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EAST AVERT Project

TECHNICAL REPORT

COMMON METHODOLOGY FOR PRFA AND HAZARD AND RISK MAPPING

2017

The prevention and protection against floods in the upper Siret and Prut River Basins, through the implementation of a modern monitoring system with automatic stations – EAST AVERT Project

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TECHNICAL REPORT

COMMON METHODOLOGY FOR PRFA AND HAZARD AND RISK MAPPING

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CONTENT

1. INTRODUCTION

In the last 10 years most rivers in eastern Romania (Siret, Prut, Trotus, etc.) far exceeded historical flows and damages to property or loss of life are increasing.

The Prut hydrographic area is located in the north - eastern part of the Danube basin and bordered by the Tisza River to the north-east, Siret River to the west and Nistru River to the north and east.

The Prut river basin is located on the territory of three countries: Ukraine, Romania and Moldova. The total area of the basin is 28,433 km^2, almost 40% being located in Romania. The second longest tributary of the Danube River, the Prut River (991 km) forms the border between Ukraine and Romania on 39 km and between Romania and Republic of Moldova on 713 km.

The Prut River has its source in the Cenahora Massif (Wooded Carpathians of Ukraine) at an altitude of 1580 m, flowing into the Danube at an altitude of 2 m. The total length of the hydrographic network is 4540 km with a density of 0.413 km/km^2. The average altitude varies between 130 m in the central area and 2 m at the confluence. The average slope of the basin is 2 ‰. A feature of the Prut river basin is its elongated shape with an average width of about 30 km. River basins of the encoded tributaries keep the same high elongation and orientation parallel to the Carpathian Mountains.

Siret River Basin is located in the eastern part of Romania, on the area between 24° 49' east longitude (to the west) and 28°02' east longitude (to the east) and 45°03' north latitude (to the south) and 47°58' north latitude (to the north). Between these limits, the basin has an elongated north-south direction, spread over 3°13' latitude and 2°58' longitude. The catchment has a total area of 44742 km^2, 42651 km^2 of them in Romania assigned to a number of 8 main river basins. The surface of this area is drained by a river system consisting of 86 encoded water courses with a total length of 15157 km.

The assessment of flood potential is described by hazard and risk. Unlike hazard which only indicate the occurrence possibility of a dangerous hydrological phenomenon, flood risk indicates potential assets and human damages in the floodplains, as well as the degree to which they may be affected. The purpose of flood hazard and risk maps is the geographical identification and illustration of areas at different level of risk from flood hazard. The two types of maps are useful tools for national and local authorities in order to establish feature common measures for protection of the border areas in the upper Siret and Prut River Basins against the flood risk and reducing the environmental, economic and social vulnerability of targeted localities from the border region. The flood risk mapping highlights areas where significant damage of houses, socio-economic objectives, roads, agricultural land, etc. can be recorded, and can be used to develop regional and local flood risk mitigation plans and cost-benefit analyses for future hydraulic works. Also hazard maps can serve to carry out synthetic assessments in case of hydrological warnings.

Siret and Prut are two of the Romanian transborder river basins, part of the drainage area being located in Ukraine and Republic of Moldova. As shown in Flood Directive, effective flood prevention and mitigation requires cooperation between the third countries. This is in line with international principles of flood risk management, which can be achieved only if the parties located in a transnational river basin cooperate.

This report presents the methodological approach regarding the flood hazard and risk used in the framework of EAST AVERT project, which is in line with methods used by Romania under the Flood Directive. Applying unitary methods in order to carry-out the flood mapping by partners from Ukraine and Republic of Moldova is one of the ways for current project implementation.

This document briefly describes the achievement of the mapping step, known as Flood Hazard and Risk Mapping (FHRM). Hazard and risk maps can be used to get the knowledge on the areas exposed to floods (basically by detailing the flood extent) and associated risks, in order to be made available to national and local decision makers (government institutions, city halls, etc.) for Flood Risk Management Plans (FRMP) development, population awareness and public information regarding risks in the living or other interest areas, and for other general purposes.

2. FLOODS DIRECTIVE GENERAL REQUIREMENTS

The European Directive 2007/60/EC on the assessment and management of flood risks, endorsed in 18 September 2007, aims to reduce the adverse consequences on human health, the environment, cultural heritage and economic activity associated with floods in the Community. The Floods Directive sets out the requirement for the Member States to develop three kinds of products (Fig. 2.1):

- a preliminary flood risk assessment: the aim of this step is to evaluate the level of flood risk in each river basin district or unit of management and to select those areas on which to undertake flood mapping and flood risk management plans;
- flood mapping comprising of hazard maps and risk maps: the flood hazard maps should cover the geographical areas which could be flooded according to different scenarios; the flood risk maps shall show the potential adverse consequences associated with floods under those scenarios;
- flood risk management plans: on the basis of the previous maps, these plans shall indicate the objectives of the flood risk management in the concerned areas, and the measures that aim to achieve these objectives.

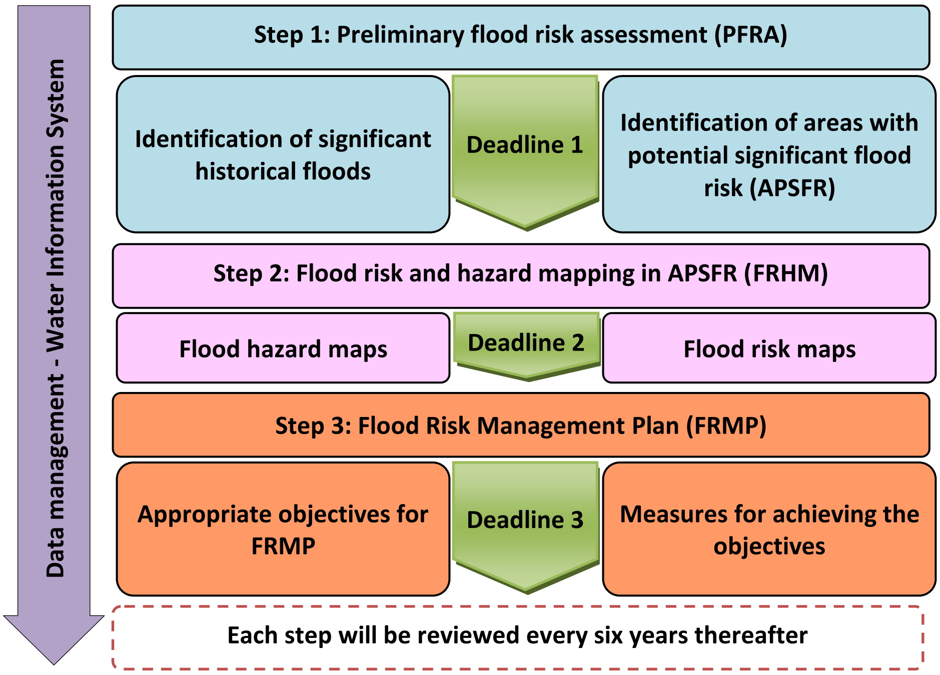

Figure 2.1 **– Steps for the Flood risk management planning process**

This directive asks the Member states to implement flood mapping according to some minimum recommendations. These are outlined in Article 6 of the Directive:

6.3. Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

(a) floods with a low probability, or extreme event scenarios;

(b) floods with a medium probability (likely return period ≥ 100 years);

(c) floods with a high probability, where appropriate.

6.4. For each scenario referred to in paragraph 3 the following elements shall be shown:

(a) the flood extent;

(b) water depths or water level, as appropriate;

(c) where appropriate, the flow velocity or the relevant water flow.

6.5. Flood risk maps shall show the potential adverse consequences associated with flood scenarios and expressed in terms of the following:

(a) the indicative number of inhabitants potentially affected;

(b) type of economic activity of the area potentially affected;

(c) installations […] which might cause accidental pollution in case of flooding and potentially affected protected areas […].

(d) 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.

This document describes the provisions for the first and second steps (see Fig. 2. 1), the PFRA content, the development of flood hazard maps and flood risk maps - and provides instructions on using the information contained in the flood risk maps.

3. PRELIMINARY FLOOD RISK ASSESSMENT

Preliminary flood risk assessment (PFRA) involves identifying significant historical floods that had significant consequences over: human activity, environment, cultural heritage and economic activity, but also designating the areas with potential significant flood risk, namely areas where floods may occur in the future.

Identifying Areas (zones or sectors) with Potentially Significant Flood Risk (APSFR) is the final purpose of the Preliminary Flood Risk Assessment (PFRA) and it is based on a series of products developed at this stage (Fig. 3.1). In these identified areas hazard maps and risk maps will be developed.

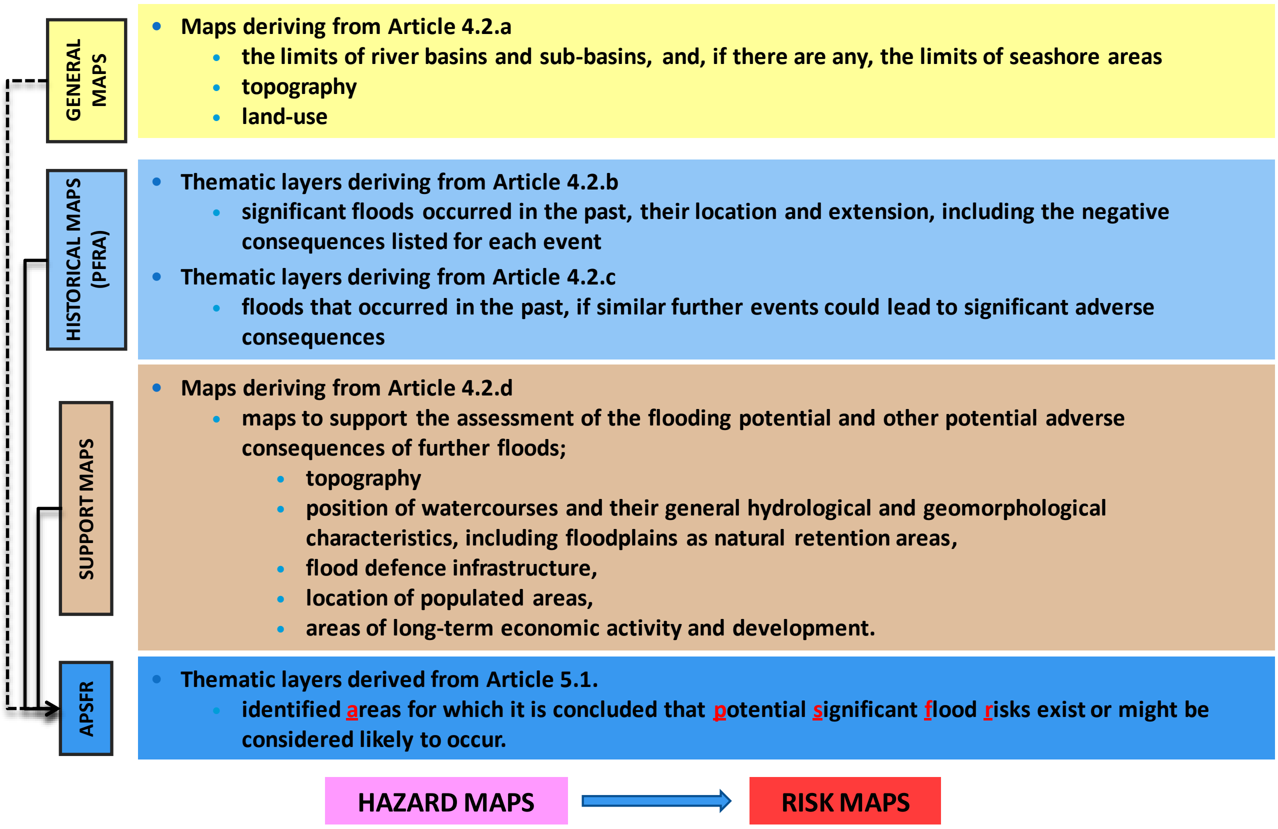

Figure 3.1 **- Types of products deriving from Flood Directive, especially for PFRA phase**

Preliminary assessment is based on information currently available and/or easily deductible. In determining APFSR areas, the following information currently available was taken into account:

- Areas where extreme historical floods have been occurred;
- Other potential flooding areas, as a wrap of extreme floods;
- Assessment of the potential impact of floods (potential consequences).

If the first criterion is covered by the detailed analysis that was done in the PFRA, identifying of other potential flooding areas (future floods) requires the development of some simple tools and methodologies. Defining and applying the criteria for selecting significant historical floods are essential because the core of the art. 4 requirements in Flood Directive are to use information on past significant floods as the basis for identifying the place where floods may occur in the future (Fig. 3.2).

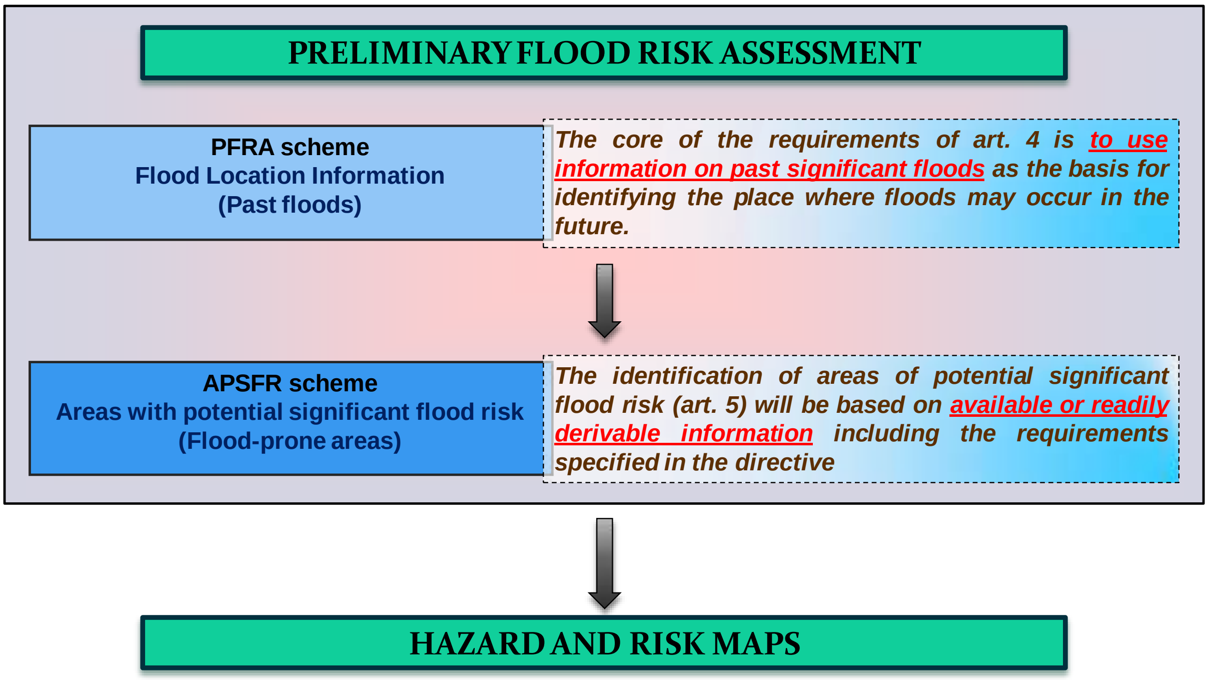

Figure 3.2 **- Place of the APSFR phase in the Flood Directive: beneficiary of the PFRA and support for Hazard and Risk**

To assess the potential consequences inside de flooding zones, a set of selection criteria must be defined and evaluated. The indicators are based on some socio-economic factors, such as: population, roads and railways, industrial areas, protected areas, bridges, buildings, arable land, other land use etc.

In order to satisfy Floods Directive requirements, collected data and information have to allow the identification of floods that occurred in the past and that have significant negative effects on human health, environment, cultural heritage and economic activity. To achieve this purpose, a relational database containing information from various documentary sources has to be created.

The reporting schemes, description of the codes and the attributes used, including data type, description of the relationships between the various elements, were developed at EU level and were the subject of Reference books for reporting within Directive. The structure of this database was imposed by the technical specifications adopted according to the Floods Directive (Table 3.1).

Table 3.1 - Features to describe the floods included in PFRA

Feature	Type/Sub-type	Description
Source of flooding	Fluvial	Flooding of land by waters originating from part of a natural drainage system, including natural or modified drainage channels. This source could include flooding from rivers, streams, drainage channels, mountain torrents and ephemeral watercourses, lakes and floods arising from snow melt.
	Pluvial	Flooding of land directly from rainfall water falling on, or flowing over, the land. This source could include urban storm water, rural overland flow or excess water, or overland floods arising from snowmelt.
	Groundwater	Flooding of land by waters from underground rising to above the land surface. This source could include rising groundwater and underground flow from elevated surface waters
	Sea water	Flooding of land by water from the sea, estuaries or coastal lakes. This source could include flooding from the sea (e.g., extreme tidal level and / or storm surges) or arising from wave action or coastal tsunamis.
	Artificial water – Bearing infrastructure	Flooding of land by water arising from artificial water-bearing infrastructure or failure of such infrastructure. This source could include flooding arising from sewerage systems (including storm water, combined and foul sewers), water supply and wastewater treatment systems, artificial navigation canals and impoundments (e.g., dams and reservoirs).
Mechanism of flooding	Natural exceedance	Flooding of land by waters exceeding the capacity of their carrying channel or the level of adjacent lands
	Defence exceedance	Flooding of land due to floodwaters overtopping flood defences
	Defence or infrastructural failure	Flooding of land due to the failure of natural or artificial defences or infrastructure. This mechanism of flooding could include the breaching or collapse of a flood defence or retention structure, or the failure in operation of pumping equipment or gates
	Blockage/Restriction	Flooding of land due to a natural or artificial blockage or restriction of a conveyance channel or system. This mechanism of flooding could include the blockage of sewerage systems or due to restrictive channel structures such as bridges or culverts or arising from ice jams or land slides.
Characteristics of flooding	Flash flood	A flood that rises and falls quite rapidly with little or no advance warning, usually the result of intense rainfall over a relatively small area.
	Snow melt flood	Flooding due to rapid snow melt, possibly in combination with rainfall or blockage due to ice jams.
	Another rapid onset	A flood which develops quickly, other than a flash flood.
	Medium onset flood	An onset of flooding, that occurs at a slower rate than a flash flood.
	Slow onset flood	A flood which takes a longer time to develop.
	Debris flow	A flood conveying a high degree of debris
	High velocity flow	A flood where the floodwaters are flowing at a high velocity
	Deep flood	A flood where the floodwaters are of significant depth
Consequences (1)	**Human health (Social aspects)**	
	Human health	Adverse consequences to human health, either as immediate or consequential impacts, such as might arise from pollution or interruption of services related to water supply and treatment
	Number of victims	Human casualties
	Community	Adverse consequences to the community, such as detrimental impacts on local governanceand public administration, emergency response, education, health and social work facilities (such as hospitals)
Feature	**Type/Sub-type**	**Description**
	Environment	

	Waterbody status	Adverse consequences ecological or chemical status of surface water bodies or chemical status of ground water bodies affected, as of concern under the WFD. Such consequences may arise from pollution from various sources (point and diffuse) or due to hydromorphological impacts of flooding
	Protected area	Adverse consequences to protected areas or waterbodies such as those designated under the Birds and Habitats Directives, bathing waters or drinking water abstraction points
	Pollution sources	Sources of potential pollution in the event of a flood, installations, or point or diffuse sources
	Other	Other potential adverse environmental impacts, such as those on soil, biodiversity, flora and fauna, etc
	Cultural heritage	
	Cultural assets	Adverse consequences to cultural heritage, which could include archaeological sites/monuments, architectural sites, museums, spiritual sites and buildings
	Landscape	Adverse permanent or long-term consequences on cultural landscapes, that is cultural properties which represents the combinesd works of nature and man, such as relics of traditional landscapes, anchor locations or zones
	Economic	
	Property	Adverse consequences to property, which could include homes
	Infrastructure	Adverse consequences to infrastructural assets such as utilities, power generation, transport, storage and communication
	Rural land use	Adverse consequences to uses of the land, such as agricultural activity (livestock, arable and horticulture), forestry, mineral extraction and fishing
	Economic activity	Adverse consequences to sectors of economic activity, such as manufacturing, construction, retail, services and other sources of employment

Areas with significant potential flood risk are mapped based on the available information about historical floods. For these areas, another database with similar attributes with the first was created at the European level.

The preliminary flood risk assessment (PFRA) involves:

- **Collection of information referring to historical floods –** data from available records and reports related to floods occurred in the basin in the past will be collected and gathered in a common data base.
- **Identification of significant past floods –** significant past floods are selected based on hydrological and impact criteria.
- **Mapping of past flood areas (GIS)** – Potential flooded areas are computed based on GIS tools and simplified procedures (modelling can be used, but it is not mandatory at this stage), that use no complex data; their representations shall be as lines or polygons.
- **Identification of areas with potential significant flood risk** by evaluating significant historical floods, potential future floods and selected indicators.

Selection of significant historical flood is performed by applying specific criteria to each country, Directive providing freedom to each Member State in definition of significant historical flood term. The criteria that led to the identification of historical floods from Romania were the hydrological criteria and criteria regarding the negative effects of floods on the four categories of consequences set out in the directive: human health, environment, cultural heritage and economic activity.

Reference historical events have been retained in two phases. In a first phase, an inventory of major floods that occurred in the past was made, based on information collected from documentary sources. This inventory identifies historical floods either in terms of hazard, either in terms of impact (damages reported). The majority of information regarding the consequences recorded and also information regarding the description of the event (in terms of precipitation amount, flow discharge, water levels recorded) was found in the reports elaborated after the flood event.

In this stage, floods were assessed by taking into account especially their probability (return period). Main hydrological criteria that led to the selection of significant historical floods were:

a) maximum flow produced > $Q_{max10\%}$;
   - $Q_{max10\%}$ is maximum flow with the 10% probability of exceeding;
b) maximum flow produced > QCI;
   - Q_{CI} represents the actual flow rate corresponding to the flood quota;
c) floods produced at hydrometric stations with large catchment area of about 100 km^2 and/or which are located in areas where relatively large floods could produce;
d) floods produced especially on the main river and tributaries at a large number of gauging stations;
e) major floods, produced on the main tributaries;

In the second phase, significant historical flood events were selected according to the various types of consequences, accordingly to Flood Directive; the approach was based on methodological criteria developed. Indicators and associated threshold values were established in order to define "significant" character in terms of damage (Table 3.2).

***Table 3.2* - Criteria for identifying significant historical national flood events according to the four categories of consequences set out in the Directive**

Categories of criteria	Indicator	Threshold values
Consequences over human activity	Life losses	Minimum 10 life losses / disappeared
	Number of social objectives affected	Minimum 2 social objectives affected (kindergarten, schools, town halls, hospitals)
Consequences over economic activity	Number of economical objectives affected	Minim 10 economical objectives affected
	Number of kilometres of road affected	Minim 200 km of roads affected
	Number of households affected	Minim 100 households affected on event or minimum 30 households for areas / localities that have been object of punctual events, with high intensity
Consequences over environment	Number of IPPC objectives affected	Minimum 1 objective affected
Consequences over cultural heritage	Number of cultural objectives affected – churches, monasteries	Minimum 1 objective affected

Following the experience of Romania, where the criteria were based on post-event reports, and the requirements of the Flood Directive (both preliminary stage and risk and hazard maps stage), a more detailed structure of indicators for consequences that should be collected after each flood is proposed (Table 3.3). The consequences are based on post-event reports.

Areas with significant potential flood risk have been defined after consulting the information currently available, in the framework of the projects Plan for prevention and protection against floods, dangerous meteorological extreme phenomena, accidental pollution and hydrotechnical constructions accidents, respectively the results obtained in the PHARE 2005 / 017-690.01.01 Contribution to the development of the flood risk management strategy (customer – Ministry of Environment and Forestry, and „Romanian Waters" National Administration). At the same time, the areas protected against floods by hydraulic works were taken into account, considering all the floods that occurred in the past and have had significant negative impacts without removal from the list of those floods that may occur in areas that have been hydraulicaly designed (embanked sectors). For Romania, Preliminary Flood Risk Assessment was followed by drawing up till December 22, 2013 hazard and flood risk maps.

Table 3.3 **- Information matching between Flood Directive requirements and detailed data gathered after flood events**

Flood Directive type of consequences		National indicators
GENERAL INFORMATION		Flood event code
		Name of flood event
		Flooded River
		Locality
		SIRUTA Code
		Local Administrative Unit
		Damage total cost Euro
Human Health	Number of inhabitants affected	Population density and affected area in each settlement
	Adverse consequences to human health	Water supply facilities (station)
		Water supply network affected (km)
		Sewerage network affected (km)
		Wells / Groundwater borehole
		Hospitals
		Victims
	Community	Town halls
		Schools
		Police office
		Movie theatre / Cultural centre
Economic Consequences	Properties	Affected homes
		Totally destroyed homes
		Household annexes
	Infrastructure	Affected railroad (km)
		Affected roads (different types) (km)
		Affected road – streets (km)
		Affected bridges, culverts or other small bridges
		Airports
		Harbour
		Railway stations
		Bus Terminal
		Electricity network (km)
		Dams

Flood Directive type of consequences			National indicators
			Reservoirs
			Affected dykes (km)
			Affected shore defences / arrangement (km)
			Hydrological or weather stations
			Channels for irrigation or draining (km)
			Other hydraulic structures
	Rural land use		Area of arable land affected (km^2)
			Area of grassland affected (km^2)
	Economic activity		Main economical facilities (included in SEVESO or IPPC)
			Manufactory
			Livestock farms / Household Livestock
			Gravel pits
			Fishing ponds
			Shopping complex
			Small shops
			Car parking
			Hotel, restaurant, B & B
			Medical offices and pharmacies
			Health resort
			Other small economic activities
Cultural Heritage	Cultural Assets		Churches
			Monuments
			Museums
Environment-Mediue	Protected Areas	Birds – SPA	Birds – SPA
		Habitats – SCI	Habitats – SCI
		National or local PA	National or local Protected area
		UWWT	UWWT
	Pollution Sources	IPPC, SEVESO	IPPC, SEVESO
		Other sources	Other sources

SPA – Special Protection Areas

SCI – Site of Community Importance

UWWT – Urban Waste Water Treatment

IPPC - International Plant Protection Convention

SEVESO - Directive 82 / 501 / EEC on the major-accident hazards of certain industrial activities

In order to map flood events optical and radar satellite data were used. For floods occurred in 2008 and 2010 in Siret and Prut basins, we identified the following data:

For 2008:

- TerraSAR-X, 27 and 29 July, 3 m resolution, Radauti-Prut area, copyright: DLR/Infoterra;
- Radarsat 1, 1 August, 12.5 m resolution, Stanca-Costesti dam area, copyright: CSA;
- DMC, 3 August, 30 m resolution, Stanca-Costesti dam area, copyright: DMC International Imaging Ltd;
- SPOT 4, 28 July, 20 m resolution, Stanca-Costesti dam area (Fig. 3.3);
- MODIS/TERRA, 28 and 29 July, 250 m resolution, Bucovina and Moldova area (Bistria and Siret rivers confluence) and Rchiteni-Pascani-Lespezi area;
- SPOT 4, 28 July, 20 m resolution, Rachiteni-Pascani-Lespezi area, Rachiteni-Saucesti (Roman-Bacau) area, Dolhasca-Halaucesti area, copyright: SERTIT, acquisition mode: International Charter;

- TerraSAR-X, 01 August, Tamaseni area;
- DMC, 3 August, Lespezi area;
- NOOA, 28/29/30 and 31 July, 1 km resolution, Bucovina and Moldova area.

For 2010:

- Radarsat-2, 30 June, 04/06/07/10/11/21/22 July, Radauti-Horia area, Mitoc-Ripiceni area, Prisacani-Grozesti (Iasi) area, Tabara-Trifesti area, Frasinesti-Nemteni area, Slobozia-Valeni area, Rogojeni-Manta areas, MacDONALD, DETTWILER and Associates Ltd (fig. 3.4).
- SPOT 5, 02 July, 20 m resolution, Botosani County, copyright: CNES.

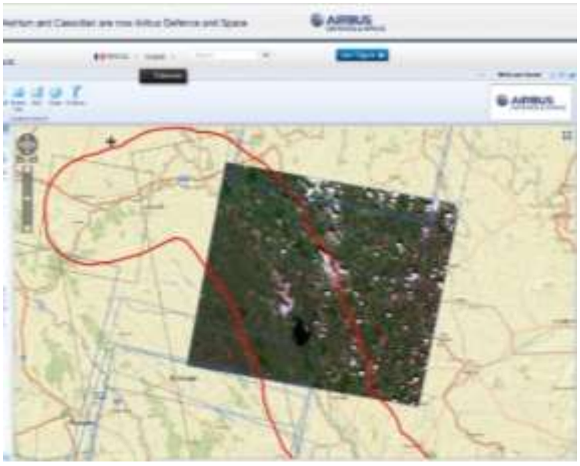

Figure 3.3 **- SPOT 4 satellite image at 20 m resolution**

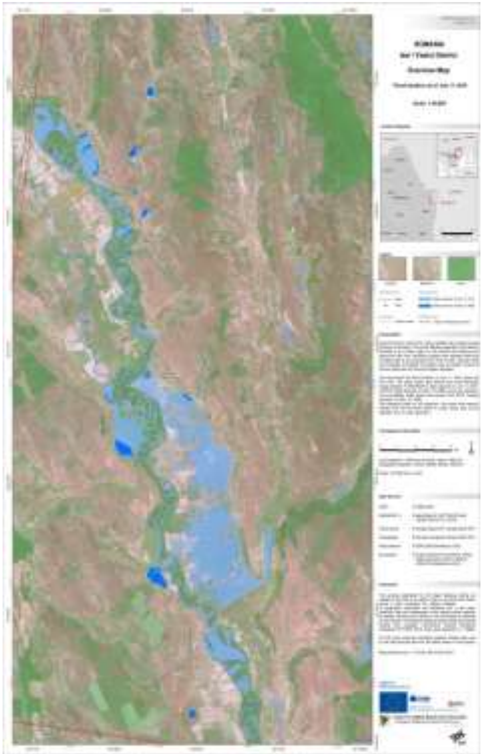

Figure 3.4 **– Flooded area in Iasi-Vaslui area based on Radarsat-2 image**

4. ANALYSIS OF THE HISTORICAL FLOODS IN SIRET AND PRUT RIVER BASINS

Floods are natural phenomena that are part of normal leakage events chain representing the peak moments in the evolution of a river's flow.

However, when they are extreme, they generate flooding, respectively overpasses the banks of the low-flow channel and temporary water covering some areas of the floodplain which normally are not below the water level.

From human perspective, a flood occurs when there are material damage and loss of life and or when the water level threatens the livelihood of society.

The selection of historical significant floods from Siret and Prut river basins was based on the following main criteria:

- The amplitude of maximum discharge;
- The size of the area on which the flood occurred;
- The amount of information available in the three countries participant in the EAST AVERT project;
- The extent of the damages;
- The accessibility to specialized publications;

The selection of the hydrometric stations for which we obtained the necessary information for the description of selected floods was mainly made in accordance to the following criteria:

- Hydrometric stations from all three countries on the rivers Prut and Siret;
- Hydrometric stations from the confluences with the main tributaries of the Siret and Prut rivers;
- Hydrometric stations in small river basins of the three countries, that allow the comparative analysis of the evolution of floods.

In Siret and Prut hydrographic basins, in the last years, there have been three major floods that can be considered "historical", in 2005, 2008 and 2010. The floods in 2005 mainly affected the lower basin of the Siret river (downstream of Movileni accumulation), being less relevant for transboundary area. Instead, the floods in 2008 and 2010 have many common features in terms of the evolution of the extreme events on the Siret and Prut watercourses.

Flood formation was favored by high rainfall due to temperate cyclone that affected north-east Romania, Republic of Moldova and Ukraine. Daily rainfall (or even hourly) data are essential for the hydrological modeling of the extreme phenomena. Torrential rains, whose values exceed in most cases 100 mm in 24 hours, even over several days (Tab. 4.1), have produced catastrophic floods.

The rainfall distribution during the the two floods periods highlight the location of maximum values (over 300 mm in 2008 and over 250 mm in 2010). They are focused on an area located in the northern part of Romania and Ukaine (Fig. 4.1 and Fig. 4.2).

Table 4.1 **– The largest amount of daily rainfall fell in the range 22-28.VII. 2008 in the Siret and Prut river basins**

River	Gaugin station	Daily precipitations recorded between 22-28. VII. 2008							Total 22-28 VII
		22	23	24	25	26	27	28	
Suceava	Brodina	3.2	23.8	52.7	102.3	107.7	10.2		299.9
Putna	Putna	3.1	27.9	107.3	39.6	25	18.4		221.3
Pozen	Horodnic	4.1	15.2	73.2	143	81.7	37.2		354.4
Prut	Oroftiana	2.8	5.5	28.9	5.7	69.6	2.1	2.5	117.1
Bahlui	Iaşi	4.5	2.7	31.2	70	0.3	13	3.3	125
Jijia	Chipereşti	14.7	3.7	29.3	58.8		13.6	1.6	121.7

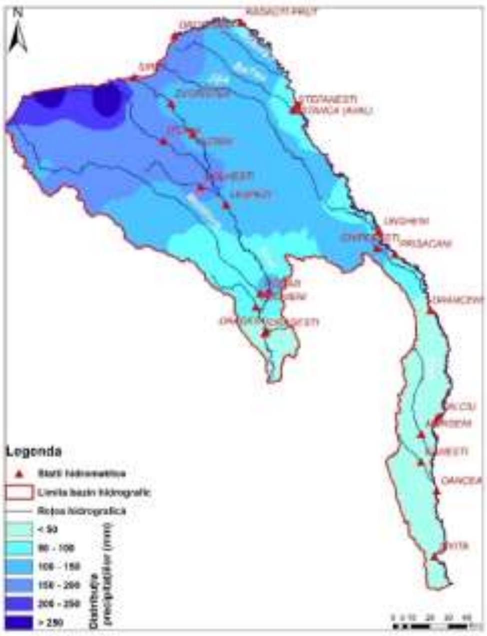

Figure 4.1 **– The distribution of cumulative precipitation quantities between 22-28.07.2008 in Siret and Prut hydrographic basins**

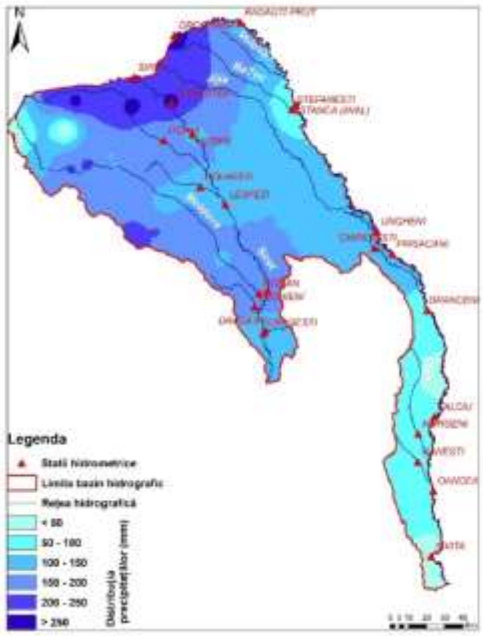

Figure 4.2 **– The distribution of cumulative precipitation quantities between 21-02.07.2008 in Siret and Prut hydrographic basins**

In case of extreme events, there are situations when maximum discharges recorded during floods are established by hydrotopographic measurements, after water withdrawal, because during high waters, the elements underlying the discharge calculation can not be measured. That was the case for the two floods with a special character, at certain stations, exceeding the values recorded up to that point. If the flood of 2008 is characterized by an extraordinary rate of flow, the one in 2010 has been defined by a very large volume, having three successive peaks (Fig. 4.3).

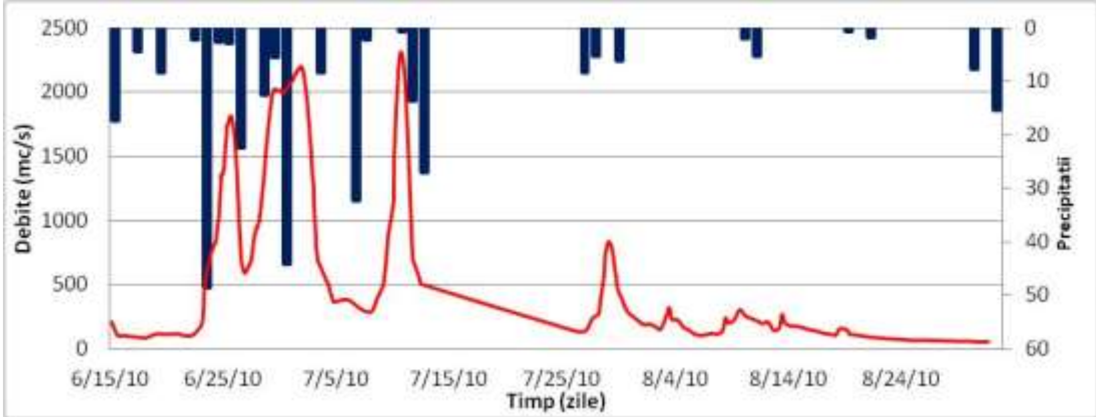

***Figure 4.3* – The flood from 15.06 - 31. 08. 2010 on the Prut River - sh Rădăuţi Prut**

Available data, as requested by the Flood Directive, for the analyzed floods, are presented in table 4.2.

***Table 4.2* – Main floods in Siret and Prut River basins**

River Basin	Flood	Flood characteristics		Flood source			Flooding mechanism		
		Natural	With remarkable levels	Fluvial	Pluvial	Artificial damming	Exceedance of riverbed transport capacity	Blockage/ Restriction	Exceedance of defence works assurance
Siret	July-2008	X	X	X	X		X		X
	June 2010	X	X	X	X		X		X
Prut	August 2005	X	X	X	X		X	X	
	July-2008	X	X	X	X		X	X	
	June 2010	X	X	X	X		X		X

For the flood characteristics the following sources of information are mainly used:

- Publications (books, magazines, papers or proceedings, etc.).
- Studies substantiating the information systems and warning of dangerous hydro-meteorological phenomena;
- Digital database existing in the 3 countries;
- Annual studies at gauging stations on rivers;
- Survey of maximum flow at gauging stations and confluences;
- Models of the greatest floods;
- Technical reports drafted after the occurrence of significant floods;
- Studies of hydrological parameters.

For historical flood descriptions, the following information is particularly required:

- Dates of occurrence;
- Flood characteristics as requested by the EU Floods Directive Framework;

- Presentation of the area where floods occurred;
- Value of the maximum flows and the empirical probability of exceeding;
- Rising time;
- Flood hydrograph at the gauging stations;
- From case to case, depending on the available data, the amplitude of precipitations that generated floods is mentioned;
- Brief description of the floods.

At a later stage, the description of floods will be supplemented with:

- Additional information with reference to the evolution in time of floods (eg. propagation time between consecutive hydrometric stations);
- Comparative analysis of floods recorded at close gauging stations (especially in areas next to Ukraine - upper basin of the Siret and Prut Rivers);
- Analysis of the impact of Stanca-Costesti reservoir in attenuation of floods;
- Information on the consequences;
- Representations in GIS.

5. SIMPLIFIED METHODOLOGY FOR PRELIMINARY EVALUATION OF FLOOD-PRONE AREAS BASED ON DEM

Representing the results of the flood simulation mathematical models, computed based on detailed stream-flow and water level data, leads to the delimitation of the flooding areas. However, first step consists of flood-prone area establishing (areas susceptible to flooding) based on terrain characteristics or recorded historical events. In addition, flood risk management usually requires consideration of much larger areas than the areas that may actually be flooded.

The development and implementation of the procedures for flood-prone area rapid mapping is an important step for knowing the potentially flooded areas, especially were no known historical events (particularly in terms of spatial covering) occurred (e.g. areas along the embankment rivers, protected by dykes).

In the preliminary assessment, the flooded areas could be considered to be not very precise, with a greater lateral extent. In the phase of the hazard maps, a more accurate extension of the flooding area will be delineated.

"Water level rise" method consists in a simplified procedure, in GIS environment, that has been developed in order to achieve flood-prone areas by using basic data: DEM (Digital Elevation Model) grid, river line (riverbed channel or riverbed thalweg) and the increasing of water level in different points (or profiles).

The core of the procedure is to generate a quasi-parallel plan to the riverbed channel passing through each value of water rise (fig. 5.1). This plan can be computed considering:

- a constant water level rise along the entire river, so that the water layer obtained by subtracting thalweg elevation from water level elevation is the same in any point;
- two different water level rise values, one for source point and one for downstream point of the river (the outlet) – fig. 5.2;
- a more complex procedure can be developed, using certain level for each cross-section: Z_1+h_1 elevation for cross section 1, Z_2+h_2 for cross section 2, etc., where “Z” represents the thalweg elevation and “h” represents the increase of the water level for each cross section.

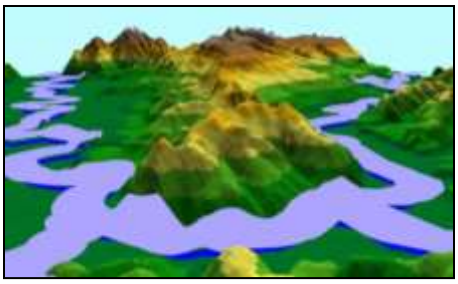

***Figure 5.1* – Computing a quasi-parallel plan to the riverbed channel**

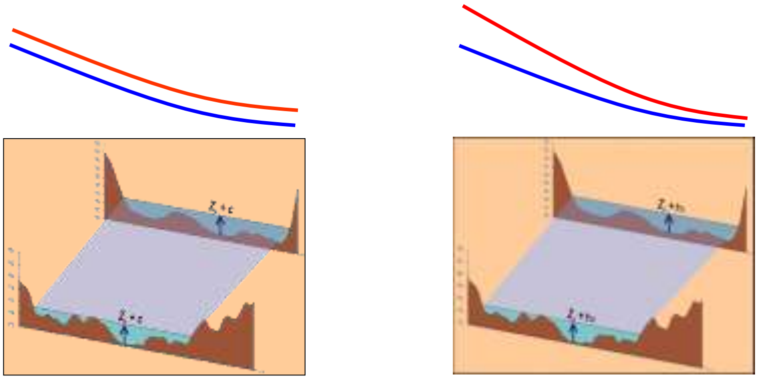

***Figure 5.2* - Computing a qusi-parallel plan that simulates the water level during extreme floods: a) using a constant value for water level rise; b) using two different values**

It is well-known that in many cases, the floodplains are wider in the lower part of the watersheds. The discharge that exceed riverbed is often characterized by a smaller layer of water comparing to the upstream sections.

The rising of water level is expressed as a relative elevation value above the elevation of the thalweg. Although the DEMs with average accuracy (ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer - or SRTM - Shuttle Radar Topography Mission) is based on interferometry technology (fig. 5.3) and do not measure elevations under water, and DEM cell resolution of 30 m lead in the case of small and medium rivers to the capture of land elevation near the riverbed, increasing the level can be considered as being above the mean water level.

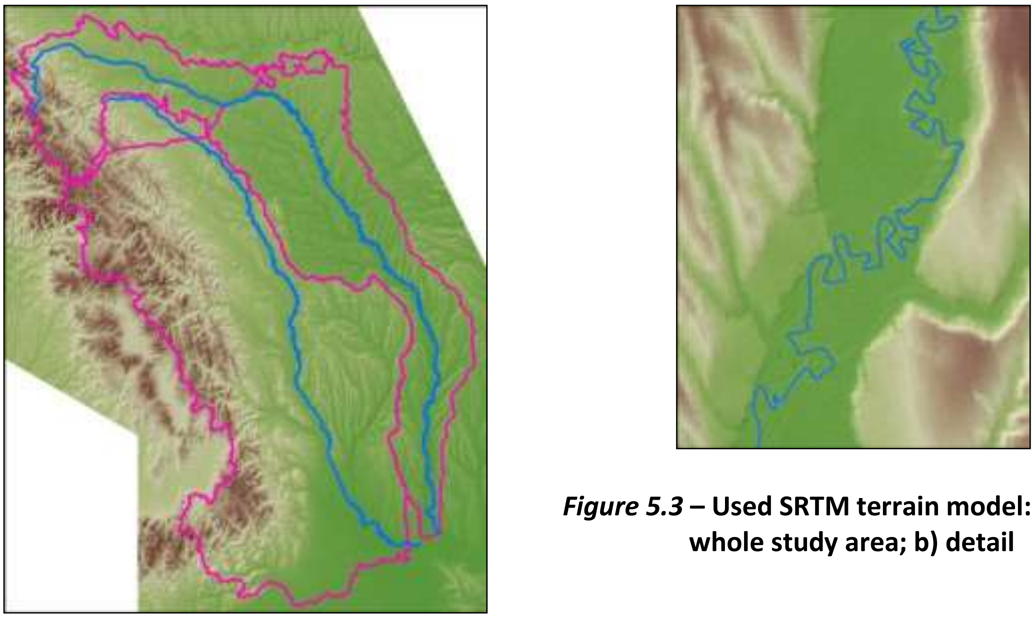

***Figure 5.3* – Used SRTM terrain model: a) at the whole study area; b) detail**

The procedure was developed using ArcGIS software. For two different values of water level rise approach and to densify vertices along a line, ET GeoWizards extension1 was needed. For constant value, only Spatial Analyst and ArcGIS functionalities were required.

[1] http://www.ian-ko.com/

To use different values for "water level rise", rivers must be connected from source to outlet. If the rivers are broken at confluences (as it is the case of the automatically generated by ArcHydro), it's easier to use a constant value (for example 5 m along entire river). If it is preferred to use a differentiated water level, that the application can complete, this connection must be computed.

The main steps in the flooding areas representation are the following:

- data collecting - DEM, river line, DEM extent polygon, maximum water level information, etc.;
- discretizing the river thalweg to points – a simple GIS procedure to convert a line to points;
- assigning to each point a value of altitude (z) based on DEM;
- calculating the water level in each point of the river thalweg, taking into account the water levels in successive cross sections:
  - for computing two different water level rise values: [RASTERVALUE]+h1-[ET_ORDER]*(h1-h2)
    - h1 - the increase of the water level in the upstream point
    - h2 - the increase of the water level in the downstream point
    - For example: 3,5 and 2 m.
  - For one level rise values is used [RASTERVALUE]+Dh, where Dh is value used for water level increasing (for example 2 m);
- computing a Thiessen polygons network corresponding to the thalweg points (fig. 5.4);
- transforming the Thiessen polygons in grid [thiessen_w], using water level in that particular point as attribute (vector – raster conversion)
- comparing water level [thiessen_w] and DEM value through the difference between the two grids (fig. 5.5):
  - positive values: the submersible area (the flood-prone area)
  - 0 value: the flood-prone area limit
  - negative values: the immersible area (above the water)
- obtaining the flooded affected area by querying and selecting the pixels having positive values - positive values of the grid is actually water depth;
- separating flood-prone areas, located in the river neighbourhood, from other potential flood-prone areas, located behind the dikes and other obstacles, representing areas with lower altitude than the forecasted water level; this step is necessary only if the water level is lower than the dike elevation (fig. 5.6).

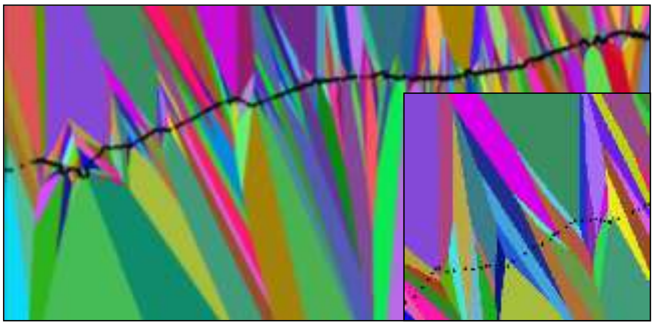

Figure 5.4 **– Computing Thiessen polygons network**

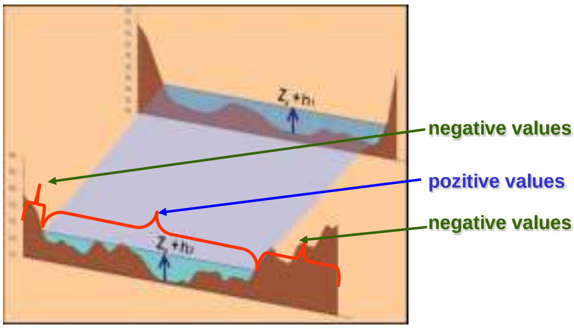

Figure 5.5 **– Types of the new grid values**

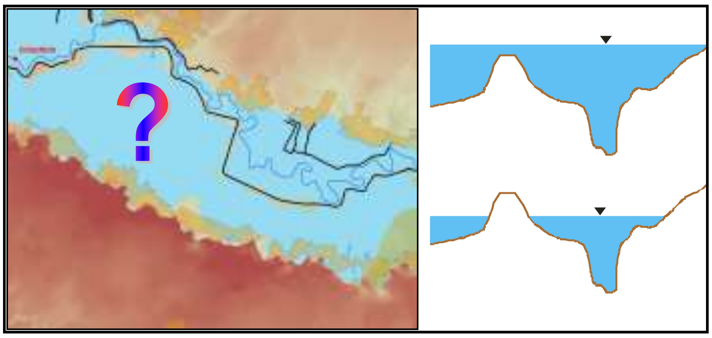

Figure 5.6 **– Potential flood-prone areas located behind the dikes**

SRTM model has been prepared for Prut and Siret basin-wide. Based on developed methodology, flood-prone areas defined by 5 m, 10 m and 15 m water level rising has been delineated (Annex 1). In order to define maximum extent for detailed DEM and other layers achievement, a 500 m buffer for +15 m water level rising will be used (Fig. 5.7).

Historical hydrological data recorded during 2008 and 2010 significant flood events allow us to evaluate the water level corresponding for an event occurred with 1% probability (1/100 years). The evaluated water level has certain accuracy, at this stage not being used a rating curve or a statistical approach.

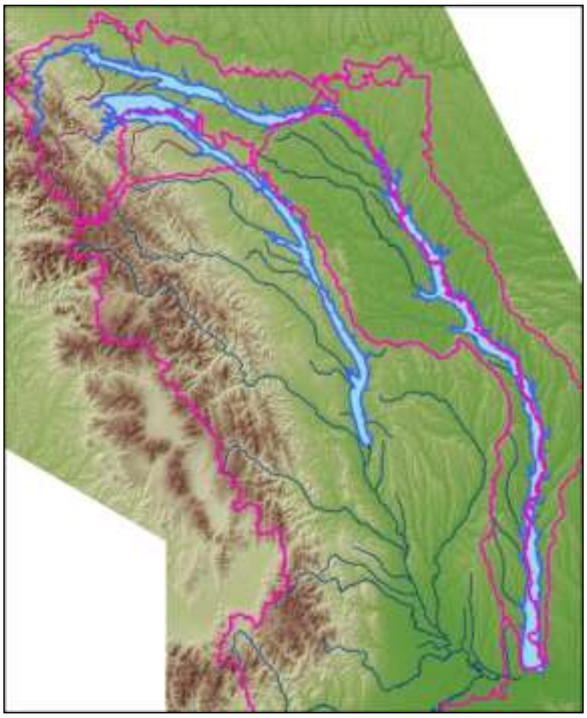

Figure 5.7 **– Preliminary maximum flood-prone areas computed based on water level rising (+15 m)**

The approximately water level rising over the talweg elevation has been established as following:

- 8 m in the Oroftiana RGS area
- 7.8 m in the Radauti Prut RGS area
- 6.2 m in the Crasnaleuca settlement area and upstream of Stanca-Costesti reservoir
- 5.5 m downstream of Stanca-Costesti reservoir
- 6.2 m in the Trifesti settlement area
- 6.5 m in the Ungheni RGS area
- 6.7 m in the Drinceni RGS area
- 6.6 m in the Falciu RGS area
- 6.2 m in the Oancea RGS area
- 5.9 m at the Prut outflow

Based on the mentioned values, the "water level rising" procedure has been applied. Based on developed work-flow, flood-prone areas defined by 5 m, 10 m and 15 m water level rising has been delineated.

For the drainage basin corresponding to Ukrainian territory, also some tributaries were considered: Maly Siret for Siret and Cheremosh and Rybnycya for Prut. For Romania and Moldova, only main rivers are taken into account (Fig. 5.8). Most likely, the flood-prone area covers about 3500 km2. An increasing of 10 m water level leads to a magnification of possible flooded area of 1000 km2 (Table 5.1).

Table 5.1 – The distribution of flood-prone areas on basins and countries.

Basin	Country	5 m	10 m	15 m
Prut	Romania	1212	1274	1340
	Moldova	714	802	867
	Ukraine	652	862	986
Siret	Romania	679	854	980
	Ukraine	298	378	434
TOTAL		**3555**	**4169**	**4607**

Comparing with the extent of flood low scenario obtained by modelling (on the middle reach of Siret River, modelled in other projects), there are locations where +5m water level not cover completely the modelling results. The area defined by +10 m water rising seems to fit quite well 1/100 years flooding area (fig. 5.8).

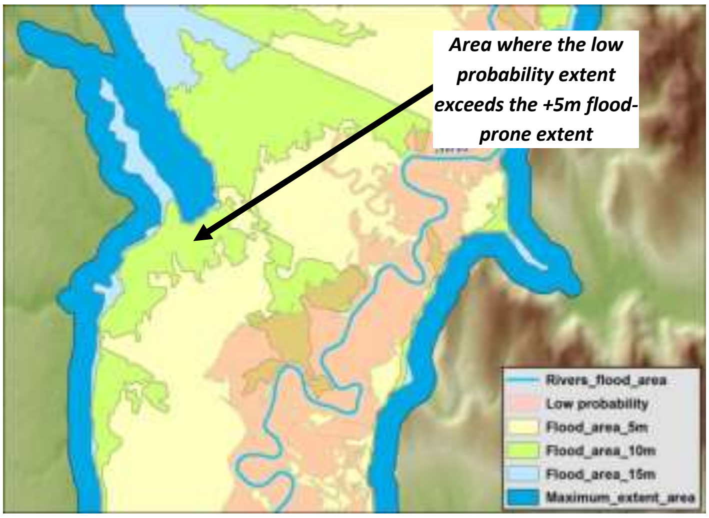

***Figure 5.8* – Comparing the extent of different water level rising and low probability scenario**

6. FLOOD HAZARD AND RISK MAPS (FHRM)

6.1 APROACHES OF FLOOD RISK

In scientific language, risk is the efect of a hazard, characterized in terms of probability. So, in order for there to be a risk, there must be a hazard, in our case a dangerous natural phenomenon, possible damages, and also a certain lack of ability to "face" that danger.

There are many methodological approaches of flood risk. In 2007 / 60 / EC Directive, flood risk is defined by the combination of two components, namely the probability (frequency) of the occurrence of floods and the potentially adverse effects on human health, environment, cultural heritage and economic activity associated with them.

One of the first papers that quantify the effects of floods by two distinct elements, namely exposure and vulnerability, is the article by W. Kron (2002), entitled "Flood risk = hazard x exposure x vulnerability".

According to the „European flood risk mapping” document, developed by the JRC under the 2005 Weather Driven Natural Hazards program, flood risk is defined as the product of three components (Barredo et al., 2005, Lavalle et al., 2005; Atlas of Flood Maps, 2007):

- Hazard: producing a natural event that is threatening, including its probability of occurrence;
- Exposure: the value of material goods and the number of population that is present in the affected area;
- Vulnerability: lack or loss of resistance to destructive forces or damages produced.

Flood hazard is one of the two main components of risk, being defined by the probability of exceeding of peak discharges (return period). Statistically, the period during which a certain discharge is exceeded is even higher as that discharge is higher.

Flood hazard maps include the main features of a flood generated by a flow with a certain probability of exceedance. Knowing that in hazard maps is modelled a future event rather that one which has already occurred, they shall be considered as “scenarios”. In fact, these maps provide more accurate information in areas that have been identified as susceptible to flooding (Fig. 6.1).

In most documents, including the Floods Directive, it is recommended to use 3 hazard classes and 3 flooded areas, with low, medium and high probability of exceeding.

The link between probability of exceeding P and return period RP can be determined by relation P(%) = 100 / RP (years). The most used periods in practice are presented in Tab. 6.1.

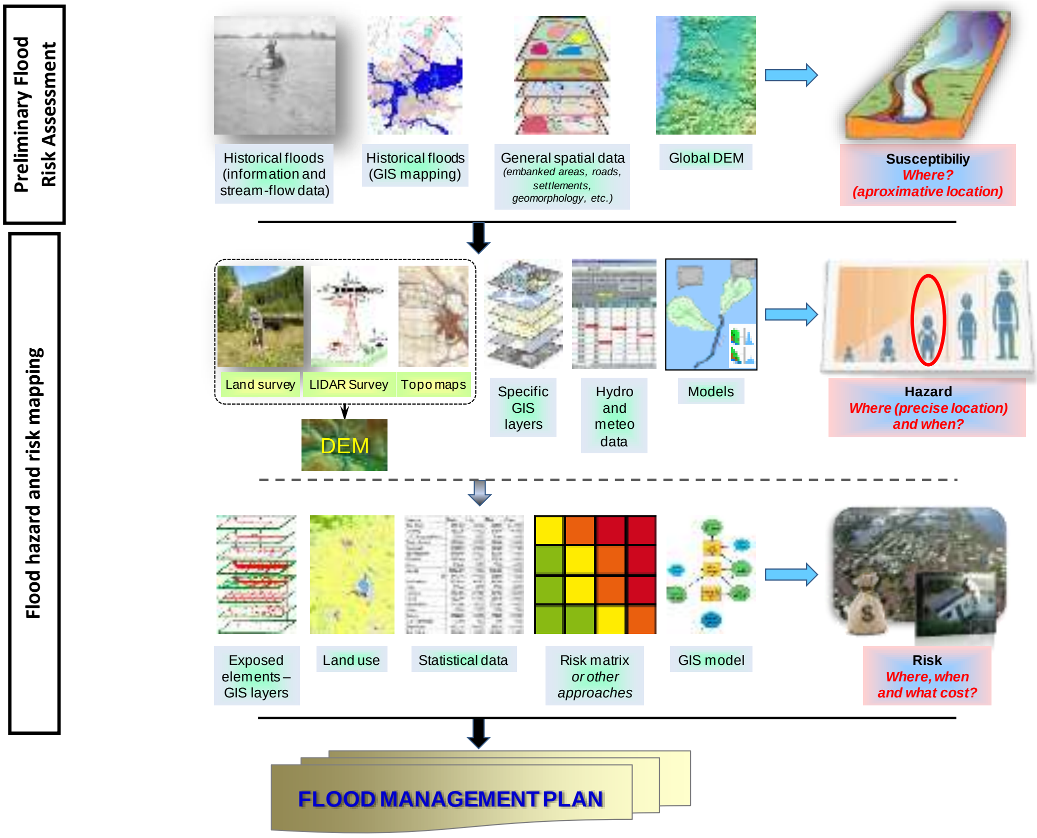

Figure 6.1 **– The place of FHRM phase in the framework of flood management and main data involved**

Table 6.1 – Correspondence between return period and probability

Return period (years)	**1000**	**500**	**200**	**100**	**50**	**30**	**10**
Probability (%)	0.1	0.2	0.5	1	2	3.3	10

The flood characteristics highlight the magnitude of the phenomenon through water depth, velocity and flood duration. However, in most cases, the hazard map only represents flood-prone areas in the river floodplains and water depth generated by peak discharge with a certain probability of exceeding.

Flood risk maps show not only where floods can occur and their magnitude, but also their potential consequences, in quantitative (monetary) or qualitative (intensity) terms, being a combination of hazard and vulnerability.

Vulnerability is difficult to quantify, this parameter must indicate the potential to react to a dangerous phenomenon and / or to support it, to adapt to it (FLOODsite, 2008). For example, in UK, is defined the vulnerability of the territory, depending on the effectiveness of hydrological warnings, the speed of installation and propagation of the phenomenon, the nature and usefulness of the buildings, as well as the vulnerability of the population, depending on the number of the very aged population, sick, infirm or long-term disabilities people (De Bruijn, 2009; DEFRA, 2006).

One of the FAME (The Floodrisk and damage Assessment using Modelling and Earth observation techniques) reports suggests risk assessment through a matrix (Fig. 6.2) as a function of hazard level (P1, P2, P3) and exposure (E0, E1, E2, E3). This scheme can be easily adapted, even if the probabilities of exceedances are other than those currently used. The exposure classes depend on land use (Willems et al., 2003).

Exposure class	**Hazard level**		
	P1 100 < T < 1000	**P2 10 < T < 100**	**P3 T < 10**
E0	R0	R1	R1
E1	R1	R2	R3
E2	R2	R3	R4
E3	R2	R4	R4

where:

R0 = very low flood risk;
R1 = low flood risk;
R2 = medium flood risk;
R3 = high flood risk
R4 = extreme flood risk.

Figure 6.2 **– Methodological approaches to risk assessment - Flood risk matrix (source: Raport FAME);**

Most approaches use qualitative classes, since quantitative classification requires more detailed data. An example of such qualitative approach are the damage functions that are applied to each of the different asset classes: a damage function describes the damage in percent of the total value of a specific land use (Fig. 6.3). Different land uses may also have a different susceptibility to floods (Danube Atlas. Hazard and risk maps, 2012).

The interpretation of FHRM documents, developed as support for Flood Directive reporting, lead to the definition of flood risk maps as a document showing flooded areas in various scenarios (various probabilities of exceeding), potential consequences (economic activities, including infrastructure, pollution sources, protected areas, cultural sites, other useful information, etc.), and potentially affected population, referring to the number of inhabitants living in the flooded area.

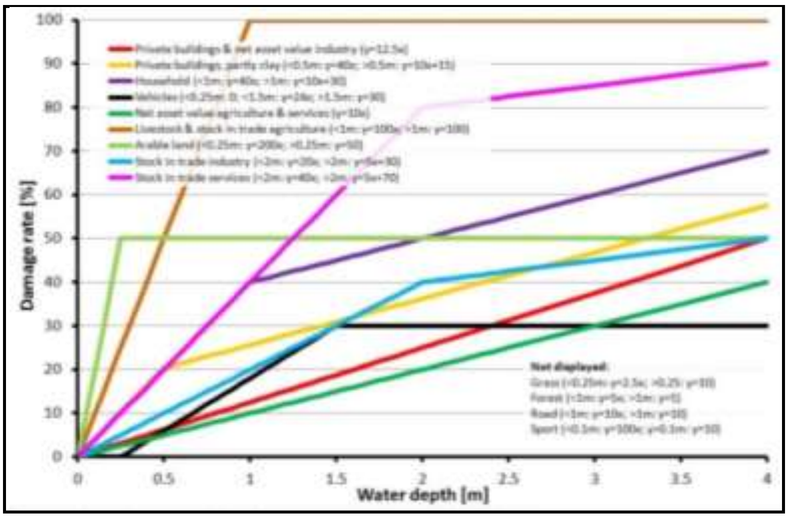

Figure 6.3 **– Damage functions used for damage assessment (According to Andre Assman – Geomer GMBH)**

Hazard maps developed under the Floods Directive in Romania have no legal or ruling scopes and don't provide the adequate degree of accuracy required by buildings / construction designation, especially those of industrial type, roads, wastewater treatment / sewage facilities, etc. However, knowing the floods and the boundaries of flooded areas can allow to reduce the floods' damages by forbidding the building of new constructions in flooded areas and impacting the urbanisation rules.

The mapping step will result in the production of maps of flood risk areas, as well as a Geographic Information System (GIS). This GIS is intended not only to offer the necessary support for modelling, but also to make the maps, facilitate the dissemination of information and improve the visibility for the public.

6.2. MAIN PRODUCTS FOR FHRM REPORTING

For each Area of Potentially Significant Flood Risk (APSFR), Member States shall prepare flood hazard maps and flood risk maps. There are some differences between information type reported at EU level and the one prepared for national dissemination, with more accuracy and more detailed products for the last one (Fig. 6.4).

The data related to the description of the flood consequences, needed for completing the FHRM database, is common with the data used for Preliminary Flood Risk Assessment (PFRA). Even if in most cases, the database has to be filled-up only with a general code, at the national level more detailed data must exist.

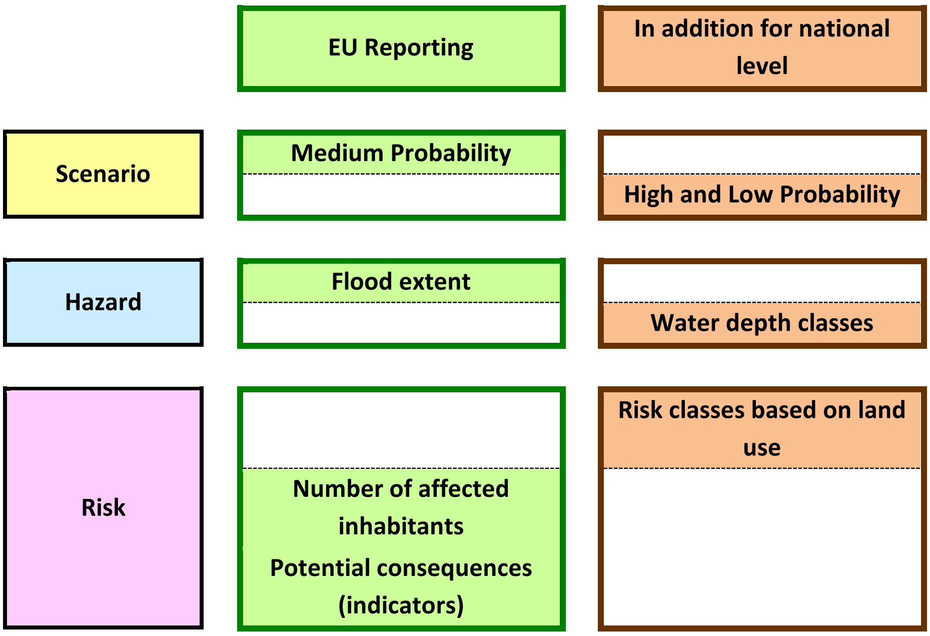

Figure 6.4 **- Mandatory flood hazard and risk information required by FD and those additional disseminated just for national level**

6.3. FHRM DISSEMINATION

Information to be reported includes geographical information (i.e. maps), alphanumerical data, summary text and other information. Detailed maps should not be directly reported to EU, but only maps displaying the flood extent. For detailed maps, the Member States should provide links to Web Map Services (WMS), Web Feature Services (WFS) or PDF versions.

The preferred solution is WMS or WFS with compliance to the INSPIRE Directive. This requires that the Member States implement public web mapping platforms for public consultation and dissemination requirements (WMS).

National authorities have the responsibility to implement a public web mapping platform both for the active information of the public (as requested by the Directive) and for providing remote access to maps required for the EU reporting.

Optionally it may contain more data than will be represented on maps and subsequently be enriched by new knowledge on hazards or issues (Fig. 6.5).

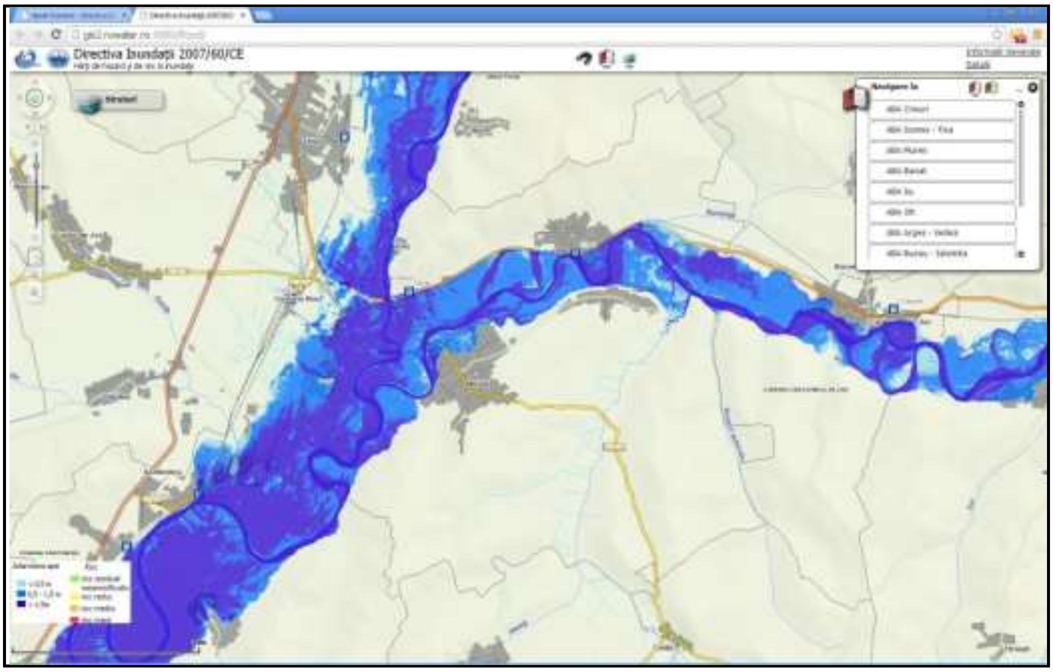

Figure 6.5 **– Example for Romanian data portal for hazard and risk maps dissemination**

7. METHODOLOGY FOR HAZARD COMPUTATION

Probabilistic approaches are mainly described in this section, but geomorphologic approaches and the possible complementarity between both approaches can also be applied.

Hydotechnique works, such as dams or dykes, can affect the results of hazard computation. For average hazard, mapping without and with flood protection works failure allows the comparison of affected areas and the assessment of vulnerability in this two working hypothesis. Thus, it can be determined if the effect of the protection structures is important or not. The scenario of extreme hazard can show the failure of overflow dams.

The global warming is difficult to take into consideration for rivers.

7.1. HYDRAULIC TOOLS BASED ON MONO-FREQUENCY ASSESSMENT

Mono-frequency studies often imply studies section by section; for every reach, an input hydrograph is specifically designed according to the result of hydrological analyses. The flow after a confluence cannot be obtained by addition of upstream contributions, otherwise the estimated frequency would change (a 100-yr peak arriving from a tributary at the same time as a 100-yr peak from another tributary leads to a higher flow and a more important flood, with an estimated return period superior to 100-yr).

As a consequence, mono-frequency maps should not appear correlated, but show discontinuities at confluences. They are usually corrected afterwards to make the maps easier to read and avoid technical explanations.

The available methods can be listed from a simple local application of the Chezy formula, giving the water depth corresponding to a discharge, to the a full 2D model based on shallow water equation (St. Venant equations). Enhanced versions of 1D models exists, as well as simplified 2D models (Rapid Spreading Flood Model), which mostly computes a mass balance between cells, the fluxes between cells being estimated by weir equations.

For most hydraulic modelling studies in any river, canal, culvert, stream, creek, etc. both 1D and 2D models will provide all the information required for an analysis and / or design. Understanding the underlying assumptions of each model is very important when deciding on which type of model to use.

Because of the differences in how each model computes all of the hydraulic parameters, 2D models have advantages over 1D models in several situations. These include:

- Complex Floodplain Geometry (wide floodplains, variations in channel and floodplain flow paths, etc.)
- Complex Bridge Crossings (multiple openings, roadway overtopping, skewed embankments etc.)
- Braided Streams
- Asymmetric Floodplains

- Highly Meandering
- Bank Protection Design
- Levee Protection Design
- Habitat Analysis

Chosen hydraulic model should contain a number of modules that can be used either separately or combined. Minimum functionality should be:

- 1D hydraulic (hydrodynamic) modelling;
- hydrological modelling, rainfall-runoff type;
- results representation in GIS format.

The other specific functionality is given by a topographical module that allows to automatically extract river geometry from DEMs. This method is easier to implement, cross-section definition being a task that usually require expertise.

Hydraulic modeling program used to simulate water flow corresponding to the maximum flows with 10%, 1% and 0.1% exceedance probabilities, as well as those corresponding to the maximum flow rates resulting from scenarios of breaking the Stanca Costesti accumulation, was HEC-RAS 5.0.

The HEC-RAS modeling software, developed by the Hydrologic Engineering Center (HEC), allows the determination of characteristic data of non-permanent and permanent water flow, uniformly or progressively, for rivers in natural or modified hydrological regime.

The mathematical model is based on the integration of the equations of non-permanent and permanent movement by finite differences. Free water surface elevation is calculated from one profile to another by solving the energy equation by an iterative routine called the standard step method.

In some locations, where the flood flow is concentrated in one or more streams parallel to the main water course or in the flow areas behind the dykes, the loop system called quasi 2D was used (Fig. 7.1).

The entire flooded area, especially downstream of the o Stanca Costesti accumulation, was covered with a loop riverbed network and its parallel courses.

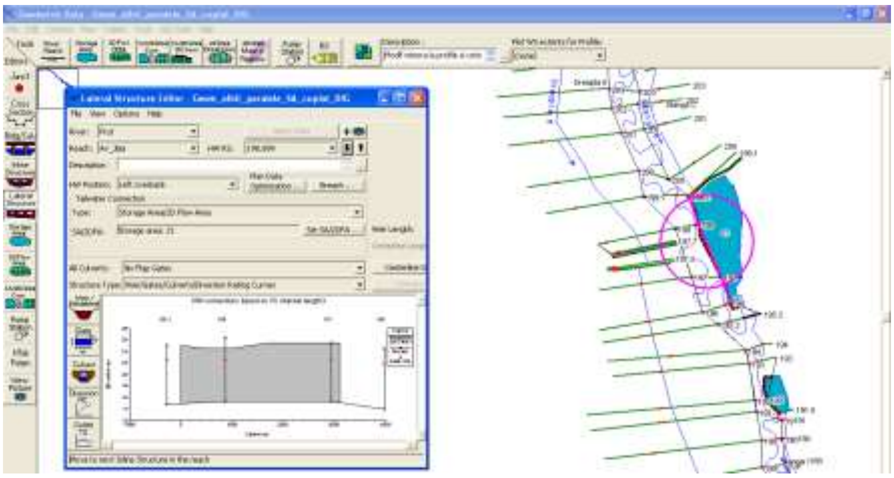

Figure 7.1 **– Modelling of secondary parallel riverbeds located in the major bed**

The connection between the main riverbed of the Prut river and the secondary parallel riverbeds located in the major bed and left and right accumulation areas was made using hydraulic reversible spillway structures having the length and elevations of the ridges corresponding to the lengths / crests of the dykes. The discharge of the crests of the defence dykes was done without considering their breaking.

The calibration and validation processes of the hydraulic models aim at determining the hydraulic parameters of the riverbed and the calculation coefficients so as to reproduce by calculation the discharge and the level hydrographs recorded in the control sections represented generally by the hydrometric stations of the studied riverbed.

Main parameters on which the calibration and validation processes of the hydraulic model reproducing the propagation of the flood waves can be acted upon are:

- roughness coefficients (ni), which models the hydraulic strength of the riverbed;
- the length of the major riverbed for the purposes of general axis of propagation the flood recorded;
- determining the hill areas and their elevation where strarts flooding the major riverbed, identifying and modeling local depressions (located below the banks of the minor riverbed) from the major riverbed with polder effect witch do not participate in leakage but it influences the propagation and volume of recorded floods;
- locating and modeling afflux areas
- optimal adjustment of the calculation coefficients of the model, by adjusting the length of time and distance calculation steps along the river (DT, DX), the number of cycles in the integration of equations, etc.

It was established that entering the model for the floods recorded in 2008 and 2010, to represent the discharge hydrograph in the Oroftiana h.s. section, reconstituted after the limnimetric key in Oroftiana h.s. and level hydrographs recorded during the two floods. The discharge hydrographs from the hydrometric posts on the Prut River sections, corresponding to the floods recorded in 2008 and 2010, highlight the role of Stânca-Costeşti accumulation in the mitigation of floods (Fig. 7.2).

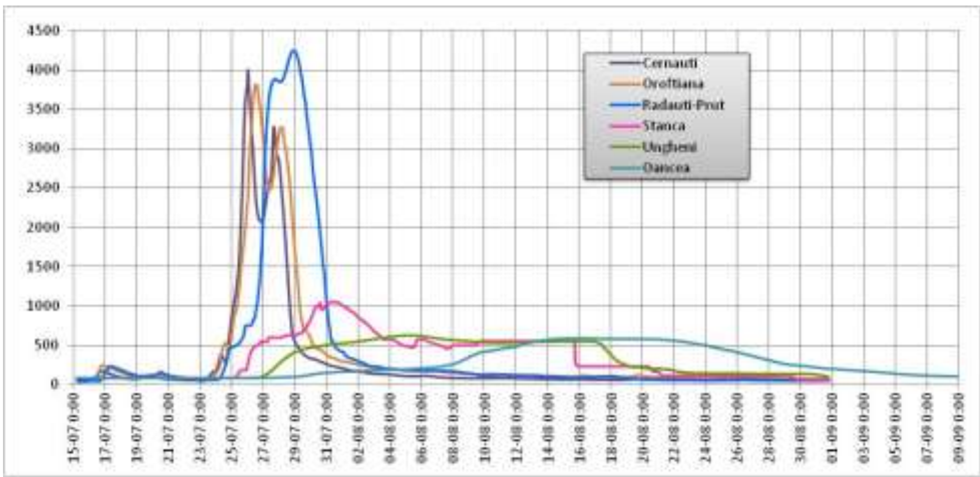

***Figure 7.2* – Hidrografele de debit ale viiturii din 2008 la staţiile hidrometrice de pe râul Prut**

7.2. MAIN DATA FOR HAZARD COMPUTATION

According to Floods Directive specifications, the hazard maps should show the flood extent, the water depth, and, where appropriate, the flow velocity or the relevant water flow.

During the modelling phase the following data has to be collected:

- Topographic maps,
- Hydrological data:
  - Discharge and water levels
  - Precipitation data
  - Recorded flood extent
- Geometrical data:
  - Cross sections
  - Longitudinal profile
  - Digital Terrain Model (DTM)
  - Hydraulic structures (dykes, weirs with operational rules, sills etc.)
- Hydrographical data (watercourse network, gauging station locations, lateral inflows),
- Extent of past floods.

Discharge and water level data as well as precipitation and evaporation data have to be verified and some statistic tests could highlight the inaccurate values. The identifying of the outliers is one of the main steps for hydrological data assessment.

The accuracy of both the models and the hazard maps can be improved with a better DEM. Besides the mathematical model results of the flood routing, the precision and the quality of the DEM is another main element to obtain some flood-prone areas with a high accuracy. Unlike the DEM used for general purposes, accomplished only on the basis of the topographical information, having maps (contour level and elevation points) as source, the ones used in hydrologic (especially in the hydraulic) modelling involve a very accurate river channel drawing up, through field measurements.

For defining the necessary DEM accuracy, it should be taken into account that a significant part of the water discharge flow inside the river channel, so that its shape reliability, described by dense elevation points that can be obtained by field measurement, leads to more precise results.

DEM quality is very important in dikes areas, too. The relative small width of crest dikes (5 m generally) makes important not only the accuracy of the DEM, but also its resolution, especially when topographical maps are used as information source for elevation. In these cases, a lower resolution averages a large range for altitudes, leading to distortions of real dike elevation (Fig. 7.3).# DTM based on information from topographic maps at the scale 1:25,000 can be obtained at 15 - 30 m resolution, and could be reduced at 5 – 10 m by cross section integration. But small width of dikes requires a higher-resolution data (around 0.5 - 2 m), that could be obtained from LIDAR (LIght Detection And Ranging) type DEM (Fig. 7.4) or from detailed field measurements.

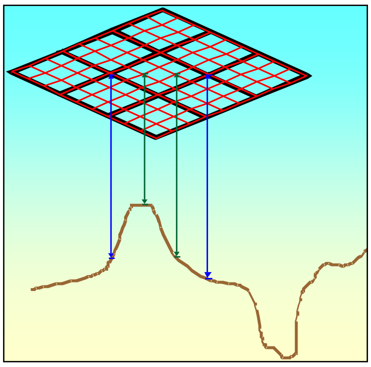

Figure 7.3 **– The effect of resolution on dike crests elevation**

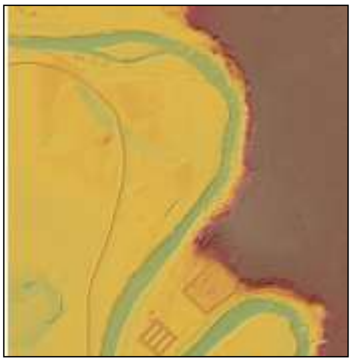

Figure 7.4 **– LIDAR type DEM for Prut river and floodplain**

8. METHODOLOGY FOR FLOOD RISK COMPUTATION

As shown above, the level of flood damages depends on many factors: the depth and flow rate, the duration of impact and the vulnerability of people, infrastructure or ecosystems exposed (Messner and Meyer, 2005; Büchele et al., 2006). Therefore, in many practical applications for flood risk assessment, the simplified definition of risk (probability x consequences) is used

The approach where a single flood risk map highlights all three hazard scenarios is less practical because the areas that are potentially flooded at high frequency will be affected at some point by floods with low probability of exceeding, but these are phenomena of much greater severity, and thus with other consequences.

Currently, in Romania, for high hazard class is used flow rate with probability of exceeding 10% and less, at 3.33% (every 10 or 30 years) to medium hazard class the flow rate with the probability of exceedance of 1% (1 / 100 years) is used and for the low hazard class the rate of 0.1% is used and the rate of 0.2% (1 / 1000 years, respectively 1 / 500 years).

8.1. RISK APPROACHES

Risk assessment provides decision-makers with an improved understanding of risks that could affect achievement of objectives, and the adequacy and effectiveness of controls already in place. This analysis tries to answer the following main questions:

- what can happen and why (by risk identification)?
- what are the consequences?
- what is the probability of their future occurrence?
- are there any factors that mitigate the consequence of the risk or that reduce the probability of the risk?

Therefore, risk assessment is the overall process of risk identification, risk analysis and risk evaluation and provides a basis for decisions about the most appropriate approach to be used to treat the risks

The purpose of **risk identification** is to identify what might happen or what situations might exist that might affect a territory, an organization or the achievement of the objectives of the system. Once a risk is identified, the organization should identify any existing controls such as design features, people, processes and systems.

Risk analysis leads to developing of risk understanding. It provides an input to decisions about whether risks need to be treated and consists of determining the consequences and their probabilities for identified risk events, taking into account the presence (or not) and the effectiveness of any existing controls. The consequences and their probabilities are then combined to determine a level of risk.

Methods used in analysing risks can be qualitative, semi-quantitative or quantitative. The degree of detail required will depend upon the particular application, the availability of reliable data and the decision-making needs of the organization.

Qualitative assessment defines consequence, probability and level of risk by significance levels such as "high", "medium" and "low", may combine consequence and probability, and evaluates the resultant level of risk against qualitative criteria.

Semi-quantitative methods use numerical rating scales for consequence and probability and combine them to produce a level of risk using a formula. Scales may be linear or logarithmic, or have some other relationship; formulae used can also vary.

Quantitative analysis estimates practical values for consequences and their probabilities, and produces values of the level of risk in specific units defined when developing the context. Full quantitative analysis may not always be possible or desirable due to insufficient information about the system or activity being analysed, lack of data, influence of human factors, etc. In such circumstances, a comparative semi-quantitative or qualitative ranking of risks by specialists, knowledgeable in their respective field, may still be effective.

In cases where the analysis is qualitative, there should be a clear explanation of all the terms employed and the basis for all criteria should be recorded.

Even where full quantification has been carried out, it needs to be recognized that the levels of risk calculated are estimates. Care should be taken to ensure that they are not attributed a level of accuracy and precision inconsistent with the accuracy of the data and methods employed.

Levels of risk should be expressed in the most suitable terms for that type of risk and in a form that aids risk evaluation. In some instances, the magnitude of a risk can be expressed as a probability distribution over a range of consequences.

In most European countries flood risk maps and related products are much less developed than flood hazard maps. The following information can be mapped with regard to flood risks:

- Population: number of people, special groups, etc.
- Economic assets and activity: private property, lifelines, infrastructure, etc.;
- Environmental issues: installations potentially damaging the environment
- Potential risk (qualitative classes or quantitative information - loss per unit area in a given period of time)

Risk is unlikely to remain constant in time and it is often necessary to predict changes in risk in the future, to make better decisions. Some causes of change are for example:

- Vulnerability parameters can rapidly change:
  - Increasing vulnerability: development, changing value of assets at risks, land use, behaviour of people during the flood, capacity for recovery
  - Decreasing vulnerability: delocalisation/moving of assets, reducing sensibility of assets, improvement of flood warning, changing use of land, behaviour of people during the flood, capacity for recovery

  - Permanent, semi-permanent or non-permanent flood defences (deterioration, maintenance, new works)
- The hazard parameters can change due to:
  - Climate (natural variability, climate change)
  - Environmental change (deforestation, reforestation, major forest fires,
  - Erosion rate (changing geological exposures)
  - Man's intervention

Risk evaluation uses the understanding of risk obtained during risk analysis to make decisions about future actions. Ethical, legal, financial and other considerations, including perceptions of risk, are also inputs to the decision. Decisions may include: whether a risk needs treatment; priorities for treatment; whether an activity should be undertaken; which of a number of paths should be followed.

The nature of the decisions that need to be made and the criteria which will be used to make those decisions were decided when establishing the context but they need to be revisited in more detail at this stage now that more is known about the identified risks.

8.2. ESTABLISHING WATER DEPTH CLASSES

For each scenario, a certain location could be affected with different intensity. The water depth, one of a common element used to define the magnitude or intensity of a flood, will generate different degrees of damage.

Since it is difficult to take into consideration all types of consequences with only water depth classification, property and population should be treated in priority. In order to achieve risk maps, 3 thresholds can be defined for water depth, as proposed for the project and showed in Fig. 8.1. Depth classes are obtained by converting grid data, resulting from mathematical modeling, in vector data (Fig. 8.2).

Index	Level of magnitude	Depth (m)
H1	Low	< 0.5
H2	Medium	0.5-1.5
H2	High	> 1.5

Figure 8.1 **– Magnitude of hazard depending on water depth**

8.3. RISK COMPUTING

The agreed method is based on water depth, and CORINE land cover classes. Adaptation of the methodology presented in the FAME Report by replacing scenarios (probability of exceedance) with the magnitude of the flood (water depth) leads to simplification of the content of the risk maps, respectively to a better structuring and improvement of the possibilities for use, even if there are three different risk maps.

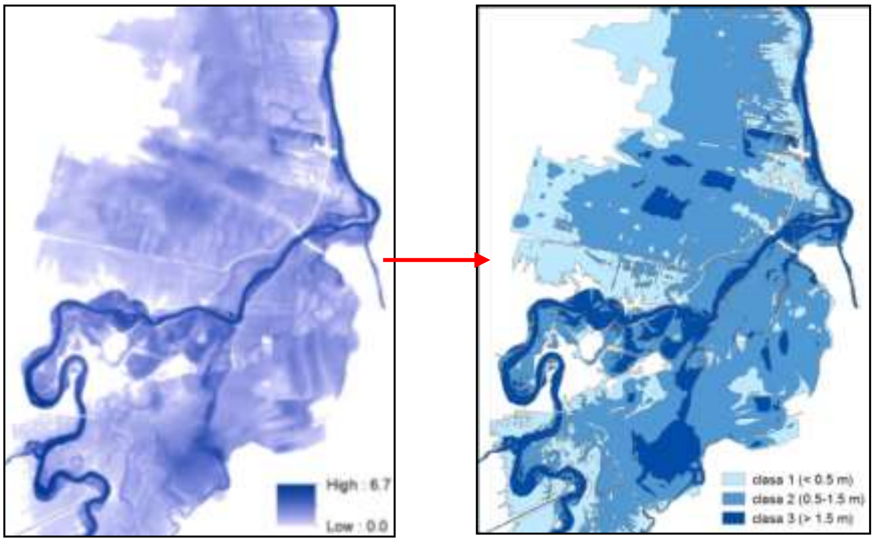

Figure 8.2 **- Preparing hazard maps: a) initial depth grid; b) depth classes in vector format**

By applying the proposed method, the flood risk (degree of intensity) is assessed qualitatively, being a combination between hazard and the presence or exposure of the receptors (Fig. 8.3).

RISK			**Hazard magnitude (water depth)**		
			H1	**H2**	**H3**
			Low (<0.5)	**Medium (0.5-1.5)**	**High (>1.5)**
Consequences	**C1**	**Low**	R0	R0	R1
	C2	**Medium**	R1	R1	R2
	C3	**High**	R1	R2	R3

where:
R0 = insignificant flood risk;
R1 = low flood risk;
R2 = medium flood risk;
R3 high flood risk

Figure 8.3 **– The adapted flood risk matrix**

In order, to achieve the risk maps, it is necessary to define the types (classes) of the consequences (goods) which are found in the flood prone area and how they are affected by the different water depth classes. These classes were ser based on the land use classification specific to the CORINE Land Cover database, to which new classes were added to meet practical needs.

There are several possibilities for obtaining potential damages, qualitatively expressed (grades or classes of risk intensity). It has been chosen to assign degrees of intensity to each combination of types of goods and depth classes (Fig. 8.4).

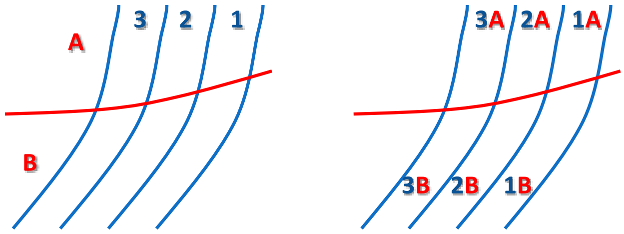

Figure 8.4– **Mapping of teh combination between various types of assets (A, B) and depth classes (1, 2, 3)**

In order to detail the vulnerability to floods expressed through different elements which lie inside the flood-prone areas, each type of CORINE Land Cover classes is ranked based on expert judgement and taking into account two different issues:

- Value of assets
- Resilience of assets, defined as "ability to cope with flooding and to recover from flooding" (strength and behaviour of various assets in case of a flood of a given magnitude)

Starting from principles stated before, different classes of risk and relation between vulnerability and water depth classes have to be established. 4 risk classes have been establishe, as follows:

- R0 = no significant flood risk;
- R1 = low flood risk;
- R2 = medium flood risk;
- R3 = high flood risk;

Basically, each combination between the types of consequences and depth classes was assigned to a certain degree of risk, resulting in a risk matrix (Tab. 8.1).

The rank file is prepared in a Microsoft Excel file, which shall be connected with CLC shapefile.

Table 8.1 – Example for risk classes defined based on CLC ranking and hazard classes

CLC CODE	Land use classes	Risk class corresponding to the water depth		
		Low <0,5	Medium 0,5-1,5	High >1,5
112	Discontinuous urban fabric	2	3	3
131	Mineral extraction sites	2	3	3
132	Dump sites	2	3	3
133	Construction sites	2	3	3
141	Green urban areas	0	1	1
…	….	…	…	…

The data necessary for the execution of the flood risk maps is:

- Flood hazard maps (water depth);

- CORINE Land Cover database
- File ranking the CLC Classes
- Thematic layers for flood risk receptors (inhabitants, socio-economic activities, environmental, etc.), represented as polygons, lines or points.

All the thematic layers are achieved and prepared with the help of the ArcGIS software. Based on them, quantitative assessments of the risk prone elements are determined.

The presented approach leads to achieving a more detailed risk assessment compared with Flood Directive specifications for EU reporting. However, this detailing is resulting from the same documents, where is stated that the goal of reported maps is not the same as the national level maps: the first are designed to draw the attention of the user or citizen to areas of interest and to show where national FHRM are available and the user can zoom in through national tools.

According to the Floods Directive, other simpler methodologies could be adopted, in which case the risk maps shall show only the mandatory potential adverse consequences (the indicative number of inhabitants potentially affected, type of economic activity, IPPC facilities, and the protected areas mentioned in the Water Framework Directive.

8.4. CALCULATION OF AFFECTED INHABITANTS

The settlements are the most important element in the risk computation, taking into account the consequences on inhabitants and properties, as well as their vulnerability.

Inhabitant data is retrieved from the National Institute of Statistics (INS) and contains the number of inhabitants per settlement. The data is provided from national census.

Determination of the number of affected inhabitants in a certain area is carried out statistically, in proportion to the flooded area, resulting an approximate value. The hazard area is intersected with settlements, containing information about population density, in order to get the potentially affected population (affected area x density).

The value determined for the affected population depends on the accuracy of the geometry of the settlements or the built-up area, the accuracy of the statistical data regarding the total population of the localities and the degree of detail of the information regarding the residential space (for example, the types of predominant buildings: houses or blocks).

Determining the number of inhabitants involves a series of steps (Fig. 8.5). Preparing the initial data refers to:

- the population of the settlement at the latest census, 2011 for Romania, in the *[POP_2011]* field
- the total area of the localities in m^2 in the *[S_T_mp]* field
- Population density in the *[DENSITY]* field

Next, the following steps are required:

- preparing the flood prone area
- clipp the localities for the area of interest
- recalculating cutting area in m^2 in the *[S_ZI_mp]* field
- calculating the population in the area of interest using the formula:

[POP_ZI] = [S_ZI_mp] x [DENSITY]

Ex. Radauti-Prut

S_T_mp = 1552837 sq.m.

POP_2011 = 3577 inhabitants

DENSITATE = 0.0023 inhab./sq.m.

S_ZI_mp = 651701 sq.m.

[POP_ZI]=[S_ZI_mp] x [DENSITATE]

↓

POP_ZI = 1499 inhabitants

***Figure 8.5* – Example of affected inhabitants**

For the extent to which the population is affected (second legend category), it was taking in consideration both the potentially affected population and proportion of affected population of the total population of each settlement (Tab. 8.2).

Three classes of inhabitants shall be displayed by one human, two human, three human, for example.

***Table 8.2* – Criteria for Degree of Affected Population indicator**

Symbol	Class	Criterion 1	Operator	Criterion 2
0	Insignificant	Pop% > 15	OR	Pop% > 25 and Pop. affected < 9
1	Low	0 < Pop% < 15	AND	Pop. affected > 9
2	Medium	Pop% > 15	OR	Pop% > 25 AND Pop. affected < 400
3	High	Pop% > 25	AND	Pop. affected > 400

8.5. OTHER RECEPTORS EXPOSED TO FLOOD RISK

Content of the public disseminated flood risk maps has been set up in accordance with the requirements of the Floods Directive regarding the types of potential consequences, as well as the practical needs at national level. The types of data and and information of national risk maps are (Fig. 8.6):

- risk classes (insignificant residual risk, low, medium and high);
- the degree of affected the population (insignificant, small, medium and high);
- potentially affected hotspots:
  - economic units included in IPPC and EPRTR

- secondary economic activities
- stations, stops
- drinking water intakes from underground and surface
- education units, hospitals, dispensaries
- churches, museums, monuments

• localities

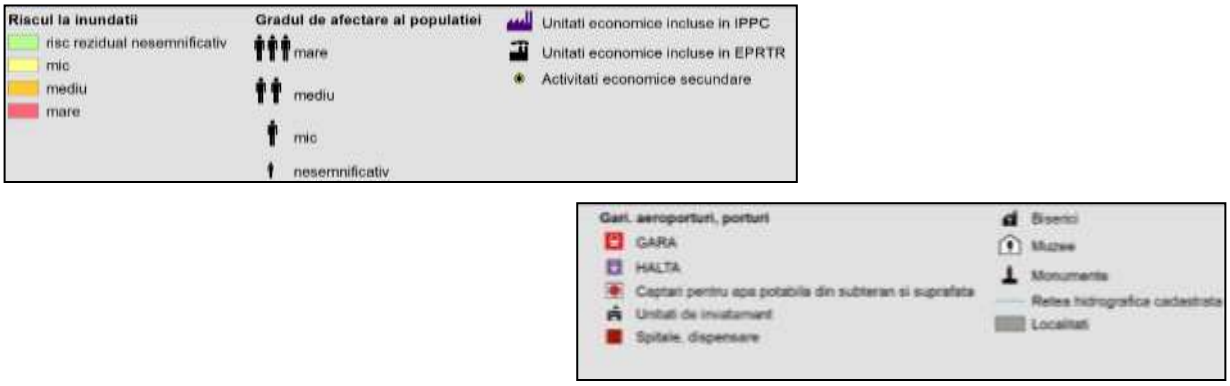

***Figure 8.6* – The legend of the contents of the risk maps**

9. FHRM CONTENTS AND VISUALIZATION

Flood hazard maps are a practical tool for spatial planning, population warning and public information. The maps shall display not only the extension of the floods with high, medium and low probability, but also the water depth. Where appropriate, Members States could also prepare information on flow velocities or the relevant water flow for all three scenarios.

Hazard maps will be achieved by converting the grid file of water depth resulted from modelling into three water depth classes:

- 0 - 0.5 m;
- 0.5 - 1.5 m;
- over 1.5 m.

The proper use and application of flood hazard maps into planning processes and awareness campaigns require the consideration of some very basic information on the map. The most important aspects are as following:

- Title of the map: making clear reference to the map content such as
  - Flood parameters: Flood extent, depth, past event etc.
  - Probability consideration: defining more precisely what mean low, medium and high probability of occurrence
- Location of the map as part of the catchment or country: provision of a small inset map
- Legend:
  - parameters shown on the map with easy to read symbols or colour schemes;
  - class or ramp for numerical values
- North and scale: preferably using scale bar as this allows for changes in page size
- Responsible authority or institute with address, website (and / or telephone number)
- Base date for the data and date of publication
- If necessary: a disclaimer, including remarks on the quality of information can be added.

For representation of hazard layer, 3 classes of blue will be used. Also, a 30% transparency has to be applied in order to make the background usable.

Colour shades are chosen using “http: / colorbrewer2.org”, in order to be colour-blind safe and printing friendly, as shown below (Fig. 9.1.).

Depth class	Red	Green	Blue
0 - 0.5m	225	230	245
0.5 - 1.5m	130	180	225
> 1.5m	5	110	175

***Figure 9.1* – Colour shades for flood hazard classes**

Flood risk maps are an important basis and a practical tool for presenting and sharing existing information on flood risks. One map for each scenario shall be prepared. Since the extension of the floods with high, medium and low probability is different, the displayed elements (exposed areas of various land-uses, settlements, number of affected inhabitants and indicators) have to be prepared separately for each of three maps.

For representation of risk maps, three classes on red-orange-yellow, which correspond to high risk, medium risk and low risk, can be defined, to which is added "no risk" class symbolised as light green colour.

As in the case of hazard layer, for flood risk layer (grid or vector), a 30% transparency will be also used.

Colour shades are chosen using "http: / colorbrewer2.org", in order to be colour-blind safe and printing friendly, as shown below (Fig. 9.2.).

Risk class	Colour	Red	Green	Blue
High	Red	255	60	70
Medium	Orange	255	180	25
Low	Yellow	255	240	140
No risk	Green	190	240	180

***Figure 9.2* – Colour shades for flood risk classes**

Flood receptors (points of interest) are represented by symbols (accordingly to legend shown in Fig. 8.6).

The reference scale and the degree of detail for the dynamic display of hazard and risk maps were selected taking into account the technical details of the CORINE Land Cover thematic layer. Therefore, maps can be available on the data portal (1: 25,000 scale)

Public disseminated flood risk maps, along with hazard maps, summarize essential flood information along the main watercourses. This can be an important tool to implement different national or local plans and strategies in areas such as land use planning, urban planning, flood risk management, informing the general public, etc.