BUILDING AN EARTH OBSERVATION FLOOD RISK ANALYSIS PORTFOLIO RESPONDING TO THE FLOOD DIRECTIVE

Author: Han TAMBUYZER
Co-Authors: Nicolas DOSSELAERE – Julie DELEU

Abstract
By combining satellite observation data with exogenous data and modelling techniques, several customized products were developed in the support of decision making for flood risk management. Part of the R&D process is accomplished within the frame of the GMES program. Special attention was put to continuous user participation, a solid validation of the services and the matching up between existing and upcoming legislations. This resulted in a service portfolio of flood risk analysis products, fully in support of the requirements of the EU Flood Directive and indispensable in the prevention, crisis or post-crisis phase of flood risks and emergency situations.

1. Introduction

1.1 Background

Over the last decennia many regions in Europe have suffered from natural hazards. Disasters like floods are affecting people more than ever: houses and infrastructures are destroyed, people drowned, toxic chemicals are released by inundated industry areas,… All these social, economic losses and environmental damages have severe consequences. Since 1998 floods in Europe have caused some 700 deaths, the displacement of about half a million people and at least €25 billion in insured economic losses. Due to climate changes it is likely that more floods will occur in the future, even causing more economic losses. The threatening of human life, environment and property enhance the need of an effective risk management. In this matter the geographical aspect is important to underline.
Therefore a portfolio of geo-information services was developed making use of remote sensing data and exogenous data in combination with modelling techniques.

1.2 Flood Directive

All these facts triggered a pan-European action and need for a general policy. The Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive requires all European Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. This Directive also aims to give the public access to this information and to involve them in the planning process.
The Directive requires Member States to first carry out a preliminary assessment by 2011, to identify the river basins and associated coastal areas at risk of flooding. For such zones, flood risk maps need to be prepared by 2013 and by 2015 flood risk management plans need to be established focused on prevention, protection and preparedness. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU.

1.3 GMES & RiskEOS project

Even before the enforcement of the Flood Directive, a portfolio of flood risk analysis products was developed within the RiskEOS project (Risk Earth Observation Services), financed by the European Space Agency, based on user needs and risk management experience. This project was part of the GMES Programme (Global Monitoring for Environment and Security), supported by EC and ESA. Customized Flood Risk Analysis products were provided to risk management duties of Slovakia and Bulgaria, respectively ‘the Slovak Water Management Enterprise’ and ‘Ministry of Regional Development and Public Works’, both responsible for the flood risk management in their country.

1.4 Flood Risk Management in Slovakia and Bulgaria

Slovakia
In Slovakia the products were demonstrated and applied to the Danube river catchment with focus on Bratislava city.
In general there are two main flooding risks in Slovakia that illustrate the necessity of a thorough flood risk analysis in Slovakia. One of them is the Danube culmination in spring, caused by snow melting in the Alps, and the culmination in summer, caused by the rising summer rains in the retention area of south Germany and Austria. This culmination implies a

major danger for Bratislava since a part of this dense populated agglomeration (south east part of city) is situated up to 4-5 meter under the level of the Danube. The east part of the city and a part of the oil-refinery is situated below the Danube level "normal flow" as can be illustrated by a digital terrain model (DTM) visualisation.

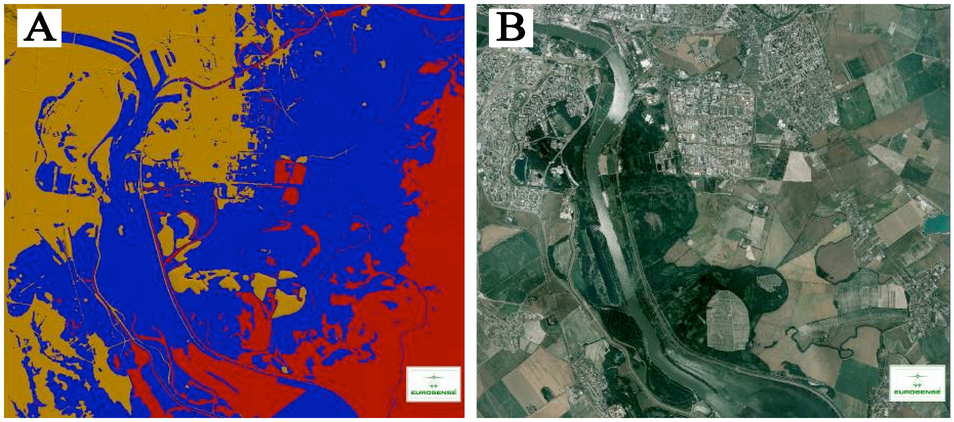

Fig. 1A: represents a DTM-visualisation of the region of Bratislava, situated along the Danube River, with areas coloured blue and red are equal or (far) below the Danube 'normal' flow water level. Orange coloured areas are higher lying areas; Fig 1B: the corresponding orthophoto. (imagery © EUROSENSE)

In Bratislava City there are dikes located along the river banks. Although the level of the water is regulated by the Gabcikovo dam (40 km downstream from Bratislava), an overflow and the related risk of a break of the dikes, would mean a major flooding of the housing of approx. 80.000-100.000 citizens in a relatively short time. Even more danger comes from the fact that potential evacuation roads would be flooded by 3 to 4m in a very short time. The last risk period was in August 2002, when the level culminated approx. to only 12 cm below the dikes. There exists a Governmental programme of Flooding Prevention with a list of 20 potentially risky areas. Recently the extension of the river body on the left bank in Bratislava and the construction of a new dike along the new urbanisation of approximately 1,5 km on the right bank of Danube has been executed.

The second main flood risk is the occurrence of local floods on small streams and small rivers (without special dikes). These are mainly caused by extremely intensive retention of summer storms in concentrated areas in the mountainous areas of Slovakia. This causes a big risk for relatively small villages in mountain valleys and for the related infrastructure. Often there's only 1 road or bridge to evacuate and access the related population. In the last 5 years this occurred repeatedly in unforeseen areas.

The Water Management Authority of Slovakia did not have data in required precision and of adequate update frequency. Up to date data is very important since there is a very fast development of Bratislava settlements along the Danube by housing and infrastructure. The geo-information products can help tremendously in the flood risk management of the Danube river and to take precautionary measures.

Fig.2A: represents historical flood events located along the Danube, Fig.2B & Fig. 2C: some pictures of Bratislava during the floods of 2002

Bulgaria
In Bulgaria, the area of interest stretched along the Maritsa river basin, with main alertness to the City of Pazardzhik and the City of Plovdiv. The main causes and problems of floods in Bulgaria can be summarized as follows:

- Inadequate regulation of river beds: by straightening the river the regulated areas are shortened by 1,5 to 3 times and their width is diminished with an increase in river depth and flow speed which leads to erosion, damage to dikes, … More than 90 % of the large rivers' lower streams in Bulgaria have been regulated.
- Rivers are detached from the natural areas for water retention, riparian floodplains and retention basins through the construction of dikes.
- Some of the existing dams are in a poor technical state: caused by the lack of an integrated dam management, by extraction of inert materials and by destruction of forests in water catchments
- Low institutional capacity, insufficient equipment, qualifications and instruments
- Construction in floodplains and bad planning and implementation of infrastructure developments
- Insufficiënt hydro-meteorological information

The recent floods in Bulgaria (e.g. 2005) prove that flood risk mapping is a necessity, to avoid devastating floods in the future and to lead to a sustainable and permanent prevention. The flood risk mapping, assets mapping and flood damage assessment can deduct which actions must be taken and where.

2. Flood Risk Analysis Service portfolio

The "Flood Risk Analysis" services comprise information about past and potential flood events as well as an estimation of potential damages and losses. They are customized to support decision making in risk management duties and indispensable in the prevention phase, crisis or post-crisis situation of all sorts of risks and emergency situations.

2.1 Past Flood Maps

Past Flood Maps are based on optical (e.g. SPOT, IRS, Ikonos,…) and radar (e.g. Envisat, Terrasar-X,…) earth observation data. This product identifies -among others- the flood extent of former events at the time of image acquisition.

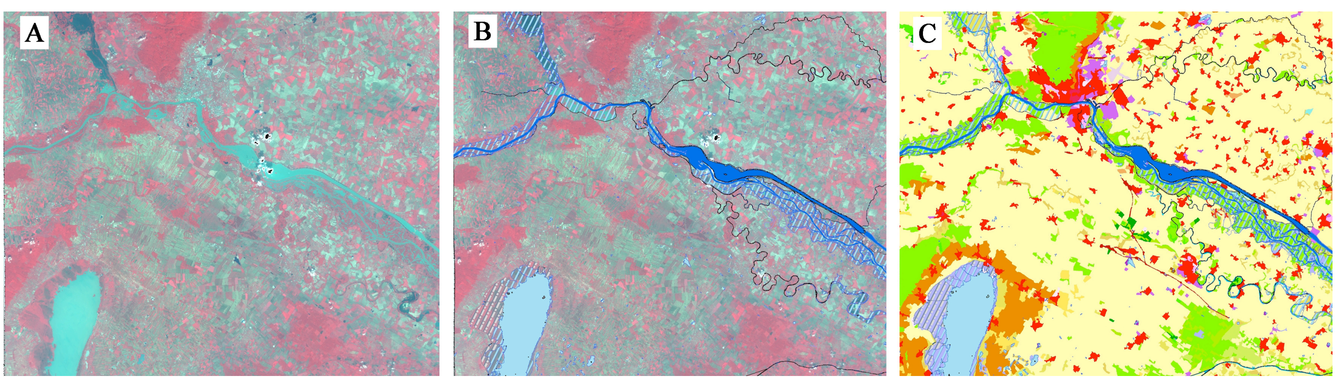

Fig.3A: satellite image of the Danube at the borders of Austria – Slovakia – Hungary acquired during the flood of 17/08/2002 Fig.3B: overlay of the past flood vector, Fig. 3C: past flood map overlayed on CorineLandcover2000 (background imagery © spotimage)

These products are not generated in real time, but from archive data. Based on satellite observation data this product identifies the flood extent of former events at the time of image acquisition. For a given river (basin) an inventory of all the past flood events during the last decades can be made. For the peak moment or other different time instants of the flood, the data and time of the event itself can be deducted and used for the EO archive data search. As well radar as optical imagery can be integrated into the past flood extent detection procedure. By using a semi-automatic classification method, all inundated areas are segmented, detected and classified. The past flood map makes a distinction in 2 classes. The 1st class are certainly flooded areas and the 2nd class are potentially flooded areas (e.g. forest completely surrounded by flooded area are considered as potentially flooded as the tree canopies prevent the spectral reflectance of the water).

From the "past flood map" product also other information can be extracted when combining other past flood maps of the same event with each other: the flood duration per area and the maximum flood extent. Combining past flood maps of different events for the same area also enable the deduction of the maximum historical flood extent and the flooding frequency per area.

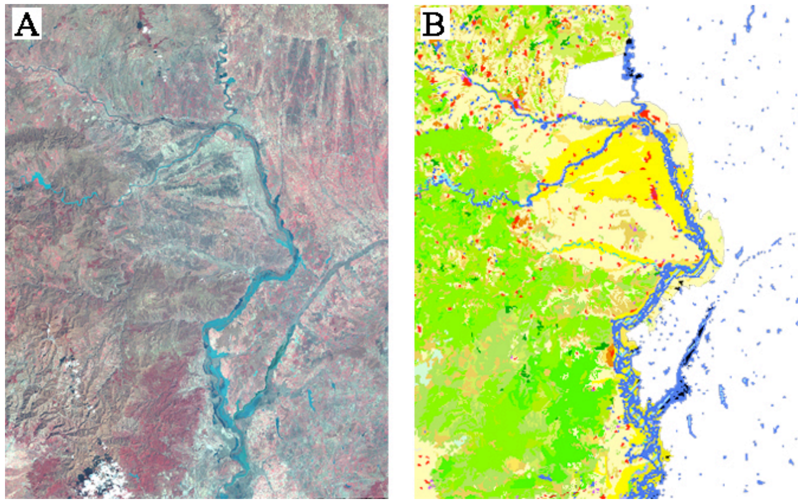

Fig.4A represents a satellite image of the border area between Bulgaria-Turkey and Greece , situated along the Maritsa River, acquired during the flood of 16/03/2005. Fig.4B: represents the deducted past flood map overlayed on a CorineLandcover 2000 (background imagery © spotimage)

Past flood event mapping allows a “look to the past” by providing essential information including potential flood extents. This information is very interesting among others for flood risk preparedness and the planning of protection measures e.g. construction of dams and infrastructures. A similar application enables the collection of flood information from future events. Satellites can be tasked as soon as a flood happens, which enables a quick and precise detection of all flooded areas. A major benefit of the use of EO-data is the trans-border basin approach of the flood events, as illustrated in the examples for the Danube (Slovakia-Hungary-Austria) and the Maritsa (Bulgaria-Turkey-Greece).

2.2 Flood Hazard Maps

Flood hazard modelling provides a multiplicity of information on flood risk zones. The Flood Hazard Maps give an idea on the potential flood extent and its expansion, the run velocity and direction and this for a whole river basin or a part of it. Historical or statistical hydraulic data together with topographic and land use information are used as input to a quasi-2D hydraulic simulation model using the ‘Manning equation’. The software used for the modelling of the floods is FloodArea which works as an extension on the spatial analyst module of ArcGIS software. FloodArea is primarily intended to calculate areas affected by a flood. Essentially it is a simplified two-dimensional hydraulic model, integrated in a GIS. The simplifications made, mainly affect the open channel hydraulics, which can be described only roughly with the available parameters (resolution of the elevation model in the channel, no cross sections).

In general the method is based on 3 main input layers into the model, in combination with area specific information (working of dams, weir, history of flood prevention, specific problems in the past/future) and the experience of continuous repeated calibration of the parameters. The 3 input layers respectively consist of ‘a Digital Terrain Model’ covering the area of interest (catchment or buffer of the river), a ‘Drainage network and water surface’- representing the water causing the flood - and a ‘Roughness layer’ based on Manning roughness coefficients taking into account the influence of the soil roughness on the flow velocity. Depending on the simulation time (y) and output rate (x), the situation after x time will be represented for y time long. Based on several outputs, an animation of the flood can be created. The different parameters and input data are dependent on the kind of event and scenario one wants to simulate. Several scenarios can be simulated: e.g. dam failure, extreme events, flash flood... In the RiskEOS project different scenarios are simulated (as requested by the risk management duties). 4 of them are explained below and they have the following characteristics:

A - The occurrence of an extreme river flood event (HQ1000) in the Danube region of Bratislava.

- Use of water levels which only occur once in 1000 years (statistically calculated HQ1000 by a 1D simulation model based on cross-sections)
- Use of a very high resolution DTM with a vertical accuracy error of only 15cm

- Roughness values attributed taking into account Corine Landcover2000 and updated with precise vector layers representing roads, railways, built up areas,,..

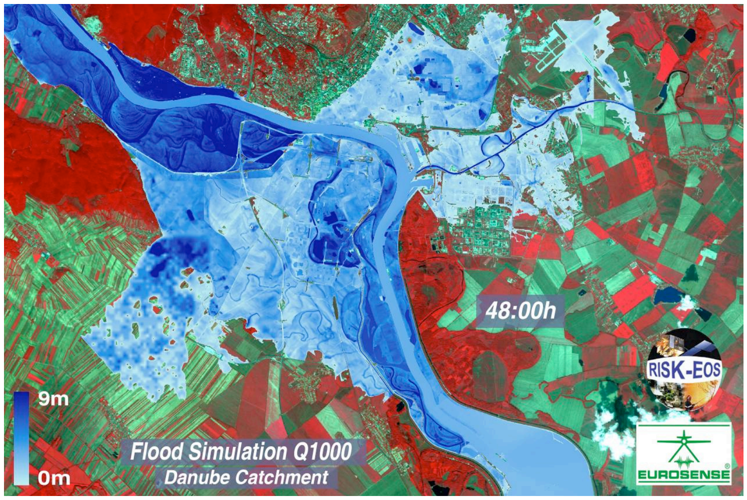

Fig. 5 represents a river floodplain flood for an extreme event along the Danube river situated in Slovakia-Austria-Hungary after 48 hours of simulation illustrating the water depth in blue colours (background imagery © IRS)

The obtained Flood Hazard Maps reveal the weak locations in the surrounding area of the Danube river, illustrating where the water overtops the dams and to which extent and how fast the water will propagate. It also shows the disastrous catastrophe when such an event would happen, inundating main city areas affecting thousands of persons.

B - The occurrence of a dam break along the Danube in Bratislava City during a river flood event of once in the 100 years (HQ100)

- Dam break location between the old and new bridge on the bank of Bratislava City (a location subject to high risk)
- Use of water levels which only occur once in 100 years (statistically calculated HQ100).
- Use of a very high resolution DTM with a vertical accuracy error of only 15cm. This DTM is updated with a vector layer containing the delineation and height of all the city buildings.

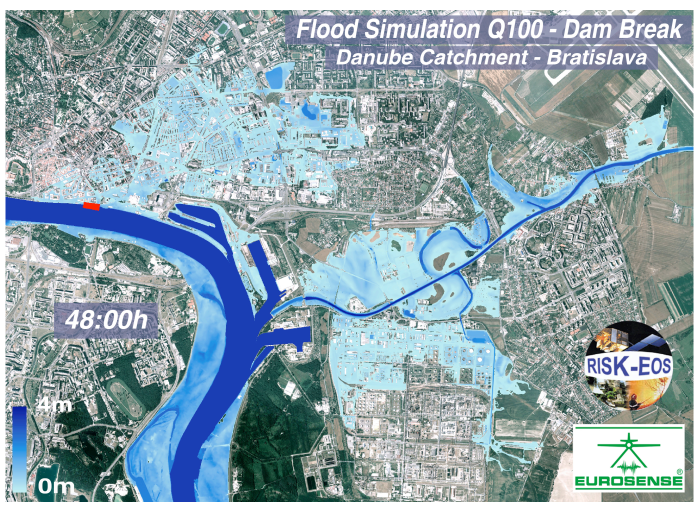

Fig. 6 represents a dam break during a 100 year flood event along the Danube river in Bratislava City after 48 hours with the water depth in colours blue. The location of the dam break is indicated with a red dot (imagery © EUROSENSE))

Due to the inclusion of the buildings heights, the flood hazards maps clearly show the water propagating trough the streets. One can deduct the water height and the time it takes for the water inundating a specific building into the city and which areas are prone to flood risk. It seems the historical city center of Bratislava as well as the oil refinery are not spared from damage.

C - The re-simulation of a past rainstorm event in the Bulgarian Maritsa River basin: the Ihtiman Event of 2005

- The Ihtiman event that started at the 4th of August 2005. A frontal zone remained almost stationary for as long as 24 hours covering a band of about 50km wide. The exceptional amounts of precipitation which led to floods were caused by a relatively regular and normal though strong and intensive cloud system.
- Another factor causing the very intensive rain is the mountainous area which enhanced the convective system. For that period (04-08/08/2005) the precipitation amount over the Maritsa river was between 150 and 350mm with daily maximums at Ihtiman of 230mm and with torrential rainfalls varying between 160 l and 234 l/day. These amounts were extrapolated and put into the model.
- This intensive precipitation caused several (flash) floods along the Maritsa river.
- In several articles and news-items the flooded villages and cities are mentioned

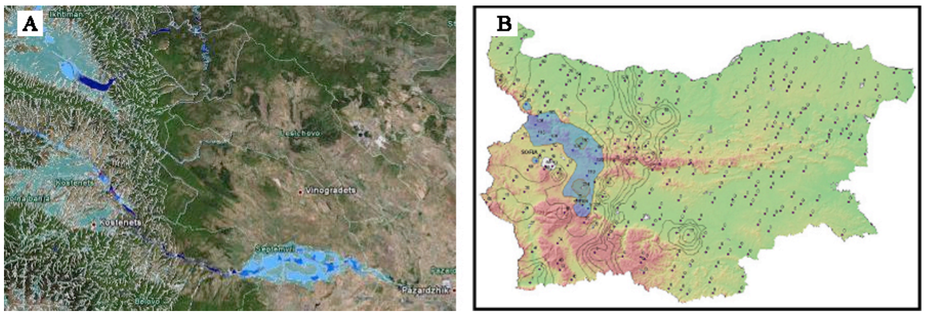

Fig. 7A: represents the runoff consequences of the Ihtiman rainstorm (background imagery© google earth) in the Bulgarian Maritsa river basin; Fig. 7B 24h cumulative amount of precipitation, 07h30 local time, 05.08.2005

The very high precipitation amounts, resulted in a very high runoff, causing a gathering of large volumes of water into the rivers, not capable to hold the water between the river banks. The simulated Flood Hazards maps show a good correspondence with the reference information (inundated areas and cities mentioned in articles and newspaper).

D- Dam break of the Topolnitsa mountain lake (reservoir) in Bulgaria.
This mountain lake has some danger of flooding by a dam break caused by high pressure due to very fast filling of the reservoir by side rivers ending in the lake. The Flood Hazard Maps show the very fast propagation of the water downstream, causing a very prompt inundation of the cities and villages lying close to the river.

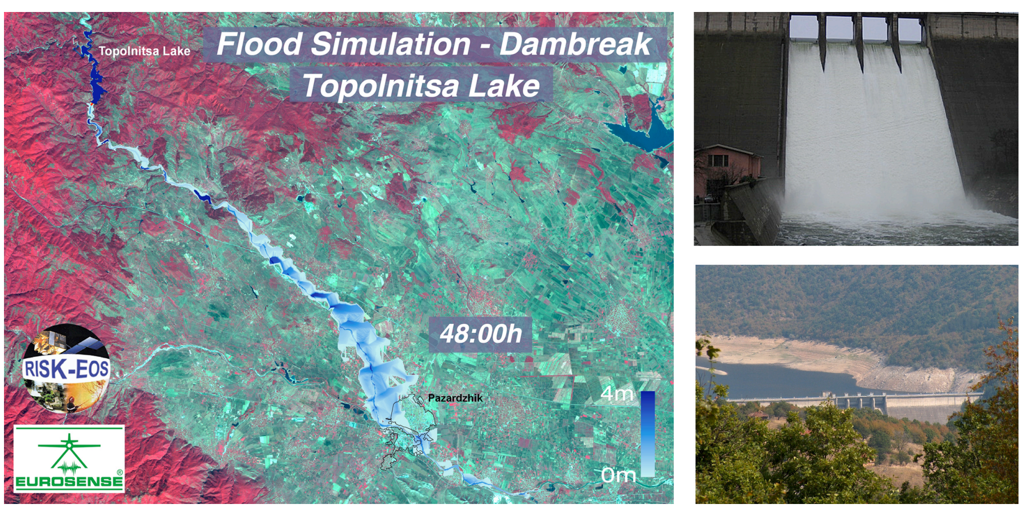

Fig. 8 represents a dam break of the Topolnitsa mountain lake in Bulgaria after 48 hours with the water depth in colours blue (background imagery ©IRS)

2.3 *Flood Risk Maps*

Flood Risk Maps contain information on the damage caused by a flood, the affected people and victims. The damage calculation can be based on “Flood Hazard Maps” but also on ”Past Flood Maps”, respectively resulting in a “potential damage assessment map” or a “past damage assessment map”.The calculation of “Flood Risk Maps” is modelled using - among others- damage functions, land use information and ancillary data. Damage functions express the relation between the susceptibility of assets at risk and certain characteristics, example given the inundation depth.

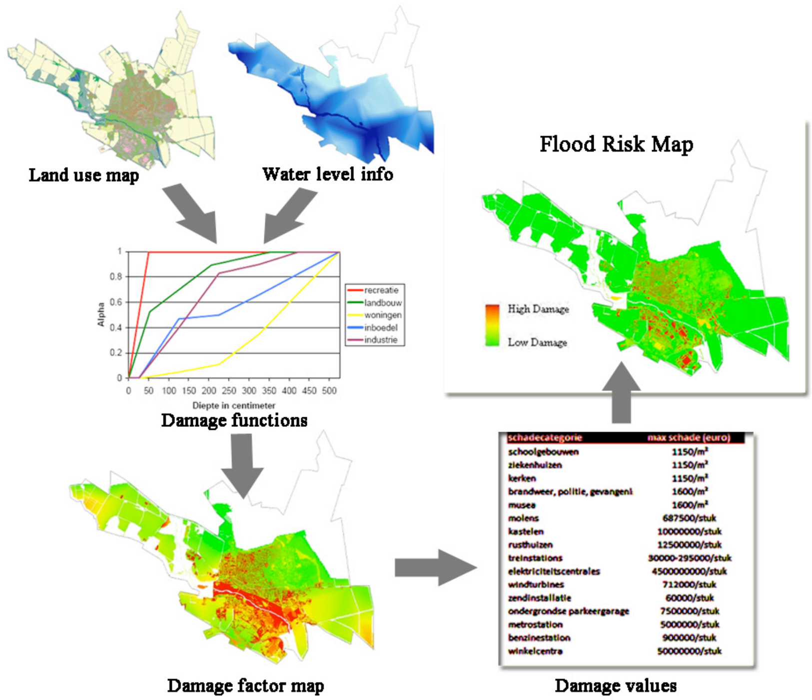

Fig. 9 represents a generalized workflow of the Flood Risk Mapping procedure

The damage is calculated by multiplying a damage factor with the maximum dame value of the specific damage class. The damage factor is deducted on the base of a damage function which depends on the water depth and the damage (land use) class. At the end, the calculation per pixel results in a Flood Risk Map representing the calculated damage per pixel.

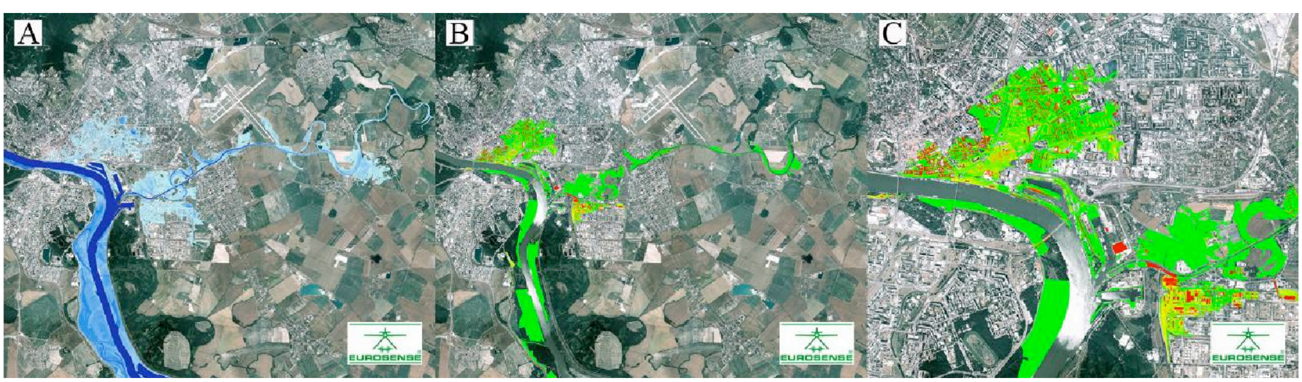

Fig. 10 represents the city of Bratislava, situated along the Danube River. Fig.10A: the inundation depths for a simulated dam break event, Fig.10B: the potential damage map, Fig. 10C: detailed view on the potential damage map (background imagery © EUROSENSE)

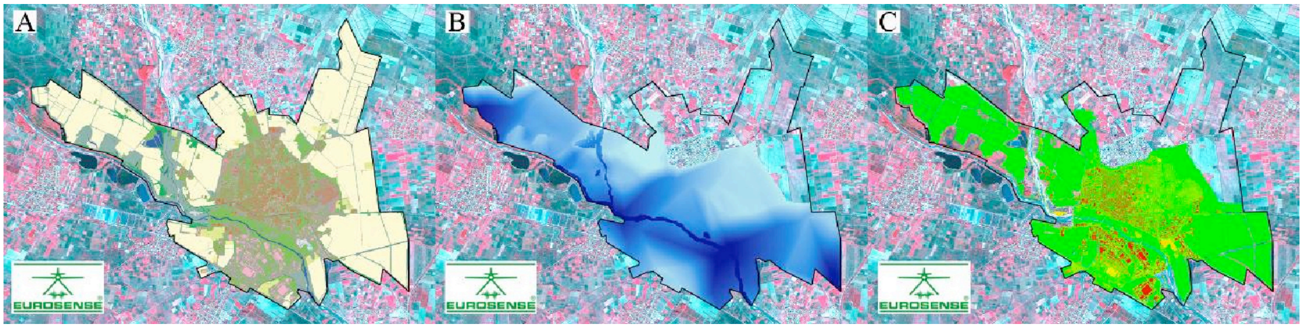

Fig. 11 represents the city of Pazardzhik, situated along the banks of the Maritsa River in Bulgaria (© EUROSENSE). Fig.11A: the land use map for Pazardzhik, Fig.11B: the simulated inundation depths for a flood event, Fig. 11C: the potential damage map (background imagery © IRS)

This product can be used by the customers to analyze the consequences of possible scenarios (dam failure, extreme events…) and to calculate the potential damage.

2.4 Validation procedure

Within the project RiskEOS, a strict validation protocol for all the products and service chains was followed and executed. The validation contained a technical validation, a scientific validation and an operational validation:

- A "technical validation is defined as a quantitative measurement of a selected number of parameters useful to evaluate the service/products performances. For each product, the compliance of the products to the key performance parameters (accuracy, reliability …) specified for the product (e.g. check of geometrical and thematic accuracy (commission, omission), the qualification of the flood model, ...), is verified.
- The "operational validation" allows the end-users and clients to assess the adequacy of the general service characteristics (products content, delivery mode, delays, support…) to their needs.
- A scientific validation is defined as the scientific review of the methodology used to derive products performed by an independent body.

All flood services are qualified by this validation protocol.

2.5 Accordance to the Flood Directive

The Flood Risk Analysis portfolio was set up in order to be in accordance with the European Flood Directive. The services described above are all a necessary input for the execution of the Flood directive. Following requirements in the directive illustrate this:

- "… description of the floods which have occurred in the past …" (Preliminary Flood Risk Assessment / Article 4): the Past Flood Maps fulfill this requirement completely also providing necessary geo-information on the river basin.
- "Member states shall… prepare Flood Hazard Maps and Flood Risk Maps" (Article7): Member States have to prepare these maps for different scenario's, containing information on among others flood extent, water depth (and/or velocity), affected inhabitants,… The products of the Flood Risk Analysis portfolio, entitling the same name, contain all the required information and fully correspond to these compulsory requirements.
- „Member States shall make available to the public the preliminary flood risk assessment, the flood hazard maps, the flood risk maps and the flood management plans" (Article14): By integration of the flood risk analysis products into a management system, an efficient and supportive use of information is enabled to be used on local as well as national or transnational river basin level. Using a user interface and high level internet geo-application makes it possible to give the public access to the results, answering to another objective of the Flood Directive.

3. Conclusion

As the products are fully operational and ready to use, the different risk management entities declared the applicability of the services for their daily activities, answering certain specific questions and providing the right tools for measures management. The Flood Risk Analysis services support the implementation of the Floods Directive by providing appropriate information for implementation of flood risk management plans applicable to all major catchments across the countries and regions of the Community. It takes also into account the particular geographic, hydrologic and other relevant circumstances of the river basins or sub-basins to provide tailored solutions. The Flood Risk Analysis portfolio is developed in close cooperation with daily users and can provide a cost-effective, easy to use, harmonized and qualitative dataset across Europe.

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Han TAMBUYZER has a Master of Science in Bioscience Engineering from the University of Leuven, Belgium (2002). He started as project manager in the engineering office D+A Consult where he gained research and engineering experience in environment and land planning. In Eurosense he has built up a high expertise concerning remote sensing in risk management, agriculture and environment. He has an important role in the development, engineering and consolidation of the remote sensing applications services and GIS related projects. With a career as project manager on several projects, he has a good expertise on project management and with all kinds of applications of remote sensing

The author(s) of this article are working at the company EUROSENSE, a prominent commercial and highly specialized remote sensing organization, existing since 1964. It has offices in Belgium (Wemmel, near Brussels), The Netherlands (Breda), Germany (Cologne), France (Lille), Hungary (Budapest), The Czech Republic (Prague), Slovakia (Bratislava), Poland (Nadarzyn, near Warsaw), Bulgaria and Romania. The flood risk portfolio described above shows EUROSENSE' thorough experience in risk management services. All these described services were also produced and delivered in the frame of the GMES-project RISK-EOS, funded by ESA. Besides Risk-EOS, EUROSENSE is actively involved in several other GMES-projects.

Affiliations
MSc in Bio-Engineering, Han TAMBUYZER
EUROSENSE
Nerviërslaan 54
B-1780 Wemmel BELGIUM
T: +32 (0)2 460 70 00
F: +32 (0)2 460 49 58
han.tambuyzer@eurosense.com