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Artigo

FLOOD RISK MANAGEMENT:
IMPLEMENTATION OF THE EUROPEAN DIRECTIVE 2007/60/EC IN THE AUTONOMOUS REGION OF MADEIRA

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ABSTRACT – The Decree-Law no. 115/2010, of October 22 transposed the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks into Portuguese national law establishing a framework for the assessment and management of flood risks. Flash floods and debris events have a long history in the island of Madeira resulting in several adverse impacts on human health, the environment, cultural heritage and economic activity. For this reason and since the catastrophic debris event of 20 February 2010 the establishment of a flood risk management plan in the Autonomous Region of Madeira (ARM) has assumed double importance. The aim of the paper is to present flood risk analysis methods and technical options adopted in the elaboration of flood hazard and flood risk maps as well the flood risk management plan strategy. The hydrographic basin of Socorridos is used as case study to show the principles and stages of the implementation of the Flood Risk Directive (FRD) in the ARM. In spite of some limitations associated with the volcanic mountain island characteristics and the debris events specificities, the flood risk analysis methods used are in harmony with the requirements of the FRD. Another important issue is the flood risk management plan strategy that addresses all aspects of flood risk management.

Keywords: Flood Risk Directive; flood hazard maps; flood risk maps; flood risk management plan; Autonomous Region of Madeira.

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RESUMO – GESTÃO DE RISCOS DE INUNDAÇÃO: IMPLEMENTAÇÃO DA DIRETIVA EUROPEIA 2007/60/CE NA REGIÃO AUTÓNOMA DA MADEIRA. O Decreto-Lei n.º 115/2010, de 22 de outubro, em que a Diretiva 2007/60/CE do Parlamento Europeu e do Conselho, de 23 de outubro de 2007, relativa à avaliação e gestão dos riscos de inundações é transposta para o direito nacional português, estabelece um quadro de avaliação e gestão dos riscos de inundações. As inundações rápidas e as aluviões têm uma longa história na ilha da Madeira, resultando em vários impactos adversos na saúde humana, ambiente, património cultural e atividade económica. Por este motivo e desde a aluvião catastrófica de 20 de Fevereiro de 2010, o estabelecimento do plano de gestão do risco de inundação na Região Autónoma da Madeira assume uma importância redobrada. O objetivo é apresentar os métodos de análise de risco de inundação e as opções técnicas adotadas na elaboração das cartas de zonas inundáveis e cartas de riscos de inundações, bem como a estratégia do plano de gestão de risco de inundação da Região Autónoma da Madeira. Para demonstrar os princípios e etapas da implementação da Diretiva de Riscos de Inundações na Região Autónoma da Madeira, a bacia hidrográfica dos Socorridos é utilizada como estudo de caso. Apesar das características vulcânicas e montanhosas da ilha da Madeira e das especificidades das aluviões, os métodos de análise de risco de inundação utilizados estão em harmonia com os requisitos da Diretiva de Risco de Inundações. Outra questão importante é a estratégia do plano de gestão dos riscos de inundações que aborda todos os aspetos da gestão dos riscos de inundações.

Palavras-chave: Diretiva Riscos de Inundações; cartas de zonas inundáveis; cartas de riscos de inundações; plano de gestão dos riscos de inundações; Região Autónoma da Madeira.

RÉSUMÉ – GESTION DES RISQUES D'INONDATION: MISE EN OEUVRE DE LA DIRECTIVE 2007/60/CE POUR LA RÉGION AUTONOME DE MADÈRE. Le Décret-Loi no. 115/2010, du 22 octobre, où la directive 2007/60/CE du Parlement Européen et du Conseil du 23 octobre 2007 concernant l'évaluation et la gestion des risques d'inondation est transposée dans la législation nationale portugaise, établit un cadre pour l'évaluation et la gestion des risques d'inondation. Les inondations rapides et les débris ont une longue histoire à Madère et ont eu plusieurs conséquences négatives pour la santé humaine, l'environnement, le patrimoine culturel et l'activité économique. Pour cette raison et depuis l'événement catastrophique des débris du 20 février 2010, l'établissement d'un plan de gestion des risques d'inondation dans la région autonome de Madère revêt une double importance. Le but de cet article est de présenter les méthodes d'analyse de risque d'inondation et les options techniques adoptées dans l'élaboration des cartes de zones inondables et de risques d'inondation ainsi que la stratégie du plan de gestion des risques d'inondation. Pour montrer les principes et les étapes de la mise en œuvre de la Directive sur les Risques d'Inondation dans la Région Autonome de Madère, le bassin versant de Socorridos est utilisé comme cas d'étude. Malgré, les limitations liées aux caractéristiques volcaniques et montagneuses de l'île de Madére et aux spécificités des événements de débris, les méthodes d'analyse des risques d'inondation utilisées sont en harmonie avec les exigences de la Directive sur les risques d'inondation. Une autre question importante est la stratégie du plan de gestion des risques d'inondation qui aborde tous les aspects de la gestion des risques d'inondation.

Mots clés: Directive Risques d'Inondation; cartes des zones inondables; cartes des risques d'inondation; plans de gestion des risques d'inondation; Région Autonome de Madère.

RESUMEN – GESTIÓN DE LOS RIESGOS DE INUNDACIÓN: APLICACIÓN DE LA DIRECTIVA EUROPEA 2007/60/CE EN LA REGIÓN AUTÓNOMA DE MADEIRA. El Decreto Ley nº. 115/2010, de 22 de octubre, en el que la Directiva 2007/60/CE del Parlamento Europeo y del Consejo, de 23 de octubre de 2007, relativa a la evaluación y gestión del riesgo de inundación se transpone a la legislación nacional portuguesa, estableciendo un marco de evaluación y gestión del riesgo de inundación. Las inundaciones rápidas y los aluviones tienen una larga historia en la isla de Madeira, lo que resultado en varios impactos adversos en la salud humana, el medio ambiente, el patrimonio cultural y en la actividad económica. Por este motivo y, desde el catastrófico aluvión del 20 de febrero de 2010, el establecimiento de un plan de gestión del riesgo de inundación en la Región Autónoma de Madeira ha adquirido una mayor relevancia. El objetivo de este documento es presentar los métodos de análisis de riesgo de inundación y las opciones técnicas adoptadas en la elaboración de las cartas de zonas inundables y de riesgo de inundación, así como la estrategia del plan de gestión de riesgo de inundación de la Región Autónoma de Madeira. Para demostrar los principios y etapas de la implementación de la Directiva de Riesgo de Inundaciones en la Región Autónoma de Madeira, la cuenca hidrográfica de los Socorridos se utiliza como estudio de caso. A pesar de las características volcánicas y montañosas de la isla de Madeira y las especificidades de los aluviones, los métodos de análisis de riesgo de inundación utilizados en el plan están en línea con los requisitos de la Directiva de riesgo de inundación. Otro tema importante, es la estrategia del plan de gestión del riesgo de inundación que aborda todos los aspectos de la gestión del riesgo de inundación.

Palabras clave: Directiva de Peligro de Inundación; gráficos de zonas de inundación; cuadros de riesgo de inundación; plan de gestión del riesgo de inundaciones; Región Autónoma de Madeira.

I. INTRODUCTION

The Autonomous Region of Madeira (ARM) is risk-prone to natural hazards of many kinds including landslides, debris, floods, storms and storm surges or forest fires. Flash floods and debris events have a long history in Madeira island (Quintal, 1999) resulting in several adverse impacts on human health, environment, cultural heritage and economic activity. Considering the occurrence in the past of several events, with adverse impacts and the obligation described in the Decree-Law nº 115/2010, of October 22 (transposition of the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks into Portuguese national law), twenty-seven risk areas were identified in the ARM. Bearing in mind the flood hazard maps and flood risk maps for these twenty-seven areas and following the Flood Risk Directive (FRD) principles, the ARM established a flood risk management plan (Resolution no. 805/2017 – JORAM no. 187, I Series, October 27). The European Floods Directive 2007/60/EC, defined the management framework for this flood risk management plan, following the change on the concept of managing flood risk to a more holistic view, by expliciting covering the prevention, mitigation, preparation, response, recovery components of the disaster cycle (Albano, Mancusi, Sole, & Adamowski, 2015). The flood risk management plans vision described in the European Floods Directive 2007/60/EC should address all aspects of flood risk management, considering where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity. Supported by flood hazard maps and flood risk maps, the flood risk management plans must have a summary of the measures and their prioritisation aiming to achieve the appropriate objectives of flood risk management. The management approach for these plans requires that the measures, if considered appropriate, should have a focus on nonstructural initiatives and/or on the reduction of the likelihood of flooding (Mileu, 2018). The structural initiatives can be considered, but the flood risk management plans shall take into account relevant aspects such as costs and benefits. This aspect is particularly important given the limited financial resources for structural initiatives. The relation between flood risk analysis technical issues and the consecutive, development of flood risk management plans in Europe have been studied by different authors (Dráb & Riha, 2010; Mysiak *et al*., 2013). However for mountainous islands of volcanic origin the references about the implementation of flood risk management plans are scarce.

In this paper, the process of implementing the FRD in ARM is analysed. The methods and technical options adopted in the different stages of flood risk management are described and at the same time the problems and decisions made in the implementation process are discussed. Together with this discussion the flood risk management plan strategy is presented, including the measures for achieving the plan objectives.

The objectives of the paper are to introduce the principles and stages of FRD implementation in the ARM. The preliminary flood risk assessment approach, the flood hazard and risk map elaboration, and also about the development of flood risk management plan are described and discussed. The principles adopted are demonstrated in a case study within the critical area of Socorridos watershed. The paper is structured as follows: the first section is the introduction where the main objective is presented; in the second section the three stages of FRD implementation are presented, followed by section 3 where the case study is the focus. Finally, the conclusions and notes for the next generation plan are presented in section 4.

II. IMPLEMENTATION OF FLOOD RISK DIRECTIVE 2007/60/EC

1. Preliminary flood risk assessment

To provide an assessment of potential risks, the FRD requires a preliminary risk assessment. In ARM, the Regional Direction of Spatial Planning and Environment identified the critical areas to be mapped considering the adverse impacts of floods

(DROTA, 2015). The criteria used for the selection of critical areas were the following: a flood event with occurrence of at least one victim (dead, missing); a flood event with occurrence of affected persons (evacuated, homeless, injured); a flood event with damage to at least one public/private infrastructure; and hydraulic interventions of watercourses, for protection and mitigation, in particular those following the debris event of 20 February 2010. These criteria led to the selection of 27 critical areas (fig. 1) in the ARM.

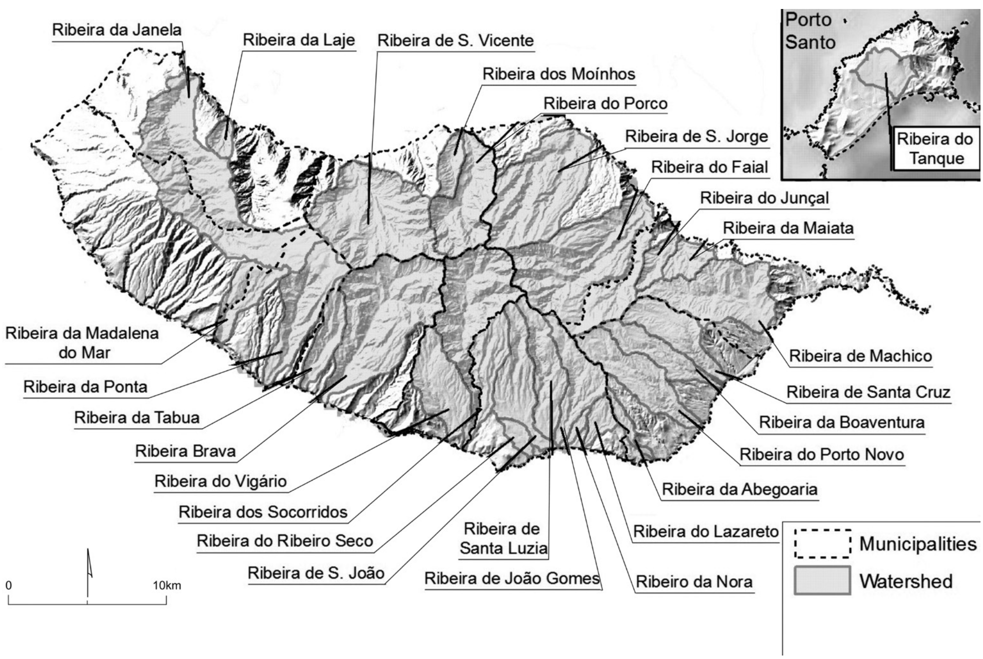

Fig. 1 – Preliminary flood risk assessment critical areas.

Fig. 1 – Áreas críticas definidas na avaliação preliminar dos riscos de inundações.

An important issue in the preliminary flood risk assessment was the description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity (table I). The historical flood records in ARM correspond to different dates; have several sources and contexts of elaboration, showing the importance of the phenomenon, namely the debris events. In this context, the historical description made by Silva (1940) and Quintal (1999) "Debris of Madeira from the 19th Century" deserve particular attention. More recently and after the disaster of February 20, 2010, the "Madeira Island Debris Risk Assessment – Base Report" (SRES, 2010) summarizes the main debris events in the island of Madeira up to the year 2010.

Table I – Historical overview of the flash floods and debris events on the island of Madeira.

Quadro I – Síntese histórica das inundações rápidas e aluviões na ilha da Madeira.

Date	**Location**	**Victims and damages**
10. 09. 1803	Funchal	800 – 1000 victims
02. 26. 1920	Funchal Ribeira Brava, Camacha	5 victims
03. 06. 1929	São Vicente	32 victims, 11 houses e 100 barns destroyed
12. 30. 1939	Madalena do Mar (main damages)	4 victims
02. 11. 1956	Curral das Freiras	2 victims
11. 03. 1956	Machico, Santa Cruz	6 victims
01. 3 to 6. 1963	Ribeira Brava, Serra de Água	5 victims
01. 9. 1970	Ribeira Brava, Serra de Água	4 victims
09. 21. 1972	Santo António	2 victims
12. 20. 1977	Estreito de Câmara de Lobos	4 victims e 45 homeless
01. 23 and 24. 1979	Machico, Porto da Cruz, Camacha, Canhas, Calheta e Fajã do Penedo	14 victims
10. 29. 1993	All Madeira island	4 victims, 4 missing people, 306 homeless, 76 houses e 27 injured
03. 5 and 6. 2001	Curral das Freiras and S. Vicente	5 victims (German tourists) e 120 homeless
12. 22. 2009	Madalena do Mar and S. Vicente	Several roads and houses destroyed

Source: SRES (2010)

More recently and after the event of February 20, 2010, there were other relevant events, such as the storm of November 6, 2012 that affected the municipalities of Porto Moniz and S. Vicente and the storm of November 29, 2013 that affected the municipalities of Machico and Santana (table II).

Table II – Important flood events after 2009.

Quadro II – Ocorrências de inundações significativas após 2009.

Date	**Location**	**Victims and damages**
02. 02. 2010	Faial Porto da Cruz	several roads destroyed
02. 20. 2010	Ribeira Brava Câmara de Lobos Funchal Santa Cruz	48 deaths 250 injured 600 homeless 500 damaged cars 800 houses with damages
10. 21. 2010	Funchal	several roads destroyed 5 homeless
12. 20. 2010	Curral das Freiras Funchal	houses with damages several cars damaged 2 injured
11. 6. 2012	Porto Moniz S. Vicente	several roads destroyed 6 injured 52 homeless in São Vicente 19 in Porto Moniz several cars damaged 11 houses affected
11. 29. 2013	Porto da Cruz Santo António da Serra	houses with damages Several roads destroyed 5 injured 6 families homeless

Source: DROTA (2015)

After the catastrophe of February 20, 2010, several research projects focused on hydrologic and hydraulic aspects were developed. Sepúlveda (2011) calculated two extreme precipitation indices and concluded that the areas of Madeira Island with the highest number of intense precipitation phenomena are located at higher altitudes in the Northwest-Southeast direction. Fragoso *et al.,* (2012) analysed the meteorological component of the 20 February flash-floods in Madeira and verified that the 20 February 2010 event was preceded by an equally outstanding anomalous accumulated precipitation, particularly on the upper parts of Eastern Mountains. Couto, Salgado, and Costa (2012) analysed the intense rainfall events on Madeira Island during the 2009/2010 winter and concluded that the high rainfall amounts observed were directly related to the orographic forcing. Reis (2014) modelled the annual maximum of daily rainfall using a generalized extreme value distribution, checking that the spatial distribution of precipitation in Madeira Island is affected by its topography. Caetano (2014) calculated the flood peak discharge in different sections of 39 watersheds in Madeira and notes that rainfall parameter has a significant effect but is not the only influencing factor.

Focusing on the debris event from February 20, 2010, Castro (2011) characterized the basin of the Ribeira de João Gomes from the point of view hydraulic, hydrologic and sediment transport, achieving estimates of values of liquid flow rates and flow velocities. Barreto (2013) analysed the basin of the Ribeira de Machico from the hydrological and hydraulic point of view, prepared a vulnerability map and a list of possible intervention works and mitigation measures to be implemented. In Santa Cruz municipality, Peixoto (2013) analysed the flash floods, urban floods and costal erosion. The conclusions of the analysis are that the most frequent events are urban floods due to the incapacity of the drainage network.

Using the municipality of Funchal as case study, Góis (2014) analysed the vulnerability to flash floods, noting that the downtown has a high exposure to flash floods. The Ribeira dos Socorridos and Ribeira do Vigário basins were characterized from hydraulic and hydrologic aspects by Marques (2014), where the difficulty in calculating solid transport is highlighted.

In the context of climate change strategy for ARM and its hydrogeological risks analysis, Reis, Bergonse, Simões, and Filipe (2015) point out a potential future decrease in the frequency of intense precipitation events, that may lead to a higher accumulation of deposits in slopes and riverbeds, which may cause floods/debris to become more severe due to the amount of material available, the strangulation effect and future evolution of soil erosion.

2. Flood hazard maps and flood risk maps

The second stage of FRD 2007/60/EC is the preparation of flood hazard maps and flood risk maps. The concept of risk adopted was established in Decree-Law no. 115/2010, of October 22, where "Flood risk" means the combination of the probability of flooding, taking into account its magnitude, and their potential adverse consequences for human health, the environment, cultural heritage, infrastructure and economic activities, being their harmful consequences evaluated by identifying the number and type of activity affected and can sometimes be supported by an analysis quantitative.

The overall risk analysis relates the hazard maps with the vulnerability of the 27 critical areas. The following flow chart (fig. 2) summarizes the analysis that leads to flood risk mapping.

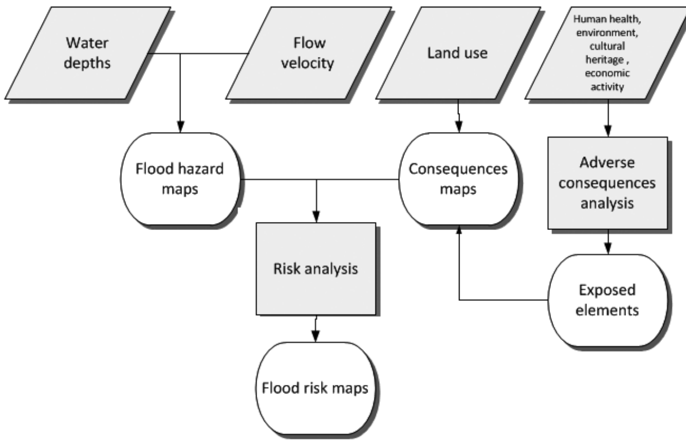

Fig. 2 – Flood risk analysis flowchart.

Fig. 2 – Esquema de análise dos riscos de inundações.

The first step to obtain flood hazard maps is the calculation of flood intensity and results from the following expression adopted from Wallingford (2005):

$$HR = d \times (v + 0.5) \quad (1)$$

where HR is (flood) hazard rating, d is the depth of flooding (m) and v is the velocity of floodwaters (m/sec).

The hydrological modelling was made for the return periods of 20, 100 and 500 years as required by the Portuguese legislation. In order to calculate peak flow data, the precipitation values were obtained in two different ways: 1) In the island of Madeira, the hydrological modelling was supported by the precipitations defined in the work of Caetano (2014). This work used precipitation data provided by the Regional Civil Engineering Laboratory (LREC) and Investment and Water Management (IGA), consisting of 44 stations with annual maximum daily rainfall records over 15 years, dating back to the hydrological year 1935 / 1936 and 2) In the island of Porto Santo, the precipitations for the three return periods were obtained from rainfall intensity-duration curve, calculated from the Porto Santo/Aeroporto weather station data. The Porto Santo/Aeroporto daily rainfall data for the series between 1961 and 2016 and hourly rainfall data for the series between 1999 and 2016 were provided by the Portuguese Institute of Sea and Atmosphere. For all the basins, the peak flow data was obtained through the application of the HEC-HMS hydrological precipitation-runoff model.

The HEC-GeoRAS/HEC-RAS hydraulic model was used to map flood extent, flood velocity and flood depth. Considering that in mountain basins flash floods may trigger the mobilization of varying amounts of solid load (Garrote *et al.,* 2018) the integration of the solid material in the Madeira island basins was done by establishing in the cross-sections the deposition volume. A more detailed description of the technical aspects of hydrologic and hydraulic models is outside the scope of this paper, but can be accessed in the report describing the studies for obtaining the flood risk maps the flood risk maps of the ARM (DROTA, 2016).

After obtaining the flood velocity maps and flood depth maps, the flood hazard maps were calculated based on the critical values described in table III.

Table III – Risk description.

Quadro III – Descrição do risco.

HR = d × (v + 0.5)	Level of flood threat	Risk description (considering only the population)
< 0,75	Nonexistent (N)	–
0,75 – 1,25	Low (L)	Caution
1,25 – 2,5	Medium (M)	Danger to some
2,5 – 7	High (H)	Danger to most people
> 7	Very High (VH)	Danger for the whole population

The adverse consequences mapping was carried out as a result of the reclassification of land use, and integrating the potentially affected areas, trough identifying and locating the exposed populations and infrastructures. The following types of potential adverse consequences were considered: number of inhabitants potentially affected; cultural heritage; economic activity; and environmental consequences.

The flood risk maps combine the hazard flood mapping and the potential adverse consequences maps. The degree of flood risk is obtained intersecting the flood hazard class and the potential adverse consequences level, following the risk matrix in figure 3.

Consequences \ Hazard	Insignificant	Low	Medium	High	Very High
Minimum	N	N	L	L	M
Low	N	L	M	M	H
Medium	L	M	M	H	H
High	L	M	H	H	VH
Maximum	M	H	H	VH	VH

Fig. 3 – Risk matrix. N: Nonexistent; L: Low; M: Medium; H: High; VH: Very High. Colour figure available online.

Fig. 3 – Matriz de risco. N: Inexistente; L: Baixo; M: Médio; H: Alto; VH: Muito Alto. Figura a cores disponível online.

In addition to the representation of the risk class deduced from the risk matrix, some mountain streams that cross populated areas were mapped. These watercourses were identified from the list provided by the Regional Direction of Social Equipment and Conservation and are classified into two classes of risk. The high risk class includes areas adjacent to mountain watercourses that have been affected by known historical events of landslides and consequent formation of floods. The medium risk class includes all other areas of flood trajectories that can to be affected by extreme events, whose future human occupation is unfeasible, or which have undergone structural reinforcement and protection interventions.

3. Flood risk management plan

As required by the FRD 2007/60/EC and Portuguese legislation, on the basis of the flood hazard maps and flood risk maps, a flood risk management plan was established. The general objective of the ARM Flood Risk Management Plan is to reduce the potential harmful consequences of floods to human health, the environment, cultural heritage, infrastructure and economic activities, in areas identified as having significant potential risks. This general objective integrates the following strategic objectives: i) Increasing the perception of flood risk and strategies of action in the population and in the social and economic stakeholders; ii) Improve knowledge and predictive capacity for a better flood risk management; iii) Improve spatial planning and exposure management in flood areas; iv) Improve resilience and reduce the vulnerability of elements located in areas of possible flood; v) Contribute to the improvement or maintenance of good water bodies.

The ARM Flood Risk Management Plan followed the disaster management cycle phases. For this effect, establishes the measures to be implemented according to four types: Recovery and Learning, Prevention, Protection and Preparedness. This plan composed of a set of 46 measures that have as strategic framework the obligation to reduce the risks associated with floods, considering the time period that takes to execute the measure and the time available to carry out it, until 2018, 2019 or 2021. The measures are applied considering the following aspects: a) the type of exposed elements, and the risk to which they are exposed; b) The geographical areas where several relevant exposed elements (e.g. population) are or may be located; c) The basin or part of the river basin, where the Critical Zone is integrated, (aiming to reduce the gravity of the phenomenon). Finally, the effectiveness of the measures must be assessed, which depends, of course, on the return period for which results are to be achieved.

An important issue in the ARM Flood Risk Management Plan development was the strong public participation and stakeholder involvement. Besides the meetings with the main stakeholders, two public presentations were made focused on the presentation of flood risk maps and the flood risk management plan. In parallel, the plan was subject to a period of public consultation resulting in a report containing the answers to all participants.

The preliminary flood risk assessment, the flood hazard maps, the flood risk maps and flood risk management plan were uploaded into the European Environment Agency (EEA) reporting obligations database (available at https://rod.eionet.europa.eu/obligations/603/).

For simpler and faster access to flood hazard maps and flood risk maps, geographic information was uploaded into a webgis application (fig. 4).

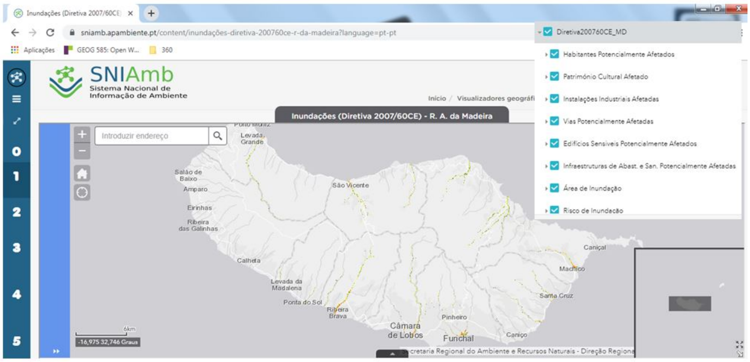

Fig. 4 – Geographic information viewer. Colour figure available online.

Fig. 4 – Visualizador de informação geográfica. Figura a cores disponível online.

Source: National Environment Information System (available at https://sniamb.apambiente.pt/content/inunda%C3%A7%C3%B5es-diretiva-200760ce-r-da-madeira?language=pt-pt)

III. CASE STUDY

This section demonstrates the procedures described above using the Socorridos critical area as case study.

The watershed of Ribeira dos Socorridos is located in the south coast, flows in a steep valley surrounded by mountains and is one of the most extensive on the island (fig. 5). A business park, several companies and important regional infrastructures, are located in the terminal section.

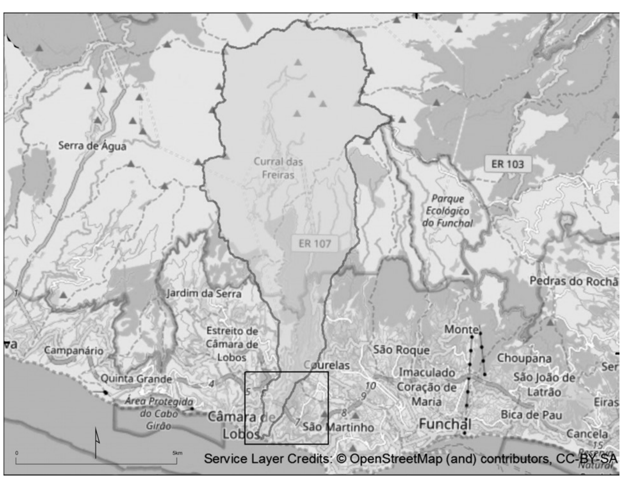

Fig. 5 – Case study (Socorridos catchment) location.

Fig. 5 – Localização do caso de estudo (bacia hidrográfica da Ribeira dos Socorridos).

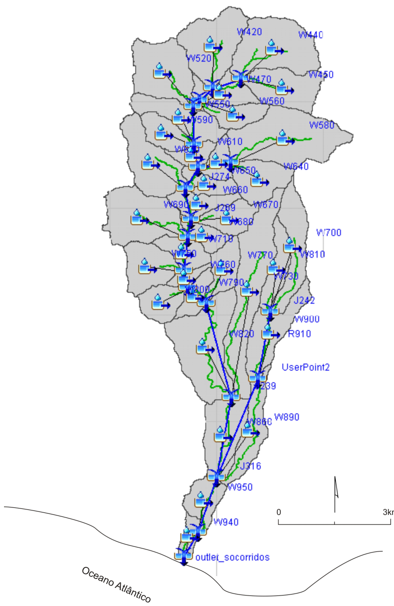

Fig. 6 – Topology considered in hydrological modelling in Ribeira dos Socorridos watershed. Colour figure available online.

Fig. 6 – Topologia considerada na modelação hidrológica da Ribeira dos Socorridos. Figura a cores disponível online.

Figure 6 shows the topology considered in the hydrological modelling of the Ribeira dos Socorridos watershed. The hydrological model allowed obtaining the flow rates for different return periods in several river cross-sections. At the outlet of Socorridos stream, the maximum flood discharges, are 844.7m$^{3/s}$ (Q20), 1067.2m$^{3/s}$ (Q100) and 1326.3m$^{3/s}$ (Q500) (fig. 6).

In the geometric hydraulic model, the sections were located taking into account transitions along the watercourse, changes in direction, contractions, expansions and steep slopes, resulting for the Ribeira dos Socorridos watershed in a hydraulic model with 795 river cross-sections cutlines (fig. 7).

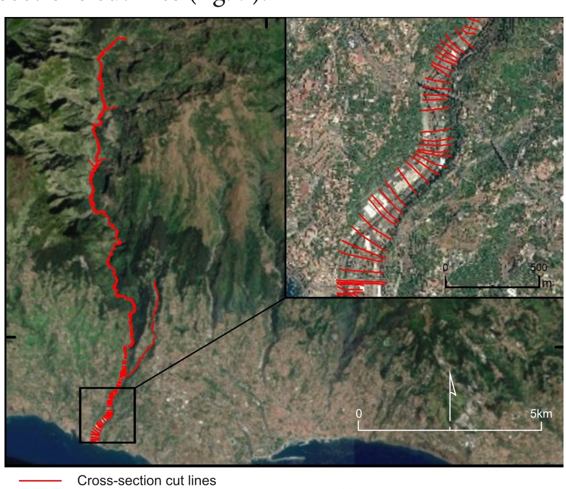

Fig. 7 – Socorridos river cross-section cutlines. Colour figure available online.

Fig. 7 – Secções da Ribeira dos Socorridos. Figura a cores disponível online.

Part of the ARM Flood Risk Management Plan was the proposal of flood protection measures in the watershed of Ribeira dos Socorridos based on hazard and risk maps (figs. 8 and 9) obtained from the hydraulic modelling.

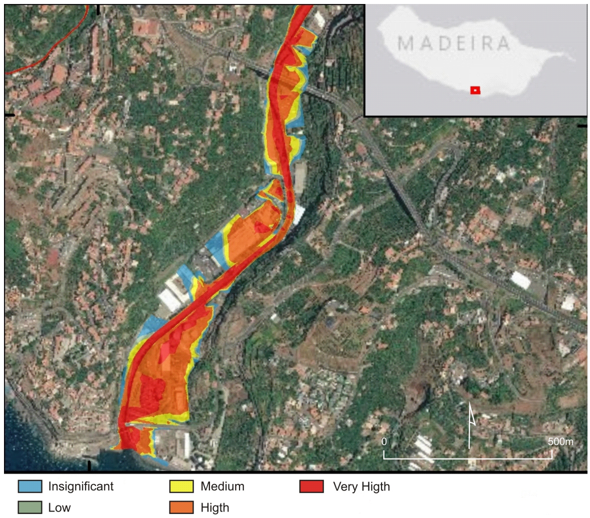

Fig. 8 – Socorridos flood hazard map. Colour figure available online.

Fig. 8 – Carta de zonas inundáveis dos Socorridos. Figura a cores disponível online.

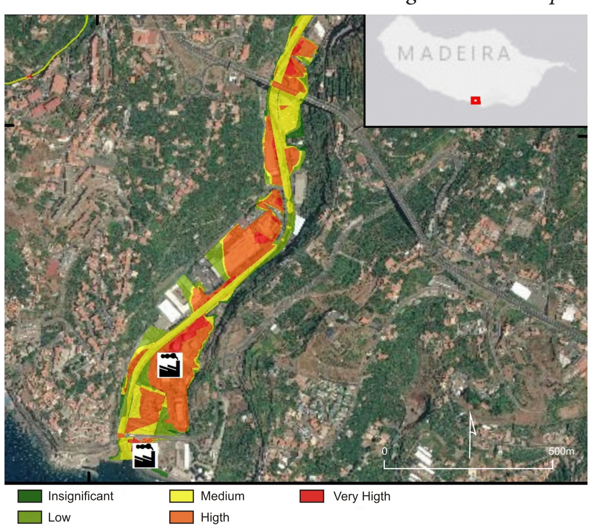

Fig. 9 – Socorridos flood risk map. Colour figure available online.

Fig. 9 – Carta de riscos de inundações dos Socorridos. Figura a cores disponível online.

Although the population potentially affected in the different scenarios is small, in terms of exposed elements there is a high economic vulnerability due to the number and type of potentially affected companies (table IV).

Table IV – Summary of Socorridos watershed exposed elements.

Quadro IV – Resumo dos elementos expostos na bacia hidrográfica dos Socorridos.

Return period, T (years)	Population potentially affected	Water infrastructures	Industries (SEVESO&IPPC)	Agriculture (ha)	Tourism accommodation	Heritage buildings
T20	138	5	2	1,033	–	–
T100	192	7	2	1,286	–	–
T500	210	7	2	1,524	–	–

In this critical area, two important facilities are established and were identified in the plan. The Thermal Power Station of Vitória and the Autonomous Unit of Natural Gas are two companies in the energy field that operate in the critical area of the Socorridos and develop their activity for the whole island. The Thermal Power Station of Vitória aims the production of electric energy, from petroleum fuels. This industry is covered by the Directive 2012/18/EU and the Decree-Law no. 127/2013 on the control of major-accident hazards involving dangerous substances. The Autonomous Unit of Natural Gas is covered by the Directive 2010/75/EU on integrated pollution prevention and control.

The ARM Flood Risk Management Plan measures are organized in generic and specific measures. For the critical area of the Ribeira dos Socorridos, 27 generic measures were established. The generic measures include studies, legislation, topographic surveys or dissemination and awareness actions. The specific measures are dedicated to the critical zone, and in Socorridos the following can be highlighted: reinforcement of longitudinal structures (walls), compatibilization with the Internal Emergency Plan and strengthening the Thermal Power Station of Vitória self-alert system.

IV. DISCUSSION AND CONCLUSIONS

In this paper the strategy regarding the implementation of the Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks is discussed within the context of ARM. The research shows that ARM Flood Risk Management Plan is focused on prevention, protection, preparedness and recovery measures, addressing all aspects of flood risk management. One of the central aspects of the plan is the implementation of measures to increase the knowledge of the debris hazard in the context of Madeira island. Further research in mountain basins flash floods and debris hazard need to be carried out to improve the models and outputs. Although some structural measures were still defined, the focus of the measures was the implementation of non-structural initiatives on the reduction of the likelihood of flooding like spatial data collection, providing flood information to citizens, debris forecasts and early warning systems or the development of emergency plans. The promotion of sustainable land use practices and spatial planning restrictions to be included in municipal master plans are also other important measures that will prevent urban development in risk-prone areas.

The methodology adopted in hydrological modelling was conditioned by the availability of hydrometric data as well as the existence of previous studies. In hydraulic modelling, although several altimetric data sources were available, it was decided to use altimetric data from the 2007 aerophotogrammetric survey at 1:5000 scale, notwithstanding the limitations associated with the scale and temporal outdating. These limitations associated with hydrometric data availability, altimetric accuracy and temporal outdated data were considered in the development of the plan through data acquisition and studies development actions.

It is expected that in the next revision/update of the ARM Flood Risk Management Plan these difficulties will be overcome, allowing an evolution of the plan that takes into account the likely impacts of climate change on the occurrence of floods.

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