and evacuation action implemented in LSM thanks to the opportunity to define where warning points should be locate to disseminate the flood alert in the entire territory and when impose people evacuation from their location to move towards shelter points defined according with Sardinian Civil Protection procedures during emergency situations. Focusing the attention on losses of life damages, LSM Object Damage Loss Function algorithms scripts gave information about survivors and victims and how this loss occurs. For example the no warning scenario models an emergency flood situation that could determine a number of fatalities equals to 806 among drowned people, victims of exhaustion, building collapse, drowned in the building or due to vehicles that could be toppled, Table 3-26.

A deep observation of the results led to enhance the study running the scenarios different times changing when the authorities spread the evacuation issuance. The outcome of this test shows up particularly interesting as support of flood emergency plan identifying conveniently when the evacuation warning should be disseminate to avoid and/or reduce victims or when should be better leave people the decision how to act in order to prevent a number of fatalities higher than the number obtainable during a no controlled flooding emergency. This conclusions are summarised in Figure 3-62 where the number of fatalities-evacuation issuance curve is shown and describes the total amount of potential victims that could be registered with different evacuation issuances.

5. Perspectives

The evaluation of damages inside the network environment proved to be essential to support and explain a network's susceptibility to flood. The general methodology herein presented aimed to reduce the lack on flood damage comprehension and evaluation methods highlighted in literature.

The applied methodology for the evaluation of the tangible damage could be improved including in the analysis more hydraulic variables than water depth and velocities to describe more in detail the floods and obtain more reliable results. If data collected from previous floods occurred in Sardinian were provided by detail information about the structures, inventory and people damaged, the project could be developed without considering a significant level of uncertainty. Moreover, the study on flood damages could be improved managing field works in the immediate post-event situation and observe the flood consequences right away.

The categorisation of the damage with the twelve land use categories are not be provided by a validation for all of the categories. The collection of detail information of damages on commercial, industry, infrastructures, support systems and protected areas would be useful to validate properly the JRC Model verifying its applicability in the territory under study. In addition, the identification of drawback due to flood could support a better comprehension of how the disasters make discomforts to the population helping the evaluation of the indirect tangible damage.

More important could be the application of Life Safety Model on local scale of council territory. In fact, a synergy among authorities, civil protection and population could lead to an optimum flood emergency plan to reduce potential damages when flood occurs reducing costs of emergency and rescue actions, but also avoid physical or mental traumas to people. These aspects should be coupled with an improvement of the evacuation model shown in this project regarding the distribution of shelters and definition of PARU strength parameters. In fact, each council territory might be organised by limited number of Safe Havens to manage accurately rescue actions and evacuation movement. In addition, knowing better the characteristics of each person strength parameter could be set conveniently for each one considering that an elderly or a child has lower resistance of a an adult.

Finally, results and potential improvement underline the relevance of a well organise preparedness of people and authorities to guarantee limited damages in case of flood emergency.

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