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SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common Borders. Common Solutions.

A Scientific Network for Earthquake, Landslide & Flood Hazard Prevention

Current Status Assessment

(Evaluation of existing hazard assessment models AND Development/modification/adaptation of existing models)

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4	06.12.2014	Release of draft document on seismic hazard Prepared by V. MARGARIS	I.02c
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9			
10			

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 BACKGROUND OF THE DOCUMENT

1.1 A BRIEF INTRODUCTION TO THE PROJECT’S SCOPES

Natural Hazards especially Earthquakes, Landslides and Floods (ELF), pose a serious threat to societies and a block to sustainable development both in the European Union (EU) and the Black Sea Area [10]. These natural hazards can lead to natural disasters if combined with insufficient capacity to reduce the potential risks. The problem is widely recognized by the EU and a lot of effort has been made evident by directives issued, bodies formed, organizations established and research projects funded by various instruments and funding programmes [1], [11]. The current trend in the EU regarding natural hazard mitigation suggests an integrated approach to disaster mitigation taking into account all four stages of the Natural Hazard Mitigation Cycle – prevention, preparedness, response and recovery – [3], [4], [5], [6], and [7]. The proposed approach to hazard mitigation also suggests that prevention is the primary target, complemented by impact assessment so that preventive measures leading to effective preparedness and response can be planned [2], [5], [8], and [9]. Among the major problems recognized regarding the implementation of the aforementioned targets are: information gaps (data quality, availability, and accessibility), multitude of methodologies used to assess hazards (so there cannot be comparable results) and the lack of applied research on local scales (which could lead to designing of the appropriate preventive measures).

The primary targets of the SciNetNatHaz Project as they are defined in the ANNEX A document submitted are: i) the harmonization of methodologies used to assess each of the ELF hazards, ii) the harmonization of data used, the open/free access over a WebGIS platform, to all the data, maps and results produced by the project partners, iii) the creation of the respective metadata files according to the INSPIRE directive so that data and results provided can be evaluated and used by anyone interested and iv) Earthquake, Landslide and Flood hazard assessment, implemented in pilot areas on a local scale so that preventive measures can be designed.

In this way, the project will contribute to the targets already set by the EU regarding Earthquake, Landslide and Flood hazard mitigation in the near future.

The deliverable D.01.02 presents the outcomes of the efforts made by project partners to achieve the first of the primary SciNetNstHaz project targets which is the harmonization of methodologies used to assess Earthquake, Landslide and Flood Hazards in the wider Black Sea area.

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1.2 SUMMARY

The first Group of Activities, GA1 of this Project, for which this Deliverable is an output, provides the necessary base for scientific exchange and transfer of technical knowledge regarding the ELF hazard assessment, taking into account the experience and expertise of each partner.

This Deliverable, named "*Current Status Assessment"*, includes review and evaluation of the existing methodologies regarding natural hazard impact assessment. In addition, modified or appropriately adapted hazard assessment models are also presented for use in regional scale. In the previous Deliverable of GA1, actions dealing with the identification of the current status in terms of legislation and state-of-practice regarding landslide, flood and seismic hazards and their effects on the environment and on societies were included. By these two Deliverables, a clear perspective of the current status for the implementation areas and the possibilities to develop and to implement advanced scientific procedures have been investigated.

1.3 SCOPE AND OBJECTIVES

The scope of GA1 can be summarized in the following items:

a. recording of the existing legislation framework in every one of the participant countries regarding landslide, flood and seismic hazard prevention and management,

b. review of the available bibliography (existing projects, relative publications, registered events) regarding landslide, flood and seismic hazard at regional and local scales, which is necessary in order to achieve a common base of data and state of art and/or practice,

c. evaluation of existing models and methodologies assessing seismic, landslide and flood hazards in terms of scientific soundness, data demands and credibility of produced results. Therefore, the aforementioned hazard assessment models will be modified, adapted, or even new ones may be developed according to the local conditions in order to assess hazards at a regional scale.

The last item given above is the objective of this Deliverable. The Activities corresponding this objective are as follows:

1. Evaluation of existing landslide (A1.7), flood (A1.8) and seismic (A1.9) hazard assessment models in terms of scientific soundness, data demands and result credibility.

2. Landslide (A1.7) and flood (A1.8) hazard assessment models used in different partner countries will be tested / confronted to related hazard events recorded. Their effectiveness will be evaluated according to the successful assessment of the hazard in close relation with the nature of data needed to be used as input or the difficulty / cost to obtain them. Widely accepted seismic (A1.9) hazard assessment models will be evaluated in the proposed areas of the project, in order to define the most appropriate; theoretical results will be confronted to empirical data collected per country, as a consequence of seismic events.
3. Development/modification/adaptation of existing landslide (A1.11), flood (A1.12) and seismic (A1.13) models that will be used to assess related hazard, based on local conditions and needs of the proposal. Landslide hazard will be examined for both, excessive hydraulic and seismic conditions, at a regional scale on the areas proposed for implementation. Flood and seismic hazard will be examined at a regional scale on the areas proposed for implementation. Strong motion parameters, necessary for assessment of seismically induced landslides will be calculated.

As a result of these Activities, Development, modification and appropriate adaptation of scientifically sound and reliable methodologies in order to support decisions and strategies about preventive measures against seismic, landslide and flood hazards are expected as outputs.

1.4 RELATED DOCUMENTS

1.4.1 INPUT

List of former deliverables acting as inputs to this document

Document ID	Descriptor
1.	1st Progress Meeting Report (GA 5. Management and Coordination, Activity A 5.4)
2.	D.4.01: 1st Workshop Minutes
3.	D.1.01: Current status assessment - legislation and bibliography review

1.4.2 OUTPUT

List of other deliverables for which this document is an input.

Document ID	Descriptor
1.	D.2.02. Geodatabase development
2.	D.2.03. WebGIS Development / Update and completion of geodatabase
3.	D.3.01 : Results from seismic, landslide and flood hazard assessment coming from regional implementation of adopted methodogies

2 INTRODUCTION

The Deliverable is an output to the Activities: 1.7, 1.8, 1.9, 1.11, 1.12, and 1.13 of Group Activities 1 of the Project.

In the following chapters, the evaluation of existing hazard assessment models (for landslide, flood and seismic hazard, respectively), and modified or appropriately adapted hazard assessment models for use in regional scale will be presented.

3 LANDSLIDE SUSCEPTIBILITY AND HAZARD ASSESSMENT METHODS AND SELECTION OF MODELS FOR IMPLEMENTATION (ACTIVITIES A1.7 & A1.11)

3.1 INTRODUCTION

During the past years, climatic change in many countries worldwide brought in unpredictable rainfalls. If the devastating effect of earthquakes is added to the rainfalls and is combined with the mountainous nature of regions across the wider Black Sea area, it is rather easily conceived that landslides might become a serious threat for urbanized areas and infrastructure (lifelines, motorway and road axes, dams, etc).

As it seems to be the case for most of the involved in the project countries, little has been done in terms of Integrated Landslide Hazard Assessment and its modelling Practices. Actually, as is evident by relevant literature, there is no coordinated and organized methodology in terms of Landslide Hazard on a national level.

On the other hand, a considerable number of scientific efforts in terms of diploma undergraduate and graduate theses, National and European research projects and engineering projects deal with the subject of landslide vulnerability, landslide hazard assessment, landslide risk assessment and mitigation measures. The multitude of proposed methodologies and methods for assessing landslide hazard, even though it proves the increasing interest on the subject, it is also an index of heterogeneity and highlights the need for harmonization.

Authorities and decision makers need maps depicting areas that are prone to sliding and may be seriously affected by landslides; they also need practical, reliable and user friendly methods in assessing landslide susceptibility, hazard and even risk. Several institutions and scientific societies have proposed guidelines for the preparation of landslide hazard maps (i.e. OFAT, OFEE, OFEFP 1997; GEO 2006; AGS 2007; Fell et al 2008a, b); the common goal of all the above guidelines is the use of a unified and harmonized terminology and the need to highlight the most important data needed to prepare the relevant hazard maps at regional scales, to guide practitioners in their analyses, and to assist decision makers and authorities in making up their mind in a rational way, regarding infrastructures and urbanization. However, methods used and implemented to this end, not only differ from country to country, but might also diverge significantly within the same country (Corominas et al., 2010; 2013).

The risk for a single landslide can be expressed as follows (Corominas et al., 2013):

$$R = P(M_i) * P(X_j / M_i) * P(T / X_j) * V_{ij} * C \qquad (1)$$

where, R is the risk due to a landslide of magnitude M_i, on an element at risk at a distance X from the landslide, $P(M_i)$ is the probability of occurrence of a landslide of magnitude M_i, $P(X_j/M_i)$ is the probability of a landslide reaching a point located at a distance X from the landslide source with an intensity j, $P(T/X_j)$ is the probability of an element being at the point X at the time of occurrence of the landslide, V_{ij} is the vulnerability of the element to a landslide of magnitude I and intensity j, and finally, C is the value of the element at risk.

As it can be seen in Eq. (1), three basic components appear for the assessment: the hazard, the exposure of the element at risk and its vulnerability.

In our case, it is obvious that we are only interested in the first component; landslide hazard is characterized by both its intensity (severity of the hazard) and its probability of occurrence. In fact, the determination of the temporal occurrence of a same type of landslide at the same location is a critical issue in landslide hazard assessment. A critical prerequisite to this end is a well developed landslide inventory map, not only with spatial variability but also with a temporal one. Unfortunately, there is a lack of such data in many countries, thus preventing the application of a quantitative determination of the probability of a slope failure or a landslide reactivation within a defined time lag. Despite this limitation, it is necessary to make decisions regarding landslide hazard, or even landslide risk, based solely on the spatial distribution of existing or potentially existing landslides. This is based only on the landslide predisposing factors, and this is a susceptibility analysis. Significant efforts have been made to develop procedures for preparing landslide hazard maps from susceptibility maps.

Landslide hazard assessment depends seriously on the event-based landslide inventories, which are inventories of landslides caused by the same triggering event. If we link landslide distribution to the temporal probability of the triggering event, it is possible to carry out a magnitude frequency analysis.

3.2 LANDSLIDE ZONING AT DIFFERENT SCALES

Landslide zoning is the division of land into homogeneous areas or segments and their ranking according to their actual or potential landslide susceptibility, hazard or even risk. The developments on landslide zoning till the end of the decade 1990-2000, are well described in Ho et al. (2000) and Wong (2005), whereas more recent developments can be found in the Australian Geomechanics Society (AGS 2000, 2007), Nadim et al. (2006), Hong et al. (2007), JTC-1 Guidelines (Fell et al., 2008a) and Corominas et al. (2013).

Landslide zoning as a process which leads to a respective outcome can be classified into: a) landslide inventory maps, b) landslide susceptibility zoning maps, c) landslide hazard zoning maps and d) landslide risk zoning maps. The current practice in Europe

(Corominas et al., 2010, 2013) proved that scale landslide zoning maps required by state and local authorities might greatly differ from country to country, depending upon input data and methods used, as well as, the provided output. Bearing in mind the aforementioned and that landslide zoning might also be of use for land developers and developers of major infrastructure, the most common zoning maps are summarized in Table 3.1, hereafter. Table 3.1 also provides landslide hazard descriptors to be considered in zoning, according to the scale chosen.

Table 3.1**:** Examples of hazard descriptors for dealing with potential landslides at different scales of work (Corominas et al., 2013)

Scale of work	Runout	I(M)/F[a]	Hazard descriptor
National <1:250,000	Not included	Not considered	No. of landslides/ administrative unit/year
Regional 1:250,000–1:25,000	Usually not included	Often a fixed (constant) magnitude value	No. of landslides/ km^2/year
Local 1:25,000–1:5,000	Included	Spatially distributed magnitude (intensity)	Annual probability of occurrence (or return period) of a given magnitude or intensity
Site-specific >1:5,000	Included	Spatially distributed intensity	Annual probability of occurrence (or return period) of a given intensity

[a] Intensity (magnitude)/frequency

Regional scale work and zoning maps are usually suitable for planners’ activities in early phases of regional development projects or for engineers evaluating slope stability in areas where regional development plans or large engineering projects will take place. Typical areas to be investigated usually exceed 1,000km^2 and reach up to tens or thousands of square kilometres. The local scale zoning is detailed enough to support slope stability analyses over large areas and combine outputs with runout analyses. Zoning at a local scale is very sensitive on input data quality and resolution of the Digital Elevation Model (DEM), thus the input topographic data. The local scale is often used for statutory purposes and is typically the scale reference for planning and implementing urban developments and emergency plans. The local scale zoning typically refers to areas ranging from 10 to 1,000km^2. It is also the most suitable scale zoning in order to classify areas most at risk and prioritize areas where mitigation works need to be undertaken.

Last, site-specific zoning maps can be used either for statutory purposes and they can also be used for site investigation, just before the design phase. Size of examined areas at this scale, typically range from a few to some tens of square kilometres.

3.3 INPUT DATA FOR LANDSLIDE HAZARD ANALYSIS

This section refers to input data necessary for assessing landslide susceptibility and hazard. Given that the relative to the subject literature is huge, only a summary of the most used and the most suitable parameters for analyzing the occurrence of different landslide mechanisms will be given herein. The main input data, necessary for assessing landslide susceptibility and hazard can be subdivided in the following three groups: landslide inventory, environmental factors and triggering factors (Soeters and van Western, 1996; van Western et al., 2008). Of those three groups, landslide inventory is of great importance, as it gives insight for past landslides, their failure mechanisms, causal factors, frequency of occurrence, volume of the landslide and even damages caused.

3.3.1 PARAMETERS CONTROLLING THE OCCURRENCE OF LANDSLIDES

The occurrence of frequency-magnitude of mass movements is controlled by a large number of factors, divided into two main categories: a) predisposing or intrinsic factors that contribute to the instability of the slope, and b) triggering or extrinsic factors.

An indicative, but not exhaustive list of factors controlling landslide occurrence is as follows: topography, geology, soils, hydrology, geomorphology, land use and anthropogenic factors, earthquakes and volcanoes, weather and climate.

The large amount of predisposing and triggering factors complicates the analysis of landslide susceptibility and hazard. The methods, the approaches, the data required and the scale used, differ considerably from case to case. Data availability, model complexity and user friendliness and success in predictive capacity are critical points in order to make a choice for the most suitable model of landslide susceptibility and hazard. Therefore, it seems rather impossible to provide guidelines on the necessary data required for landslide hazard analysis, in terms of a well defined list of predisposing and triggering effects. However, a list (rather indicative, than exhaustive) of possible factors to control the occurrence of landslides is given in Table 2 (Corominas et al., 2013).

Table 3.2: Overview of factors controlling the occurrence of landslides and their relevance in landslide susceptibility and hazard assessment (R=rockfalls, S=shallow landsides and debris flows, L=large, slow-moving landslides; Corominas et al., 2013)

Group	Parameters	Relevance for landslide susceptibility and hazard assessment	Type of factor		Landslide mechanisms		
			C	T	R	S	L
Topography	Elevation, internal relief	Elevation differences result in potential energy for slope movements	●		H	C	H
	Slope gradient	Slope gradient is the predominant factor in landslides	●	●	C	C	C
	Slope direction	Might reflect differences in soil moisture and vegetation, and plays an important role in relation to discontinuities	●		C	M	M
	Slope length, shape, curvature, roughness	Indicator of slope hydrology, important for runout trajectory modelling	●		C	H	H
	Flow direction and accumulation	Used in slope hydrological modelling, e.g. for the wetness index	●		M	C	H
Geology	Rock types	Determine the engineering properties of rock types	●		C	H	C
	Weathering	Types of weathering (physical/chemical), depth of weathering, individual weathering zones and age of cuts are important factors	●		C	H	H
	Discontinuities	Discontinuity sets and characteristics, relation with slope directions and inclination	●		C	M	H
	Structural aspects	Geological structure in relation to the slope angle/direction	●		H	H	H
	Faults	Distance from active faults or widths of fault zones	●		H	H	H
Soils	Soil types	Origin of the soil determines its properties and geometry	●		L	C	H
	Soil depth	In superficial formations, depth determines the potential movable volume	●		L	C	H
	Geotechnical properties	Grain size, cohesion, friction angle, bulk density	●		L	C	H
	Hydrological properties	Pore volume, saturated conductivity, PF curve	●		L	H	H
Hydrology	Groundwater	Spatial and temporal variations in depth to groundwater table, perched groundwater tables, wetting fronts, pore water pressure, soil suction	●	●	L	H	H
	Soil moisture	Spatial and temporal variations in soil moisture content	●	●	L	H	H
	Hydrological components	Interception, evapotranspiration, throughfall, overland flow, infiltration, percolation, etc.	●	●	M	H	H
	Stream network and drainage density	Buffer zones around streams; in small scale assessment, drainage density may be used as an indicator for type of terrain	●		L	H	H
Geomorphology	Geomorphological environment	Alpine, glacial, periglacial, denudational, coastal, tropical, etc.	●		H	H	H
	Old landslides	Material and terrain characteristics have changed, making these locations more prone to reactivations	●		M	H	C
	Past landslide activity	Historical information on landslide activity is often crucial for determining landslide hazards and risk	●		C	C	C
Land use and anthropogenic factors	Current land use	Type of land use/land cover, vegetation type, canopy cover, rooting depth, root cohesion, weight	●		H	H	H
	Land-use changes	Temporal variations in land use/land cover	●	●	M	C	H
	Transportation infrastructure	Buffers around roads in sloping areas with road cuts	●		M	H	H
	Buildings	Slope cuts made for building construction	●	●	M	H	H
	Drainage and irrigation networks	Leakages from such networks may be an important cause of landslides	●	●	L	H	H
	Quarrying and mining	These activities alter the slope geometry and stress distribution. Vibrations due to blasting can trigger landslides	●	●	H	H	H
	Dams and reservoirs	Reservoirs change the hydrological conditions. Tailing dams may fail	●	●	L	H	H

Table 2 continued

Group	Parameters	Relevance for landslide susceptibility and hazard assessment	Type of factor		Landslide mechanisms		
			C	T	R	S	L
Earthquakes and volcanoes	Seismicity	Earthquake magnitude/frequency relations, historical intensity maps linked with co-seismic landslide inventories		●	C	C	C
	Fault mechanism	Fault locations, fault type, length of fault rupture, buried or exposed, distance from fault, hanging wall/footwalls	●	●	H	H	H
	Volcano type	Height and composition of volcanic edifice, magma chamber stability	●	●	M	H	H
	Volcanic eruption types	Lateral explosions, collapse of magma chambers, pyroclastic flows, lahars	●	●	M	H	H
Weather and climate	Precipitation	Daily or continuous data, weather patterns, magnitude/frequency relations, IDF curves, rainfall thresholds, antecedent rain, PADF curves		●	C	C	C
	Temperature	Important influence on hydrology and the condition of vegetation. Rapid temperature changes, snowmelt, frost–thaw cycles, permafrost	●	●	H	H	H

The relevance is indicated as *C* (crucial), *H* (highly important), *M* (moderately important), and *L* (less important). The type of factor is indicated as either *C* (conditioning factor) or *T* (triggering factor)

3.3.2 LANDSLIDE INVENTORIES

Landslide inventories usually display (or, should display) information on landslide activity (according to definitions given by Cruden and Varnes, 1996). It is important to have insight into spatial and temporal frequency of landslides. Therefore, a quantitative analysis of landslide hazard or risk should start with a well informed inventory in terms of spatial and temporal variation according to international statements (i.e. IAEG Commission on Landslides, 1990). Nowadays, an important number of methods based on remote sensing (Michoud et al., 2010; Stumpf et al., 2011) are used with success, whilst Google Earth is also a very useful and promising tool, since it covers many parts of the world with a high-resolution imagery that can be easily downloaded and be used in combination with a GIS and a high-resolution DEM, in order to generate stereoscopic images and provide landslide interpretation.

A more detailed analysis on Remote Sensing applications on Landslide Hazard assessment and disaster prevention is included in the output of Activity A.1.10 and the respective deliverable.

3.3.3 PREDISPOSING FACTORS

Since **topography** is an important predisposing factor, as well as its derivatives (slope steepness, slope gradient, orientation, length, curvature, etc), the use of high-resolution DEMs is crucial. Nowadays, global DEMs are available from several sources and they can be derived from various techniques such as differential GPS measurements, digital photogrammetry (InSAR and LiDAR).

Traditionally, **geology** is another crucial predisposing factor that is taken into account. It has been suggested that instead of geologic maps with legends focusing in the lithological stratigraphy of geological formations, it would be much better if geologic maps were converted into a more engineering geological classification, emphasizing in the mechanical behaviour of Quaternary (often soils classified in this category present significant divergence of geotechnical parameters and subsequently, mechanical behaviour) and rock composition and rock mass strength. Apart from pure lithological information, **structural information** regarding geologic planes which form surfaces of "weakness" (stratification, foliation, joints etc) is important for landslide hazard assessment. However, attempts to include structural information in terms of dip direction and dip angle based on field measurements, proved to be less promising than initially thought, and this has been attributed to the insufficient number of structural measurements or/and mostly to the complexity of the geological structure (Ghosh et al., 2010).

When **physically based slope stability models** are used for landslide hazard assessment, especially when shallow type landslides are implicated (debris flow, debris slide), the **regolith depth** or soil depth according to engineers is of critical importance (soil depth is defined as the depth from free surface to a rather consolidated material). Even though it is considered to be a major predisposing factor, affecting seriously landslide modelling, it has the obvious draw-back that it presents an important spatial variability which a lot of times is neglected (especially in small scales), as it is given a constant value per land unit, which it can be considered as an over simplification of real conditions (Bakker et al., 2005; Bathurst et al., 2006; Talebi et al., 2008). Soil thickness can be modelled using physical based models that take into account the rates of denudation, weathering and accumulation, or empirical methods that correlate it with topographical factors, such as slope Tsai et al., 2001; Van Beek, 2002; Catani et al., 2007). On top of inaccuracies implied by large spatial variability of the soil depth, as well as, from geotechnical and other hydrological parameters, measurement accuracy and temporal variability, are two more sources of errors for slope hydrology and stability (Kuriakose et al., 2009).

Geomorphological maps are of a considerable interest for physically based models, since they show land units based on their shapes, materials, processes and genesis. However, do to the lack of standardization there are no widely accepted legends for geomorphological maps, and moreover a lot of countries do not have compiled such maps at all. Therefore, this parameter is often neglected.

Land use is considered to be a stable (unchanged) factor of landslide hazard assessment studies. This is obviously not true, and a significant effort has been undertaken to quantify the effect of land use modifications on landslide susceptibility assessment (Glade, 2003). For physically based models it is quite important to have temporal land-use and land-cover maps and to correlate temporal variations to mechanical and hydrological parameters implicated in landslide modelling. Despite the fact that a number of recent studies have proved the above, it is quite difficult to obtain this information and thereof it is of limited practical use for the time being.

3.3.4 TRIGGERING FACTORS

This is another set of important input data for landslide hazard assessment. Rainfall and temperature data can be gathered from different meteorological stations in the broader area of interest. Then, by means of interpolation, values are derived at different points of interest. If dates of landslides that occurred in the past can be correlated to precipitation indicators, it is possible to establish rainfall thresholds which have triggered landslides. As is obvious, accurate and reliable data regarding rainfall prediction are useful and promising in landslide hazard assessment studies.

Physically based models for landslide susceptibility can incorporate rainfall data as a dynamic input of the model, and offer the opportunity for creating landslide susceptibility maps dependent on climate changes in the future. If this is easily conceived for rainfall and precipitation triggered landslides, it is more complicated to extend this idea to earthquake-triggered landslide susceptibility, combining possible earthquake scenarios with precipitation indicators and their associated co-seismic landslide distributions (Keefer, 2002; Meunier et al., 2007; Gorum et al., 2011). In order to establish well documented relationships between seismic, geological and topographical factors, more digital, event-based co-seismic landslide inventories need to be established at different environments, different earthquake magnitudes, distances and frequency content.

Another type of approach regarding the production of landslide earthquake-induced susceptibility maps is based on the use of tools like GIS, which need as input, factor maps related to shaking intensity (shake maps data), slope gradient, material type, moisture (or other precipitation factors), slope height and terrain roughness (Miles and Keefer, 2009).

3.3.5 DATA QUALITY

There is a delicate border between the wish of the existence of an exhaustive catalogue of reliable and accurate predisposing and triggering factors related to landslide susceptibility (either rainfall-triggered or earthquake-triggered) and reality, imposing lack or scarcity of input data and data with a large degree of uncertainty. Therefore, important problems related to uncertainty, accuracy, objectivity, reproducibility of input data can be sources of miscalculation of landslide susceptibility or hazard assessment models, seriously affecting the output (usually, the hazard maps produced). The quality of input data for landslide susceptibility and hazard, is related to a considerable number of factors, such as the scale of analysis, the size of the examined area, local geology, topography (slope angle), geotechnical and hydrological parameters, availability and reliability of existing maps, and a lot of others, not to mention parameters like subjectivity and experience of researchers dealing with this kind of issues. Landslide databases and inventories are often incomplete or even biased in terms of spatial and temporal variability of landslides.

3.4 LANDSLIDE SUSCEPTIBILITY ASSESSMENT

Landslide susceptibility assessment must be considered as the first step of a landslide hazard assessment, but also an output on its own, useful for future land planning or development; this is usually the case of small-scale maps where data regarding spatial and temporal variability of landslides that occurred in the past, is incomplete. Landslide susceptibility maps contain information about the type of landslide that might occur, as well as their initiation point according to geological, topographical and land-cover conditions.

A basic assumption of methods used for landslide susceptibility assessment, is that locations where landslides occurred in the past are indicative of future landslides, since they maintain the same topography, geology, geomorphology, land use and climate. It is obvious that for this kind of methods, detailed and well developed landslide inventories, are necessary. As for the content of susceptibility maps, they should include:

- Zones with different classes of susceptibility to sliding (it is recommended for reasons of clarity, that susceptibility classes should not exceed five).
- A well documented inventory of past landslides, so that historic landslides and susceptibility classes can be directly compared.
- Clear explanations on susceptibility classes with information on expected landslide densities.

Susceptibility maps must provide a ranking towards spatial probability of landslide occurrence, but they usually do not provide information on landslide return periods.

In international bibliography a considerable number of methods assessing landslide susceptibility can be found. A number of papers attempt to review those methods (Carrara et al., 1999; Dai et al., 2002; Fell et al., 2008a,b). In general, methods for the landslide susceptibility assessment can be divided into two major categories: qualitative and quantitative.

The former include inventory-based and knowledge-driven methods, whereas the latter, include data-driven and physically based methods.

In knowledge-driven methods, landslide susceptibility maps are prepared by geomorphologists on site, based on direct observation of phenomena and geological or geomorphological settings.

Data-driven methods are based on data from past landslides that occurred, in order to obtain information on relative importance of instability and of triggering factors. Different statistical methods are applied, in order to learn which combination of factors play an important role in initiation of a landslide. Those techniques are quite often used in the case of regional scale landslide susceptibility assessment, provided that there exists a complete inventory of landslides that occurred in the past and that factors that triggered landslides are well defined.

Physically based landslide susceptibility assessment methods are essentially based on modeling the slope failure processes. Implementation of such methods necessitates considering simple types of landslides and relatively homogeneous geological and/or geomorphological conditions. A lot of those models are based on the infinite slope model, being appropriate for analyses of shallow landslides (just a few meters of depth). Physically based models can also be applied in areas where landslide inventories are incomplete. If those models are implemented in a GIS environment, they can help calculate, in every unit of analysis, the requested values based on the equations incorporated. Results from physically based methods are concrete and usually present a higher degree of predictive capability. They are considered to be more suitable for quantitative assessment of landslide susceptibility, as they can provide quantitative values of slope stability, such as: factor of safety and / or probability of failure. However, the simplifications needed in order to implement the above models in a GIS environment, as well the large number of the required accurate and reliable input data, are major drawbacks for physically based models, especially when they are applied at regional scales (1:25,000 to 1:250,000).

The selection of the most appropriate method of analysis is a difficult task, as it has to satisfy both scale requirements, required data and anticipated outputs in terms of reliability and accuracy, according to the method used. A number of issues have to be considered to this end:

- Physically based methods used at small scales might imply either important over-simplifications regarding geotechnical data, or, extremely time consuming data collection.
- The use of data and of a scale inappropriate for the susceptibility or hazard problem investigated, may lead to erroneous results.

- The fact that different type of landslides or other slope instabilities exist and are controlled by different combinations of triggering or pre-disposing factors, has to be taken into consideration in the analysis.
- Interference on natural environment, such as construction of a highway / roadway, a dam, etc might largely affect and subsequently modify landslide hazard.

3.5 LANDSLIDE HAZARD ASSESSMENT

Hazard assessment aims to determine the spatial and temporal probability of occurrence of landslides in the target area, along with their mode of propagation, size and intensity (Corominas et al., 2013). According to Varnes (1984), a well established definition of landslide hazard refers to the probability of occurrence of a landslide of a given magnitude. However, it is questionable whether this definition is the most appropriate or not, since there are a number of cases where large volume creeping landslides with a low rate of displacement of a few mm/year, barely affects buildings and infrastructure in terms of structural damage. These mass movements are considered as an almost negligible threat to people. As opposed to that, a rockfall of only some hundreds of cubic meters traveling at a speed of some tenths of m/s, can cause considerable damage to buildings or infrastructure and even human losses. A more appropriate index to assess landslide destructiveness is “intensity” (Hugr, 1997) which dependents upon the mechanism of propagation. More specifically, velocity or kinetic energy, differential or total displacement, impact pressure and other parameters may be used as an index to “quantify” the intensity of a landslide according to the mechanism of propagation. On top of the already existing complications regarding quantification of “landslide intensity”, it must be considered that it is not an intrinsic characteristic of the landslide, but it also depends on the path, so, quantification of a landslide’s destructiveness is a demanding task, and consequently the same stands for a reliable landslide hazard assessment.

Another parameter to account for, when referring to landslide hazard assessment, is the temporal occurrence of landslides in the examined area, expressed in terms of frequency, return period or probability of exceedence. Irrespectively of which of the available ways will be used to assess the temporal distribution of landslides, it is necessary to use one of them, in order to quantify this parameter.

For landslide hazard assessment maps at a scale less than 1:25,000 the approach of assessing the probability of occurrence of landslides is traditionally used. Namely, the following groups of methods may be used:

- heuristic methods based on experts judgments,

- rational methods which assign a probability of occurrence coupling the stability analysis to a triggering factor with a known probability,
- indirect approaches such as: the definition of a rainfall or earthquake threshold
- the landslide magnitude-frequency relation
- Frequency-Magnitude relations

The purposes of a landslide hazard analysis determine the methodology used and the resulting outputs. According to Corominas and Moya (2008), hazard analysis may have different targets, such as:

- Analysis of areas for regional or local planning; the potential of slope failure is evaluated at every terrain unit (pixel, cell, polygon, etc); temporal variation is expressed in terms of number of landslides / per unit area or per year or as a probability of exceedence.
- Linear analysis for infrastructure and linear facilities (e.g. motorways, railways, pipelines ...) with a linear layout. The hazard analysis usually focuses on the landslides that affect or might affect the linear type infrastructure.
- Object-oriented landslide hazard analysis which is performed at specific sites.

Landslide runout models are not considered in short-displacement landslides, as these remain close enough to their initiation zone; in this case, hazard assessment mapping includes the potential for slope failure, but landslide intensity is not calculated.

Regional and national scale maps, hazard analyses are non-spatially explicit, as slope analyses and runout models are not accurate enough. Therefore, hazard assessment in any case, can be considered as partially completed, given that intensity is not taken into account.

Combination of spatially distributed hydrological and stability models can be used in regional or local scale analyses, in order to calculate the probability of landslide occurrence in a land unit. Landslide hazard is expressed as the conditional probability of slope failure once a triggering factor for landslide occurs.

The factor of safety for the slope is computed at each terrain unit using an infinite slope stability model, where probability of failure is expressed as the annual exceedance probability of a critical rainfall event (Savage et al., 2004; Salciarini et al., 2008). For earthquake-induced failures, a probabilistic hazard assessment analysis, based on regional or local attenuation relations, can be used in order to determine the peak ground accelerations (PGA) for different return periods and the stability of slopes subjected to earthquakes are examined based on pseudo-static stability analyses (Dai et al., 2002).

As a conclusion, it seems that most of the time, researchers have to face a counterbalance between well advanced and complete landslide susceptibility and hazard models, with strict requirements in terms of input data (predisposing and rainfall or earthquake-triggering factors) and reality, where incompleteness (not to say, inexistence in a lot of cases) of reliable, certain and accurate input data is often the case.

As a general rule, data availability is a crucial, often a decisive parameter, in selecting the appropriate model to assess landslide hazard and risk.

The problem of lack of accurate and reliable data has already been faced during the implementation of this project, where no landslide inventories are available in almost all of the involved countries and moreover, data even if found have no additional information (meta-data) so they cannot be evaluated in terms of reliability and accuracy.

Moreover, the harmonization of methodologies used to assess any type of hazard, defines up to a certain point the complexity of the model, which can be adopted. A landslide hazard assessment model, in order to be applied over the entire Black Sea area as in this case, has to be flexible/adaptable to local conditions, it’s data requirements must be covered by the intersection of the partner countries available data sets, and the results it produces must be reliable and accurate enough to be used for locating at a regional scale, landslide prone areas with a high level of hazard.

A review of available landslide hazard assessment models, many of which have already been used in the area must be made in order to select the most appropriate one(s) to propose for use throughout the Black Sea area for assessing landslide hazard. The qualified model must be, at a next stage, evaluated by applying it in pilot implementation areas in order to compare its results with actual facts.

The goal of this action is to evaluate the methods currently used in the countries of the Black Sea Basin for landslide hazard assessment at regional scales (from 1:250,000 to 1:25,000) and subsequently to adapt, modify, or even improve them, according to available regional data.

An effective solution to that end, is to finally select one or two LH assessment methods that can fulfil a number of requirements: a) they need to be easily adapted to local conditions and be applied across the entire Black Sea area, b) they need to provide reliable and accurate enough results to support decision making regarding planning prevention measures at a regional scale and especially to provide “hot spot” detection; i.e. areas prone to sliding where risk assessment and detailed studies on a local scale should be carried out if necessary; c) the entire proposed procedure must be applicable by stakeholders, meaning Public State and Local administration employees, young researchers and in general, all people involved in LH assessment who could work together to tackle the problem in their respective areas of interest, and d) if possible, provide the necessary tools for LH hazard assessment, preferably freeware, or at a relatively low cost and a satisfactory degree of friendliness in their use so that implementation by a higher number of people, can be promoted.

Some aspects of the process have been considered; model data requirements versus to data availability, accuracy, completeness and reliability; anticipated results; flexibility to adapt to local conditions and ability to be applied in all eligible areas of Black Sea Basin; user friendliness in order to be easily adopted and used by stakeholders (governmental agencies, central administration, local authorities, educational institutions, etc).

In order to satisfy the aforementioned parameters, there is a number of steps to be taken and various factors to be identified: 1. Problem definition; 2. Specification of the objectives; 3. Study of the available data; 4. Determination of the available computer/hardware facilities; 5. Specification of social and economic constrains; 6. Adoption of a particular class of landslide models; 7. Selection of a particular type of model within the already selected class; 8. Calibration / Adaptation / Modification to local conditions of the selected model; 9. Performance evaluation of the selected model; 10. Potential use of the model for prediction purposes.

3.5.1 BASIC CONSIDERATIONS FOR SELECTING THE APPROPRIATE LH MODEL

Several approaches in terms of assessing Landslide Susceptibility and Hazard have been presented and applied worldwide. They range from simple and straightforward engineering approaches to using complex scientific models. However, the final choice depends on several parameters and on the goals to be met each time. A lot of discussion has been done between qualitative (knowledge driven) and quantitative (data driven & physically based) methods. The approach applied in each case comes as a result of the combination of the following parameters:

- Availability of input data
- Cost of the necessary data
- Cost of implementation (including software and hardware costs)
- Adaptability of the method used in different situations
- Complexity of the method used
- Amount of expertise and special knowledge needed for implementation of the method used
- Required accuracy and reliability of the output

3.5.2 INPUT DATA: AVAILABILITY AND COST

Data availability, reliability, cost and format are the basic parameters to be carefully considered in order to decide upon a method for assessing Landslide Susceptibility & Hazard. The term "input data", refers to all possible data requirements including both geological, hydrologic, topographic, seismic and any other additional thematic maps and data.

In many cases, landslide historic data (landslide inventory) are difficult to obtain due to lack of systematic observations and systematic recording of past landslides. Even if such data sets are available, there is still the question of their cost as usually we face limited budgets and limited access to field sites. Hydrologic historic data are equally difficult to obtain as rainfall data are often scarce and not systematic in terms of temporal and spatial variation.

In the majority of the EU countries, landslide and hydrologic information and datasets result from a variety of protocols and methods. Therefore, data retrieval and harmonization is, in most cases complex, time consuming and rather expensive because there is no central repository where researchers can easily access this kind of information.

On the other hand, topographic data are easier to obtain but their accuracy and reliability is always an issue especially in applied research on local or site-specific scales. The desirable accuracy of the topographic datasets is connected to the extent of the examined area and the scale of implementation. When dealing with large areas, regional scale data may be obtained from satellite images, aerial photography with photogrammetric interpretation and/or from digitizing of maps of proper scale. When it comes to local scale where accuracy and levelling are mostly needed, topographic data must be obtained from field surveying and/or from digitizing of topographic maps of a large scale (greater than 1:1.000. The topographic data needed are usually vector-based data.

In most cases, geological data are needed and can be obtained from geological maps by digitizing. The same applies for land cover and land use where information may be extracted from relevant maps, field observations and EU Organizations, such as the Joint Research Centre (http://ec.europa.eu/dgs/jrc/).

A method, no matter how sophisticated and complete it can be, cannot be applied if its data requirements necessitate time and money consuming conditions.

Data availability has already been recognized by the EU Commission as an important part of the "information gap" and plays a restrictive role in the adoption of methods to assess natural hazards throughout Europe. Selection of data is maybe the most challenging part of the whole process.

The data cost depends on the extent of the examined area, on data availability and on the desirable accuracy of the results. Although datasets are more available now than previous years, it still remains a serious budget issue for numerous reasons; existing datasets are not always available or are expensive to be purchased, their production is expensive, experts are needed, data production is time consuming and thereof, costly.

Improved and new data collection methods are promising in terms of accuracy and cost reduction in the future, as is LIDAR and InSAR techniques, most useful tools for landslide inventory mapping and monitoring using remote sensing (Van Den Eeckhaut et al., 2009; Razak et al, 2011; Jaboyedoff et al., 2012; Farina et al., 2006).

Open Data Initiatives can greatly help research, because they reduce time consuming procedures and costs, simplifying thus implementation of methodologies regarding Natural Disaster mitigation issues.

3.5.3 COMPLEXITY OF THE METHOD USED

Landslides may be described and modelled by using different methods. These methods often require a certain number of assumptions to develop governing equations. Simple landslide modelling methods are fairly sufficient to assess landslide susceptibility under static (hydraulic) and seismic conditions, as well as, landslide hazard assessment. It is evident that more complex and advanced models including an important number of parameters and necessitating a serious number of data result in more accurate results. The question always raised is whether this time and cost consuming methods would offer a substantially different zoning map regarding landslide susceptibility and hazard assessment at a regional scale that would allow Decision Makers to make better decisions regarding landslide risk mitigation measures.

From a purchasing cost reduction perspective, there is a number of available for free software (freeware) including: Quantum GIS and SAGA GIS as the GIS platforms to implement regional Landslide Hazard assessment and open source software for slope stability analyses including the following:

1. **STB**. Software dedicated in the stability analysis of slopes. The software uses Bishop's simplified method for calculating of the safety factor of a circular slip surface. The safety factor of a slope is determined by comparing the moment of the weight of a soil wedge about the center of a slip circle, with the resisting moment provided by the shear stress along the slip surface. The software also allows for a possible horizontal body force, to simulate the effect of an earthquake.

2. **PSLOPE,** which can be used for two-dimensional slope stability analysis. It has the ability to analyze both a single user-defined non-circular failure surface and to search for the minimum non-circular failure surface. It calculates safety factors for circular and non-circular slope failure surfaces, using a number of widely used limit equilibrium analysis approaches such as the Bishop, Janbu, Carter's and Mongenstern-Price.
3. **DLISA**. It is a 25 years old software program that works in MS-DOS environment without model simulation ability. The user cannot define the geometry of the slope (just only its depth). It just calculates the factor of safety with the deterministic way. It can also calculate the necessary root cohesion when the desirable safety factor is known.

3.5.3.1 Expertise / Special knowledge required

Expert users are in most cases needed in LHA methods. A combination of geological, geotechnical, hydraulic, seismological, CADD and GIS knowledge would be an ideal combination to deal with LHA issues at a regional or local scale. It is clear that a broad area of knowledge at different topics is needed and it is not easy to be met by one single user. Maybe a combination of two users, closely collaborating could offer best results. Anyhow, the user(s) should choose a method for Landslide Susceptibility Analysis (LSA) & LHA that best meets the needs in relation to his/her knowledge and ability to comprehend fundamental concepts. A more accurate but more complex method is of no use if the users can not apply it correctly; on the opposite, its use by non expert users increases the risk of leading to erroneous results. In any case, at least a minimum level of expertise is required to implement landslide susceptibility and hazard assessment methods. On the other hand, the use of a fairly simple method in terms of implementation, combined with the presence of readily available data, references, guides and tutorials can support any user interested in using that method to provide reliable and accurate enough results for screening purposes. In such a case, areas of interest are limited to those which present a high level of landslide hazard thus reducing the time needed and the cost of required high detailed data because implementation on a site-specific scale (slope stability analyses) is restricted to those specific areas.

3.5.3.2 Adaptability and Cost of Implementation

The term "adaptability" refers to the ability of a method to be adjusted or calibrated in individual and particular cases. A method that is generally more easily adjusted to a specific project is preferable to one that's not easily or not at all adaptable. In fact, as one of the prime targets of the project is the maximum possible harmonization of methods and the implementation of the same method, if possible, over the entire area. Bearing that in mind, methods that cannot easily be adapted to local conditions or applied in locations across the wider Black Sea area should be excluded.

Methods and models of “limited adaptability” are generally less desirable especially when dealing with local scale Landslide Hazard Assessment Methods.

The cost of the implementation of a method is in most cases, a combination of data collection and software purchase which impose a direct cost, but there are additional parameters which should also be considered as they contribute to the overall cost of each approach/method indirectly (i.e. if experts are needed the cost rises, if the method chosen is more complex then it is more time consuming and the cost rises as well, etc).

Given the economic situation in most countries around the Black Sea, researchers and even public Services have difficulties in purchasing expensive software. For that reason the adoption of Open Source software where applicable provides a viable solution. In such a case, it is absolutely necessary that the selected/adopted software must meet the requirements in terms of accuracy and reliability of the results it provides.

As in any case the decision must be based on the methodology to be adopted, in relation to its data requirements and the provided results/outcomes and the software (tool) to apply it, in terms of its cost, its user friendliness and the anticipated outputs.

3.5.3.3 Completeness, Accuracy and Reliability

The term of completeness refers to results with respect to their usability for decision making regarding Landslide Disaster mitigation issues. Methods are classified according their results completeness into: Low (cover only a few aspects. The use of additional methods is required); Medium (cover most aspects of the problem. Minor issues still remain unsolved); High (cover every aspect of the problem).

Accuracy and Reliability are related to the amount and impact of uncertainties and errors on the outputs of each method. Uncertainties and errors are introduced throughout the development and the process in every case of any method implemented. The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing, and theoretical assumptions, can render results inaccurate and ultimately misleading. In this case, additional data (statistical, historical, morphological, seismic, hydrological and geological) must be used to evaluate the results.

3.5.4 DESCRIPTION, IMPLEMENTATION AND EVALUATION OF LHA METHODS USED

As already stated in paragraph 3.5, ***predisposing factors*** play an important role in landslide susceptibility and landslide hazard analysis, under both static and/or seismic conditions. Therefore, the following points are highlighted as being crucial for a reliable assessment, given the detail dictated by the scale used:

- **topographic information** and its derivatives (clear need for high-resolution DEMs)
- **geological maps** focusing traditionally in lithological and stratigraphical subdivision need to be converted into an engineering geological classification with emphasis on Quaternary sediments and rock texture / structure, as well as, rockmass strength
- **structural information** is important for landslide hazard assessment; attempts to incorporate dip & dip direction based on either filed measurements or geological maps can improve reliability of output, but also depends strongly on the number of measurements and complexity of structure
- **Soil properties** in the use of physically based slope stability models for LHA are key parameters, especially for shallow depth failures. Soil depth, defined as the depth from free surface down to a consolidated material (also known as regolith depth)
- **Spatial variability** is also a crucial parameter, often ignored in landslide modeling due to lack of appropriate data
- **Soil thickness** can be modeled throughout physical based methods that model rates of weathering, denudation and accumulation

Physically based landslide susceptibility and hazard assessment methods are based on the modelling of slope failure processes. They can be applicable over large areas, if geological and geomorphological conditions are fairly homogeneous and landslide types relatively simple. They also apply to areas with incomplete or inexistent landslide inventories; this is considered as a major advantage for countries with incomplete landslide inventories, such as the case of Greece.

Most of physically based landslide susceptibility and hazard assessment methods use the **infinite slope model**, therefore they are suitable for shallow landslides and this is one of the reasons why they have been used extensively in Greece. The above models account for different triggering parameters, such as: rainfall and transient groundwater response or to the effects of earthquake excitation (Corominas et al., 2013).

The main advantages and pitfalls of physically based methods for landslide susceptibility and hazard assessment include:

1. Main advantages
    a. They can be easily implemented in GIS environment
    b. Results/outputs are more concrete and consistent compared to other approaches
    c. They present higher predictive capability and appear to be more most suitable to quantify the influence of individual parameters contributing to shallow landslide initiation
    d. Based on slope stability models, they allow the calculation of quantitative values of stability (safety factor, probability of failure)
2. Main drawbacks
    a. Parameterisation can be a difficult task as well as, access to critical parameters (soil depth, transient slope hydrological processes & temporal changes in hydraulic properties)

There is a risk of over simplification, since a large amount of reliable input data is often necessary.

As it appears, the physically based methods for landslide susceptibility and hazard assessment offer relatively reliable results, their accuracy being dependent on the amount or available input data, whereas their use is rather well conceived, even by non experts, but scientific personnel with a minimum of training. It must be pointed out at this point, that the scope of the present study, within the SciNetNatHaz project's scopes, is to select one or two LH assessment methods that can fulfil a number of requirements: a) they need to be easily adapted to local conditions and be applied across the entire Black Sea area, b) they need to provide reliable and accurate enough results to support decision making regarding planning prevention measures at a regional scale and especially to provide "hot spot" detection; i.e. areas prone to sliding where risk assessment and detailed studies on a local scale should be carried out if necessary; c) the entire proposed procedure must be applicable by stakeholders, meaning Public State and Local administration employees, young researchers and in general, all people involved in LH assessment who could work together to tackle the problem in their respective areas of interest, and d) if possible, provide the necessary tools for LH hazard assessment, preferably freeware, or at a relatively low cost and a satisfactory degree of friendliness in their use so that implementation by a higher number of people, can be promoted.

Some aspects of the process have been considered; model data requirements versus to data availability, accuracy, completeness and reliability; anticipated results; flexibility to adapt to local conditions and ability to be applied in all eligible areas of Black Sea

Basin; user friendliness in order to be easily adopted and used by stakeholders (governmental agencies, central administration, local authorities, educational institutions, etc).

In order to satisfy the aforementioned parameters, there is a number of steps to be taken and various factors to be identified: 1. Problem definition; 2. Specification of the objectives; 3. Study of the available data; 4. Determination of the available computer/hardware facilities; 5. Specification of social and economic constrains; 6. Adoption of a particular class of landslide models; 7. Selection of a particular type of model within the already selected class; 8. Calibration / Adaptation / Modification to local conditions of the selected model; 9. Performance evaluation of the selected model; 10. Potential use of the model for prediction purposes.

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- Availability of input data
- Cost of the necessary data
- Cost of implementation (including software and hardware costs)
- Adaptability of the method used in different situations
- Complexity of the method used
- Amount of expertise and special knowledge needed for implementation of the method used
- Required accuracy and reliability of the output

3.5.6 INPUT DATA: AVAILABILITY AND COST

Data availability, reliability, cost and format are the basic parameters to be carefully considered in order to decide upon a method for assessing Landslide Susceptibility & Hazard. The term “input data”, refers to all possible data requirements including both geological, hydrologic, topographic, seismic and any other additional thematic maps and data.

In many cases, landslide historic data (landslide inventory) are difficult to obtain due to lack of systematic observations and systematic recording of past landslides. Even if such data sets are available, there is still the question of their cost as usually we face limited budgets and limited access to field sites. Hydrologic historic data are equally difficult to obtain as rainfall data are often scarce and not systematic in terms of temporal and spatial variation.

In the majority of the EU countries, landslide and hydrologic information and datasets result from a variety of protocols and methods. Therefore, data retrieval and harmonization is, in most cases complex, time consuming and rather expensive because there is no central repository where researchers can easily access this kind of information.

On the other hand, topographic data are easier to obtain but their accuracy and reliability is always an issue especially in applied research on local or site-specific scales. The desirable accuracy of the topographic datasets is connected to the extent of the examined area and the scale of implementation. When dealing with large areas, regional scale data may be obtained from satellite images, aerial photography with photogrammetric interpretation and/or from digitizing of maps of proper scale. When it comes to local scale where accuracy and levelling are mostly needed, topographic data must be obtained from field surveying and/or from digitizing of topographic maps of a large scale (greater than 1:1.000. The topographic data needed are usually vector-based data.

In most cases, geological data are needed and can be obtained from geological maps by digitizing. The same applies for land cover and land use where information may be extracted from relevant maps, field observations and EU Organizations, such as the Joint Research Centre (http://ec.europa.eu/dgs/jrc/).

A method, no matter how sophisticated and complete it can be, cannot be applied if its data requirements necessitate time and money consuming conditions.

Data availability has already been recognized by the EU Commission as an important part of the “information gap” and plays a restrictive role in the adoption of methods to assess natural hazards throughout Europe. Selection of data is maybe the most challenging part of the whole process.

The data cost depends on the extent of the examined area, on data availability and on the desirable accuracy of the results. Although datasets are more available now than previous years, it still remains a serious budget issue for numerous reasons; existing datasets are not always available or are expensive to be purchased, their production is expensive, experts are needed, data production is time consuming and thereof, costly.

Improved and new data collection methods are promising in terms of accuracy and cost reduction in the future, as is LIDAR and InSAR techniques, most useful tools for landslide inventory mapping and monitoring using remote sensing (Van Den Eeckhaut et al., 2009; Razak et al, 2011; Jaboyedoff et al., 2012; Farina et al., 2006).

Open Data Initiatives can greatly help research, because they reduce time consuming procedures and costs, simplifying thus implementation of methodologies regarding Natural Disaster mitigation issues.

3.5.7 COMPLEXITY OF THE METHOD USED

Landslides may be described and modelled by using different methods. These methods often require a certain number of assumptions to develop governing equations. Simple landslide modelling methods are fairly sufficient to assess landslide susceptibility under static (hydraulic) and seismic conditions, as well as, landslide hazard assessment. It is evident that more complex and advanced models including an important number of parameters and necessitating a serious number of data result in more accurate results. The question always raised is whether this time and cost consuming methods would offer a substantially different zoning map regarding landslide susceptibility and hazard assessment at a regional scale that would allow Decision Makers to make better decisions regarding landslide risk mitigation measures.

From a purchasing cost reduction perspective, there is a number of available for free software (freeware) including: Quantum GIS and SAGA GIS as the GIS platforms to implement regional Landslide Hazard assessment and open source software for slope stability analyses including the following:

4. **STB**. Software dedicated in the stability analysis of slopes. The software uses Bishop's simplified method for calculating of the safety factor of a circular slip surface. The safety factor of a slope is determined by comparing the moment of the weight of a soil wedge about the center of a slip circle, with the resisting moment provided by the shear stress along the slip surface. The software also allows for a possible horizontal body force, to simulate the effect of an earthquake.
5. **PSLOPE,** which can be used for two-dimensional slope stability analysis. It has the ability to analyze both a single user-defined non-circular failure surface and to search for the minimum non-circular failure surface. It calculates safety factors for circular and non-circular slope failure surfaces, using a number of widely used limit equilibrium analysis approaches such as the Bishop, Janbu, Carter's and Mongenstern-Price.
6. **DLISA**. It is a 25 years old software program that works in MS-DOS environment without model simulation ability. The user cannot define the

geometry of the slope (just only its depth). It just calculates the factor of safety with the deterministic way. It can also calculate the necessary root cohesion when the desirable safety factor is known.

3.5.7.1 Expertise / Special knowledge required

Expert users are in most cases needed in LHA methods. A combination of geological, geotechnical, hydraulic, seismological, CADD and GIS knowledge would be an ideal combination to deal with LHA issues at a regional or local scale. It is clear that a broad area of knowledge at different topics is needed and it is not easy to be met by one single user. Maybe a combination of two users, closely collaborating could offer best results. Anyhow, the user(s) should choose a method for Landslide Susceptibility Analysis (LSA) & LHA that best meets the needs in relation to his/her knowledge and ability to comprehend fundamental concepts. A more accurate but more complex method is of no use if the users can not apply it correctly; on the opposite, its use by non expert users increases the risk of leading to erroneous results. In any case, at least a minimum level of expertise is required to implement landslide susceptibility and hazard assessment methods. On the other hand, the use of a fairly simple method in terms of implementation, combined with the presence of readily available data, references, guides and tutorials can support any user interested in using that method to provide reliable and accurate enough results for screening purposes. In such a case, areas of interest are limited to those which present a high level of landslide hazard thus reducing the time needed and the cost of required high detailed data because implementation on a site-specific scale (slope stability analyses) is restricted to those specific areas.

3.5.7.2 Adaptability and Cost of Implementation

The term "adaptability" refers to the ability of a method to be adjusted or calibrated in individual and particular cases. A method that is generally more easily adjusted to a specific project is preferable to one that's not easily or not at all adaptable. In fact, as one of the prime targets of the project is the maximum possible harmonization of methods and the implementation of the same method, if possible, over the entire area. Bearing that in mind, methods that cannot easily be adapted to local conditions or applied in locations across the wider Black Sea area should be excluded.

Methods and models of "limited adaptability" are generally less desirable especially when dealing with local scale Landslide Hazard Assessment Methods.

The cost of the implementation of a method is in most cases, a combination of data collection and software purchase which impose a direct cost, but there are additional parameters which should also be considered as they contribute to the overall cost of each approach/method indirectly (i.e. if experts are needed the cost rises, if the method chosen is more complex then it is more time consuming and the cost rises as well, etc).

Given the economic situation in most countries around the Black Sea, researchers and even public Services have difficulties in purchasing expensive software. For that reason the adoption of Open Source software where applicable provides a viable solution. In such a case, it is absolutely necessary that the selected/adopted software must meet the requirements in terms of accuracy and reliability of the results it provides.

As in any case the decision must be based on the methodology to be adopted, in relation to its data requirements and the provided results/outcomes and the software (tool) to apply it, in terms of its cost, its user friendliness and the anticipated outputs.

3.5.7.3 Completeness, Accuracy and Reliability

The term of completeness refers to results with respect to their usability for decision making regarding Landslide Disaster mitigation issues. Methods are classified according their results completeness into: Low (cover only a few aspects. The use of additional methods is required); Medium (cover most aspects of the problem. Minor issues still remain unsolved); High (cover every aspect of the problem).

Accuracy and Reliability are related to the amount and impact of uncertainties and errors on the outputs of each method. Uncertainties and errors are introduced throughout the development and the process in every case of any method implemented. The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing, and theoretical assumptions, can render results inaccurate and ultimately misleading. In this case, additional data (statistical, historical, morphological, seismic, hydrological and geological) must be used to evaluate the results.

3.5.7.4 Conclusions

There is a multitude of models and methodologies applied worldwide and in the wider Black Sea area to assess Landslide Hazard. They provide a variable level of accuracy and reliability and have also very different data and "infrastructure" requirements. A list of basic principles was considered in order to select the "appropriate" LHA methodology to adopt for the SciNetNatHaz project demands. This list contains a number of factors suggested mainly by the necessities created in real world conditions regarding applied research implementation. The factors considered include: data demands (crucial/decisive factor); the adaptability in local conditions; the complexity/user friendliness (because it needs to be disseminated and used by as many as possible); the cost of implementation (including software and hardware costs) and of course the high accuracy and reliability of the outputs, required for making informed decisions (decisive parameter).

The current situation in respect to LHA in the participant to the project countries reveals the drawbacks and necessities that will play a decisive role in the final Landslide Hazard Assessment model proposed.

The current situation in terms of LHA models used and implementations carried out in all these countries, follows in the next chapters.

3.6 GREECE

3.6.1 INTRODUCTION

Landslide hazard (LH) is a real threat for Greece, especially in the mountainous part of it. Landslides usually occur in mountainous areas with a pronounced topography relief, geological formations prone to different kinds of sliding and triggering factors usually related to rainfall or earthquake events. As already mentioned in the previous paragraphs, even though an important number of different methods regarding landslide susceptibility and hazard assessment are used in a European or universal scale, a relatively small number of them have been used in Greece, according to the scope of the work, the scale used, the completeness, quality, accuracy and reliability of existing data, and in relation to the predisposing and triggering factors. The economic cost and the time consuming procedure to collect the necessary data, are often an important obstacle to overcome. If to the aforementioned, the degree of perplexity regarding the predisposing and triggering factors implicated in the occurrence of a landslide, as well as, spatial and temporal variation issues are added, then it is understandable why only a very limited number of landslide hazard assessment studies have been undertaken at a regional or even at a local scale, not only in Greece, but also in the wider area of Black Sea.

3.6.2 DESCRIPTION, IMPLEMENTATION AND EVALUATION OF METHODS USED IN GREECE

As already stated in paragraph 3.5, ***predisposing factors*** play an important role in landslide susceptibility and landslide hazard analysis, under both static and/or seismic conditions. Therefore, the following points are highlighted as being crucial for a reliable assessment, given the detail dictated by the scale used:

- **topographic information** and its derivatives (clear need for high-resolution DEMs)
- **geological maps** focusing traditionally in lithological and stratigraphical subdivision need to be converted into an engineering geological classification with emphasis on Quaternary sediments and rock texture / structure, as well as, rockmass strength
- **structural information** is important for landslide hazard assessment; attempts to incorporate dip & dip direction based on either filed measurements or geological maps can improve reliability of output, but also depends strongly on the number of measurements and complexity of structure
- **Soil properties** in the use of physically based slope stability models for LHA are key parameters, especially for shallow depth failures. Soil depth, defined

as the depth from free surface down to a consolidated material (also known as regolith depth)

- **Spatial variability** is also a crucial parameter, often ignored in landslide modeling due to lack of appropriate data
- **Soil thickness** can be modeled throughout physical based methods that model rates of weathering, denudation and accumulation

Physically based landslide susceptibility and hazard assessment methods are based on the modelling of slope failure processes. They can be applicable over large areas, if geological and geomorphological conditions are fairly homogeneous and landslide types relatively simple. They also apply to areas with incomplete or inexistent landslide inventories; this is considered as a major advantage for countries with incomplete landslide inventories, such as the case of Greece.

Most of physically based landslide susceptibility and hazard assessment methods use the **infinite slope model**, therefore they are suitable for shallow landslides and this is one of the reasons why they have been used extensively in Greece. The above models account for different triggering parameters, such as: rainfall and transient groundwater response or to the effects of earthquake excitation (Corominas et al., 2013).

The main advantages and pitfalls of physically based methods for landslide susceptibility and hazard assessment include:

3. Main advantages
    a. They can be easily implemented in GIS environment
    b. Results/outputs are more concrete and consistent compared to other approaches
    c. They present higher predictive capability and appear to be more most suitable to quantify the influence of individual parameters contributing to shallow landslide initiation
    d. Based on slope stability models, they allow the calculation of quantitative values of stability (safety factor, probability of failure)
4. Main drawbacks
    a. Parameterisation can be a difficult task as well as, access to critical parameters (soil depth, transient slope hydrological processes & temporal changes in hydraulic properties)

There is a risk of over simplification, since a large amount of reliable input data is often necessary.

As it appears, the physically based methods for landslide susceptibility and hazard assessment offer relatively reliable results, their accuracy being dependent on the amount or available input data, whereas their use is rather well conceived, even by non experts, but scientific personnel with a minimum of training.

3.6.2.1 Landslide Susceptibility under static conditions

An evaluation of some approaches / methods used in Greece in order to assess Landslide Susceptibility and Hazard at regional scale (1:250,000 to 1:25,000), is attempted herein. The scope of this chapter is neither the exhaustive description of all methods used in Greece for LHA, nor the ranking in terms of best or worst; the scope is to come up with a method complying at best to the project’s needs, conditions and requirements.

Given that, there is no well established inventory of landslides in Greece, covering in a complete way spatial and temporal variation of landslide occurrence, it is easily conceived that we have to deal with an inherent handicap; therefore we will try to use methods that are less sensitive to this lack.

Bearing that fact in mind, the methodology proposed by FEMA (USA) also known as (HAZUS-SR99, 1999) methodology for Landslide Susceptibility under static and seismic conditions is presented. This methodology presents high adaptability to local conditions, has low data requirements and provides reliable and accurate enough results. All of these are facts highly appreciated.

Table 3.3: Landslide Susceptibility of geologic groups under static conditions (according to the FEMA method – HazUS99-SR2, Technical Manual, Chapter 4-PESH, 1999)

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	**Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)**	None	None	I	II	IV	VI
B	**Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)**	None	III	IV	V	VI	VII
C	**Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)**	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	**Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)**	None	III	VI	VII	VIII	VIII
B	**Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)**	V	VIII	IX	IX	IX	X
C	**Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)**	VII	IX	X	X	X	X

As demonstrated in Table 3.3, a triple criterion is used for assessing Landslide Susceptibility in a qualitative and rather crude approximation: a) geologic group, b) slope angle (deg) and c) hydraulic conditions by means of terms “wet” and “dry”:

- The geologic groups of the examined area are classified as A, B & C.
- Characterization of groundwater conditions as ***dry*** implies that groundwater is set below sliding level, whilst ***wet*** implies that groundwater is set over sliding level.
- Slope angles (deg) are classified in the following categories: 0^0-10^0, 10^0-15^0, 15^0-20^0, 20^0-30^0, 30^0-40^0 and >40^0
- Geologic groups with null slope angle are not susceptible to slide (None)

Arbitrary scale ranging from **I** to **X** level, classifies in a qualitative way areas in a landslide susceptibility scale, from the less susceptible (class I) to the most susceptible to slide (class X).

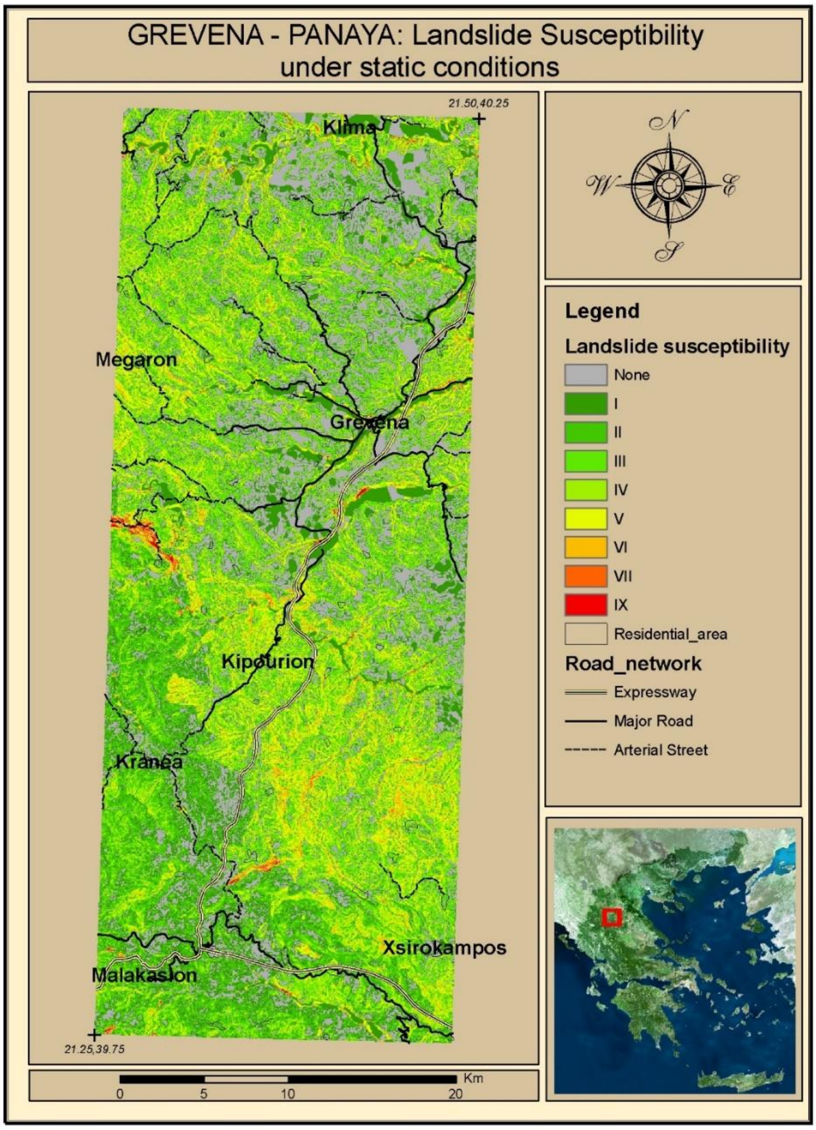

Fig. 1: Landslide Susceptibility Assessment under static (hydraulic) conditions based on FEMA method (scale 1:50,000; area of Grevena-Panaya, SyNaRMa project).

Because of the conservative nature of the Wilson and Keefer (1985) correlation, an assessment is made of the percentage of a landslide susceptibility category that is expected to be actually susceptible to a landslide. This percentage is selected from Table 4, as a function of the susceptibility categories, based on Wieczorek et al., (1985). **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** represents the percentage of the examined susceptible area.

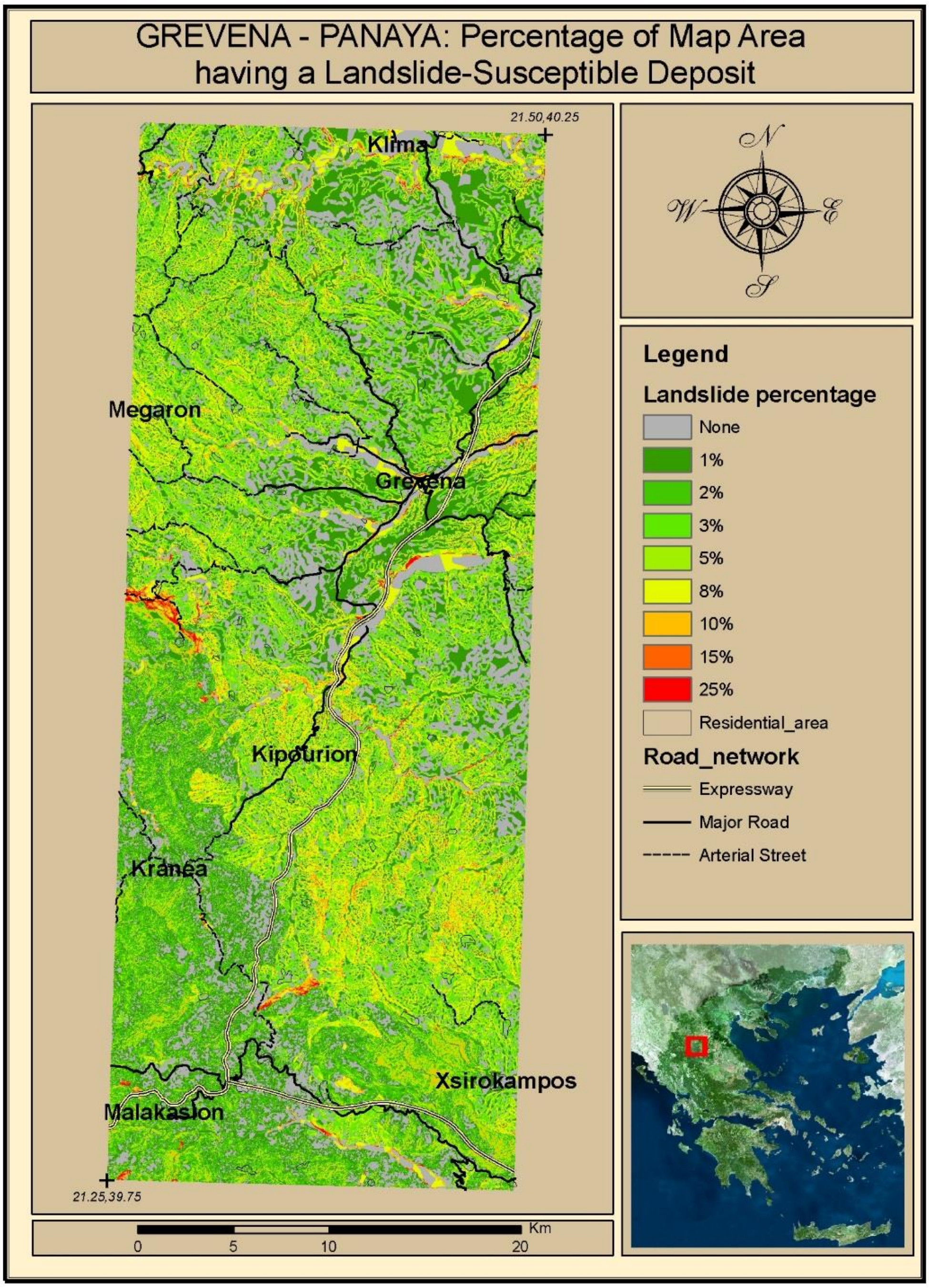

Fig. 2: Percentage of map area that will slide having already a landslide – susceptible deposit (scale 1:50,000; area of Grevena-Panaya, Greece; SyNaRMa project, 2006)

Table 3.4: Percentage of map area having a landslide - susceptible deposit (Hazus 99-SR2 Technical Manual, Chapter 4 – PESH)

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Map Area	0.00	0.01	0.02	0.03	0.05	0.08	0.10	0.15	0.20	0.25	0.30

Landslide Susceptibility and Hazard maps produced at a regional scale are usually based on the following assumptions:

1. Homogeneous geological conditions.
2. All slopes have the same probability of failure.
3. Exact location of failure is not required.
4. All landslides are of similar size.
5. Runout models are not included; or spatial distribution and intensity.

From the aforementioned, it is deduced that a significant number of assumptions substantially simplifying the complex phenomenon of landslides is used, in order to come up with a relatively simple and efficient method to assess Landslide Susceptibility and Hazard. It is our belief that, landslide susceptibility and hazard maps at regional scale can be improved if “***structural***” information is added to the 2^{nd} assumption of the above mentioned. Structural information is related to the characteristics of low shear strength surfaces in geologic formations as bedding planes, schistocity and foliation, dip and dip direction of discontinuities/joints and the presence of faults/fractured zones. Incorporation of the aforementioned basic structural information in terms of its basic geometric characteristics as location, dip and dip direction can play a very positive role in increasing the reliability and accuracy of the landslide susceptibility assessment process.

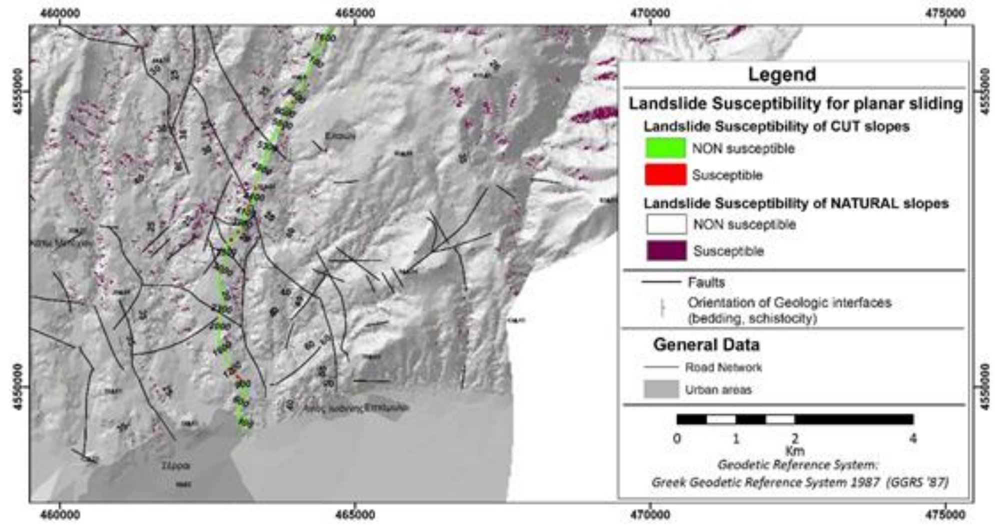

Fig. 3: Planar sliding susceptibility of cut and natural slopes. An indicative application of the planar rock slope failure criterion.

3.6.2.2 Landslide Susceptibility under seismic conditions

Whenever static plus inertia forces developed by a seismic event cause an instant reduction of the factor of safety below 1.0 within a sliding mass, then an earthquake-induced landslide occurs. The value of the peak ground acceleration within the sliding mass required to reduce the factor of safety below 1.0 is specified as critical or yield acceleration (A_c). This value of acceleration is determined based on a pseudo-static approach of slope stability analysis. Whenever a part of an accelerogram exceeds the above critical value, then an earthquake-induced permanent displacement is registered in a cumulative way. In fact, the smaller the ratio A_c/A_{is} is, (A_{is}: induced acceleration of a sliding mass), the greater the number and the duration of times that the downslope movements occur and consequently the bigger the amount of downslope permanent movements caused.

The induced acceleration, A_{is}, represents the average peak acceleration within the entire sliding mass. For relatively shallow and laterally small landslides, induced acceleration A_{is}, is not significantly different from the surface induced peak ground acceleration (PGA). For deep and large landslides, A_{is}, is less than PGA (surface induced peak ground acceleration). The deeper and larger the sliding mass, the smaller the fraction of PGA (no amplification due to topography effects is however taken into account) which represents A_{is}. For relatively shallow and laterally restricted landslides, the induced peak ground acceleration within the sliding mass, is considered equal to peak ground acceleration: $A_{is} \cong$ PGA; whereas for massive, deep and large landslides, A_{is} is considered as part of the induced surface peak ground acceleration: $A_{is} \cong 0.67$*PGA.

According to FEMA’s method, seismic susceptibility for sliding under seismic conditions, is characterized by: the geologic group, the slope angle and the underground water table (as in the case of static conditions), plus critical acceleration. Since characterization of geologic groups already exists in three different categories (A, B and C: see Table 3.3), wet or dry, and the slope angle can be determined by the elevation contour lines, then by implementation of the relationship proposed by Wilson and Keefer (1985), the acceleration needed to initiate slope movement can be assigned (Fig. 4). Critical acceleration is a crucial parameter and it is a complex function of slope, steepness, groundwater table, type of landslide and history of previous slope performance.

In an attempt to avoid calculation of unrealistic landslides for very low slope angles or critical accelerations, lower bounds are imposed and therefore extrapolation of relationship is prohibited on both sides (they are only valuable for the range of values shown in Fig. 4).

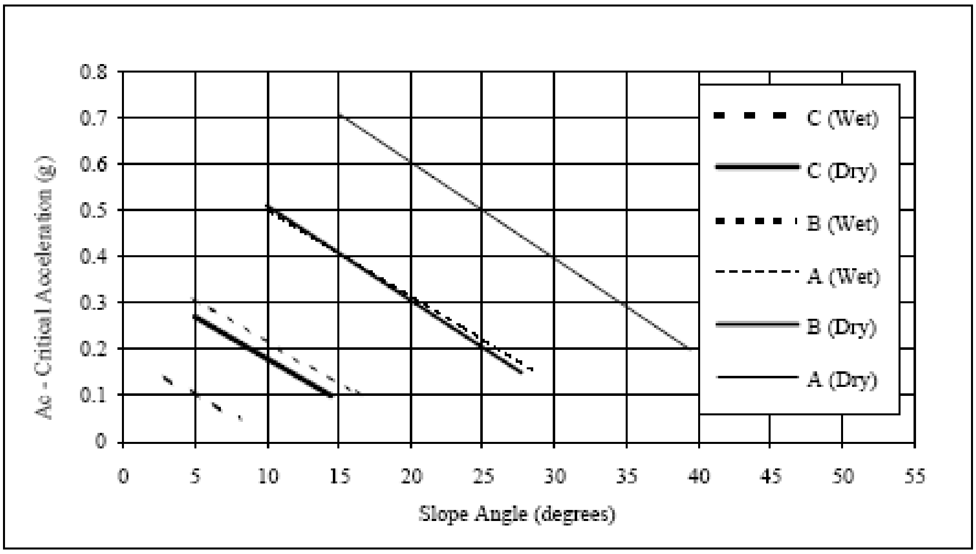

Fig. 4: Critical acceleration as a function of geologic group, slope angle and position of underground water table (Wilson and Keefer, 1985 - (Hazus 99-SR2 Technical Manual, Chapter 4 – PESH)).

If all the geologic groups at the examined area are considered as dry (i.e. groundwater table passing underneath the sliding mass), the information of slope angle can be calculated from the elevation contour lines, then by applying the expressions relating the slope angle with the critical acceleration per geologic group, always taking into consideration the upper and lower limits, critical acceleration is obtained (Fig. 5).

The ratios A_c/PGA (for shallow landslides) and A_c/A_{is} (for deep seated landslides) can be used as indices for exhibiting landslide susceptibility for earthquake-induced downhill displacements. As already mentioned above, the smaller the values those ratios have below 1.0, the bigger permanent displacements are expected during and after a seismic event. The range of values between 0 and 1.0 is divided into 4 categories, whereas the range of values >1.0, into 2 categories, as follows:

- Very high: <0.3
- High: 0.3 – 0.6
- Moderate: 0.6 – 0.8
- Low: 0.8 – 1.0
- Very low: 1.0 – 3.0
- None: >3.0

An example of the above "subjective" qualitative categorization of the ratio, A_c/PGA, is outlined in Fig. 6, as an index concerning induced – earthquake displacements of "shallow" landslides for a seismic hazard of a mean return period of 475 years. For "deep seated" landslides, the ratio A_c/A_{is} ($A_{is} \cong 0.67$*PGA) is respectively used as an index concerning induced – earthquake displacements for seismic hazard of 475 (Fig. 6).

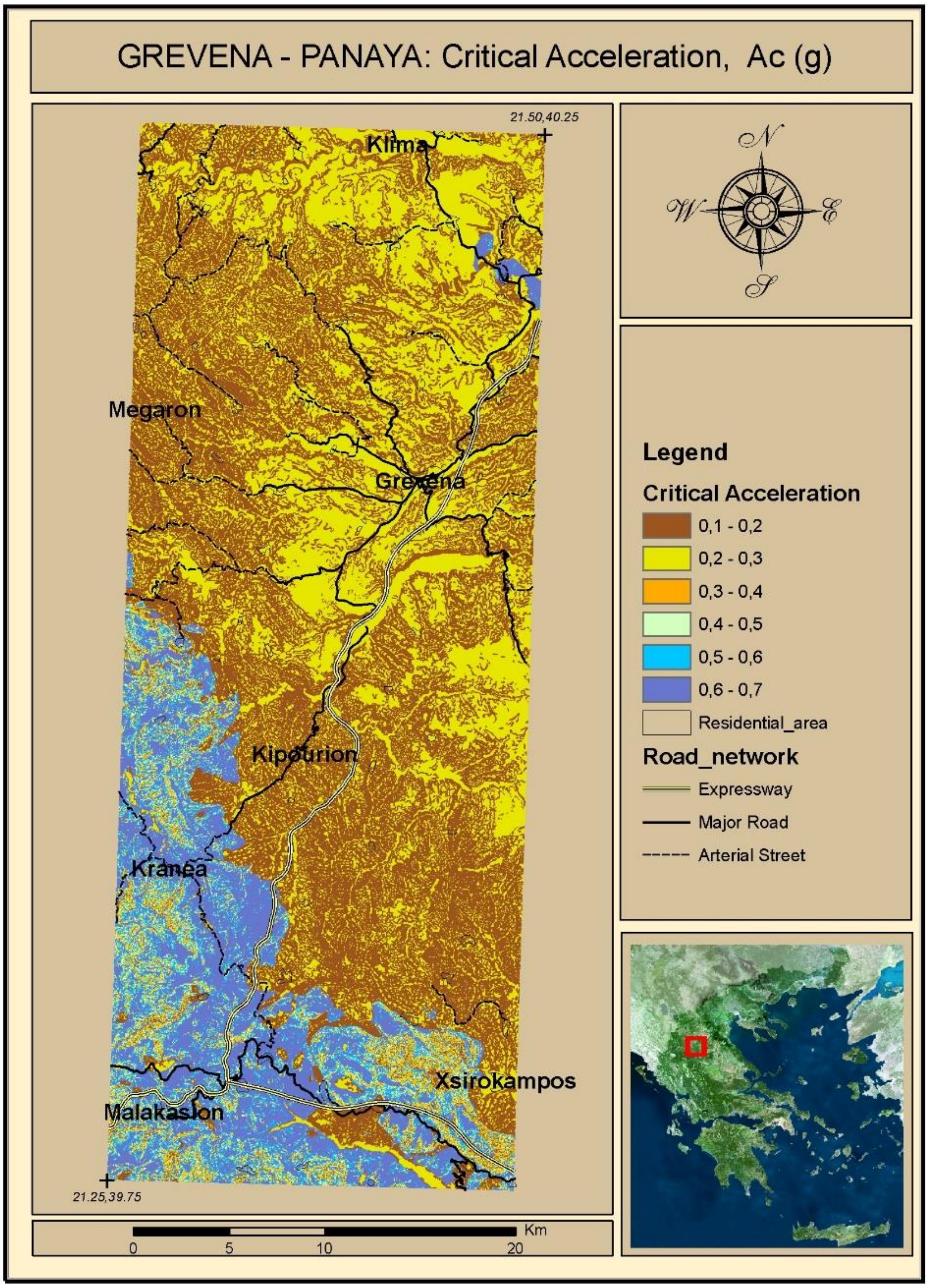

Fig. 5: Critical acceleration as a function of geologic group, slope angle and position of underground water table (Wilson and Keefer, 1985 - (Hazus 99-SR2 Technical Manual, Chapter 4 – PESH); SyNaRMa project, 2006).

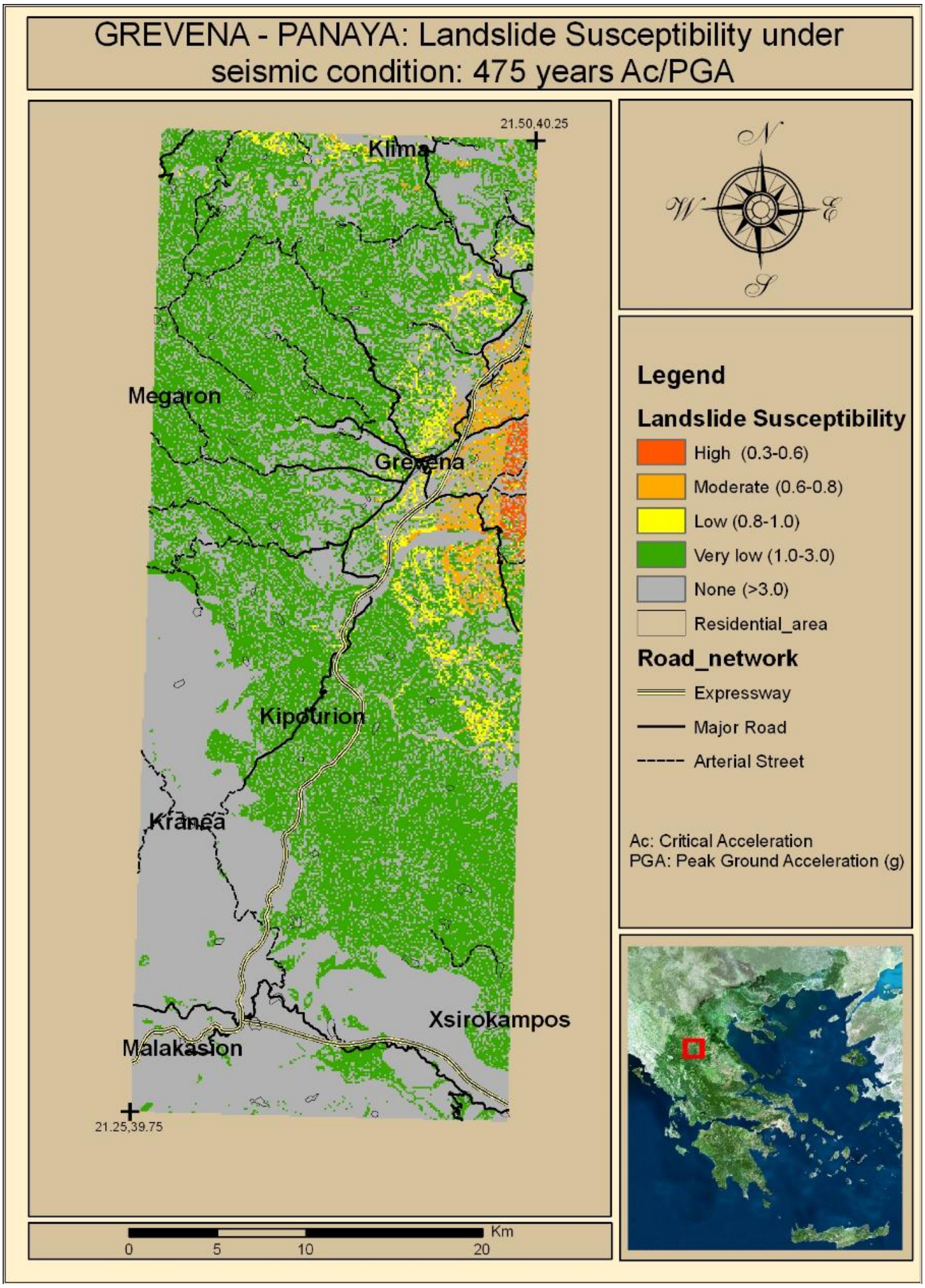

Fig. 6: "Shallow" landslide susceptibility to earthquake-induced displacements, as specified by the index A_c/PGA ($A_{is} \cong$ PGA) for 475 years return period (SyNaRMa project, 2006)

Every point with null slope angle (flat area) is excluded of any susceptibility assessment and is coloured grey. Two examples are subsequently presented respectively from the area of Grevena-Panaya (Fig. 6); a mountainous area in western and northern Greece and of Lefkada Island in Ionian Sea (Fig. 7).

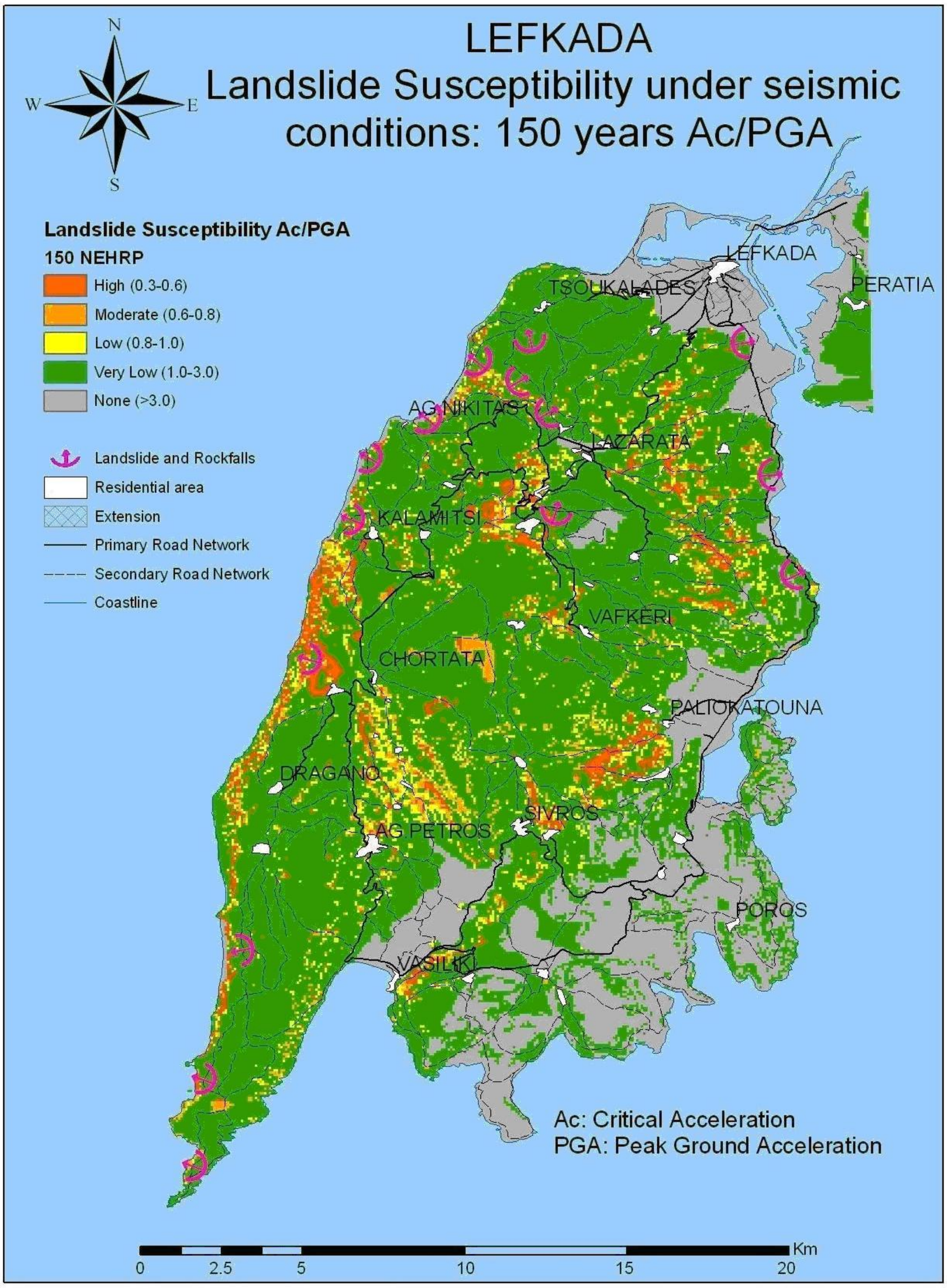

Fig. 7: Landslide susceptibility under seismic conditions for "shallow" landslides, as those observed after the seismic event of 14 August 2003 at Lefkada Island. Location

of earth and rock instabilities observed, are also depicted on the same thematic map (Papatheodorou et al., 2007)

3.6.2.3 Landslide Hazard Assessment under static conditions

Natural hazard is defined as the probability of occurrence of potentially damaging phenomena within a specified period of time and within a given area (Varnes, 1984). Zonation refers to the division of the land in homogeneous areas or domains according to the degree of actual or potential hazard (Varnes, 1984). Hence, the proposed models should be able to predict landslide prone areas without any clear indication when they are likely to take place. So, in this work, hazard is used as a quantitative estimation of landslide occurrence over a given region, whilst a time period is not defined in the model, since parameters such as lithology, slope inclination, structure, and geomorphology are not time dependant and can be calculated in a deterministic way, by means of a safety factor.

Those models are hybrid models and can be applied at regional or local scales; in physical based models (or else, geotechnical landslide hazard models), the probability of occurrence of a landslide is expressed throughout F_S values.

The factor of safety landslide hazard assessment method can be calculated according to the assumed failure mechanism:

- Infinite slope model: $$F_S = \frac{c'}{\gamma * t * \sin\beta} + \frac{\tan\phi'}{\tan\beta} + \frac{m * \gamma_w * \tan\phi'}{\gamma * \tan\beta} \quad (1)$$

  where,

  φ': effective angle of friction of geomaterial (^{0})
  c' : effective cohesion of geomaterial (kPa)
  γ : specific weight of geomaterial (kN/m^3)
  β : slope angle (deg)
  γ_W: specific weight of the water (kN/m^3)
  t : normal thickness of failure slab (m)
  m : percentage of the water saturated failure slab (%)
  $r_u = \gamma_W/\gamma$ (pore pressure ratio)

- Deterministic model for plane landslides: $F_S = \tan\varphi' / \tan\beta$ (2)

where,
  φ': effective angle of friction of geomaterial (^{0})
  β : slope angle (deg)

- Deterministic model for circular landslides (Ferentinou et al., 2006):

$$F_S = 4.32 * \left[\frac{c'}{\gamma * \mathrm{H} * \sin\beta} \right] + 1.22 * (1 - r_u) * \frac{\tan\phi'}{\tan\beta} + 0.005 \qquad (3)$$

where,

- φ': effective angle of friction of geomaterial (^{0})
- c': effective cohesion of geomaterial (kPa)
- H: height of the slope
- γ : specific weight of geomaterial (kN/m^3)
- γ_w: specific weight of the water (kN/m^3)
- β : slope angle (deg)
- r_u: pore pressure ratio ($r_u = \gamma_w/\gamma$)

In the above geotechnical landslide hazard models three basic advantages are added to the already widely used physically based methods (deterministic methods):

1. The factor of safety is calculated for every single terrain unit of the examined area, overcoming thus the problem of spatial extrapolation of F_S values, calculated only for certain slopes on the entire area.
2. The proposed tool is a dynamic tool which enables the user to modify as necessary the values of the geotechnical parameters, optimizing accordingly the landslide hazard model and producing landslide hazard maps referring to the temporal variability of geotechnical and hydrological or even seismological parameters.
3. Using the determinist model, the user can estimate F_S, assuming circular, planar or infinite slope failure mechanisms.

The above physically based method using the infinite slope model has been tested in the area of Magnesia Prefecture, where an important number of "shallow type" landslides has been recorded on cut slopes with a design inclination vertical : horizontal = 2:1. An example is presented next, where a thematic map of the safety factor on a scale 1:50,000 has been compiled for the aforementioned area (Fig. 8), as calculated via the infinite slope model under static conditions. In Fig. 9, locations where landslides (including rockfalls) have occurred essentially in cut slopes, are presented. By a straightforward comparison of 67 sites where landslides occurred and have been registered, against the calculated safety factor values (Fig. 10) it can be easily deduced that the landslide hazard map under static conditions has proved to be really successful as a percentage of almost 85% of the landslides that occurred was attributed a value of safety factor less than 1.0.

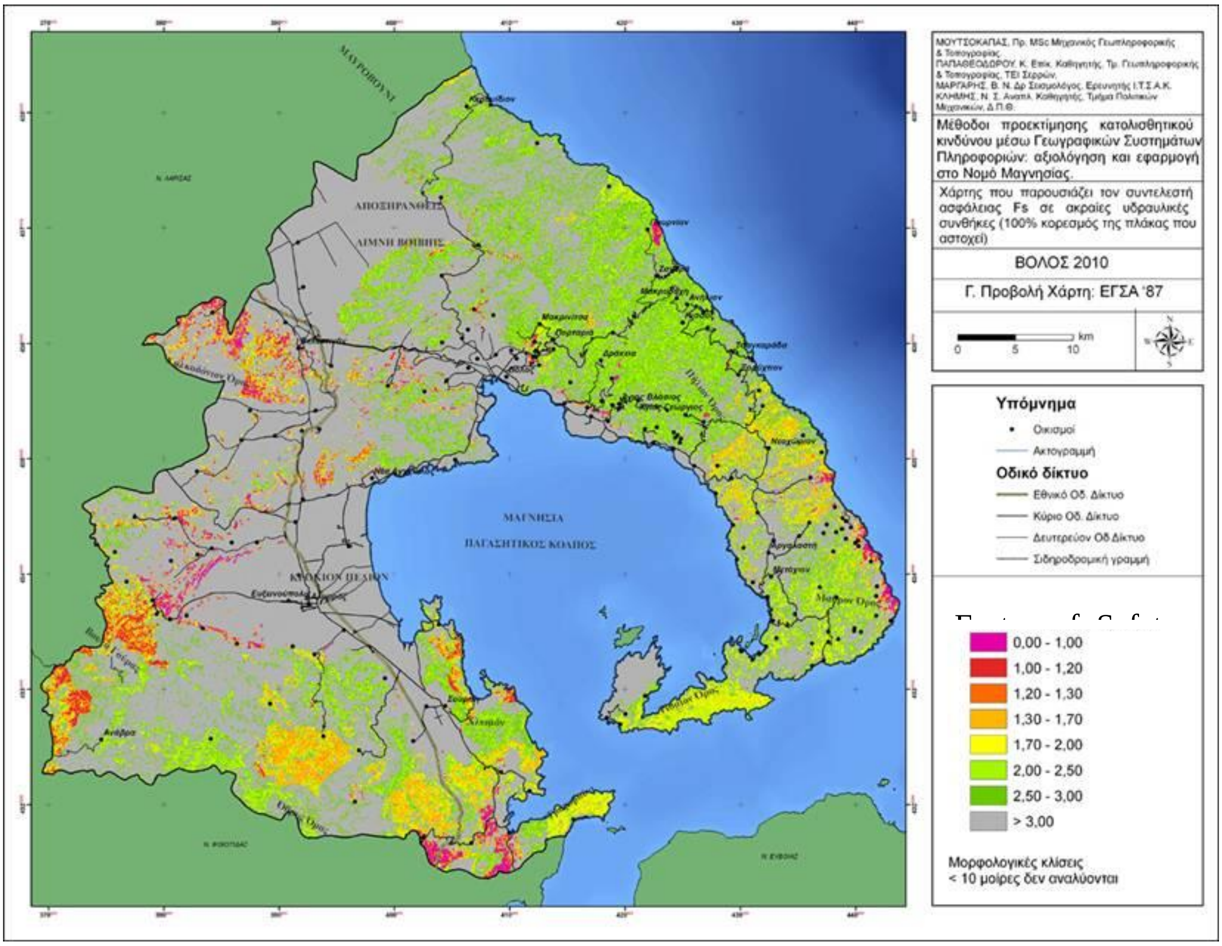

Fig. 8: Landslide hazard map (area of Magnesia Prefecture; Moutsokapas et al., 2010) under static conditions for "shallow type" landslides, by calculation of safety factor, based on the failure mechanism as given by the infinite slope model. The colour scale is used in order to dissociate values of safety factor, as noted in the memo of the thematic map. Slope inclination less than 10^0 are not considered and consequently factors of safety are not calculated

According to Eq. 1, normal thickness of failure slab (t) must be determined as a function of slope angle, in order to calculate the factor of safety.

Thickness of failure slab "t" (m)	Slope angle (deg)	Thickness of failure slab "t" (m)	Slope angle (deg)
0	$90^{(0)} – 80^{(0)}$	2,5	$50^{(0)} – 40^{(0)}$
1,0	$80^{(0)} – 70^{(0)}$	4,0	$40^{(0)} – 30^{(0)}$
1,5	$70^{(0)} – 60^{(0)}$	10,0	$30^{(0)} – 0^{(0)}$
2,0	$60^{(0)} – 50^{(0)}$		

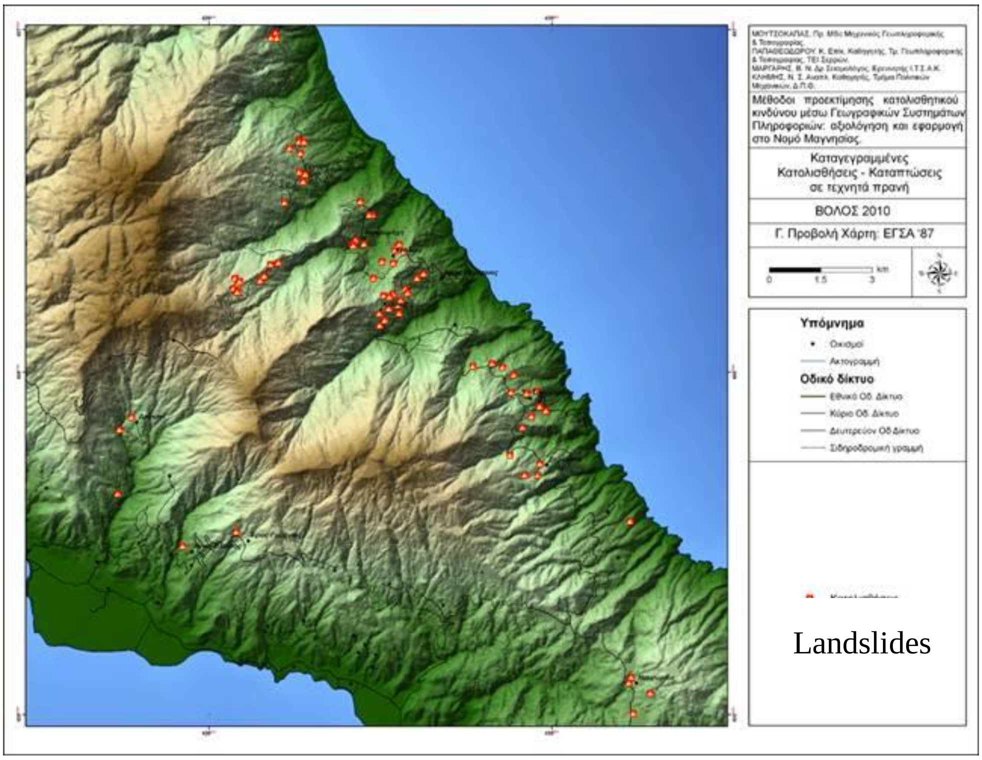

Fig. 9: Landslides locations that occurred on cut slopes with an inclination of v : h = 2:1, at Magnesia Prefecture area (Moutsokapas et al., 2010)

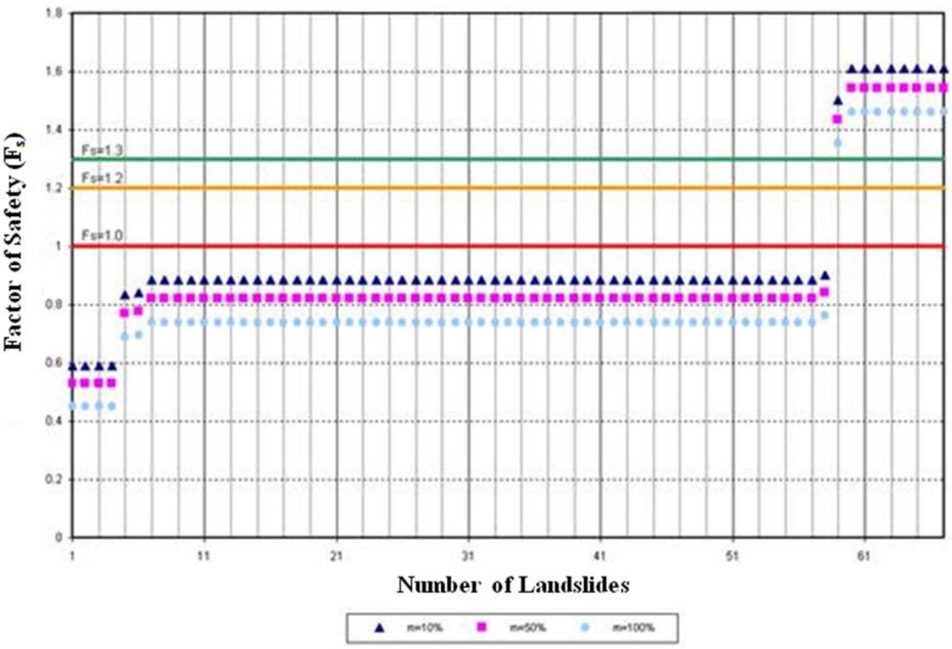

Fig. 10: Calculation of the factor of safety under static conditions, with parameterization of the percentage of saturation of the failure slab (m%) for cut slope inclination v:h = 2:1

3.6.2.4 Landslide Hazard Assessment under seismic conditions

Two different methods regarding Landslide Hazard Assessment when triggering factor is an earthquake have been used and tested:

- **FEMA method**

The FEMA method is based on the landslide susceptibility, the earthquake being considered to be the triggering factor (§8.3.2). The quantitative approach for LHA is based on the estimation of the expected permanent ground displacements.

Permanent ground displacements are determined using the following expression:

$$E[PGD] = E[d/A_{is}]*A_{is}*n \quad (4)$$

where,

$E[d/A_{is}]$ is the expected displacement factor (see Fig. 11)

A_{is} is the induced acceleration (in decimal fraction of g's)

N is the number of cycles (see quation 5)

A relationship between number of cycles and earthquake moment magnitude (M_w) based on Seed and Idriss (1982) is expressed as follows:

$$n = 0.3419M_w^3 – 5.5214M_w^2 + 33.6154M_w – 70.7692 \quad (5)$$

The above method has been tested in the case of the earthquake of Lefkada (M_w 6.2, August 2003). The crucial point in this case is to assess the moment magnitude based on a reliable seismic hazard scenario. There are various approaches to estimate the ground motions appropriate for FEMA methodology calculations including the probabilistic assessment and the numerical modeling technique. The latter approach is usually applied in areas where lack of strong motion data and empirical predictive relations exists. In the examined case, there were available strong motion data recorded during the Lefkada 2003 (M_w6.2) strong earthquake, and empirical predictive relationships for Hellas, thus a probabilistic assessment of the seismic motion could be applied.

Seismic hazard calculations have been carried out for the parameter of peak ground acceleration (PGA) and for a variety of return periods, ranging from 10 to 1000 years. Based on this analysis and taking into account the recorded peak ground accelerations of the mainshock, 330 and 408cm/sec^2 (the two horizontal components of the mainshock) at the Lefkada station (Hospital) characterized as soil site conditions, it was concluded that the specific earthquake of 2003/8/14 (M_w 6.2) corresponds approximately to a seismic event of 100 to 200 years return period (hereafter, mean return period of 150 years).

The empirical predictive relationships used, are the one proposed by Skarlatoudis et al. (2003), the most suitable for Hellas (Greece), according to the latest instrumental data. Those relationships are as following:

$$\log PGA = 0.86 + 0.45M - 1.27\ln(R^2 + h^2)^{\frac{1}{2}} + 0.10F + 0.06S \pm 0.286 \quad (6)$$

$$\log PGA = 1.07 + 0.45M - 1.35\ln(R + 6) + 0.09F + 0.06S \pm 0.286 \quad (7)$$

where,

PGA: is peak ground acceleration (cm/sec^2),

M : is the earthquake magnitude ($4.5 \leq M \leq 7$),

R : is the distance from seismic source to the examined site ($1 \leq R(km) \leq 100$,

h : is a variable describing the average focal depth,

F : is a variable that describes the effects of focal mechanisms; the F variable equals 0, 1, 2 for normal, strike and thrust slip faults respectively.

S : is a variable describing site conditions; S=0 for class B, S=0.058 for class C and S=0.125 for class D (soil classification according to NEHRP, 2000)

Eq. (5) is used when focal depth is known, whereas Eq. (6) is used when focal depth is unknown.

Therefore, for a known moment magnitude (M_w), the number of cycles is determined. In the examined case (Lefkada island), the moment of magnitude corresponding to 150 years is, M_{150}=6.2. Once the induced acceleration within the sliding mass and the number of cycles are known, then the expected displacement factor is calculated either as an upper, or a lower bound according to Fig. 10 (Makdisi and Seed, 1978).

According to FEMA method the sites prone to slide and the expected permanent ground displacements for a seismic event with a mean return period of 150 years (with use of local GMPEs) have been calculated and have been straightforward compared to the sites where landslides occured due to the seismic event of August 2003; this comparison is clearly demonstrated in Fig. 12 (Papatheodorou et.al., 2007).

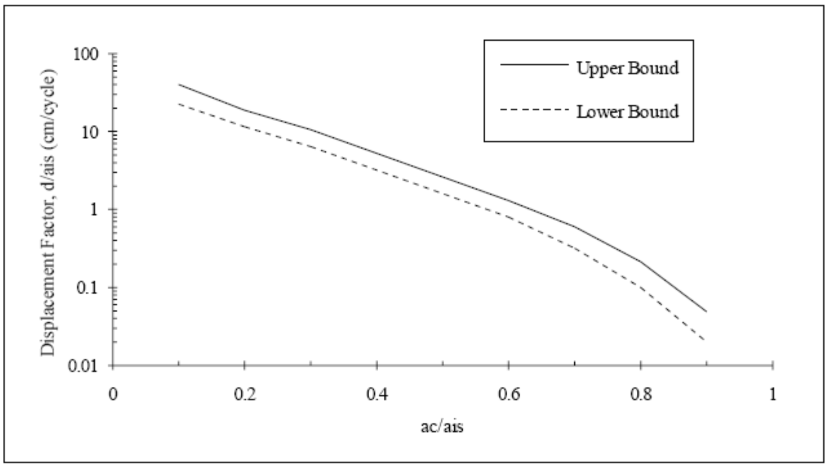

Fig. 11: Relationship between displacement factor and ratio of critical acceleration (a_c) and induced acceleration (a_{is} = PGA for laterally restricted and shallow landslides) - (Hazus 99-SR2 Technical Manual, Chapter 4 – PESH)).

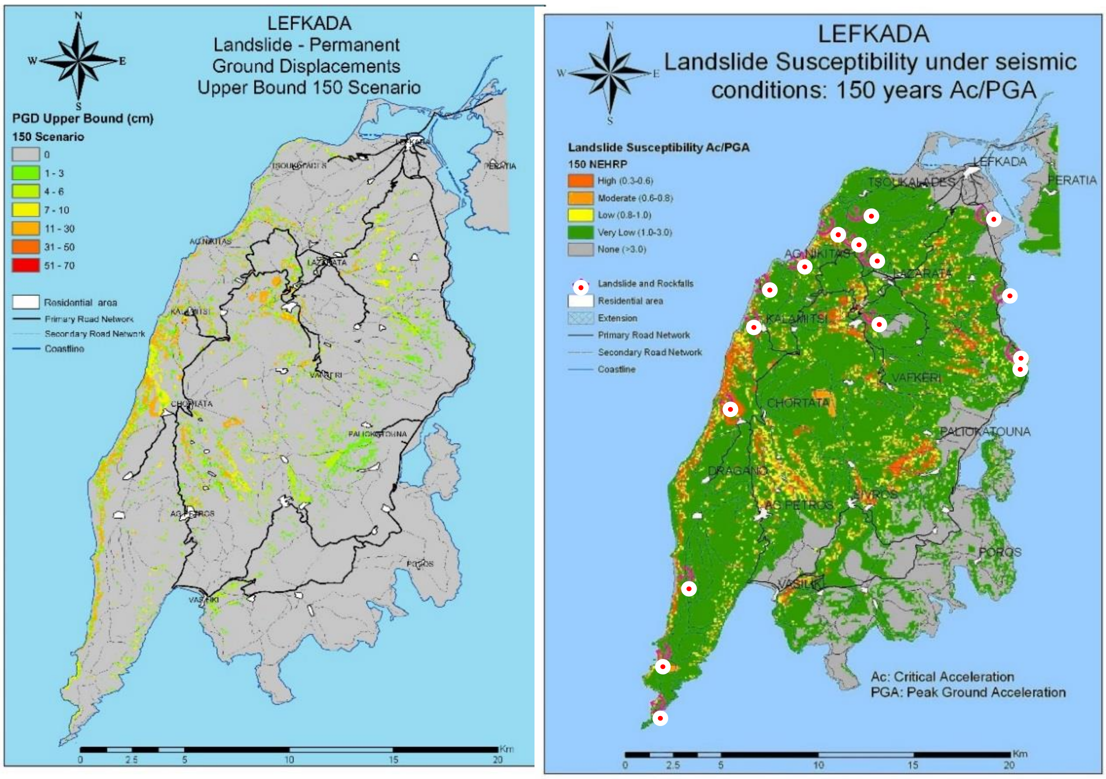

Fig. 12: Comparison of expected peak ground displacements as a result of an earthquake of a mean return period of 150 years (upper bound) according to FEMA method on the left part of the figure, with the sites (right part) where landslides occurred due to the earthquake of August 2003 (M6.2), considered as the earthquake with a mean return period of 150 years (Papatheodorou et.al. 2007).

All points with null slope angle (flat) are excluded from the above thematic maps and no permanent ground displacement is therefore calculated.

- **Modified Newmark method**

Newmark's method models a landslide as a rigid-plastic friction block having a known yield or critical acceleration, the acceleration required to overcome frictional resistance and to initiate sliding on an inclined slope. The analysis calculates the cumulative permanent displacement of the block, as it is subjected to the effects of an earthquake acceleration time-history, and the user judges the significance of the permanent earthquake-induced displacements. Laboratory model tests and analyses of earthquake-induced landslides in natural slopes confirm that Newmark's method is fairly accurate in predicting slope displacements, provided that slope geometry, soil properties and earthquake ground accelerations are known. Newmark's method and its derivatives are relatively simple to apply and provide a quantitative prediction of landslide inertial displacement that will result from a given level of a seismic motion.

Once the critical acceleration of a landslide has been determined and the acceleration-time series have been selected, Newmark displacements can be calculated by double integration of those parts of the strong-motion record exceeding critical acceleration. Several methods for doing that, either in a rigorous way (Wilson and Keefer, 1983), or in a highly simplified way, can be found in international bibliography. Albeit the rigorous approach is a straightforward one, many of its aspects are difficult for the average user: acquisition of digitized strong-motion data can be time and money consuming; location of an appropriate recording for the conditions to be modelled is not always an easy task, whereas, writing of the integration program can also be problematic for the vast majority of users.

For all the above reasons, a simplified approach for estimating Newmark displacements might be very helpful. Among different parameters tested, it results that Arias Intensity (I_a) and critical acceleration (a_c) are well correlated with the expected Newmark earthquake-induced displacements, via a multivariate regression model of the following form:

$$\text{Log } D_N = A^*\log I_A + B^*a_c + C \pm \sigma \tag{8}$$

where

D_N : Newmark displacement (cm)

I_A : Arias Intensity (m/sec),

where $I_A = \frac{\pi}{2g}\int_0^\infty [a(t)]^2\, dt$ g: ground acceleration; a(t): time series acceleration

a_c : Critical acceleration (g)

A, B, C : Regression coefficients, and
σ : estimated standard deviation of the model

The resulting model has an R^2=0.87 and all coefficients are significant above the 99.9% confidence level:

$$\log D_N = 1.460*\log I_A - 6.642*a_c + 1.546 \pm 0.409 \tag{9}$$

The model yields the mean Newmark displacement when σ is ignored; the variation (σ) about this mean, results from the stochastic nature of the ground motion. Therefore, two strong motion recordings with identical Arias intensities and for slopes with the same critical acceleration might produce different Newmark earthquake-induced displacements. In Fig. 13, Newmark displacements are presented as a function of Arias intensity and critical acceleration as modeled by the above regression equation.

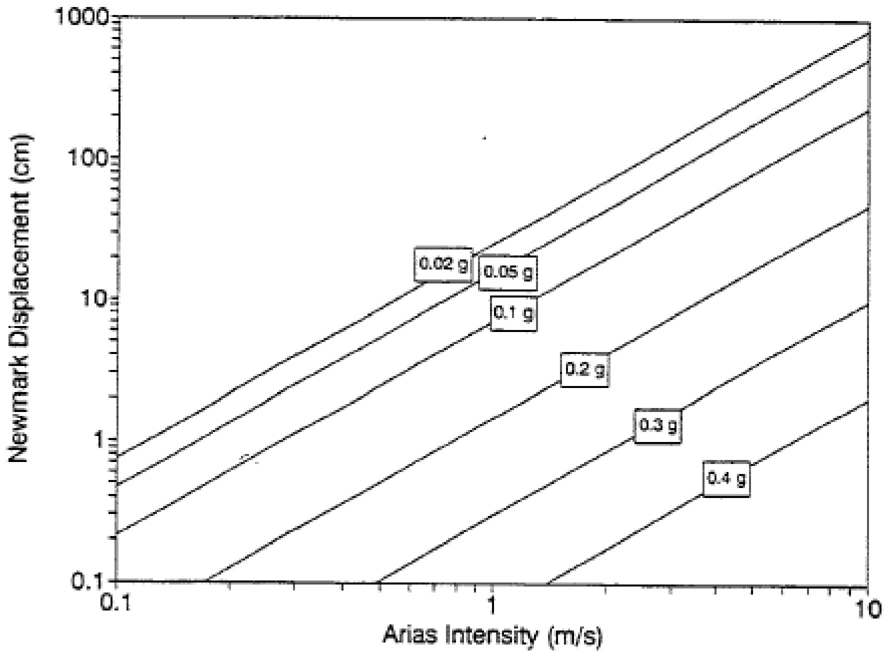

Fig. 13: Newmark displacement as a function of Arias intensity for several values of critical acceleration as modelled by the regression equation (Jibson, 2007)

Newmark displacements must be considered upon their effect on a potential landslide. Wiezorec et al. (1985) used 5cm as a critical displacement resulting in ground cracking and eventually failure of slopes, essentially based on data from California. Keefer and Wilson (1989) used 10cm as the critical displacement for coherent landslides in California as well; finally Jibson and Keefer (1993) used the range of 5-10cm as the critical displacement for initialization of landslides essentially in Mississippi valley.

The California Geological Survey provided guidelines (2008) for mitigating seismic hazard. According to the above, displacements of 0-15cm are unlikely to correspond to serious landslide movements and damage; displacements ranging from 15 to 100cm could be serious enough to cause strength loss and initiate slope failure or damaging landslide movement. As for displacements exceeding 100cm are very likely to correspond to serious damaging landslide movements.

All the above refer mainly to deep landslides; smaller, shallow landslides are usually triggered by much lower displacements of the order of 2 to 15cm (Jibson et al., 2000). Jibson and Michael (2009) used a similar range of Newmark displacements in order to provide landslide hazard maps of Anchorage in Alaska in a quantitative way: 0-1 cm (low LH), 1-5cm (moderate LH), 5-15cm (high LH) and >15cm (very high LH).

As it can be concluded, limits regarding critical displacement to cause ground cracking may differ seriously since they are dependent on the parameters of the problem to be studied; characteristics of the landslides materials may accommodate less or more critical displacements, whilst the “failure” is not a universally adopted notion, often dependant on the needs of the user or the project examined. Also, predicted seismic-induced displacements do not correspond necessarily to slope movements in the field; predicted modeled displacements should be rather considered as an index to correlate with field performance (Jibson et al., 1998, 2000; Rathje and Bray, 2000). Jibson et al. (1998, 2000) compared the inventory of all landslides triggered by the Northridge earthquake with predicted Newmark displacements. By regressing then the results using a Weibull model they managed to calculate a probability of failure as a function of Newmark displacement (in cm).

$$P(f) = 0.335 * \left[1 - \exp\left(-0.048 * D_n^{1.565}\right)\right] \tag{10}$$

Equation 6 can be used in any ground shaking conditions to predict probability of slope failure as a function of Newmark displacement. The above equation resulted from data coming from the area of California at a regional scale, primarily including shallow type landslides and debris fall, and so it can be rigorously be implemented in those types of landslides.

3.6.2.5 Discussion - Conclusions

As in any other case, all LHA models are limited by their restrictive simplifying assumptions. Newmark’s fundamental assumption is that landslides behave like a rigid-plastic material; therefore, no displacement occurs below critical acceleration, whilst displacement occurs at constant shearing resistance whenever critical acceleration is exceeded. This assumption is reasonable enough for a certain kind of landslides and geomaterials, whereas for some other type of landslides and materials is not appropriate; therefore, this model certainly does not apply universally for all type of landslides and geomaterials. For example, some highly plastic, fine-grained soils behave rather as viscoplastic, than rigid-plastic materials. Newmark’s method would underestimate the actual displacement because the shear strength loss would reduce the critical acceleration as displacement occurs. In such cases, the Newmark displacements should rather be considered as a minimum displacement. In general, Newmark’s method considers as equal static and dynamic shear strength and ignores dynamic pore-pressure build-up. Therefore, for highly plastic clays, or organic clays, silty sands or sandy silts or sands poorly graded in a relatively loose state and when saturated, static tests are not appropriate and should either be replaced by dynamic tests, or at least corrected by reducing empirically the static shear strength.

Although Newmark modified method presents a number of positive aspects, the assessment of Arias Intensity for a region to be studied, remains an important issue since no GMPEs (Ground Motion Predictive Equations) regarding this ground motion parameter have been developed in Greece and in most of the rest of the Black Sea Basin countries.

As it therefore appears, Newmark’s modified method is not suggested as an appropriate method to define LH with earthquake being the triggering factor and given the availability and reliability of data, we suggest that FEMA’s method could be used instead, provided that local GMPEs and probabilistic seismic hazard are implemented.

As for rainfall / hydrology being the triggering factor, the method of factor of safety could be used, based on the infinite slope model for planar type landslides and a deterministic model for circular type landslides.

However, we underline the fact that there are definitely also other approaches that could be used, depending on the main parameters exposed herein (availability and cost of input data, cost of implementation, adaptability and complexity of the method used, expertise needed for implementation, required accuracy/reliability of the output, scale and scope of the project).

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3.7 TURKEY

3.7.1 METHODS FOR RAINFALL – INDUCED SLOPE STABILITY ANALYSIS

It is widely known and experienced that rainfall may generate lanslides mainly due to (1) decrease of the shear strength capacity with saturation, (2) increase of the driving forces due to seepage. There have been significant research to develop methods in order to cope with such possible devastating effects of this hazard that each methodology makes its unique assumptions and imposes certain boundary conditions depending on the type of problem.

These methods are based on the estimation of that the saturated zones after rainfall will have the capacity to transmit the incoming water flow. The tranmissivity of soil may be estimated based on conductivity characteristic of corresponding site with the help of lithological classification or lab measurements performed on undisturbed samples. Thus the drainage feature of interested site indicating that how the subsurface flow occurring after rainfall is transmitted to the downstream based on the soil transmissivity, hillslope gradient and wetness state, characterized by the base flow discharge from catchment area. These quantities pertaining to corresponding slope are employed to assess the hydrological response of soil during rainfall.

The starting point is to develope a criterion so that the topographic features of hillslope under consideration and drainage characteristic of corresponding soil layer(s) can be lumped into a dimensionless parameters. There is a nonlinear relationship between this parameter and saturated areas where chances are available that area of catchment can be determined. This routine is preliminary analysis allowing one to focus on saturated areas or those exposed to surface runoff which may be elaborated by means of detailed slope stability analysis.

There is possibility to establish threshold levels in the context of this method in that contraction or expansion of saturated areas with respect to different rainfall magnitudes can be mapped. This means that required improvement on corresponding waterlogged site may be performed to provide the transmission of percolating rain water.

3.7.1.1 Method proposed by Mora and Vahrson

The method proposed by Mora and Vahrson (1993) for the prediction of susceptible zones was based on case studies of slope failures in historic earthquakes and also those induced by heavy rainfall in Central America. In this method, three factors relative relief, lithological conditions, and soil moisture were considered as the factors influencing the susceptibility. In addition two factors, seismicity and rainfall intensity, are incorporated as triggering factors. By combining these factors, a degree of slope failure hazard was defined as follows:

H_ℓ = Susceptibility * Trigger

$$H\ell = (Sr * S\ell * Sh) * (Ts * Tp) \quad (11)$$

where,

H_ℓ : landslide hazard index (Table 3.11)
S_r : value of relative relief index (Table 3.5)
S_ℓ : value of lithological susceptibility (Table 3.6)
S_h : value of index of influence of natural humidity of the soil (Table 3.7, Table 3.8)
T_s : value of influence of seismic intensity (Table 3.9)
T_p : value of influence of rainfall precipitation intensity (Table 3.10)
The slope factor S_r is defined based on relative relief $Rr = (h_{max} – h_{min})/km^2$

Table 3.5. Relative relief (Rr) values and their classes of influence in landslide susceptibility (Mora & Vahrson, 1991)

Relative relief	Susceptibility	Value S_r
0-75 m/km^2	Very low	0
76-175	Low	1
176-300	Moderate	2
301-500	Medium	3
501-800	High	4
>800	very high	5

Table 3.6. Classification of lithological influence, according to general conditions, representative for Central America (Mora & Vahrson, 1991)

Lithology	Susceptibility	Value S_l
Permeable limestone, slightly fissures intrusions, basalt, andesits, granites,ignimbrite, gneis, hornfels, low degree of weather, low water table, clean-rugose fractures, high shear strength rocks	Low	1
High degree of weathering of above mentioned lithologies and hard massive clastic sedimentary rocks; low shear strength; shearable fractures	Moderate	2
Considerably weathered sedimentary, intrusive, metamorphic, volcanic rocks, compacted sandy regolithic soils, considerable fracturing, fluctuating water tables, compacted colluvium and alluvium	Medium	3

Considerably weathered, hydrothermally altered rocks of any kind, strongly fractured and fissured, clay filled; poorly compacted pyroclastic and fluvio-lacustrine soils, shallow water tables	High	4
Extremely altered rocks, low shear resistance alluvial, colluvial and residual soils, shallow water tables	Very high	5

Each monthly average precipitation value is assigned to an index value as shown in Table 3.7. It has been observed that the 125mm limit value is representative for the average monthly potential evapotranspiration (PET) in Central America (Vahrson, 1991). It has also been shown that significant infiltration requires at least 40mm of rainfall accumulated in ten days, corresponding to 125 mm/month.

Once each month is evaluated, the total of all twelve monthly assigned values has to be calculated for each analyzed rain gage stations. These values range from 0 to 24. The total is classified into five groups, as shown in Table 3.8.

Table 3.7. Classes of average monthly precipitation (Mora & Vahrson, 1991)

Average monthly precipitation (mm/month)	**Assigned value**
<125	0
125-250	1
>250	2

Table 3.8. Weighting for annual precipitation (Mora & Vahrson, 1991)

Summation of precipitation averages*	**Susceptibility**	**Value S_h**
0-4	Very low	1
5-9	Low	2
10-14	Medium	3
15-19	High	4
20-24	Very high	5

*summation of the assigned values in Table 3.7 for 12 months

Table 3.9. Influence of seismic intensity (Modified Mercalli Scale) as a triggering factor for landslide generation (Mora & Vahrson, 1991)

Intensities (MM) Tr=100 years	Susceptibility	Value T_s
III	Slight	1
IV	Very low	2
V	Low	3
VI	Moderate	4
VII	Medium	5
VIII	Considerable	6
IX	Important	7
X	Strong	8
XI	Very Strong	9
XII	Exttremely strong	10

Table 3.10. Influence of rainfall precipitation intensity as a triggering factor for landslides (Mora & Vahrson, 1991)

Maximum rainfall n>10 years: T_r=100 years	Rainfall n<10 years: average	Susceptibility	Value T_p
<100 mm	<50 mm	Very low	0
101-200	51-90	Low	1
201-300	91-130	Moderate	2
301-400	131-175	Medium	3
>400	>175	High	4
		very high	5

Table 3.11. Classess of the potential landslide hazards (Mora & Vahrson, 1991)

H_ℓ	Class	Susceptibility of hazard
0-6	I	Neglible
6-32	II	Low
33-162	III	Moderate
163-512	IV	Medium
513-1250	V	High
>1250	VI	Very high

3.7.1.2 Method Proposed by Montgomery and Dietrich (1994)

Montgomery and Dietrich (1994) attempted to develop a method, bearing on the logic proposed by O’ Loughlin (1981 – 1986), which is built on the assumption that topography creates the most detrimental effect on slope stability. It is stated that since interested areas exhibit themselves as convergent or divergent topographical structures, it requires to introduce a methodology considering local surface topography as the primary parameter, and that the water transmission capacity of soil should be determined to assess whether it is capaple of conducting infiltrated rain water or not.

As a matter of fact, this routine is dependent on the combination of Darcy’s Law and infinite – slope stability concept in that elevated groundwater causes related soil mass to be exposed to failure under rainfall percolation. Therefore, one is supplied with a chance to generate hazard maps, detecting potential collapse locations, with the help of both rapid and simpler analysis. To that end, quantitative thresholds are established to take soil/topographical properties and meteorological conditions of related site into consideration in order that stability of different types of landshapes can be evaluated.

As stated, topographical effect combined with rainfall infiltration hazard on related site is extracted from catchment area which is partitioned into topographic elements consisting of contour lines and flow tubes perpendicular to these contours. Such an application enables one to derive a parameter, called wetness, which can be given as;

$$W = \frac{I_z A}{bT\sin\theta} \tag{12}$$

where,

I_z, is the net rainfall rate (≈ rainfall rate)
A, is the upslope area draining across b (Fig. 14)
b, is the lower bound to each element in interested catchment area (Fig. 14)
T, is the soil transmissivity at saturation ($K_h * z * \cos\theta$)
θ, is the slope angle.

Eq.(12) is achieved by the logic in O' Loughlin (1981 – 1986) but what is imposed upon by Montgomery and Dietrich (1994) is to associate this with the location of the groundwater table. Since wetness parameter is defined as the ratio of local flux at a given steady state rainfall to that at soil profile saturation, this Eq.(12) is able to be rearranged as:

$$W = \frac{K_x \sin\theta h \cos\theta}{K_x \sin\theta z \cos\theta} = \frac{h}{z} \tag{13}$$

where,

K_h, is the saturated horizontal hydraulic conductivity of soil
h, is the thickness of the saturated soil
z, is the total soil thickness.

This model proceeds with the infinite – slope stability assumption, in which the limiting state can be recasted as including the wetness parameter;

$$W = \left(\frac{\gamma_{sat}}{\gamma_w}\right)\left[1 - \left(\frac{\tan\theta}{\tan\varphi}\right)\right] \tag{14}$$

where,

γ_{sat}, is the saturated unit weight of soil,
γ_w, is the unit weight of water,
φ, is the internal friction angle of soil.

As can be seen, wetness is able to be computed from Eq. (14)to be substituted into Eq.(15) provided that if W is obtained as greater than 1, it should be equated to 1, as the remaining water runs off as overland flow. Hence, the topographic elements are estimated as unstable if;

$$\frac{A}{b} \geq \left(\frac{T}{I_z}\right)\sin\theta\left(\frac{\gamma_{sat}}{\gamma_w}\right)\left[1 - \left(\frac{\tan\theta}{\tan\varphi}\right)\right] \tag{15}$$

Eq. (15) reveals that T/I_z, called as infiltration rate after this point, primarily specifies the wetness state of interested topographic element, thus resulting in the fact that W is a function of rainfall intensity (I_z). In other words, increase in W is essentially dependent on I_z such an extent that if a certain treshold of I_z is exceeded, relevant element is exposed to instability. Thus, it is more feasible to express Eq. (15) as;

$$(I_z)_{cr} \geq \left(\frac{Tb}{A}\right) \sin\theta \left(\frac{\gamma_{sat}}{\gamma_w}\right)\left[1-\left(\frac{\tan\theta}{\tan\varphi}\right)\right] \tag{16}$$

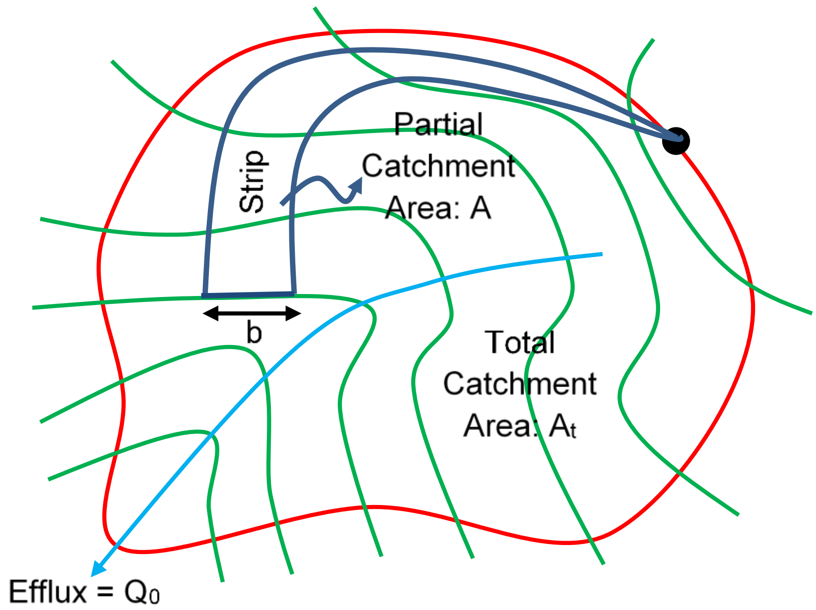


Fig. 14: Catchment Area

The Calculation of Parameters in Method Proposed by Montgomery and Dietrich (1994)

One who intents to adopt this method for rainfall – induced slope – stability analysis has to compute A, b, z, K_h, γ_{sat}, θ, φ and $(I_z)_{cr}$. The last parameter, $(I_z)_{cr}$, can be extracted from the meteorological measurements but the others depending on topographical characteristics and governing soil properties of site should be determined from GIS programs and emprical correlations, respectively. We firstly begin with the soil properties;

Determination of K_h

Hydraulic conductivity can in essence be measured both in lab (falling – head or constant – head methods) and in situ (Augerhole method). In case there are not such data available, there are empirical correlations based on gradation of soil for granular soils and Atterberg Limits of cohesive soils which can be used to assess K_h.

- Hazen’s Formula

Hazen (1892, 1911) improved a formula to compute the hydraulic conductivity, which is usually applicable for loose, clean sands with a coefficient of uniformity, D_{60}/D_{10}, less than about 2;

$$K = C_H D_{10}^2 \tag{17}$$

where

K, is the hydraulic conductivity (cm/sec),
C_H, is the Hazen emprical coefficient,
D_{10}, is the particle size for which 10% of the soil is finer (cm).

Although Eq. (17) has been widely used in engineering applications, it may lead to errenous results since it is limited to quite narrow particle diameters such as 0.01 cm < D_{10} < 0.03 cm. Also, that Eq. (17) is only constructed on D_{10} in terms of gradation parameter restricts the practicability of this relationship, thus resulting in seeking of another equation. However, if one be in the condition of employing Eq. (17), there is no harm in applying Eq. (16) to interested soil masses.

- Kozeny – Carman Formula

Kozeny (1927) and Carman (1938, 1956) derived the following relationship that predicts the hydraulic conductivity of porous media more accurately than Hazen’s Formula;

$$K(\mathrm{cm/sec}) = \left(\frac{\gamma}{\mu}\right)\left(\frac{1}{C_{K-C}}\right)\left(\frac{1}{S_0^2}\right)\left(\frac{e^3}{1+e}\right) \tag{18}$$

where,

γ, unit weight of permenant
μ, viscosity of permenant
$C_{K\text{-}C}$, Kozeny – Carman empirical coefficient
S_0, specific surface area per unit volume of particles (1/cm)
e, void ratio.

Eq. (18) is rewritten as encompassing the related properties of water, thus yielding;

$$K = 1.99 * 10^4 \left(\frac{1}{S_0^2}\right)\left(\frac{e^3}{1+e}\right) \tag{19}$$

Measuring S_0 is rather troublesome process in that it is able to be simply estimated from particle size distribution and particle shape, leading to the equality as;

$$K = 1.99 * 10^4 \left(\frac{100(\%)}{\left[\sum \frac{f_i}{D_{li}^{0.404} * D_{si}^{0.595}} \right]} \right)^2 \left(\frac{1}{SF^2} \right) \left(\frac{e^3}{1+e} \right) \quad (20)$$

where,

f_i, faction of particles between two sieve sizes

D_{li}, larger sieve size

D_{si}, smaller sieve size

SF, shape factor, which is determined as 6.0 for spherical, 6.1 for rounded, 6.4 for worn, 7.4 for sharp and 7.7 for angular.

Also, two important points for Kozeny – Carman Equation should be declared; (1) This expression is reproduced for granular soils, thus it might not be appropriate for fine – grained soils. (2) The fact that this formula is not devised as taking anisotropy into consideration causes Kozeny – Carman Formula to compute only vertical permeability. However, horizontal hydraulic conductivity (K_h) is usually greater than vertical one (K_v) such an extent that ratio of K_h/K_v ranges from 1 to 10.

Also, Steiakakis et al (2012) demonstrate that Kozeny – Carman Relationship is also applicable for cohesive with a difference that specific surface (S_0) in Eq. (18) can be computed by means of a selected Atterberg limit. Chapuis and Aubertin indicate that specific surface can be associated with liquid limit (LL) such as;

$$\frac{1}{S_0} = 1.3513 \left(\frac{1}{LL} \right) - 0.00089 \quad (21)$$

where, S_0, is in m^2/g, LL, is in percent. (limited to LL < 60 %)

The second expression is proposed by Steiakakis, et al. (2012);

$$\frac{1}{S_0} = 6.152 \left(\frac{1}{LL} \right) - 0.052 \quad (22)$$

Eqs. (21) and (22) are substituted into Eq (19) to calculate the vertical hydraulic conductivity for cohesive soils, which can be converted into that in horizontal direction by an assumption of K_h/K_v ratio.

Table 3.12: Permeability Ranges for Soils Classified with respect to USCS

Major Divisions		Symbol	Name	K (cm/sec)
Coarse – Grained Soils	Gravel and Gravelly Soils	GW	Well-graded gravels or gravel sand mixtures, little or no fines	K > 10^{-2}
		GP	Poorly graded gravels or gravel sand mixtures, little or no fines	K > 10^{-2}
		GM	Silty gravels, gravel-sand-silt mixtures	K = 10^{-3} to 10^{-6}
		GC	Clayey gravels, gravel-sand clay mixtures	K = 10^{-6} to 10^{-8}
	Sand and Sandy Soils	SW	Well-graded sands or gravelly sands, little or no fines	K > 10^{-3}
		SP	Poorly graded sands or gravelly sands, little or no fines	K > 10^{-3}
		SM	Silty sands, sand-silt mixtures	K = 10^{-3} to 10^{-6}
		SC	Clayey sands, sand-silt mixtures	K = 10^{-6} to 10^{-8}
Fine – Grained Soils	Silts and Clays LL < 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	K = 10^{-3} to 10^{-6}
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	K = 10^{-6} to 10^{-8}
		OL	Organic silts and organic silt clays of low plasticity	K = 10^{-4} to 10^{-6}
	Silts and Clays LL ≥ 50	MH	Inorganic silts, micaceous ordiatomaceous fine sandy or silty soils, elastic silts	K = 10^{-4} to 10^{-6}
		CH	Inorganic clays of high plasticity, fat clays	K = 10^{-6} to 10^{-8}
		OH	Organic clays of medium to high plasticity, organic silts	K = 10^{-6} to 10^{-8}

In addition to Steiakakis et al. (2012), Carrier and Beckman (1984) enhanced an equation, which is said to encompass a wide variety of clay types;

$$K\ (\mathrm{m/sec}) = \frac{\left\{\dfrac{e - 0.027[(PL) - 0.242(PI)]}{(PI)}\right\}^{4.29}}{1 + e} \tag{23}$$

where,

e, void ratio

PL, plastic limit

PI, plasticity index

Also, calculated values of hydraulic conductivity for both granular cohesive soils can be evaluated as whether it stays within the possible range presented in Table 1. As is known, clays or clayey soils generally possesses such degree of imperviousness that there is no need for conducting any rainfall infiltration analysis for them. Each soil layer is thought to be as uniform in site but it is widely accepted that soils may be exposed to disintegration and may have lower hydraulic conductivity at shallow depths. To that end, Montgomery and Dietrich (1994) states "The saturated conductivity of the soil in Marin Country, California, varies from 10-3 m/sec at soil depths less than 1m to 10-10 m/sec for soil depths between 3 and 4 m". This logic gives birth to the presumption of any reasonable value of hydraulic conductivity at shallow layers.

Calculation of γ_{sat} and φ

As given in Eqs. (14) to (16), the quantification of $\boldsymbol{\gamma_{sat}}$ and **φ** is needed to proceed with the calculations of thresholds set forth for selected parameters such as A⁄b (contributing area per unit contour length (m)) and/or W (wetness parameter). The available relationships for this process are presented in an attempt to display the logic that may be adopted throughout the analysis.

Since Montgomery and Dietrich (1994) is constructed on the condition of local flux at a given steady – state rainfall, it is of importance to quote the passage given in Holtz & Kovacs (1981) in order that the role of shear strength parameters in Montgomery and Dietrich (1994) Methodology can be grasped more properly; "CD Conditions (Consolidated – Drained) are the most critical for the long – term steady – seepage case for embankment dams and the long – term stability of excavations or slopes in both soft and stiff clays." Thus, the shear strength of interested soil as a function of **φ** (shear strength angle) within the context of this methodology;

$$\tau = \sigma \tan\varphi \tag{24}$$

The expected and most reliable process for attaining shear strenght angle is to perform lab tests on soil samples but this might not be applicable for always. Thus, it would be more suitable to estimate either possible ranges of shear strength angles or some empirical relationships developed for related shear strength parameter as a function of any given parameter for interested soil layer. Bowles (1996) proposes such ranges for relevant parameters in Table 3.13.

Table 3.13: Empirical values for φ, Dr and unit weight of granular soils based on the SPT at about 6 m depth and normally consolidated soils

Description	Very loose	Loose	Medium	Dense	Very Dense
Relative Density, D_r	0	0.15	0.35	0.65	0.85
SPT – N'_{70}: Fine	1 – 2	3 – 6	7 – 15	16 – 30	?
SPT – N'_{70}: Medium	2 – 3	4 – 7	8 – 20	21 – 40	>40
SPT – N'_{70}: Coarse	3 – 6	5 – 9	10 – 25	26 – 45	>45
φ: Fine	26 – 28	28 – 30	30 – 34	33 – 38	
φ: Medium	27 – 28	30 – 32	32 – 36	36 – 42	
φ: Coarse	28 – 30	30 – 34	33 – 40	40 – 50	
γ_{wet} (kN/m^3)	11 – 16	14 – 18	17 – 20	17 – 22	20 - 23

In the first place, relative density (Dr) is calculated for different depths by employing N'_{60} values such as; (Skempton, 1986)

$$\frac{N'_{60}}{D_r^2} = 32 + 0.288P'_0 \tag{25}$$

or Yoshida et al., 1988

$$D_r = 25(P'_0)^{-0.12} * (N_{60})^{0.46} \tag{26}$$

where,

P'_0, is the overburden pressure

D_r, is the relative density

N'_{60} is the SPT blow count normalized to 60% hammer energy

After that, shear strenght angle can be estimated based on Mayerhoff (1959) as;

$$\varphi = 28 + 0.15\ D_r(\%) \tag{27}$$

In cohesive soils, as identical to Holtz & Kovacs (1981), Skempton (1964) points out the pore pressure condition in clays slopes in that residual shear strength, φ_r, (or residual shear strength angle) is suggested in order that compatibility is provided between back – calculation results of occurred landslide and that obtained from site observations for given event. For both NC and OC clays, the residual strength is thought to be in the same form of Eq. (24), thus resulting in the computation of φ_r by using Eq. (24), (Residual shear strength angle). There are quite a few relationships proposed for finding residual friction angle with respect to any selected parameter, generally one of the Atterberg Limits for cohesive soils. Kanji (1974)'s Correlation was constructed on Plasticity Index (Ip), which is applicable for normal stresses ranging from 10 to 350 kPa; (Fig. 15.

$$\varphi_r = \frac{46.6}{I_p^{0.446}} \tag{28}$$

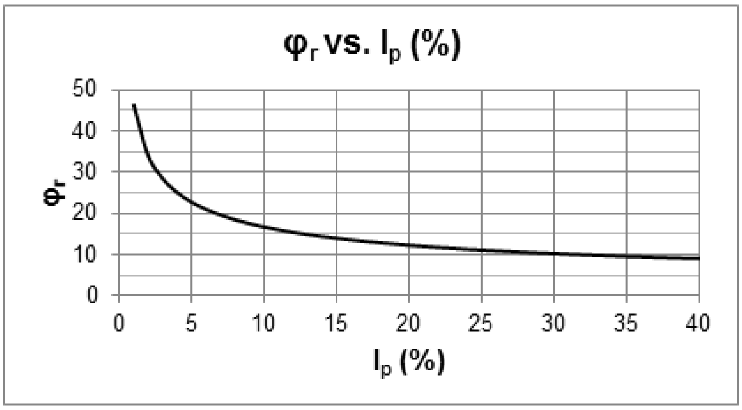


Fig. 15: Φ_r with respect to I_p (Kanji, 1974)

In addition, Cancelli (1977) also provided the following relationship, where LL (Liquid Limit) is in percent; (

$$\varphi_r = \frac{453.1}{LL^{0.85}} \tag{29}$$

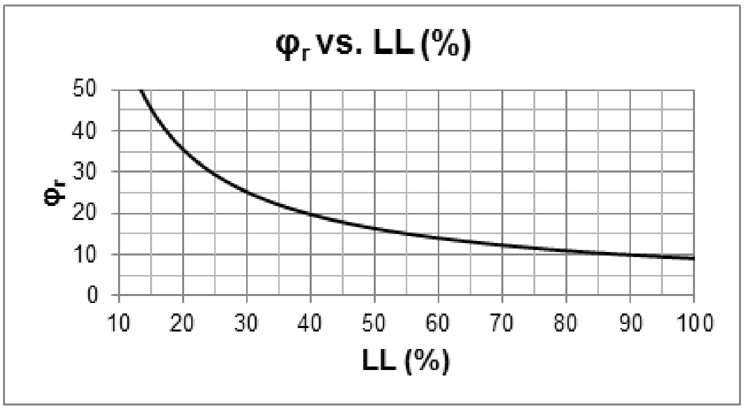


Fig. 16: Φr with respect to LL (Cancelli, 1977)

Also, utilizer of Montgomery and Dietrich (1994) Routine is anticipated to use unit weight determined by lab tests but it might not be feasible to be equipped with such data in most of the conditions. Thus, relationships that have been developed to correlate SPT – N values to unit weight can be used in the analysis (Bowles, 1977).

Calculation of Topographical Properties of Site

One of the most significant and demanding process of Montgomery and Dietrich (1994)’s Methodology is to delineate the catchment area, which is also divided by b and then called as “contributing area per unit length (m)”, such that interested site is required to be partitioned into smaller areas bounded by the trajectories drawn from lower contour to upper one. The logic declares that subsurface flux is composed of both infiltrated rain water and existing steady – state groundwater and is assumed to be deeply affected by catchment topography. Consider the hypothetical topography in Fig. 17 to illustrate the aforementioned topic as;

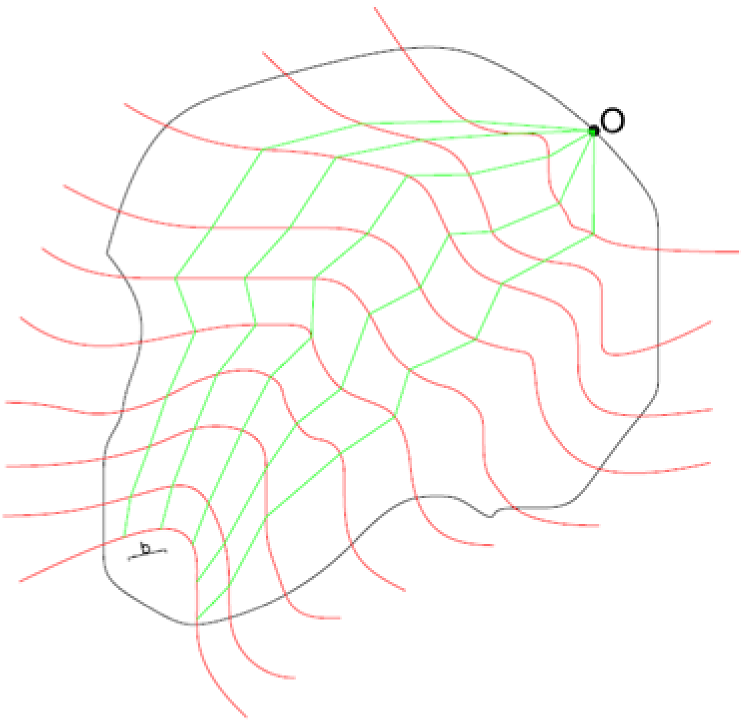


Fig. 17: Catchment Area and Compete Set of Uphill Trajectories for Hypothetical Topography

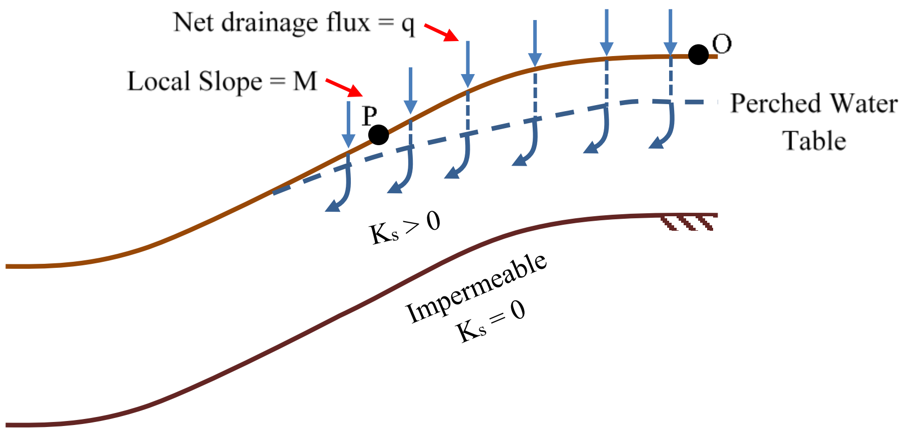


Fig. 18: Definition Skecthes for Section along Transect of Partial Catchment Area

Hypothetical catchment (in black color) and relevant contours (in red colors) are generated to typify what are expected to perform throughout the topographical operations in Montgomery and Dietrich (1994) and the longitudinal section of one of the trajectories (in green color) in Fig. 18 is provided in an attempt to delineate the assumption laying the foundation of this methodology; wetness parameter includes both percolated rain water and existing groundwater. To begin with the topographical treatments as visualized in Fig. 17, each contour line is divided into certain number of end point coordinates, which is also dependent on a selected b value. Assigned value of b is totally related to such an extent of precision determined for results that both amount of time spent for and accuracy of calculations specifies the selection of b. After the disintegration of contour lines with with respect to prescribed b parameter, boundaries are started to be drawn from lower contour to upper one in an attemp to constitute an area, which is the indication of subsurface flux route. Each path should be concluded at watershed peak (either local or global) and need to be computed as pursuing the minimum steeper distance between respective contour segments.

It may be useful to quote a passage from O'Loughlin (1981) "The contour resolution and contour element length b used in the analysis dictate the precision of the result. In any case, their choice should allow calculation of the partial catchment areas and slopes everywhere with a precision consistent with the map scale. Experience has indicated that a good match can be achieved between the resolution of the predicted wet areas and their real size and location if the contour density is such that 30 or more contours are available to describe the terrain, and a contour element length of 10 units (rescaled computer units) is used."

3.7.1.3 Quantifying the Effect of Rainfall Infiltration on Slope Stability

The algorithm is devised to quantify the transient rainfall effects on investigated site in that vertical infiltration of rain water (slope – parallel equipotentials) dominates the hydrological response of soil continuum during and immediate after rainfall and after it ceases, elevated groundwater starts to flow different regions in site, thus resulting in the occurrence of seepage forces. Infinite – slope assumption, which does not require to consider moment equilibrium, is adopted for the sake of simplicity throughout the calculations and both time – dependent pressure heads and following seepage forces are incorporated into force equilibrium equation written for slope – stability.

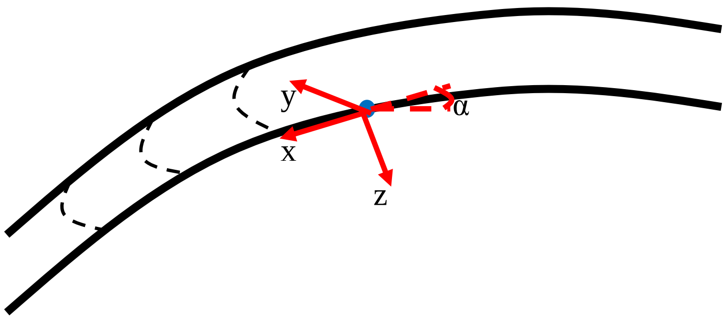


Fig. 19: 3D Slope Geometry

In general, Richards' Equation (2.1), which defines the water behaviour in soil mass, is casted in 3 – D form so that the phenomenon is able to be grasped in detail. However, such an approach for modelling the hydrological response of hillslope to incoming rainfall is quite time – consuming, thus forcing one to seek another way to proceed with calculations.

$$\frac{d\alpha}{d\Psi}\frac{\partial\Psi}{\partial t} = \frac{\partial}{\partial x}\left[K_L(\Psi)\left(\frac{\partial\Psi}{\partial x} - \sin\theta\right)\right] + \frac{\partial}{\partial y}\left[K_L(\Psi)\left(\frac{\partial\Psi}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[K_z(\Psi)\left(\frac{\partial\Psi}{\partial z} - \cos\theta\right)\right] \tag{30}$$

where

Ψ, is the pressure head

Kz(Ψ) and KL(Ψ) are vertical and horizontal hydraulic conductivity, respectively.

α, is the volumetric water content

θ, is the slope angle.

Iverson (2000) decoupled Eq.(30) into its components to evaluate both time dependent pressure head values and seepage forces arising due to the water movement through different regions in site by using appropriate time scales;

$$t^*_{Short-Term} = \frac{tD_0}{H^2} \tag{31}$$

$$t^*_{Long-Term} = \frac{tD_0}{A} \tag{32}$$

where,

$t_{(Short-Term)}^*$, represents the minimum time required for strong slope – normal pore pressure transmission from the ground surface to depth, H.

$t_{(Long-Term)}^*$, represents the minimum time required for strong slope – normal pore pressure transmission from the area, A to the point (x, y, H).

D_0, is the maximum characteristic diffusivity governing transmission of pressure head, and it thereby provides a convenient reference diffusivity.

If parameters included in Richards' Equation is normalized and short – term time – scale is also employed for rearranging it, the solution of the ultimate 2nd order partial differential equation can be given as; (Please see in Theoretical Background of "An Approach for Quantifying the Effect of Rainfall Infiltration on Slope Stability")

$$\frac{\psi}{Z}(Z, t \leq T) = \beta\left(1 - \frac{d_Z}{Z}\right) + \frac{I_Z}{K_Z}[R(t^*)] \tag{33}$$

$$\frac{\psi}{Z}(Z, t > T) = \beta\left(1 - \frac{d_Z}{Z}\right) + \frac{I_Z}{K_Z}[R(t^*) - R(t^* - T)] \tag{34}$$

In which;

$$\widehat{D} = 4D_0\cos^2\alpha \tag{35}$$

$$t^* = \frac{t}{Z^2/\widehat{D}} \tag{36}$$

$$T^* = \frac{T}{Z^2/\widehat{D}} \tag{37}$$

are normalized times;

$$R(t^*) = \sqrt{t^*/\pi}\, e^{-1/t^*} - \mathrm{Erfc}\left[1/\sqrt{t^*}\right] \tag{38}$$

is a pressure head response function, which depends only on normalized time.

As can be seen Eqs.(33) - (38), vertical infiltration governs the transient response of hillslope of incoming rainfall event and if these eqs. are plugged into infinite – slope stability equation, it yields;

$$\mathrm{FoS}(Z, t) = \frac{\tan\varphi'}{\tan\theta} - \frac{\psi(Z, t)\gamma_w\tan\varphi'}{\gamma_{sat}Z\sin\theta\cos\theta} + \frac{c'}{\gamma_{sat}Z\sin\theta\cos\theta} \tag{39}$$

where,

φ', is the internal friction angle.

c', is the cohesion intercept

γsat, is the saturated unit weight

After the dynamic effect of rainfall terminates, accrued groundwater commences to flow towards the regions whose total heads are lower than interested one, hence seepage thrust to soil mass should be taken into consideration. Luckily, Bear (1972) states that seepage force can be thought as proportional to groundwater flow such as;

$$F_w = ih\gamma_w b\cos\theta \tag{40}$$

If Eq.(40) is inserted into the limit equilibrium eq. as identical to done in short – term response, the resultant eq.can be presented as (Fig. 20;

$$F.S = \frac{S}{W\sin\theta + F_w\sin\lambda} = \frac{(W\cos\theta - F_w\cos\lambda)\tan\varphi' + c'b}{W\sin\theta + F_w\sin\lambda} \quad (41)$$

where,

h, is the ground water table height

λ, is the seepage direction angle between seepage drag and slope – normal in the clockwise direction.

To proceed with computations, with appropriate seepage directions in hillslope medium since reasonable selections can be made within ascertained values. Iverson (1986) came up with a solution at the end of a parametrich study that seepage direction, $\lambda = 90^0 - \varphi$, eventuates in the most unfavourable condition. Thus, utiliser struggling for evaluating the most damaging conditions is provided with making such an assumption rather than proceeding with his calculation by slope – parallel seepage thrust.

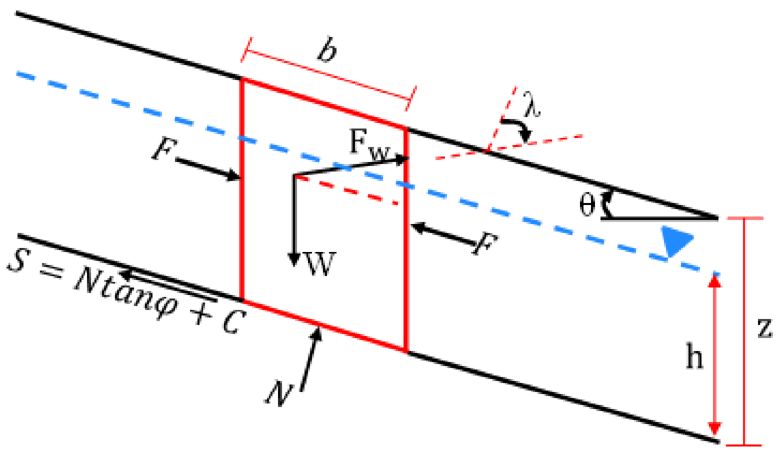


Fig. 20: Uniform Seepage in Soil Continuum

The Calculation of Related Parameters

The parameters needed to apply this routine are K_z, H, A, θ, d_Z, φ, D_0, I_z, and T such that almost each of them is assessed in Montgomery and Dietrich (1994) in terms of how it can be obtained except D_0 and H. H is able to be defined as the depth to the impermeable layer and totally dependent on the available geology. However, D_0 should be designated properly in order to go ahead with transient groundwater response calculations, which is computed in Iverson (2000) as;

$$D_0 = \frac{K_{sat}}{C_0} \quad (42)$$

where,

C_0, is the minimum value of $C(\psi)$, typically observed when the soil becomes saturated.

$C(\psi) = d\alpha/d\psi$, is the change in volumetric water content per unit change in pressure head.

There are a great number of SWCC (Soil Water Characteristic Curve), which is expressed as the variation of volumetric water content with respect to matric suction, and is generally designed as a function of certain parameters extracted from fitting process of test results. Fredlund, Rahardjo, and Fredlund (2012) presents that one of the most prominent equation is Gardner (1958b) such as;

$$\Theta_d = \frac{1}{1 + \mu_g \psi^{n_g}} \tag{43}$$

where,

$$\Theta_d = \frac{w(\psi)}{w_{sat}} \tag{44}$$

μ_g, is the fitting parameter which is a function of air – entry value of the soil

n_g, is the fitting parameter which is a function of rate of water extraction from soil once air – entry value of soil has been exceeded.

Brooks and Corey (1964) derived the relationship between water content and matric suction as;

$$w(\psi) = w_{sat} \text{ or } \Theta_d = 1 \text{ for } \psi \leq \psi_{aev} \tag{45}$$

$$\Theta_d = \left(\frac{\psi}{\psi_{aev}}\right)^{-\lambda_{bc}} \text{for } \psi > \psi_{aev} \tag{46}$$

where,

$$\Theta_d = \frac{w(\psi) - w_r}{w_{sat} - w_r} \tag{47}$$

ψ_{aev}, is the air – entry value of soil.

λ_{bc}, is the pore – size distribution index

w_r, is the residual water content located through trial – and – error process that yields straight line on semi – log plot of degree of saturation versus suction.

Finally, Van Genucten (1980)'s equation is frequently referred in articles, related to this issues such as;

$$\Theta_d = \frac{1}{\left[1 + \left(\mu_g \psi\right)^{n_g}\right]^{m_g}} \tag{48}$$

where,

$$\Theta_d = \frac{w(\psi) - w_r}{w_{sat} - w_r} \tag{49}$$

$$m_g = (1 - 1/n) \tag{50}$$

Fredlund and Xing (1994) revealed the fact that S, saturation, value is usualy employed instead of normalized water content, Θ_d, and Papa, Medina, Ciervo, and Bateman (2013) explained that C_0 can be investigated through the derivation of Van Genuchten (1980) equation. As can be seen, key parameters included in presented SWCC should be accounted for by carrying out lab tests but this might not be appropriate for most conditions, in which limited amount of data can be provided. Hence, it might be feasible to look forward to data from literature, which is expected to be based on common rule, or methodology.

3.7.2 METHODS FOR EARTHQUAKE – INDUCED SLOPE STABILITY ANALYSIS

3.7.2.1 Method Proposed by Ansal and Siyahi (1994):

This method is envisaged to carry out a parametric study on slope stability model which only considers moment equilibrium among driving forces and resisting forces in that the simplification over equilibrium equation enables one to perform zonation on interested site by only considering internal friction angle of governing soil and slope angle. The landshape is given in Figure 27, where H represents the height, β is slope angle, λ is the angle between the line joining top and toe of slope and horizontal, α is given as the center angle of sliding circle, R is the radius of sliding center, n is a dimensionless parameter that is a function of height, H and A is the earthquake acceleration.

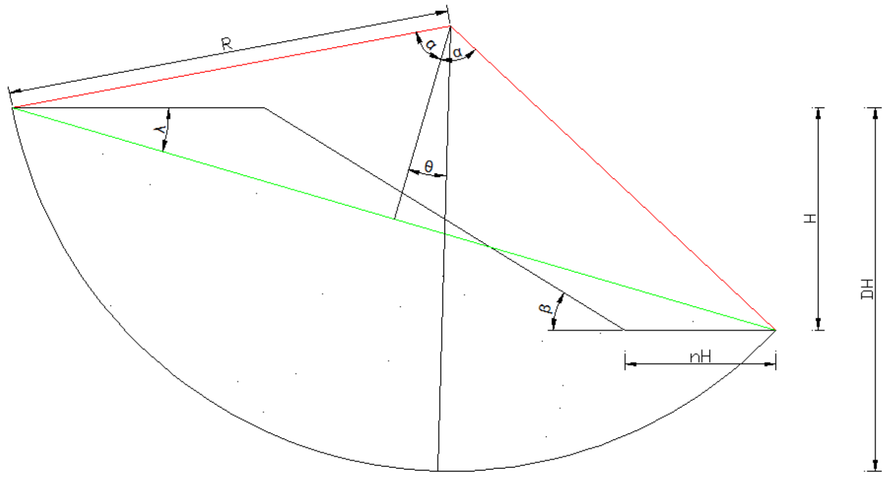


Fig. 21. Slope Geometry used in Stability Analysis

Factor of safety, F, is defined as the ratio of moment created by resisting forces (cohesion forces in this situation, M_R) and those produced by sliding forces (by soil weight and earthquake forces under this condition);

$$F = \frac{M_R}{(M_W + M_E)} \tag{51}$$

where,

$$M_W = \gamma \frac{H^3}{12}[1 - 6n^2 - 2\cot\beta(3n + \cot\beta) - 3\cot\alpha(2n + \cot\beta - \cot\lambda) + 3(2n + \cot\beta)\cot\lambda] \tag{52}$$

$$M_E = A\gamma \frac{H^3}{12}(\cot\beta - 3\cot\alpha(2n + \cot\beta)\cot\lambda + 3\cot\alpha\cot\lambda^2 + \cot\lambda^3) \tag{53}$$

At this stage, the resisting moment is computed by multiplying cohesion force obtained by integrating the cohesion value for a certain depth along sliding circle and the radius of this circle, which yields;

$$M_R = \frac{H^2}{4\sin^2\alpha\sin^2\lambda}[\alpha c_0(2 + a_0 H) + a_0 H(1 - \alpha\cot\alpha)\cot\lambda] \tag{54}$$

The factor of safety can be calculated as;

$$F = \left(\frac{a_0}{\gamma}\right) N_1 + \left(\frac{c_0}{\gamma H}\right) N_2 \tag{55}$$

where,

$$N_1 = \frac{3a_0(\alpha + \cot\lambda - \alpha\cot\alpha\cot\lambda)}{DEN} \quad (56)$$

$$N_2 = \frac{6n}{DEN} \quad (57)$$

$$DEN = \sin^2\alpha\sin^2\lambda(D_1 + D_2) \quad (58)$$

$$D_1 = 1 - 2\cot^2\beta - 3\cot\alpha\cot\beta + 3\cot\beta\cot\lambda + 3\cot\lambda\cot\alpha - 6n\cot\beta - 6n^2 - 6n\cot\alpha + 6n\cot\lambda \quad (59)$$

$$D_2 = A[\cot\beta + \cot^3\lambda + 3\cot\alpha\cot^2\lambda - 3\cot\alpha\cot\beta\cot\lambda - 6n\cot\alpha\cot\lambda] \quad (60)$$

The minimum value for N1 for each β value was determined based on a parametric study with respect to the variations of α and λ values. Eq.(55) can be further simplified assuming that normally consolidated clays have cohesion characteristics changing linearly with depth as shown in Fig. 22. Also, it is a reasonable logic that soil possesses no cohesion at the surface level, ($c_0 = 0$), thus Eq.(55) can be written as:

$$F = \left(\frac{a_0}{\gamma}\right) N_1 \quad (61)$$

In addition to this, Mohr – Coulomb Failure approach is incorporated into the analysis in that cohesion value, that is shear strength, for normally consolidated clays can be quantified as;

$$\tau = \sigma\tan\varphi \quad (62)$$

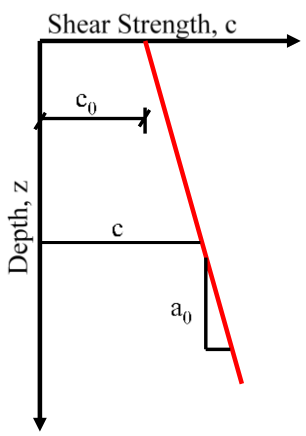


Fig. 22: Variation of shear strength with depth

If the concept in Fig. 22 can be equated to the Eq. (62), it gives,

$$\tan\varphi = \frac{a_0}{z} \tag{63}$$

All in all, the factor of safety Eq. (61) is transformed into

$$F_T = \tan\varphi N_1 \qquad (64.)$$

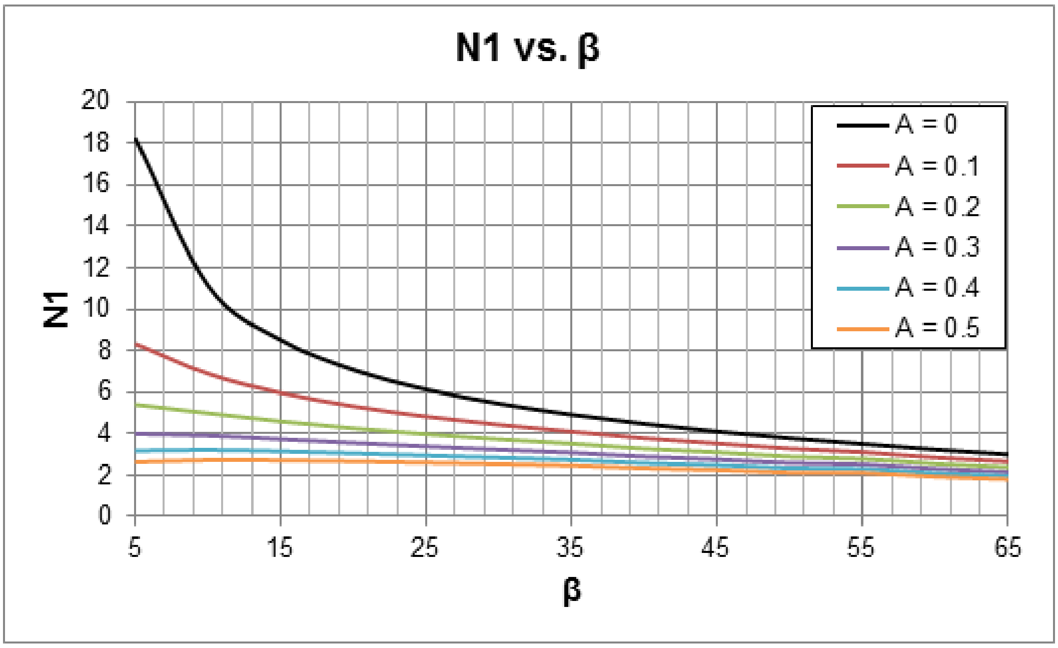


Fig. 23: The Variation of stability numbers, N1 with respect to slope angle, β, and peak ground acceleration, A

3.8 BULGARIA

The landslide hazard is one of the most important in Bulgaria. Landslides are widely spread with irregular territorial distribution. The number of slope movements is great and almost all of the types recognized by Varnes (1978) are manifested. Cases of complex landslide movements occur very often. The variety in kinds of mechanism, rate of movement, different size and shape in landslide manifestation is due to the diversity of the geological, geomorphologic, hydrogeological and engineering geological conditions in Bulgaria. The main natural factors that contribute to landslide activity in the country are endogenic: slow tectonic movements and earthquakes; and exogenic: erosion, sea erosion, precipitation, melting snow and variations in the ground water tables.

3.8.1 GEOLOGICAL CONDITIONS FOR LANDSLIDE OCCURRENCE

Engineering-geological conditions in Bulgaria are various and complex due to the variety of geological units in the country's territory. From the geotechnical point of view, the lithological variety of rocks has been organized into 4 main groups of engineering-geological types of rocks and soils (Fig. 25). The types of solid rocks include hard and dense magmatic, metamorphic and sediment rocks with strong structural bonds and high strength parameters (such as granites, diorites, gneisses etc.) When these kinds of rocks are tectonically disturbed, broken, weathered or somehow changed, their strength parameters are lower, which characterize types of soft rock. Clayey and cohesionless soils are the youngest lithological formations (Neogene and Quaternary).

Considering mainly geological, tectonical, morphological and geotechnical criteria, five large regions and some inside zones have been distinguished in the territory of Bulgaria (Kamenov & Iliev, 1963). The names of these engineering-geological regions and zones as well as the main geological processes are given in Fig. 25.

Of the geological conditions, which contribute to the landslide manifestations, the presence of clayey and sandy-clayey material in the structure of slopes is the most important, as well as some weak interbeds and surfaces. These kinds of geological conditions are especially characteristic for the structures formed by Tertiary and Quaternary sediments. About 90% of the Bulgarian population lives in such sediment terrains. The hilly parts of these basins, the basin boundaries and the river slopes inside the basins are the areas vulnerable to landslides.

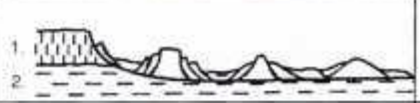
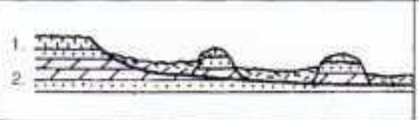
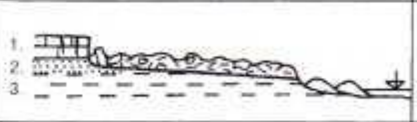
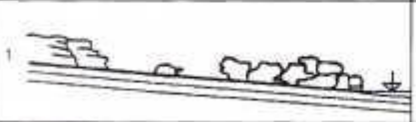
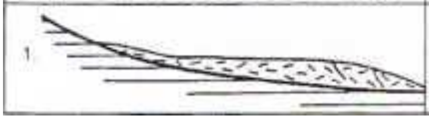
Fig. 24: Engineering geological regions in Bulgaria (according to Kamenov & Iliev, 1963)

3.8.2 LANDSLIDE DISTRIBUTION

The distribution of landslides in Bulgaria is irregular in the country's territory. However in some areas, the landslides are more numerous, bigger and more frequent than in other areas. Thus, these areas qualify as landslide regions. Such large regions are the high Danube River Bank, the Northern Black Sea coast, the Tertiary basins in Southern Bulgaria - East-Maritsa coal basin, Sofia and the Pernik valleys. Many landslides are manifested also on the river slopes in the Fore Balkan and the Balkans, in the Rila-Rhodopes fault zones and the periphery of the lava flows in the Rhodopes. The largest and most destructive landslides that have occurred over the last 60 years are distributed in these regions of the country. The variety of landslide profiles is too big to be presented in detail but the most characteristic and frequent cases are shown in Table 3.14.

The high Danube River Bank is a region where the landslides are ancient and the slip surfaces are situated deeply, usually more than 20 m below the terrain level. There are many urban areas affected by landslides and erosion. Tectonically, the Danube Plain coincides with the Moesian Platform. Its geological profile from bottom to top is as follows: bedrock made by magmatic and metamorphic rocks; thick cover of sedimentary rocks - sandstones, limestones and marls; surface zone made by gravels, sands, clays and loess. Loess formation is widely spread on the high Danube River Bank. Ordinarily, its thickness varies from 15 to 80 m.

Table 3.14 Representative profiles of landslides in the territory of Bulgaria

Representative profile	Geological structure	Regions	
	1. Loess, Q 2. Clays, N_2	West Danube River bank	
	1. Loess, Q 2. Sandstones and marls, K	Central Danube River bank	
	1. Limestones, N_1 2. Clays, N_1	Black Sea Shore Line	Taukliman
	1. Limy marls, N_2 2. Clays, N_1		Balchik Town
	1. Limestones 2. Sands 3. Clays		Varna City
	1. Flysch, K_2		Emine Cape
	1. Limestones, K_2 2. Marls, K_1	Plateaus in NE Bulgaria and the Fore-Balkan	
	1. Clays, Pg or N_2	Graben's border strips	
	1. Rhyolites, Pg 2. Clays, soft sandstones, Pg	Rhodope Mts.	
	1. Clays, N_2	Maritza-Iztok open-pit coal mine	
	1. Clays, N_2 or Q	Slopes in the country	

The main instability factors for landslides along the Danube riverside are erosion, contemporary Earth crust movements, earthquakes, precipitation, fluctuation of the ground water table, as well as human activity. The riverbank between the town of Dunavtsi and the point of flow of the Iskar River represents an almost continuous landslide section, more than 120 km along the Danube River. The most frequent cause of landslide manifestation is that the slip surface is predetermined and lies in weak Pliocene clays. The loess formation situated above acts as a static load. Due to the river erosion, the weak clay layers outcrop on the river slope. The present landslide activation is connected with variation in the ground water table in slopes. The permanent erosion of the Danube River and seasonal fluctuation of the river water level are the main factors for slope instability. The landslides have a volume of more than 15 million cubic meters.

The Sofia valley is a region where geological and tectonic conditions predetermine landslide occurrence mainly in the periphery of the valley and along the bank slopes of the rivers crossing the valley. As a geological structure, the Sofia valley is a graben filled with Neogene and Quaternary sediments - gravels, sands, clays and coal strata of limnic origin, irregular thickness and continuity. The main trends of the present tectonic movements are the uplifting of the northern and southern parts of near mountains (up to 2 mm/a) and the sinking of the central parts of the graben (approx. 1 mm/a). In this way, the vertical tectonic movements slowly change the geodynamic equilibrium and the slopes along the northern and southern borders of the Sofia valley are prone to creep and landslide manifestations. The delluvial and debris fan deposits con-taining sands and clays are favorable media for the development of these processes. The creep usually precedes the active sliding phase and it is observed mainly along the southern periphery.

Landslides in the Rila-Rhodope region are numerous with ancient and recent activity. The biggest ones are situated in the eastern part of Rhodope around the towns of Smolyan, Peshtera and Djebel. The landslide "Schupenata planina" ("The Broken mountain") near the town of Djebel is the most remarkable natural phenomenon, formed about 100 years ago. Depending on the lithological composition, the morphological conditions and the properties of the rocks and soils, three groups of terrain can be distinguished in the Rila -Rhodope region - mountain massifs (horsts), valleys (grabens) and contact zones (Broutchev et al. 2001). All three types of terrain are prone to landslide occurrence.

The territory of the Bulgarian Black Sea coast has a high degree of landslide hazard in economic loss, social and environmental consequences. In areas along the Black Sea coast, more than 120 landslide events have been registered until now. 80% of landslides in the districts of Varna and Dobrich affect the coast line. Most are active landslides in the northern Black Sea coast of Varna to Kavarna (between the resorts of St. St. Constantine and Elena, Zlatni Pyasatsi, Albena, and the Balchik area). These are old and recent, deep-seated and complex type landslides. The depth of the main slip surface is usually up to 50-60 m or more (reaching more than 100 m at some places). The slopes, on which they are developed, are in a state close to equilibrium and the activation of landslides could be provoked by sufficiently small additional destabilizing factors - abrasion, erosion, prolonged rainfalls, seismic and man-made impact (Evstatiev and Rizzo 1984; Konstantinov 1991; Frangov et al. 1997; Varbanov et al. 1997, Avramova-Tacheva et al. 1998 and others). Many of slope phenomena (including rock deformations) that are depicted in the World classification of Varnes (1978) of slope movements can be found here: rockfall, earth fall, earth slump, earth block slide, rock lateral spread and rapid earth flow.

Depending on the depth range, geological and tectonical structure, and the engineering geological properties of the geological units, the Bulgarian Black Sea coast can be divided into 3 landslide zones: Northern zone, Middle zone and Southern zone.

There is frequent landslide activity along the Bulgarian Black Sea coast. The seashore line is about 400 km long. It crosses the large morphological-tectonic structures of the Strandja anticlinorium, the Balkanide structures and the Moesian platform (Fig. 25) in a south- north direction.

Historical evidence shows that disastrous landslides destroyed ancient towns within the boundary of the Moesian Platform - the Northern Black Sea coast (Iliev 1973; Stakev et al. 1994; Koleva-Rekalova et al. 1996). Miocene and Quaternary sediments form the coast slope of the Moesian Platform. The Miocene sediments include mainly marls, sands, clays and limestones. The Balchik deep-seated landslides were formed into unconsolidated aragonite sediments of the Miocene (Sarmatian) age (Koleva-Rekalova, 1994; Koleva-Rekalova et al. 1996). The Quaternary deposits are represented mainly by loess formation, the thickness of which is about 10-15 m. In the southern part of the Moesian Platform, a steep slope is raised up to 250 m above sea level (Kamenov et al. 1973). This part of the seacoast is the most vulnerable in terms of landslide occurrence.

The Northern Black Sea coast is the region where landslide activity causes the most destruction because the coastline is densely urbanized. In 1997, after heavy rainfalls in a short period, 4 big landslide activations provoked a lot of material damage, destroying a number of houses and cutting in several places the main road to the biggest seaside resort in Bulgaria - Zlatni Pyassatsi. The landslides along the Northern Black Sea coast have been triggered several times during the last 50 years but the landslides in 1997 were the most significant ones, causing considerable damage and material losses (Varbanov et al. 1997; Evstatiev et al. 1997).

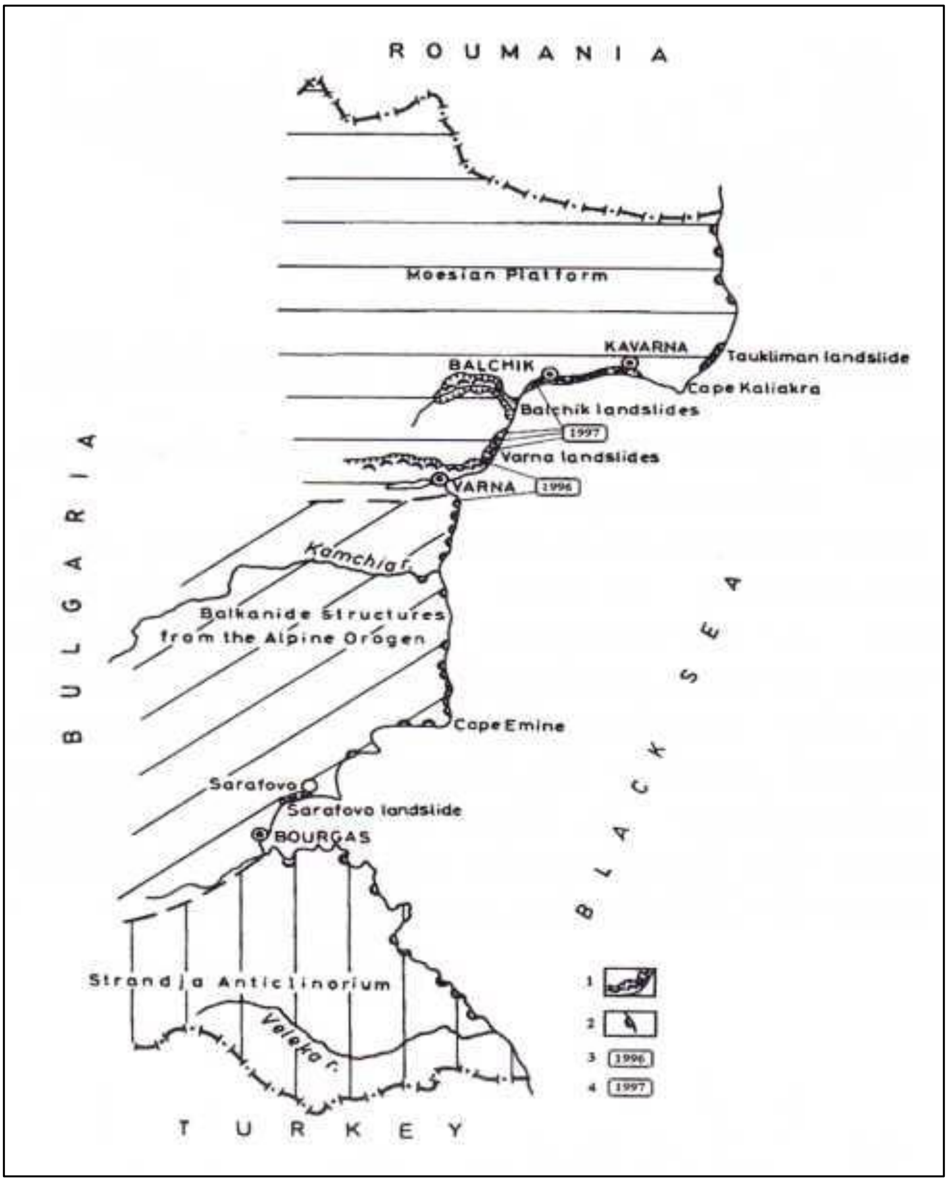


Fig. 25: Landslide distribution on the Bulgarian Black Sea coast: 1 - landslide zone ; 2 - separate landslide ; 3 - landslides triggered in 1996; 4 - landslides triggered in 1997 (according to Kamenov et al. 1973 and Evstatiev et al. 1997)

The coastline between the towns of Varna and Kavarna represents an almost uninterrupted landslide section that is about 30 km long and up to 2-3 km wide. The most dangerous areas for slope instability are those in the towns of Balchik and Kavarna, the village of Kranevo and the Zlatni Pyassatsi resort. The landslides along the Northern Black Sea coast are represented mainly by the following types: rotational earth slump, translational block slide and are more often complex. They have one deeply situated slip surface and 1 or 2 more shallow ones. The present activations usually occur in shallow levels.

3.8.3 METHODOLOGY FOR ASSESSING LANDSLIDE HAZARD

Mapping of landslides and assessment of hazards can pass through 2 steps:

1) Inventory mapping, and

2) Susceptibility mapping.

3.8.3.1 Inventory mapping

For the inventory maps the most appropriate is the methodology used by the U.S. Geological Survey. The classification of landslides and other slope processes in activity will be tailored according to the criteria proposed by Keaton & DeGraff (1996) and WPWLI (1993). This activity includes complex of works for identification of slope deformation and their mapping. The research area will include landslide phenomena along Bulgarian Black sea coast and 30-40 km onshore strip. Attribute tables will include data for:

- Type of movement (Varnes, 1978). The criteria for identifying the landslide phenomena have to be based on the Varnes classification on slope movements (1978). Mostly predominant types are earth-flow and earth-slide (rotational and translational).
- State of activity (WPWLI, 1993). The landslides are active, reactivated, suspended, dormant, abandoned and relics.
- Depth range. Includes data of depth D [m]. Landslides are shallow (D<5 m), moderate (D=5-20 m) and deep-seated (D>20 m).
- Triggering factors: precipitation, seismicity, erosion/abrasion.

Additional data:

- Dates (periods) of activation, if available.
- Geology
- Hydrogeology
- Precipitation
- Seismicity

3.8.3.2 Susceptibility mapping

A variety of methods to assess the potential are used in World practice. The most of these methods include basic calculations of slope instability of a given area. A specific feature of the Bulgarian coast is the availability of many different geological background that requires a serious dataset for specific geotechnical properties of the various lithological units. The available data in this area is not enough for any estimation of statistical probability of occurrence (acc. to Wise et al., 2004).

This study will cover a strip of territory of several Black Sea countries, which would complicate methodology decision. For example, the application of Newmark analysis for assessment of potential earthquake triggered landslides could be applied for selected areas with known potential earthquake sources, critical acceleration assessments connected with safety factor analyses.

In accordance with discussion held in Istanbul workshop on 13-14 March, the landslide susceptibility method of Mora and Vahrson (1993) has been proposed. This method had been applied for landslide hazard assessment of the Sofia graben in 1996, and due to this reason it is applicable for Bulgarian coastal area. This approach is more comprehensive, it could be extended to more countries in the region where the conditions and factors are diverse and where the other known methods could not be combined.

Discrepancy of this method is that it includes only two activating factors such as earthquakes and rainfalls, which are typical for the region of Central America, where it is originated. The Black sea coastal area is characterized with active abrasion at many sectors. Linear erosion affects the valleys of many rivers and dales along the strip. Due to this reason we will add the factor 'abrasion/erosion' to triggering factors included in calculation of susceptibility.

The Mora and Vahrson estimations are applied by formulas:

$$H = SUSC * TR \tag{65}$$

$$H = (S_r * S_l * S_h) * (T_s + T_p) \tag{66}$$

where *H* is relative hazard level and it is multiplying between susceptibility factor *SUSC* and triggering factor *TRIG*. Susceptibility factor is multiplying of slope factor S_r, slope factor S_l and soil humidity factor S_h.

The slope factor will receive scores from 0 to 5 depending on the slope value (in m/km^2) in accordance with formula given by the authors of method.

The slope factor will be derived from simplified table as follows:

Table 3.15: Slope factor criteria, classification and scores

Lithology	Qualification	S_l
Permeable compact alluvium; permeable limestone; slightly fissured intrusions, low degree of weathering, low water table, high shear resistance	Low	1
Higher degree of weathering of above mentioned lithologies and hard massive sedimentary rocks, lower shear resistance and shearable fractures	Moderate	2
Considerably weathered sedimentary, intrusive, metamorphic and volcanic rocks, considerable fracturing, fluctuating water tables	Medium	3
Considerably weathered, hydrothermally altered rocks of any kind, strongly fractured, clay filled, poorly compacted pyroclastic and fluvio-lacustrine soils, shallow water tables	High	4
Extremely altered rocks, low shear resistant alluvial, colluvial and residual soils, shallow water tables	Very high	5

The soil humidity factor S_h will be determined in accordance with accumulated value of precipitation indices, from 1 to 5.

Seismicity triggering factor T_s will vary on the territory of Bulgaria from 4 (VI degree) to 7 (IX degree). For example, the Burgas region has T_s=5, but Shabla-Kaliakra will have T_s=7. The other triggering factor T_p will be taken from table given by the authors of method.

Due to specific peculiarities of Bulgarian sea-side strip, we will add additional triggering factor concerning the abrasion and erosion activity along the coast and rivers that has to be taken into consideration and we propose to be marked it as T_e. It is expressed in Equation 3:

$$H = (S_r * S_l * S_h) * (T_s + T_p + T_e) \qquad (67)$$

We propose to add the following scores for erosion and abrasion triggering factor (**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**)

Table 3.16: Classification of landslide hazard H

Descrioption of sea-side strip and cliff	Erosion and abrasion factor T_e

Accumulation zone	0
Rocky cliff, with abrasion and erosion processes	1
Soft soils cliff, with abrasion and erosion processes	2

Six degrees are proposed for final classification, given in Table 4:

Table 3.17: Classification of landslide hazard H

H	Class	Classification of hazard of landslide potential
<6	I	Negligible
7-32	II	Low
33-162	III	Moderate
163-512	IV	Medium
513-1250	V	High
>1250	VI	Very high

Research areas and scales for mapping

For whole Bulgarian Black sea coastal area the mapping will be in scale 1: 500000.

Detailed hazard mapping in scale 1:25000 will be for two research areas. The more detailed mapping will be applied for two pilot areas as follows:

- 1) between Byala and Cape Emine, and
- 2) the vicinity of town of Tsarevo,

where landslide processes developed, but also the conditions differ greatly. The precise specifying the areas of detailed mapping and research shall be specified on site in the working process. Proposed size of grid is 1 cm x 1 cm on the map (i.e. 250 m x 250 m).

3.8.4 MORA AND VAHRSON METHOD: A SHORT ANALYSIS FOR STRENGTH AND WEAKNESS SIDES AND APPLICATION IN BULGARIA

In accordance with discussion held in Istanbul workshop on 13-14 March, the landslide susceptibility method of Mora and Vahrson (1993) has been suggested. It is already applied for landslide hazard assessment of the Sofia graben in 1996.

Second method applied in Bulgaria is isopleth method (Wright et al. 1974, DeGraff and Canuti, 1988), applied in some places in Bulgaria for varying use.

Method of Mora and Vahrson: includes 5 parameters: Sr, Sl, Sh, Ts and Tp. I.e 3 conditions of slope factors and 2 triggering factors.

Factor Sl (lithology) - definition of geological formations in accordance of their properties with application of scores.

Weakness:

- Availability of weak zones/layers in given formation. Main geotechnical parameters (φ, c, γ) are not included.
- Second weakness is that scores are in equal intervals which is a little bit comparable.

The parameters Tp and Sh are based on hydrometeorological data from meteostations in Bulgaria.

Weakness:

- There are climate changes that are not taken into account.
- Receiving new data is impossible - there is no budget for new actual data...

Seismicity factor Ts: based on prognosis zoning of Bulgaria for 1000 year period. There is new zoning for 475 year period. Also, active faults are not included.

Weakness of Mora & Vahrson method: erosion/abrasion is not included as triggering factor. It is very important factor for slope instability along sea-side coast in research area. Due to this reason we added it as new factor Te. Other factors: man-made impact - cannot be assessed and included, as well as countermeasures (retaining walls, etc).

Other methods include "land-use data" analysis, vulnerability, risk assessment, etc. This is a very serious, responsible and huge work, and so the provided time and budget are not enough of this analysis.

Proposed scale of use: 1:50000. Pilot area: Tsarevo or Emine Cape (it will be decided after choosing of method for landslide hazard assessment).

3.8.5 REFERENCES

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3.9 ROMANIA

3.9.1 INTRODUCTION

In the literature the terms of susceptibility and landslide hazard are often used as synonyms, although they are different concepts (Guzzetti, 2005).

Landslides susceptibility is the probability that a landslide to occur in an area characterized by certain environmental conditions (Brabb, 1984). Is the degree which a surface can be affected by the landslide process.

In contrast, landslide hazard is the probability that a landslide of a given magnitude will occur in a given period of time and in a given area. In addition to prediction of where the landslide will occur, landslide hazard forecast "when" or "how frequently" it will produce and "how large" it will be (Guzzetti et al., 2005).

Thus, susceptibility is the space component of landslide hazard.

A review of the literature regarding landslide susceptibility and hazards methods reveals that landslide susceptibility can be evaluated through different methods, which can be grouped into two broad categories: qualitative methods, based entirely on the expert judgment and quantitative methods, which themselves are classified into statistical and deterministic methods (physically-based) methods.

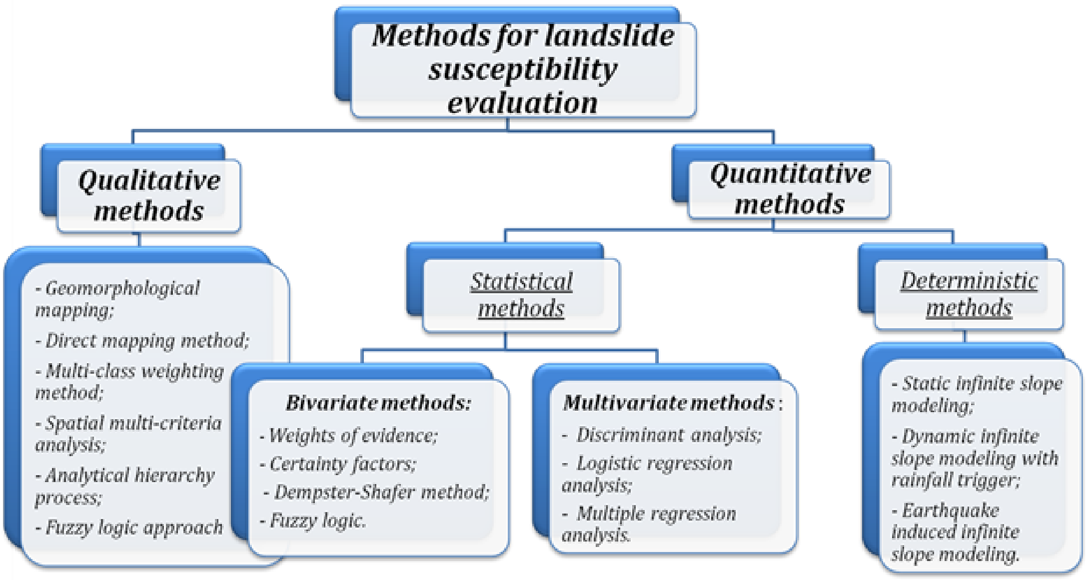

Fig. 26: Methods for landslide susceptibility assessment

In Romania, landslides are among the most widespread geomorphological processes in the hilly regions built of Neogene molasse deposits, as well as in the mountainous regions developed on Cretaceous and Paleogene flysch.

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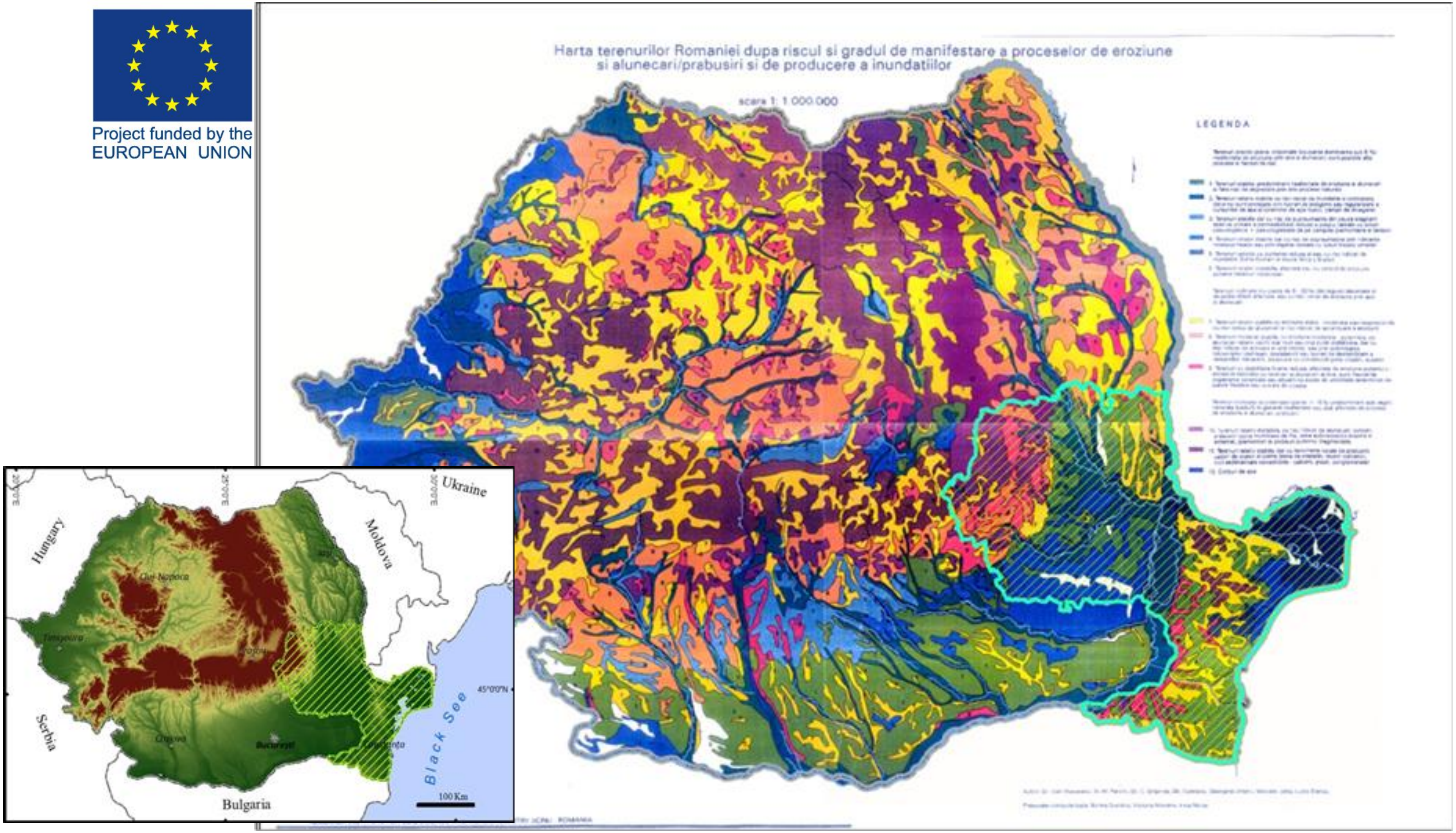

Fig. 27: Romania’s land zoning in terms of potential for erosion, landslides / falls and floods

During the '90s and early 2000s, in the estimation of landslide susceptibility was used especially qualitative approaches.

The number of quantitative ones has risen steeply in the last years (Micu & Bălteanu, 2009; Armaș, 2011, 2012; Constantin et al., 2011; Șandric et al., 2011; Grozavu et al., 2012; Armaș et al., 2013).

3.9.2 THE METHOD IMPOSED BY ROMANIAN LEGISLATION

A series of normative acts published in several stages, such as:

- Law 575/2001,
- Law 124/1995,
- Government Decision 382 and 447/2003,
- Common Order of the Ministry of Public Works and Territorial Planning, of the Chief of Department for Local Public Administration and Ministry of Waters and Environmental Protection no. 62/N-19.0/288-1.955/1998, based on the Writing guide for landslides risk maps to ensure construction durability – Indicative GT-019-98

set the methodological norms regarding elaboration way and content of the landslides hazard maps based on calculating of the **average coefficient of hazard K(m)** .

$$K_{(m)} = \sqrt{\frac{K_a \times K_b}{6}\left(K_c + K_d + K_e + K_f + K_g + K_h\right)} \qquad (68)$$

where:

- Ka = lithologic criterion;
- Kb = geomorphological criterion;
- Kc = structural criterion;
- Kd = hydrological and climatic criterion;
- Ke = hydrogeological criterion;
- Kf = seismic criterion;
- Kg = forest cover criterion;
- Kh = anthropogenous criterion,

expressed through a scale from 0 to 1.

Among the landslide affecting factors, lithology and geomorphology are considered the most important. Depending on the K(m) coefficient's value, are establish landslide occurrence potential:

- low potential, K(m) < 0.1
- medium potential, K(m) = 0.1 to 0.3
- medium-high potential, K(m) = 0.3 to 0.5
- high potential, , K(m) = 0.5 to 0.8
- high-very high potential, K(m) are above 0.8.

Table 3.18: Rating -Criterion for landslide potential and probability occurrence assessment

Crt. No.	Symbol	Criterion	Landslide occurrence potential (p)					
			Low		**Medium**		**High**	
			Landslide probability occurrence (p) and the corresponding risk coefficient (K)					
			Practically zero	**Low**	**Medium**	**Medium-high**	**High**	**Very high**
			0	**< 0,1**	**0,1-0,3**	**0,31-0,5**	**0,51-0,8**	**> 0,8**
0	1	2	3	4	5	6	7	8
1	**a**	Lithologic	Solid, massive, compacted or fissured unweathered rocks		Sedimentary rocks of overlaying formations (deluvial, coluvial and proluvial deposits) and pelitic stratified rocks (clay slate, marls, calcareous marl, chalk); metamorphic rocks (especially epizone and less mesozone schists, highly weathered and exfoliated); some weathered igneous rocks		Detrital sedimentary rocks (unconsolidated – saturated, plastic clays, with high expansive and contractile capacity); montmorillonitic clays; small or medium grain sized loose silt and sand; salt breccia	
2	**b**	Geomorphologic	Plain relief (hydrographic network integrates mature valleys)		Hilly relief representative for piedmont and plateau areas, edged by medium height slopes with, generally, medium and high declivity		Hilly and mountainous relief, highly fragmented by a dense network of young valleys (most of them, subsequent valleys) with steep and height slopes	
3	**c**	Structural	Massive igneous rocks; stratified sedimentary rocks with horizontal bedding; metamorphic rocks with horizontal schistosity planes		Most of folded and faulted geological structures affected by cleavage and fissuring; diapir structures; overthrust sheet forehead		Geological structures representative for geosynclines areas in flysch facies and molasse formations from marginal depressions; stratified geological structures highly folded and dislocated, affected by a dense cleavage, fissuring and stratification network	
4	**d**	Hydrologic and climatic	Generally dry areas with reduced average annual rainfall; the debit flow is strictly conditioned on the precipitation amount; on the river bed, deposition exceeds erosion (lateral erosion only on floods)		Moderate amount of rainfall; the hydrographic network is composed by mature primary valleys, meanwhile, the tributaries are young valleys. During floods, lateral and linear erosion along with important transport and solid discharge are being observed		Long slow rainfall conducive to water infiltration; heavy rainfall with important overflows and solid discharge transport; predominant process: linear erosion	
5	**e**	Hydrogeologic	Ground water flow at low hydraulic gradients; filtration forces are negligible; confined ground water at great depths		Moderate hydraulic gradients; the equilibrium state of the slope responds to the filtration forces values; phreatic water is situated above 5 m depth		Ground water flow at high hydraulic gradients; water sources are located at the base of the slopes; ground water flow direction is outwards; filtration forces can act as a landslide trigger	
6	**f**	Seismic	Seismic intensity on M.S.K* scale < 6^{th} degree		6 – 7^{th} degree of seismic intensity		Seismic intensity on M.S.K scale > 7^{th} degree	
7	**g**	Forestry	Timbering covering > 80%; extended deciduous forests		Timbering covering between 20% – 80%; deciduous and coniferous forests of various age and width		Timbering covering < 20%	
8	**h**	Anthropic	No important constructions on the slopes; water reservoirs are absent		A number of construction works (road platforms and railroads, coast channels, quarries etc) with limited extension with adequate slope protective measures		Overloaded slopes (dense water supply network and sewerage, roads, railroads, coast channels, quarries, dumps etc; water reservoirs.	

*Medvedev – Sponheuer – Karnik seismic intensity scale (MSK 64)

For drawing the map of landslide hazard are required the following steps:

- dividing the territory for which the hazard map is elaborated in bounded polygonal surfaces to represent as homogeneous lithologic and structural deposits ;
- estimating the weights and geographical distribution of “risk coefficients” K(a-h) depending on the criterion presented in Table 3.18;
- calculating the average hazard coefficient K(m) corresponding to each analyzed polygonal surface by using a specified Eq.(68); :
- determining the degree of potential (low , medium, high) associated with a certain probability of landslides occurrence (practically zero, low, medium , medium - high, high and very high).

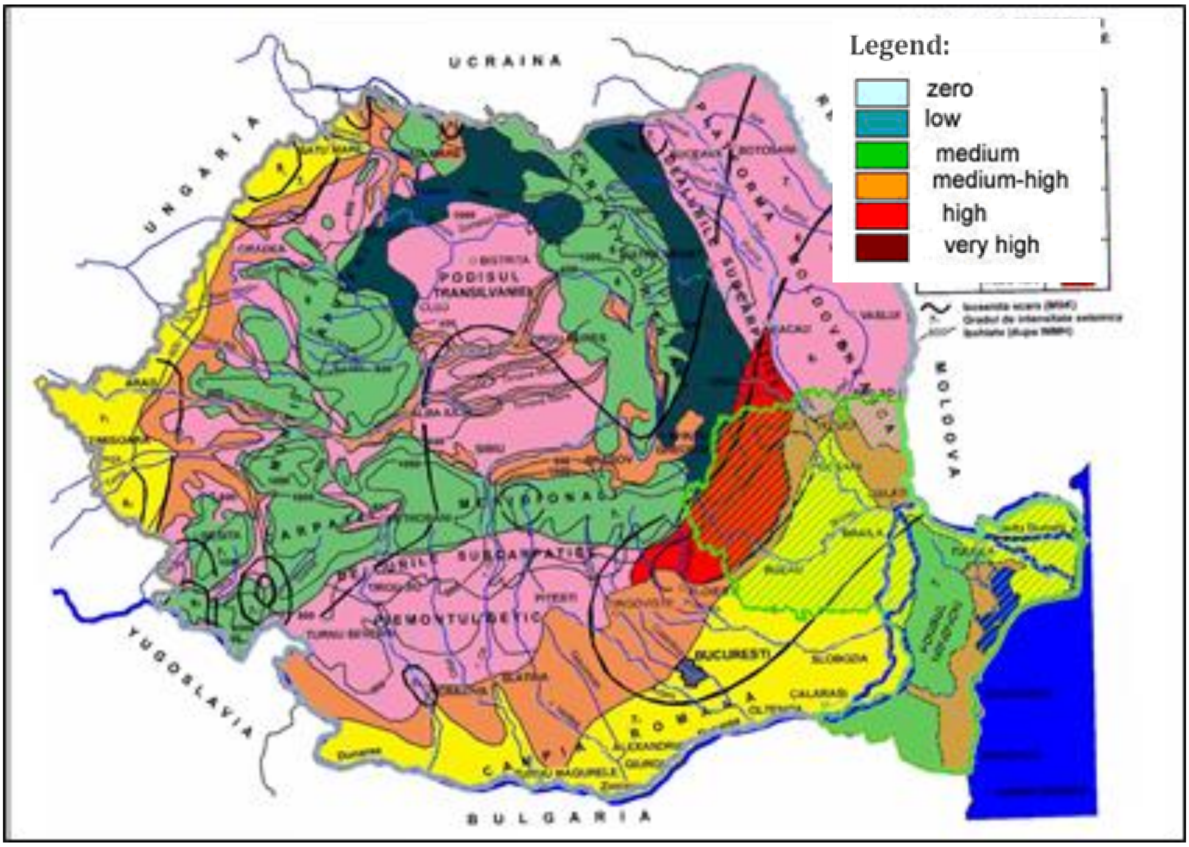

Fig. 28. Macro-zoning map of induced landslides risk in Romania

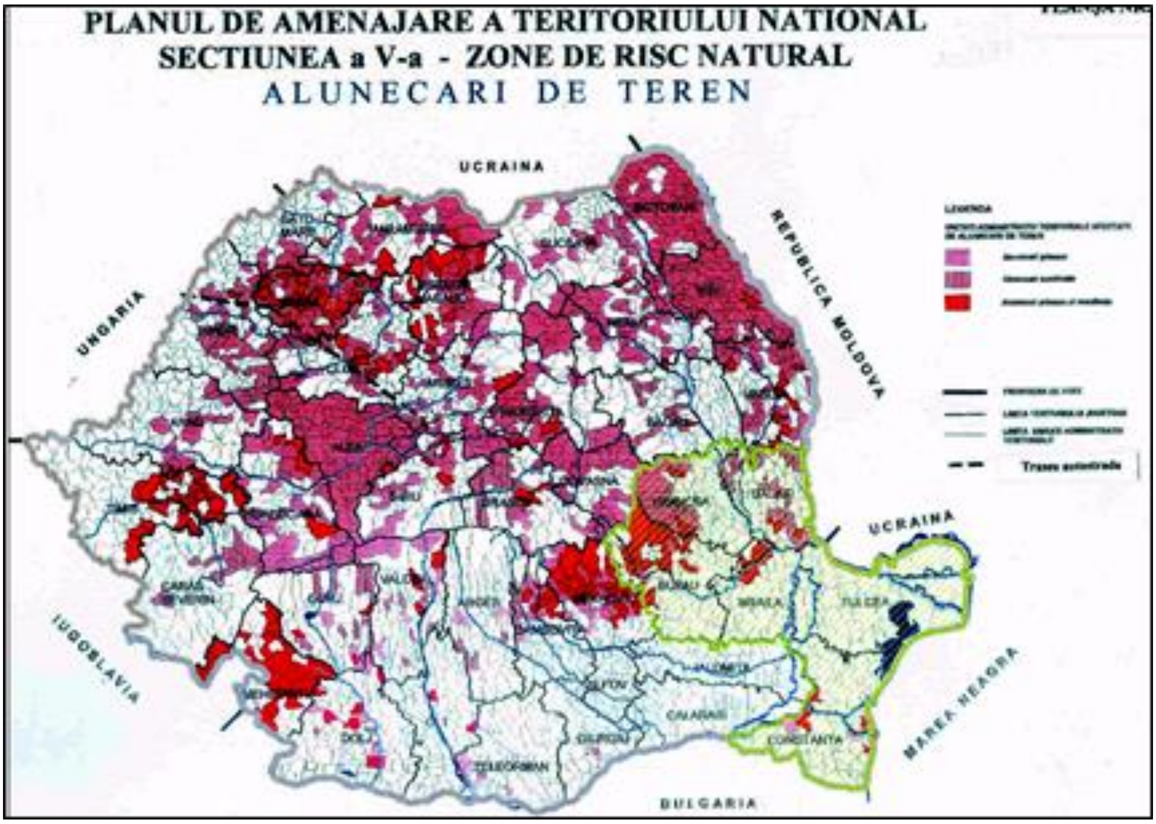

Fig. 29. Map of administrative-territorial units affected by various type of landslides

Also, the maps and tables attached to the Law no 575/2001 are providing information about the localities potential affected by landslides (Fig. 29) and zones prone to landsliding (Fig. 28).

Comments:

- in the absence of chronological information on the occurrence of landslides, spatial–temporal probabilities cannot be calculated and consequently predictions must be restricted to the spatial distribution of future landslides; that is susceptibility (Bălteanu et al., 2010).
- there is no information regarding the differentiation between landslide types in the present methodology.
- gives an overview relatively suggestive of areas with different landslide potential;
- integrates data generally easier to find;
- can be used in case of lack information about the existence of landslides (obtained from inventory using different sources).

3.9.3 LANDSLIDE SUSCEPTIBILITY INDEX

More recent, Bălteanu et al., in 2010, have developed a landslide susceptibility model for the whole country applying a scoring system to a set of conditioning factors based on expert judgement (heuristic model).

This research was carried out due to a World Bank project on losses and insurance costs relating to disasters in Romania, and aims to provide a unitary basis for addressing landslide susceptibility in the country.

Was used a Landslide Susceptibility Index (LSI) method based on quantitatively defined weighted values.

In computing a GIS landslide-susceptibility map of Romania six major triggering factors were considered:

- lithology,
- height difference,
- slope angle,
- land use,
- rainfall
- seismicity.

Each factor was classified under sub-classes carrying a rating from 0 to 10 according to its relevance for landslide susceptibility.

Further, each factor was considered to have a differential influence on such susceptibility, named 'assigned weight'.

The results were compared with different assessments from several countries.

To validate the methodology, besides expert judgement, repeated geomorphic mapping over a long period, as well as field observations and measurements in the most affected regions, were used.

The LSI was further classified under five susceptibility classes; each category based on correlation of expert judgement and existing geomorphological maps of the whole of Romania.

The established classes are:

- 'no susceptibility', represents around 39% of Romania (plains and low hills),
- 'low', 10%,
- 'medium', 38.3%,
- 'high' and 'very high' susceptibility, classes around 10% (mostly in the Subcarpathian region).

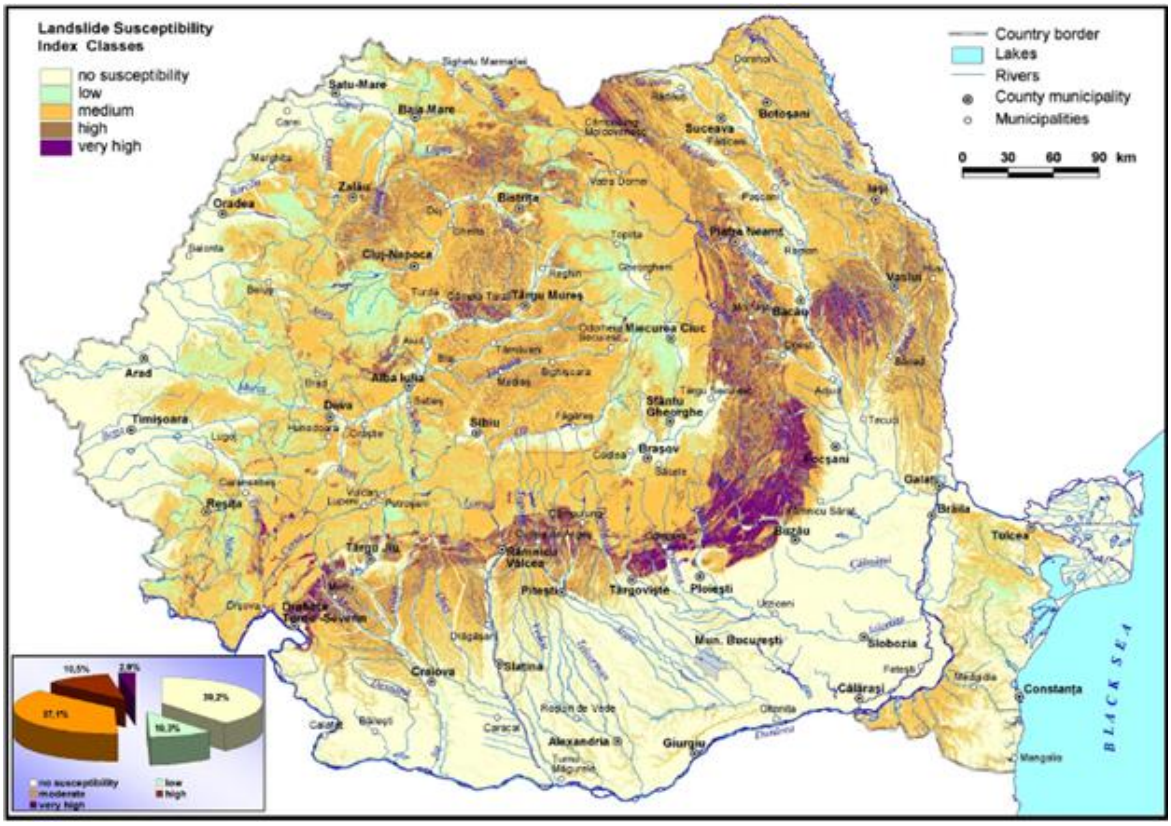

Fig. 30. Landslide Susceptibility classes - Romania

C. The method used in IncREO project - Increasing Resilience through Earth Observation

http://www.increo-fp7.eu/

(Jan. '13 – Dec. '14)

The objective of the work package which includes Romanian Space Agency –ROSA, is to assess and map in a detailed manner the risk and vulnerability of areas in Romania highly prone to landslides in the Buzau County.

For assessing the susceptibility of landslide prone areas a quantitative inventory-based probabilistic method with the approach of "Weight of Evidence" (WofE) was chosen.

The following inputs were used:

- Landslide inventory (kindly provided by the FP7 CHANGES project),
- DEM (slope, aspect, relative relief),
- geology,
- land use,
- max. rainfall in 72 h,
- distance to drainage network.

It is assumed that the landslide inventory is complete.

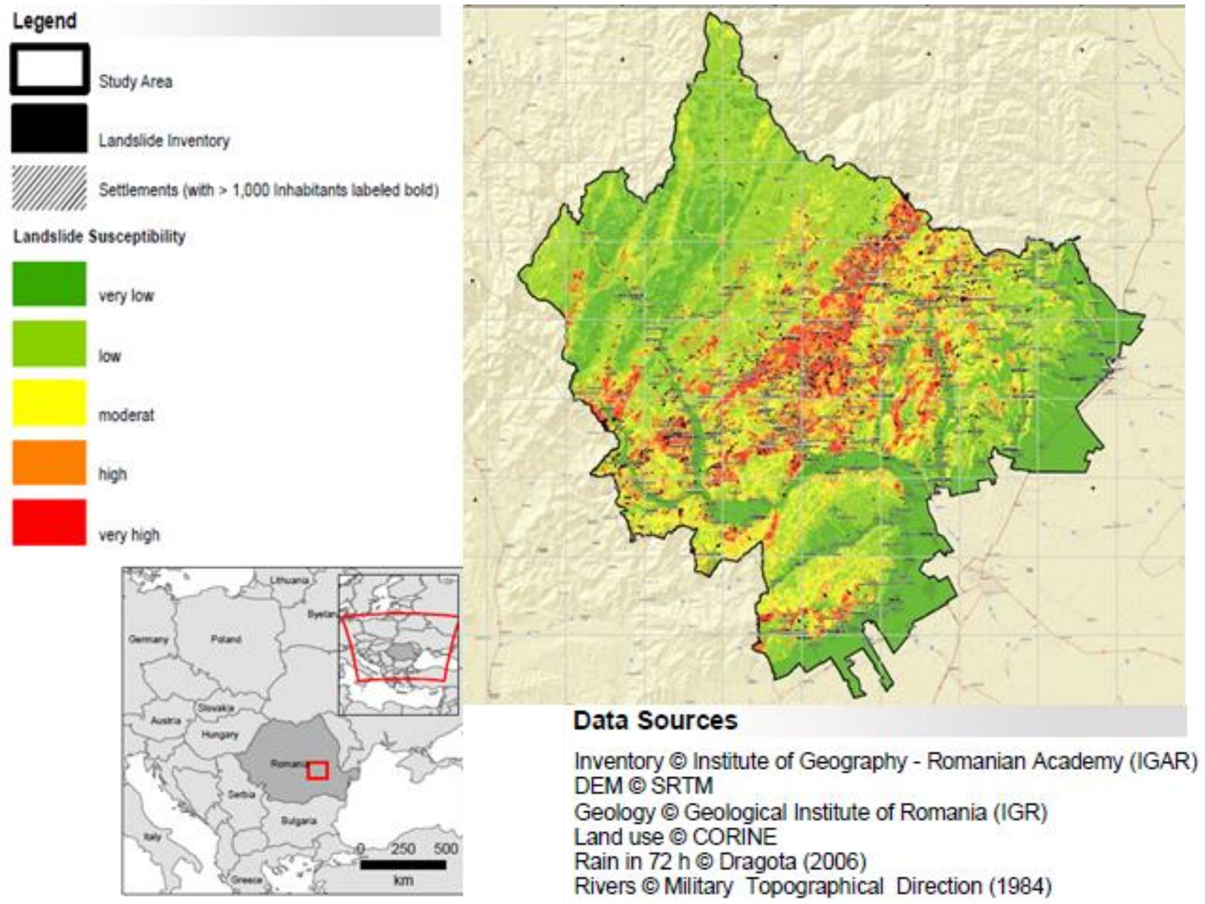

Fig. 31. Landslide Susceptibility classes – Buzau County

3.9.4 CONCLUSIONS

The methodology provided by the Ministry of Local Public Administration in 1998, 2001 and 2003 it is subjective and difficult to apply (Şandric et al., 2011), due to the uncertainties and different interpretations of the specialists that may occur in assigning weights to various landslide controlling factors in assessing susceptibility.

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3.10 UKRAINE

Engineering-geological methods of landslide hazard estimation

Method of landslide hazard estimation is based on theoretically grounded analysis of general regional assessment of landslides potential activity and also basis on prognostication of landslide activating at local territories. Assessment of landslide slopes stability takes main part in process of general estimation of landslide hazard at specified sites.

3.10.1 ESTIMATION OF LANDSLIDES POTENTIAL ACTIVITY

Zoning of territories is conducted in purpose of assessment of landslides potential activity. The following parameters are used in mentioned procedure:

1) vertical dismemberment of relief;

2) capacity of the quaternary sediments;

3) angle of inclination of earth surface;

4) prevailing type of antequaternary sediments complexes;

5) depth of burial of underground waters levels;

6) forest coverage (density of forest coverage) .

Assessment of landslides potential activity at Ukrainian shore is shown on Fig. 32 [1].

Fig. 32. Map of evaluation the danger of landslides

Hazard of landslide processes manifestations is determined by the next parameters: genetic specifies, form frequency, sizes (area) and velocity of landslide. For the regional estimating of landslide hazard were defined the following criteria: genetic specifies, frequency and intensity of landslides. One of the main factors of landslide hazard increasing is the presence of main deforming horizon (MDH) in section.

Main deforming horizon (MDH) – this is mainly horizon that has clayey or loamy composition. Into this horizon deformations and changes of water-physical state mostly occur, also in this horizon rock layers move and shift. There are three rules that determine creation of main deforming horizon in clayey-loamy sediments:

• weakened zones in dispersed rocks form like a result of unrestrained water-bearing horizon existing. Zones, usually, have local manifestation at different hypsometrical marks;

• in zone of season watering the rock transformation from hard state to viscous state occurs;

• velocity of landslide progress is directly proportional to the weathering grade of rocks, that are presented in zone of hyper-genesis.

For landslides activating is enough energy of gravity field in one case, but in other case an additional energy impact is needed.

The principles of regional assessments of landslide hazard are based on allocation of landslide areas and process intensity determining.

For estimation of intensity of landslide process the plane index of destruction is applies as criteria. This index is determined like relation between the area of all form of landslide manifestations in limits of landslide site (non-dependent from the age) and the total area of the site.

Results of the destruction index (Kp) calculations are ranked according to the range of hazard in dependence from landslide process intensity [1]:

- catastrophic - > 40 % ,
- significant - 10 - 40 %,
- average - 1 - 10 %,
- weak - < 1%.

Territory typing in accordance with the rate of landslide hazard is done in regard to mentioned scale.

3.10.2 FORECASTING OF LANDSLIDE ACTIVATION

Nowadays the cyclic (climatic) character of landslide manifestation is proved. Cycle time varies in wide range. Solar activity has the biggest impact on landslide activation. Clearly defined that cycle times of solar activity are 11-years and 70-100 years. Nature factors have defined regular cycles of manifestation and, respectively, predetermine landslide activity, so, these regular cycles can be applied for landslide prognosis.

It is practically impossible to determine regularity of anthropogenic factors, so prognosis of landslide activation by the reason of anthropogenic factors can be successfully done on conditions that analysis of types and orientation of economic activity and also analysis of geological environment expected changes are performed.

Analysis of periods of atmospheric precipitation allows to prognosis fazes of landslide activations with defined rate of possibility. Mentioned prognosis can be done only if the strict connection between different factors is proved. But such prognosis is inaccurate and it shows reliable only the tendency.

3.10.3 MODELING AS OF THE METHODS OF SLOPES STABILITY ASSESSMENT

In assessment and forecasting of slopes stability of North-Western coast of Black Sea the method of Zelinskiy I.P. [2] found a wide application. This method is based on comparison of fields of tension and strength of rocks for receiving fields of stability. Index of stability *(I_s)* is used in this method. This index is modification of Tresck-index and represents ratio between strength of soil and maximum tangential tension:

$$I_s = \frac{\tau_S}{\tau_{Max}} \tag{69}$$

where: τ_S – shear strength of the soil, τ_M – maximum tangential tension in specified point of the soil strata, MPa. In some cases instead of τ_M an actual tangential tension τ_D is used in calculation.

Data processing is done by : building of graph *Is* along the known surface of shifting (**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**) and graph of stability tessellation lines of stability (*Is* = const.) on condition of no data regarding shifting surface (**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**).

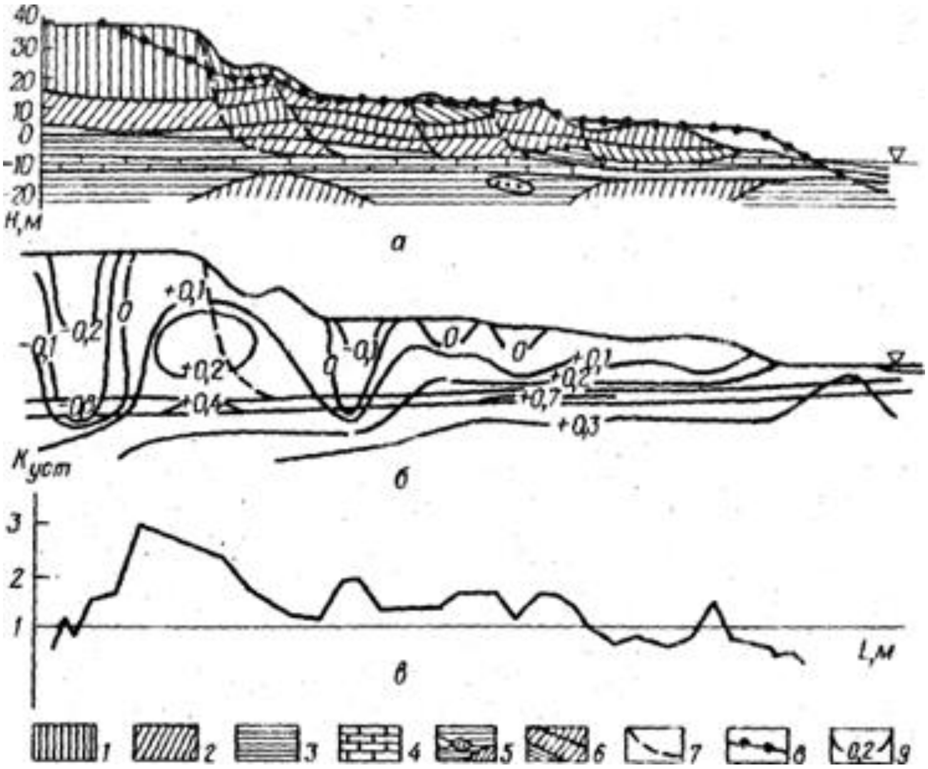
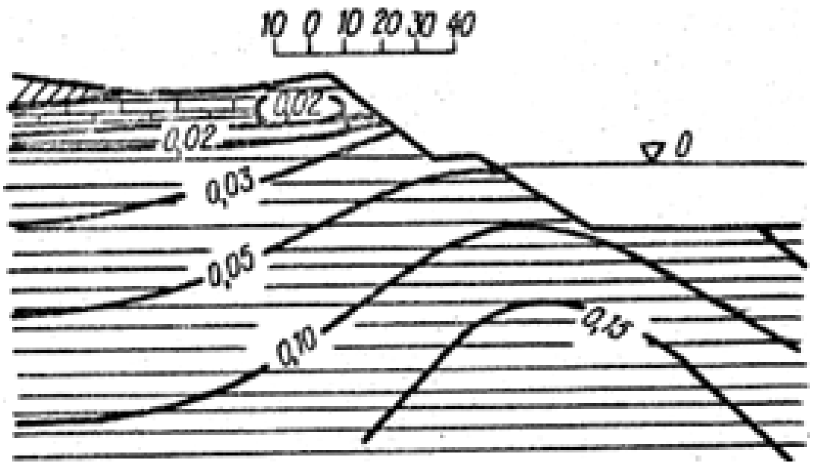


Fig. 33. Assessment of slope stability along known surface of shifting (a – geological section, б – distribution of horizontal tensions σX; в – graph of values Is along the surface of shifting) [2]

1 – loess-like loams (vd $Q_{I\text{-}III}$); 2 – reddish-brown loams (N_2^3); 3 - clays ($N_2^{2\text{-}3}$), 4 – pontic limestones (N_2p) 5 – clays, loams with lens of meiotic sands (N_1m); 6 – landslide accumulations (dp Q_{IV}); 7 – borders between landslide stages; 8 – surface of a slopeпо (with made terracing); 9 - tessellation lines of tension

a)



b)

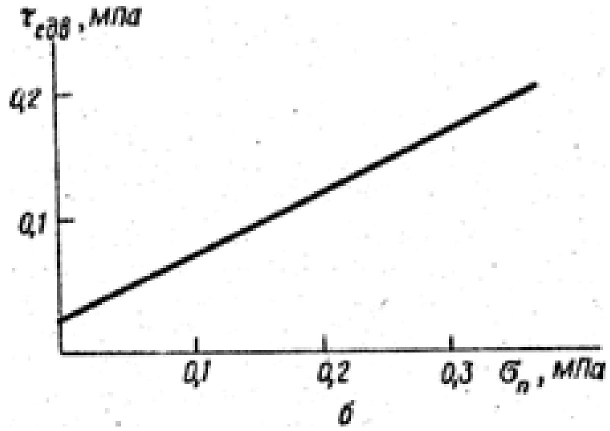


Fig. 34. Assessment of slope stability in case of unknown location of shifting surface [2]: a) tessellation lines of tangential tensions $\tau_{Д}$; b) graph of dependency $\tau_{СДВ} = f(\sigma_n)$.

For calculation of tension fields different methods are used, includes modelling with methods of tensometric net, photoelastity, electricgeodynamic analogies and equivalent materials. Different computer engineering programs are widely used, in particular for calculation with method of final elements. As results fields of normal (including σn) and tangential (τ_M , τ_D , τ_{XZ}) tensions for tasks in linear and elastic-plastic statements with regard to impact of underground waters can be obtained.

Strength of rocks (shear strength) is obtained from Kulon-More's condition as a function of normal tensions $\tau_S = f(\sigma_n)$, that allowed to determine desired value in each point of the massif. The strength characteristics of rocks, obtained from laboratory shearing test of soils ($\tau_S = \sigma_n \cdot \mathrm{tg}\varphi + C$), and tangential tensions are used as initial information in calculations. Comparison of fields of strength and acting (or maximal) tangential tensions allows obtaining stability fields. Analysis of it allows allocating in the massif (soil strata) zones with different level of stability reserve, estimate general stability of the slope or scrap, expose possible zones where the plastic deformations may occur. in limits of this field it is possible to interpolate particular values Is build-up tessellation lines of Is= const.

Method of *circular cylindrical surfaces of sliding* is used for determining value *Kycm* of slopes with complex geological structure and relief. It allows to estimate the object's stability in case of following assumptions: surface of shifting in time of forming of landslide movement is taken as circular cylindrical surface; tensioned state in each point of the massif is determined only by the weight of overlying rocks layers; strength of rocks is subordinates Kulon's law: $\tau_S = \sigma_n \cdot \mathrm{tg}\varphi + C + C$, where σ_n – normal tension that effects specified plate; φ – angle of internal friction; C – concatenation; τ_S – shear strength by which destruction of the soil occurs along specified plate.

Index of stability (Is) is being calculated for specific conditional surfaces landslide massif with the help of computer program «CILPS» elaborated at Odessa national university of I. I.

Mechnikov. Density, strength characteristics of each layer of massif, scale index, seismic index of the region in points, abscissas and ordinates of earth surface and layer borders in each point of intersection in small block are used as initial data for the program.

In cases when location of shifting surface of the landslide is known the assessment of slope stability can be done by using *Solovev's method*. This method is base on correlation between holding and shifting forces by the real or imagined movement of landslide body.

Rock massif is characterized by density ρ, concatenation C and angle of internal friction φ. Landslide body, limited by earth surface and landslide surface, conditionally divided into equal vertical blocks. It is assumed that in time of movement each selected block shifts in horizontal direction for the same distance, without ruptures and interpenetrations between of the blocks.

Application of these methods allows:

build graph of particular values of stability index Is along selected or known surface of shifting;

objectively select location of surface of possible landslide movement corresponding to the tessellation line Is =1,0;

estimate general stability of the slope along the most probable surface of shifting. Result of index may be index or stability margin;

detect into rock massif zones of potential instability where Is = 1;

quantitatively estimate rate of effect of different nature and anthropogenic factors (cutting and surcharging, landslide control, decreasing of rocks strength and other) on general stability.

Slope stability along the most probable or known surface of shifting is defined as ratio of total values of soil shear strength and tangential tensions $\tau_{D,Max}$:

$$Is = \sum_{i=1}^{n} \tau_S \,/\, \sum_{i=1}^{n} \tau_{D,M} \qquad (70)$$

where n – number of particular values τ_S and $\tau_{D,M}$ involved in calculation.

This method was successfully tested in the the unti-landslides measures for the North-Western coast of Black Sea, in particular – in Odessa-city (Fig. 35, **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**).

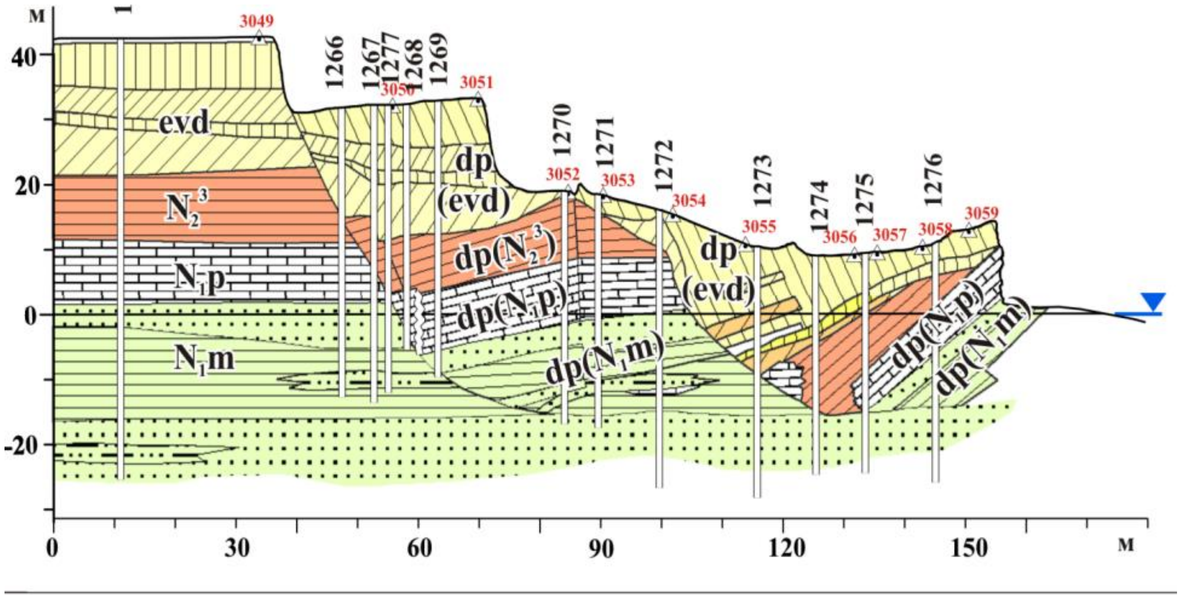


Fig. 35. Geological record of the Grigoriev landslide in Odessa region [3]

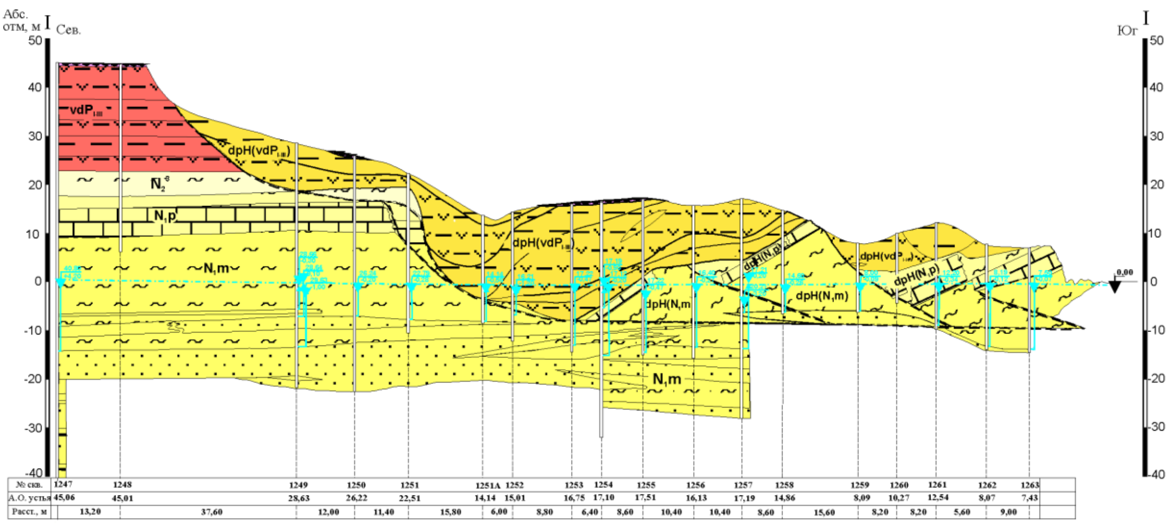


Fig. 36. Geological record of the in New Dofinovka, Odessa region [3]

3.10.4 CONCLUSION

Methodology of landslides risk assessment in the Black Sea region of Ukraine is based on an analysis of the overall regional assessment of potential landslide activity and forecasting of landslides activation. The main objective in this case is to assess the stability of landslide-prone slopes, including the determination of parameters such as:

1) the degree of compartmentalization of relief (amplitude of heights oscillation per unit of an area;
2) angles of inclination of surface relief;
3) thickness of unconsolidated (friable) sediments;
4) types of underlying (pre-quaternary) rocks consolidation;
5) presence in the basic deforming horizon over which can occur the displacement of rocks;
6) groundwater levels;
7) density and type of vegetation.

These parameters allow estimate the potential landslide hazard area.

Forecasting of landslides activity includes analysis of cycles of solar activity (11, 70-100 years) as well as periodicity of precipitation which cause excessive moistening and increasing plasticity of basic deforming horizons. Landslides risk assessment in the Ukrainian part of the Black Sea Region is carried out by continuous monitoring using surface geodetic bench mark networks, underground and wells monitoring.

To assess slopes stability of the North-West coast of the Black Sea, along with the other techniques, a technique based on a comparison of stress fields and rock strength is widely used. This technique also includes determination of areas of stability with the help of stability coefficient (which represents ratio of soil strength to the maximum shear stress). The technique involves defining the fields of normal and shear stresses using laboratory tests of soils and computer modeling.

Matching the fields of strength and current (or maximum) provides a tangential stresses stability field. Its analysis provides an opportunity to determine zones with different degree of stability assess overall slope stability and determine possible areas of plastic deformations.

Methods of assessing landslide hazard includes selection of an area of a potential landslide, determination of the slope stability and zones of instability, assessment the level of landslide forming factors and the effectiveness of anti-landslides measures, types and levels of engineering-geological studies.

Anti-landslides measures include construction of protective structures to increase slopes stability by reducing slopes angles (flattening), reduction of the groundwater level to reduce the plasticity of the basic deforming horizon, reducing intensity of abrasion and increasing vegetation cover in hazardous areas.

This method was successfully applied in the development of anti-landslide measures in the North-Western coast of the Black Sea, in particular in Odessa, where was created a unique system of engineering-geological protection of coastal slopes, including a system of breakwaters and groynes, beach nourishment to reduce extent of marine coastal erosion, terracing of slopes, many kilometers long underground drainage system, vegetation on the slopes and permanent monitoring of the coastal areas.

3.10.5 REFERENCES

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4 SEISMIC HAZARD ASSESSMENT AND SELECTION OF MODELS FOR IMPLEMENTATION (ACTIVITIES A.1.9 &A.1.13)

4.1 INTRODUCTION

It has been identified by Seismological Society of America (1910) that three parts of the earthquake phenomenon should be studied: the event itself (time, location and mechanism), the associated ground motions and the effects on structures. These constitute the fundamental elements in evaluating earthquake risk. Mitigating the seismic risk requires a logical and consistent approach to evaluating the effects of future seismic loads (with the expected uncertainty) on people and their structures. To accomplish a complete earthquake risk assessment four basic steps are taken into account (McGuire 2004). First is the seismic hazard analysis probabilistically or deterministically which gives a probabilistic description (frequency of exceedance) or a seismic worst case scenario of earthquake characteristics such as ground motion values. Second is the estimation of earthquake damage, evaluating proper damage and loss functions. Third is the assessment of the seismic risk translating the seismic hazard results into seismic risk ones (frequencies of damage or loss by utilizing the selected functions. And fourth is the formal or informal analysis of earthquake mitigations decisions, wherein the options, uncertainties, costs, decision criteria and risk aversion of the decision maker are merged in the decision process. The main target of the application of the seismic hazard assessment and the seismic risk analysis is to propose the criteria that can be used to make rational decisions on seismic safety.

Virtually every important decision regarding the evaluation of earthquake effects on people and manmade facilities is made using some form of probabilistic seismic hazard. Sometime there analyses are conducted informally, with probabilities or likelihoods assessed intuitively with subjective expert opinion. In such instances our judgment, intuition, and experience are adequate to assess relative probabilities of occurrence and to make rational decision on the optimum course of action (or inaction) to take. Sometime the judgments made are so natural and intuitive that they are made largely unconsciously; our experience and confidence allows assurance that the results are nearly optimal.

In instances involving complicated assessments of effects derived from various geo- science and engineering disciplines, decision makers often prefer formal assessments of probabilities of earthquake occurrences and associated natural effects that may produce damage to facilities and injury or life-loss to people. Such formal assessments are usually most appropriate for recommendations on (1) regional or national seismic design requirements; (2) earthquake evaluation of important facilities whose loss would imply substantial financial hardship to owners; (3) estimation of earthquake damage and losses for emergency preparedness purposes; (4) decision making regarding seismic safety of critical facilities (whose damage might lead to substantial life loss, injury, monetary and property loss, or threat to national security).

In this report we mainly focus in regional seismic hazard assessment of the Black Sea area studied within the framework of the project (e.g. Greece, Turkey, Bulgaria, Romania, Moldova and Ukraine). The earthquake hazard analysis requires the use of various scientific branches other than seismology. Geological and Geophysical sciences are demanded for defining the location and the geometrical shape of the potential seismic sources of known or unknown seismic faults as well as the radiation pattern of the generating seismic arrays of the aforementioned seismic foci. Mathematics, especially an understanding of probability and statistics, is significant in the increasingly prevalent probabilistic evaluations. Geotechnical engineering is extremely indispensable in estimating the effects of local soil conditions of the ground motions. Structural and earthquake engineering determine the way of parameterization of the most seismic hazard results.

4.2 SEISMIC HAZARD ASSESSMENT

4.2.1 METHODOLOGY

The purpose of seismic hazard analysis is to evaluate the hazard of seismic ground motion at a site by considering all possible earthquakes in the area, estimating the associated strong shaking at this site. There are two main approaches in seismic hazard analysis the deterministic and the probabilistic. In the Deterministic Seismic Hazard Analysis (DSHA), a single "maximum" earthquake is specified by magnitude and location with respect to a site of interest, and the associated ground motion is assessed and used to design or evaluate the safety of a facility. The deterministic approach may be justified; for example for major earthquakes on a given segment of a plate boundary fault that is known to break repeatedly, generating similar size earthquakes characteristic to the fault segment. The DSHA selects one or more earthquakes as the target for designing an earthquake resistant structure. The target earthquake for a critical structure (usually the "maximum seismic event" or the "maximum credible earthquake") is usually selected by consideration of the historical seismicity record and the physical characteristics of the seismic sources. The DSHA does not consider the likelihood of the occurrence of the target earthquake, nor does it offer any insight into the importance of the target earthquake relative to other possible seismic hazards, such as those due to smaller but closer earthquakes or larger but more distant seismic events.

On the other hand, the Probabilistic Seismic Hazard Assessment (PSHA) may be used to calculate the probability that a range of small and large earthquakes may occur along a given fault and that various faults in a broader region might affect the site. The PSHA addresses the questions of how strongly and how often the ground will shake, by considering all possible earthquakes that might affect the site. The range of ground motions at a site resulting from earthquakes that might occur on a variety of seismic sources, is estimated by using an empirical predictive relationship to translate to the site through distance, the ground motions associated with earthquakes that are considered. The rate of earthquake occurrence on each seismic source is also considered. Thus, PSHA combines information on earthquake size, origin location, probability of occurrence, and resulting ground motion in order to provide results in terms of ground motion and associated annual probability of occurrence (or exceedance). An important issue for PSHA is which ground motion measures will meet the needs of various users (e.g. pga, 5%-response spectra, etc).

When seismic hazard must be quantified in the face of uncertainty in the locations of seismic sources, magnitude distributions and ground motion estimates, PSHA can incorporate and display the range of scientific opinion regarding these issues. One way to do this is to identify various hypotheses and models to describe each science phenomena involved. When this is done, the range of uncertainty in the PSHA corresponding to the range of hypotheses can and should be explicitly displayed, so that the decision maker will be aware of the uncertainties and will not have a false impression of accuracy that might be associated with a single valued hazard estimate. Expert judgment can be employed to assign subjective probabilities to each hypothesis and thus identify to the decision makers where, in the range of uncertainty, the prevailing weight of opinion would assign the risk. When the uncertainty in the PSHA results is too large to be useful for decision making, a consensus could still be sought among experts who may capture, by an in depth DSHA analysis, subtle but crucial details of earth science information, which have escaped the quantification procedure in PSHA.

The design of structures considering the potential seismic actions at a given site is, for the time being, the only way for the minimization of loss of lives due to earthquakes. We can define as *seismic hazard* at a site, where a structure (building, bridge, etc) exists or will be constructed, a quantity, H, which is measured by the expected (with given probability of occurrence) *intensity of strong seismic ground motion* in this area. This parameter (Hazard) can be measured by the expected ground acceleration, "a" (peak value, spectral values, etc), the ground velocity "v", by the ground displacement "s", or by the expected macroseismic intensity "I".

The mathematical formulation of the seismic hazard can be given by the following relation:

$$Y_t = \frac{\ln N_o t}{\beta} - \frac{\ln[-\ln(1-P_t)]}{\beta} \tag{71}$$

where Y_t is the seismic hazard parameter, that has P_t probability to be exceeded within a given time window of *t* years and N_0, β are constants determined using the distribution of the seismic intensities (peak ground values, macroseismic intensities or spectral values)..

The expected final result of the seismic motion at a site (damage in structures, losses of people, etc) can be called *seismic risk*, R, and depends on the seismic hazard H, at this site and on the properties and dynamic features of the engineering structures (quality, natural period, damping, plasticity, etc). The measure of these properties of the structure is called *vulnerability* "V", of the structure. For this reason, the seismic risk "R", is considered as the convolution of seismic hazard "H", and of vulnerability "V". That is,

$$R = H * V \tag{72}$$

which in graphical form is given in Fig. 37

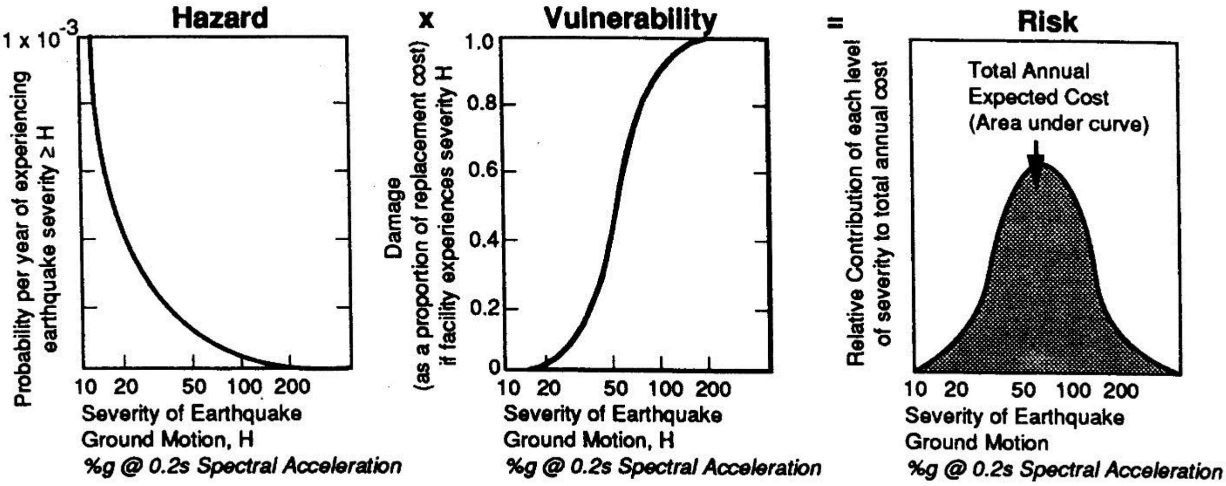

Fig. 37: Seismic Risk is the output of convolution of seismic hazard and vulnerability. Typical graphs depicting each quantity are shown. (Coburn and Spence, 2002).

The main aim of the relative sciences and technology today is the reduction of the consequences of the earthquakes, that is, the decrease of seismic risk, R. Theoretically, this can be obtained by decreasing both V and H, according to the previous relation. In practice however, we can decrease only V and not H, because the seismic hazard at a site depends on physical factors (seismicity, source and wave path properties, properties of foundation soil, etc), which cannot be controlled by the human beings. These physical factors can be studied and their effects on the seismic hazard can be understood. Vulnerability is a topic studied by Earthquake Engineering and civil engineers are mainly responsible to propose methods for reducing the vulnerability of a structure without excessive cost. This can be done successfully if accurate knowledge on the seismic hazard at the site of the structure exists. Seismic hazard is a subject studied by Engineering Seismology and seismologists are mainly responsible for its estimation.

Usually, the following two main objectives of seismic risk reduction are sought:

a) The engineering structure not to sustain any damage or to sustain slight damage (easily repaired) by the *most probable* expected seismic motion during the lifetime of the structure (e.g. 50 years).

b) The engineering structure to sustain some damage but not to collapse by the *maximum expected* seismic motion at the site of the structure.

The aim of any seismic hazard either on small or large scale is the robust determination of the constants of relation (1) which is achieved through the following main steps depending on the procedure (probabilistic or deterministic):

1. A seismic source model, based on the adoption of a reliable seismotectonic model, which best describes the active tectonics of the study area. With the term active tectonics we mean the kinematic and dynamic processes of the lithosphere that take place in the area (e.g. motion of the lithospheric plates, deformation),
2. the accurate determination of the seismicity parameters using complete and homogeneous catalogues,
3. compilation and adoption of reliable predictive relation for the attenuation of the strong ground parameters
4. Finally the selection of a methodology for the statistical analysis of the distribution of seismic intensities in time and space.

The entire list of steps in the hazard analysis is of crucial importance and their uncertainties must be considering in any hazard analysis (Fig. 37Fig. 38).

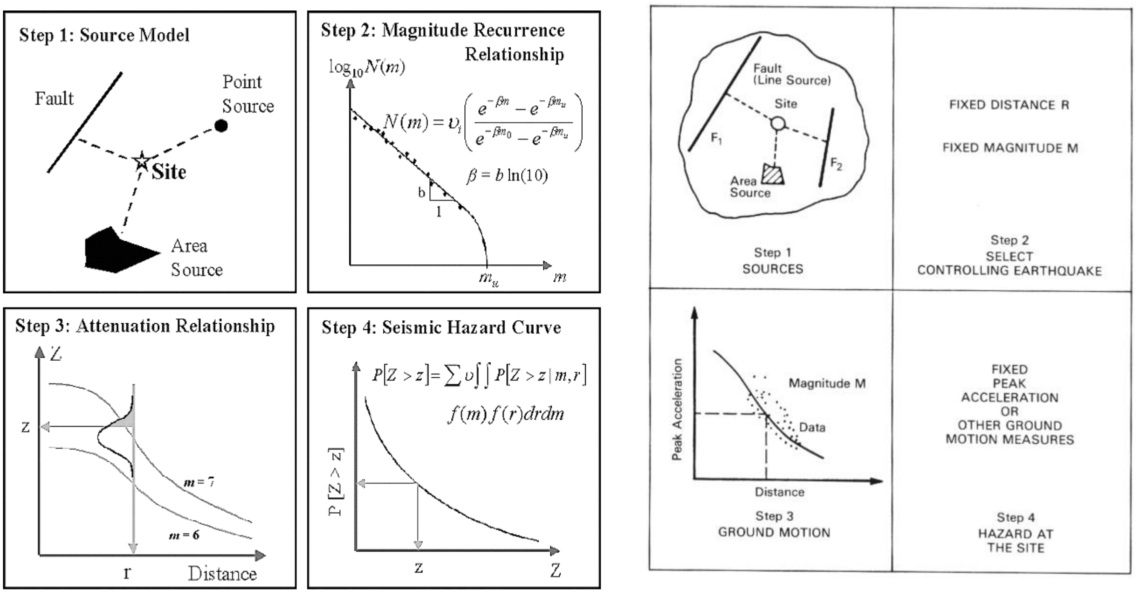

Fig. 38. Flow chart for seismic hazard assessment study based on probabilistic (left) or deterministic (right) approach. (Reiter,1990).

4.2.2 PROBABILISTIC SEISMIC HAZARD ASSESSMENT

This part of project examines a formal probabilistic seismic hazard analysis (PSHA), evaluates its strengths and weaknesses, and suggests those elements of the PSHA that are considered necessary for a reasonable statement of seismic hazard. When the probabilities calculated cannot be correlated directly with observed statistics, or the consequences of earthquake damage are significant, or the uncertainties in physical interpretation for one or more scientific fields are large, formal procedures for PSHA are generally preferred. PSHA evaluates the seismic hazard of seismic ground motion at a site considering all possible earthquakes in the area studied, estimating the associated shaking at the site, and calculating the probabilities of these occurrences. While this project focuses on the seismic hazard of ground shaking, similar probabilistic techniques can be applied to the assessment of hazard from fault movement, liquefaction, floods and landslides. PSHA procedures have several advances over less formal, more subjective evaluations.

PSHA studies typically include the following:

1. A database consisting of potentially damaging earthquake sources, including known active faults and historic seismic source zones, their activity rates, and distances from the project site. This should include a comparison with developed slip rates for faults considered. Differences in slip rates should be documented and the reasons for them explained (for example, revised slip rates or new paleoseismic information from recent studies). Use of published maximum moment magnitudes for earthquake sources, or estimates that are justified, well-documented, and based on published procedures;
2. Use of published curves for empirical predictive relations of PGA with distance from earthquake source, as a function of earthquake magnitude and travel path.
3. An evaluation of the likely effects of site-specific response characteristics (e.g., amplification due to soft soils, deep sedimentary basins, topography, near-source effects, etc.).
4. Characterization of the ground motion at the site in terms of PGA with a certain number of probability of exceedance in specific return period, taking into account historical seismicity, available paleoseismic data, the geological slip rate of regional active faults, and site-specific response characteristics.

The objective of seismic hazard analysis is to provide a formal estimate of the earthquake threat as a specific site. Typically the treat is presented in terms of the amplitude of seismic shaking (e.g. pga, pgv, 5%-psa, etc). The time span of these PSHA calculations is a time period of 30-50 years approximately the economic lifetime of engineered structures and facilities. Application to critical facilities implies much longer time periods and the uncertainties inherent in such calculations require special consideration. The hazard estimate is a function of available information relevant to earthquake activity in the region. A typical PSHA seeks to estimate the annual probabilities of exceedance as a function of a single amplitude of strong ground shaking e.g. Four steps are considered to assess PSHA.

A. Seismic source (zones or faults within which future earthquakes will occur) are delineated. From this a distribution of possible distances, $f_R(r)$, is derived.

B. A rate of earthquake occurrence ν_i and a magnitude distribution, $f_M(m)$, are derived for each source.

C. A ground-motion model is derived that, for any specified magnitude m and distance d, allows calculation of the probability that a ground - motion amplitude is exceeded.

D. An estimation is accomplished of the rate ν, with which amplitude is exceeded, using inputs A through C, by integrating overall possible magnitudes and distances and any accounting for their relative probabilities.

The third input is an "empirical predictive relation" that permits estimation of the distribution of ground-motion amplitudes as a function of magnitude and distance. The probability analysis integrates overall earthquakes sizes and distances, and sums over all seismic sources, to estimate the expected number of exceedances of amplitude per unit time, which is an accurate estimate of the annual probability of exceedance of amplitude for a low value of probability.

Use of the expected number of events ν (instead of the probability of one or more such events) greatly simplifies the formulation and makes the model more robust. As usual, in probabilistic analysis, it is easier to calculate expectations that probabilities. In PSHA, one calculates the expected number of occurrences as the sum of expected occurrences caused by many diverse earthquakes. The expectation of that sum will always be the sum (integral) of those expectations, even if future events are correlated in time, space and size. There need not be any implicit or explicit assumption of Poissonian behavior, either in space or time in the analysis. Virtually any model of future earthquake occurrence, including spatial, temporal, and size dependence, can be accommodated as (eg memoryless - poissonian or time dependent model).

4.2.2.1 Statistical Earthquake -Occurrence Models

Several earthquake-occurrence models have been proposed, showing various degrees of sophistication and incorporating different physical concepts. Anyone may consider a variety of probabilistic dependencies and memory patterns involving earthquake times, locations and sizes. Examples are time-predictable and slip-predictable, Markov, characteristic earthquake, self-exciting or double-stochastic or clustering point processes, and renewal models, all of which have been suggested as possible representations of seismic sequences. In practice, a random, memoryless (Poisson) process has been generally assumed in PSHA because of ease of application. Models with memory (time dependent) require more detailed knowledge and understanding of earthquake processes, which is often not available. The impact of non-poissonian behavor on seismic hazard may or may not be significant.

Characteristics of seismicity for which only a few modeling alternatives and estimation procedures exist are the variations of seismic rates in space (nonhomogeneity) and in time (nonstationary). Spatial variations are especially important and difficult to estimate in regions where the stress-generating process and the causative geologic features are not well known. This includes areas where a lack of a thorough understanding of the physical processes that control earthquake occurrence rates and hence nonhomogeneity. A typical approach in this instance is to define seismogenic provinces as geographical regions within which the seismicity is assumed to be homogeneous. Models of this type are popular because of their simplicity. However, hazard results are sometimes sensitive to the configuration of the seismogenic provinces and to the assumption of homogeneous activity within each province.

Temporal variations of seismicity ranging from long term (hundreds or thousands years) to short term (weeks or months) are currently ignored, but understanding these variations will provide a basis for more credible hazard estimates in the future. An important example, which is handled at an intuitive level in the process of defining homogeneous seismogenic provinces, is that regions that have been quiescent in the recent past - say during at least the period of the historical record - may suddenly become active in the next few decades.

An often influential modeling choice is that of the type of probability distribution of earthquake magnitude, including numerous variations on the distribution of one or several characteristic values. In practice, simple models such as the truncated exponential law should be preferred, unless such models are overshadowed by clear physical or statistical evidence. Significant work on statistical earthquake occurrence has concentrated on model formulation and parameter estimation. New models, with spatial and temporal variation of seismicity and with various types of probabilistic dependences, should continue to be developed, but priority should perhaps be given to studying procedures for the validation and comparison of models on the basis of available data.

4.2.3 DETERMINISTIC SEISMIC HAZARD ASSESSMENT

The essential feature of deterministic seismic hazard analysis (DSHA) is that one or more earthquakes are selected with only implicit consideration of their probabilities of occurrence. One example is the tectonic province procedure currently used for critical facilities sites, in which the largest Macroseismic intensity in the province is identified, and then assumed to occur at the site. A second example is the assignment of a maximum credible earthquake with specified magnitude occuring at a specified distance. A third example is the identification of a "characteristic earthquake" on a fault segment with specified source parameters, which enables seismologists to predict strong ground-motion parameters. Ground-motions obtained by analysis range in sophistication from peak values obtained from empirical predictive relations, to complete seismograms that may by either synthetic or selected from prior recordings under similar conditions. Probabilistic concepts enter in this analysis only in a simple form, such as scatter about a mean ground motion estimation curve.

Deterministic evaluation of seismic hazard can also be performed, and the results of correctly performed and suitably comprehensive DSHA studies can also supersede values of PGA. DSHA studies typically include the following:

1. Evaluation of potentially damaging earthquake sources and deterministic selection of one or more suitable "controlling" sources and seismic events. The deterministic earthquake event magnitude for any fault should be of a ***maximum*** value that is specific to that seismic source. Maximum earthquakes may be assessed by estimating rupture dimensions of the respective fault.

2. Use of published curves for the effects of seismic travel path using the shortest distance from the source(s) to the site (e.g., see special issue of Seismological Research Letters, v. 68, n.1, 1997);

3. Evaluation of the effects of site-specific response characteristics on either (a) site accelerations, or (b) cyclic shear stresses within the site soils of interest.

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4.3 GREECE

In the present activity, seismic hazard assessment at regional scale will be evaluated for the broader area of Kentriki Makedonia (Central Macedonia), and Thraki (Thrace - Greek part), based on the selected methodology from GA1. The selected area K-Macedonia and Thrace area is located on the Northern part of Greece located among Bulgaria (to the North), Turkey (to the East), North Aegean Sea (to the South) and Western Macedonia region (to the West). The population of the area examined is almost 2.5 million (2010).

4.3.1 BACKGROUND INFORMATION ON SEISMIC HAZARD MAPS IN GREECE.

The seismic hazard maps appeared in the various seismic codes of Greece since 50’s were based on the valid seismological knowledge during the corresponding period of compilation. The area under study was always considered as low seismicity and low hazard area.

Until the end of fifty’s several regulations were issued after disastrous earthquakes for the rehabilitation of the damaged structures (Corinthos 1926, Chalkidiki 1932, Thessaloniki 1932, Ionian Island 1953 Thessalia 1954-1957).

In the first seismic hazard map of Greece with the title *“Engineering Seismic Map of Greece”* the area of Greece was divided in 5 classes of seismic hazard (Technical Chronicles, no 184, 1939) and was compiled by Roussopoulos (1956). The classification was based on a proposed value corresponding to fraction of the horizontal acceleration which was considered as design acceleration. In the revision of 1956 (2^{nd} edition) the area of the Dodecanese islands was considered in the zonation and the new map included five seismic hazard classes with a division each of them in three subclasses depending to the soil classification. The coefficient was varied between 0.01g and 0.16g. The map is shown in Fig. 39.

This map was based on the macroseismic effects of the earthquakes during the 19^{th} early of the 20^{th} century reflecting the geographical distribution of the maximum intensities. No statistics was used.

Fig. 39: The first seismic hazard map of Greece.

The first Greek seismic code was adopted in 1959 (Royal Decree 19/26.2.1959, Gov. Gazet. 36A) and included a list of 144 sites which were grouped in 3 classes. The classification was based on the maximum observed intensity and its frequency without any scientific treatment.

Discussions of the revision of the seismic code of Greece started after the 1978 M=6.5 Thessaloniki earthquake, which caused extended damage to reinforced concrete structures, which were built according to the seismic code of 1959. These discussions were densified after the strong earthquakes of 1981-1986 which caused high degree damage including collapses at several regions.

Until that period many research papers and PhD theses were published aiming in reliable assessment of seismic hazard. These scientific efforts started on the basis of point source approximation for seismic hazard studies with the application of the probabilistic methods of mean values and the Gumbell I and III asymptotic distributions. The paper by Galanopoulos and Delibasis (1972) was the first attempt on seismic hazard even at elementary level of data statistical treatment. The first trusted attempt was made by Algermissen et al (1972). The publications of Makropoulos (1978), Papaioannou (1984), Papoulia (1988) and the papers by Drakopoulos and Makropoulos (1983), Papaioannou (1986), Makropoulos and Burton (1989), were based on the Gumbell's (1958) first and third asymptotic distributions. Following, the more detailed zonation by Hatzidimitriou (1984), the Cornell's (1968) method and its modification due to McGuire (1976) was applied by Papazachos et al (1985) using the area-type seismic sources model by Hatzidimitriou (1984) which was based on the pioneering work for the compilation of an area-type seismic sources model by Papazachos (1980). In the paper by Papazachos et al (1985) the authors adopt the opinion expressed by Cornell (1968), that the use of seismic hazard recurrence curves is more useful than ill-defined single numbers as the "probable maximum" or the "maximum credible" intensity. This is due to the fact that even well-defined single numbers, as the "expected lifetime maximum" are insufficient to give the engineers an understanding of how quickly the hazard (annual probability of exceedence) decreases as the ground motion intensity increases. Papazachos et al. (1990) attempted to perform a statistical elaboration of the macroseismic observation for selected sites in Greece and compare the results with probabilistic seismic hazard.

Improvements and contribution to the credibility of the results were made by Margaris (1994), who took into account the azimuthal variation of the seismic intensity in the calculations.

Given the proposal for the empirical predictive relation for the peak ground values by Theodulidis (1991), the seismic sources model for the shallow and intermediate depth earthquakes (Papazachos, 1990) and the compilation of the catalogue of historical earthquakes by Papazachos and Papazachou (1989), seismic hazard maps were compiled using the McGuire (1976) code and also the mean values and Gumbell (1958) probabilistic methods. These individual maps were considered as the basis of the revised version of seismic hazard zonation of Greece (Papazachos et al., 1989). In this map the area of Greece was divided into four zones of seismic hazard with design values for the ground acceleration (seismic design coefficient) equals to 0.12g, 0.16g, 0.24g and 0.36g and is shown in Fig. 40. Following the earthquake of 1995 in Kozani there was a modification for the area of W.

Macedonia due to increase level of the seismic hazard.

Even though the background work for the seismic hazard map of Greece was accomplished in 1989 the seismic code of Greece was published in the Government Gazette in 1992 being valid in parallel with the 1950 code. In 1995 two disastrous earthquakes occurred in Greece (Kozani, M6.6 and Aigio M6.2). In July-August 1996 two earthquakes of magnitude M 5.2 and 5.6 occurred in NW Greece with recorded peak accelerations 0.39g at the town of Konitsa (zone II) were a partial collapse of a reinforced concrete 4 stories building was observed. In September 1999 a magnitude M5.9 earthquake caused great damage in the metropolitan area of Athens. This was the trigger effect for the government to request for a new updated seismic hazard map of Greece on the basis of the new scientific information gained during the period 1989-1999.

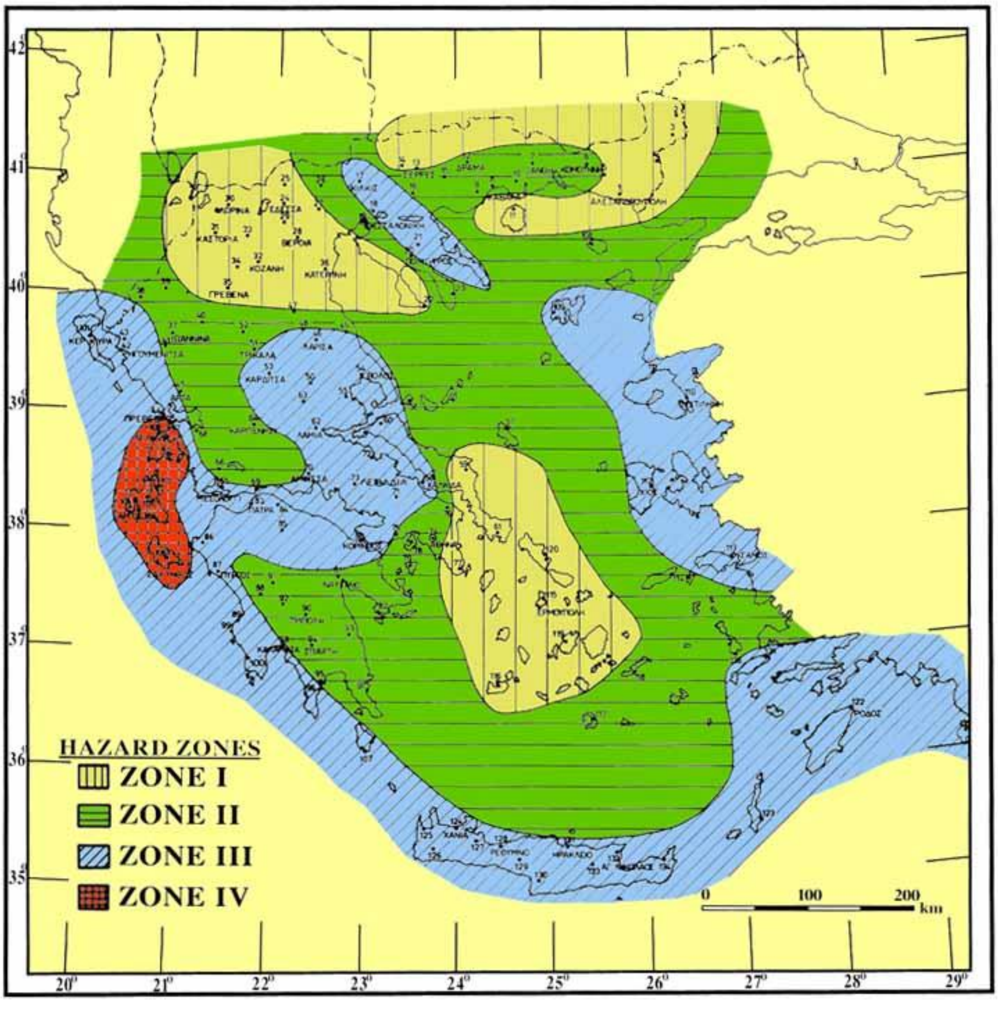


Fig. 40: Seismic Hazard map of Greece in the seismic code of 1992 (Papazachos et al., 1992).

Therefore the Institute of Engineering Seismology & Earthquake Engineering (ITSAK), the Laboratory of Geophysics of the Thessaloniki University (GL.AUTh), the Geodynamic Institute of Athens (GI.NOA) and the Laboratories of Seismology of Athens (NKUA) and

Patras Universities (UP) merged their results obtained by using various input data and procedures (seismotectonic models, seismic sources models, empirical predictive relations, parameters describing the measures of seismic hazard and software) for the compilation of their individual seismic hazard maps.

In order to accomplish its role ITSAK used the seismic sources model of area type sources by Papaioannou and Papazachos (2000) and the hybrid model of area type sources and faults proposed by Papaioannou (2002) and the empirical predictive relations by (Margaris et. al., 2002). The zonation proposed by Papaioannou (2002) took into account the paper by Papazachos et al. (2001) on the geometrical and seismological parameters of the main faults in the broader Aegean area proposed by Papazachos et al., (2001). Both are shown in the maps of Fig. 41 and Fig. 42.

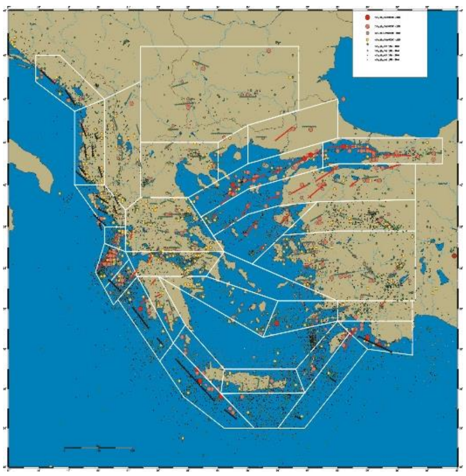


Fig. 41: Hybrid model of fault and area sources in the Aegean and surrounding area (Papaioannou, 2001).

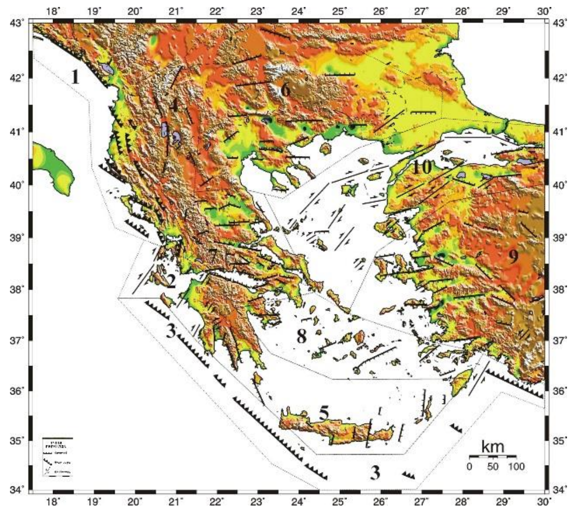


Fig. 42: The main faults of shallow strong (M≥6.0) earthquakes in the Agegean areas (Papazachos et al., 2001).

The two models of shallow and intermediate depth earthquakes compiled by Papazachos (1990) and Papazachos and Papaioannou (1993) which were used by GI.NOA, NKUA and UPatras are shown in Fig. 43 and Fig. 44.

Several empirical predictive relations for the peak ground values were used in Greece which include the publications of Makropoulos (1978), Theodulidis (1991), Theodulidis and Papazachos (1992), Ambraseys (1995), Ambraseys et al, (1996) and Margaris et al. (2001, 2002). A comparison of these relations for a magnitude Mw=6.5 earthquake and site conditions "ROCK" are shown in the graph of Fig. 45,

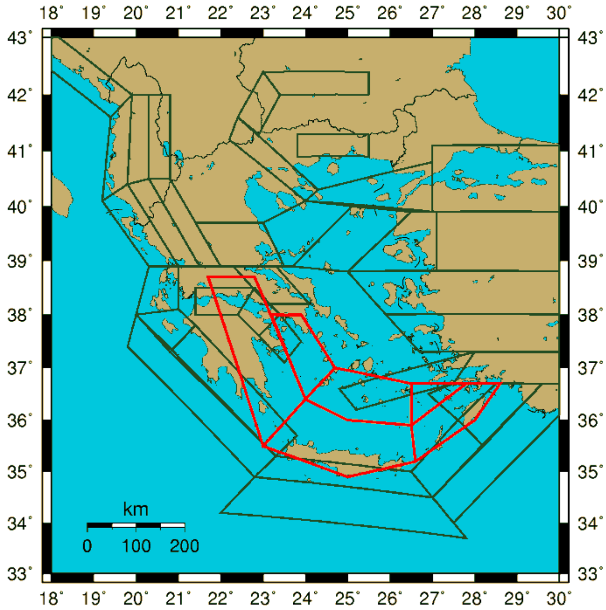


Fig. 43.Seismic sources models of shallow (black) and intermediated depth (red) earthquakes (Papazachos, 1990)

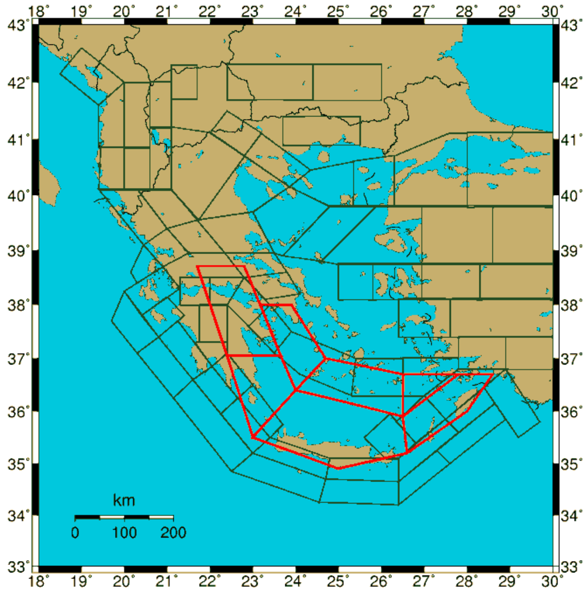


Fig. 44 Seismic sources models of shallow (black) and intermediated depth (red) earthquakes (Papazachos and Papaioannou, 1993 revised).

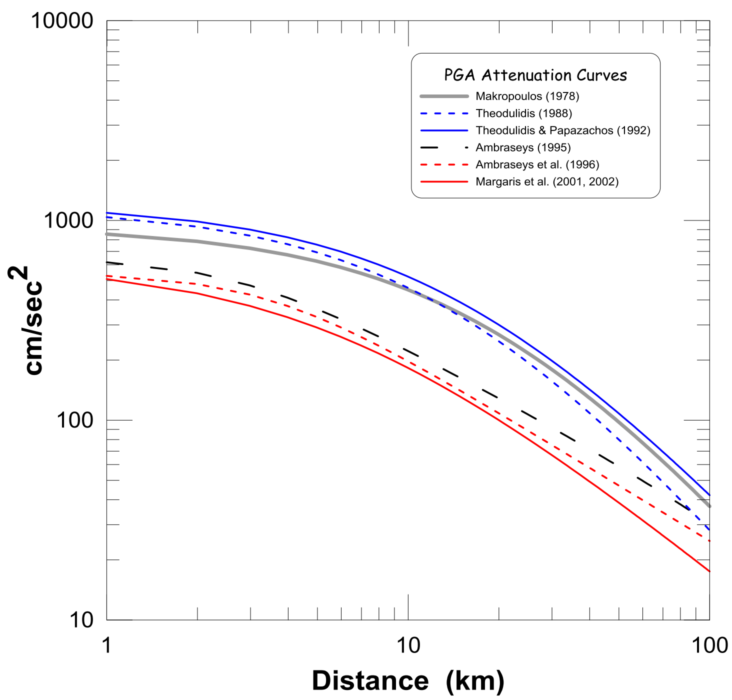


Fig. 45. Comparison of the various empirical predictive relations for the PGA, used in the present study for M=6.5 and soil conditions “rock”

A scientific committee was established by the Earthquake Planning and Protection Organization for the compilation of the official hazard map based on the results of the five seismological organizations. The committee decided to consider the hazard values of the five partners get the mean value remove the outliers and adopt the remaining values for the compilation of the final hazard map. The geographical distribution of the mean values and the standard deviation values of the peak ground acceleration are shown in the Fig. 46 and Fig. 47.

The final seismic hazard map which was included in the revision of the Greek seismic code, it was published in the Government Gazette (Φ.Ε.Κ. Β΄ 1154/12-8-2003) and is shown in the map of Fig. 48. In this map the area of Greece is divided in three zones with design values of the horizontal ground acceleration equals to 0.16g, 0.24 and 0.36g. Practically the geographic areas corresponding to the zones I and II of the previous map were merged into zone I of the new map. It must be pointed out that this map and the seismic code are valid only for ordinary structures of engineering interest. For the construction of special structures which are of significant importance and high levels of security special seismic hazard studies are required.

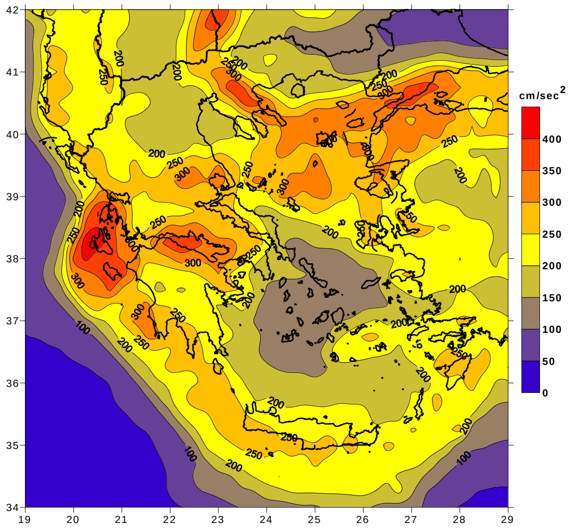


Fig. 46: Geographical distribution of the mean values of the peak ground acceleration (cm/sec^2) in Greece and surrounding area

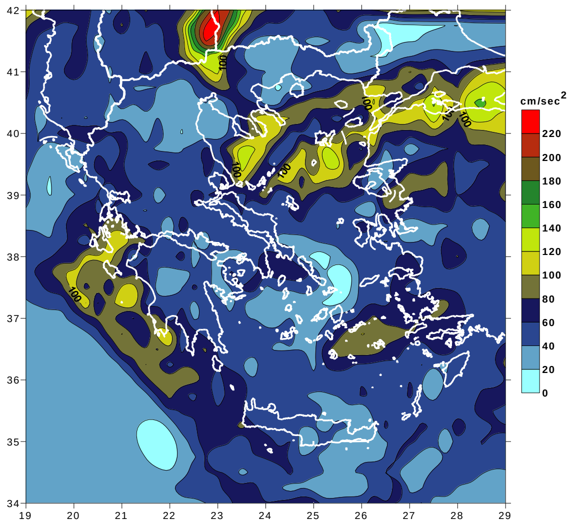


Fig. 47: Geographical distribution of the standard deviation of the peak ground acceleration values (cm/sec^2) in Greece and surrounding area

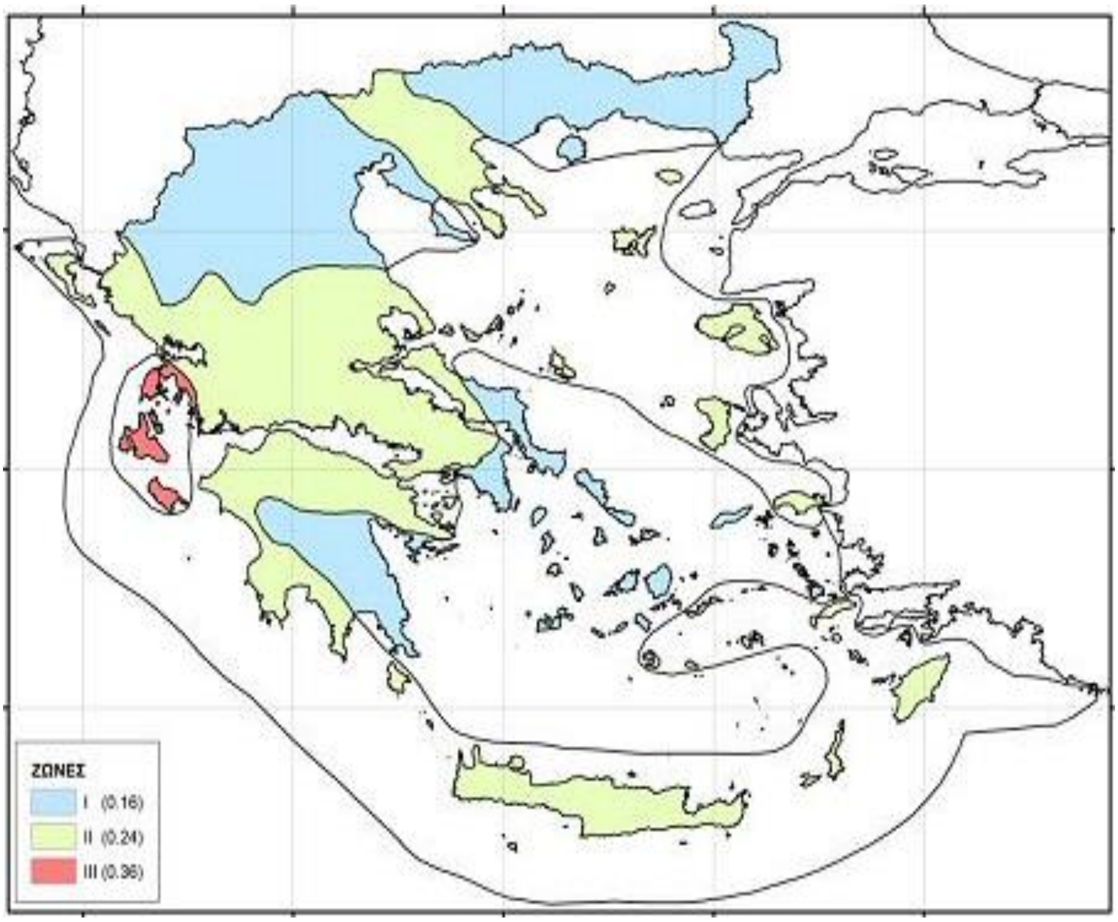


Fig. 48: The official current seismic hazard map of Greece

The comparison between the maps appeared in Fig. 40, Fig. 41, and Fig. 48 shows clearly that the examined area covers low hazard zones.

4.3.2 SEISMICITY & SEISMOTECTONICS OF THE AREA

The area under study is located in the northern part of the broader Aegean area. The map in Fig. 49 shows the main features of tectonic origin of the Aegean area. The black rectangular denotes the area of the present study. The most important tectonic feature in the broader area is the branch of the North Anatolian Fault with its termination in the North Aegean, located at the southern border of the examined area.

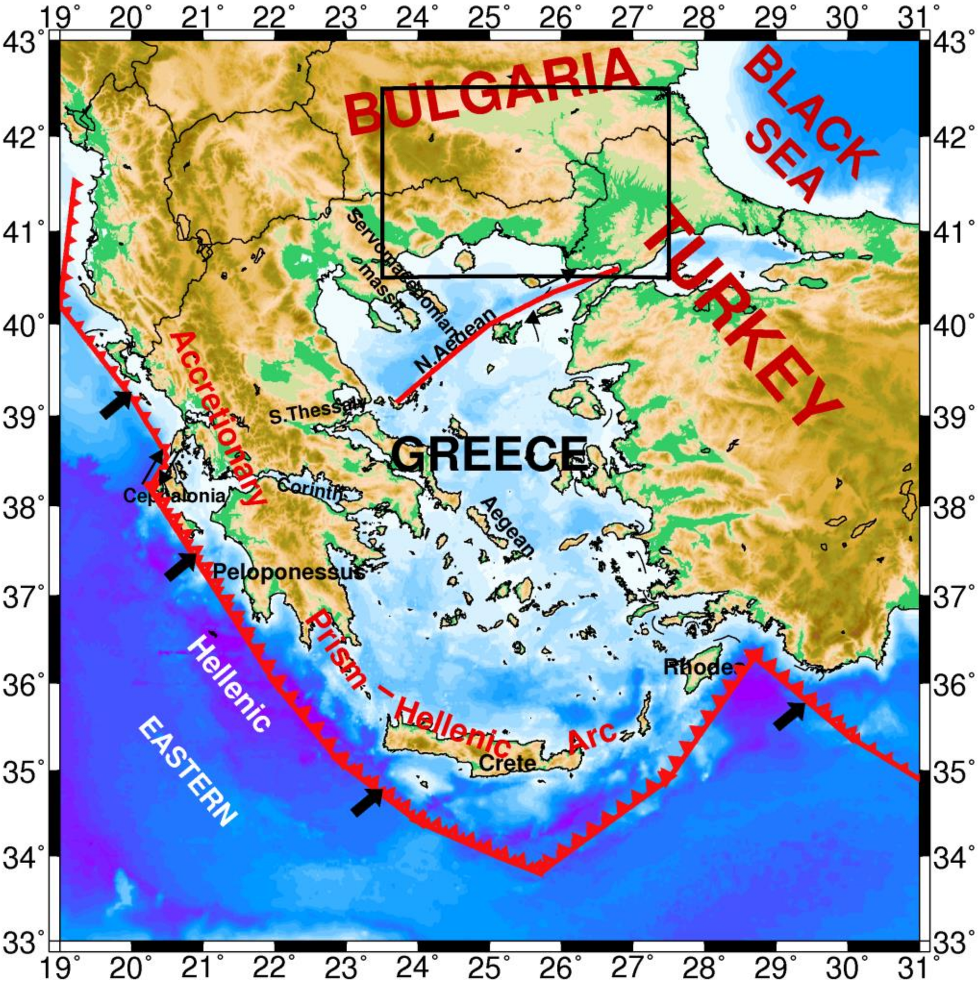


Fig. 49: The main features of tectonic origin in the broader Aegean area. The rectangular shows the investigated area.

An effective way to study the spatial distribution of seismicity in a certain area is to divide this area into seismic zones or seismogenic regions, that is, into regions with uniform seismo-tectonic features, and to define seismicity parameters in each one of them. Such efforts have been made by several authors (Papazachos, 1980; 1990; Papazachos and Papaioannou, 1993; Papaioannou and Papazachos, 2000 among others).

Using information on seismicity, active tectonics, attenuation pattern of seismic intensities, location of active faults Papazachos and Papaioannou (2000) and Papaioannou (2002) proposed seismotectonic models for the area. The reliability of these models can be proved on the basis of research and applied work numerous publications, which made use of these models.

The map in Fig. 50 shows the location of epicenters of strong $M_W \geq 6.0$ earthquakes since the historical times and the earthquake with $M_W \geq 5.5$ during the instrumental era (1911-2013). The source of the historical earthquakes is the catalogues of Papazachos and Papazachou

(2003), while the data for the period 1900-2013 are from the updated catalogue of Papazachos et al. (2012). Different size and color circles were used to denote the various magnitudes of earthquakes and time period as in legend.

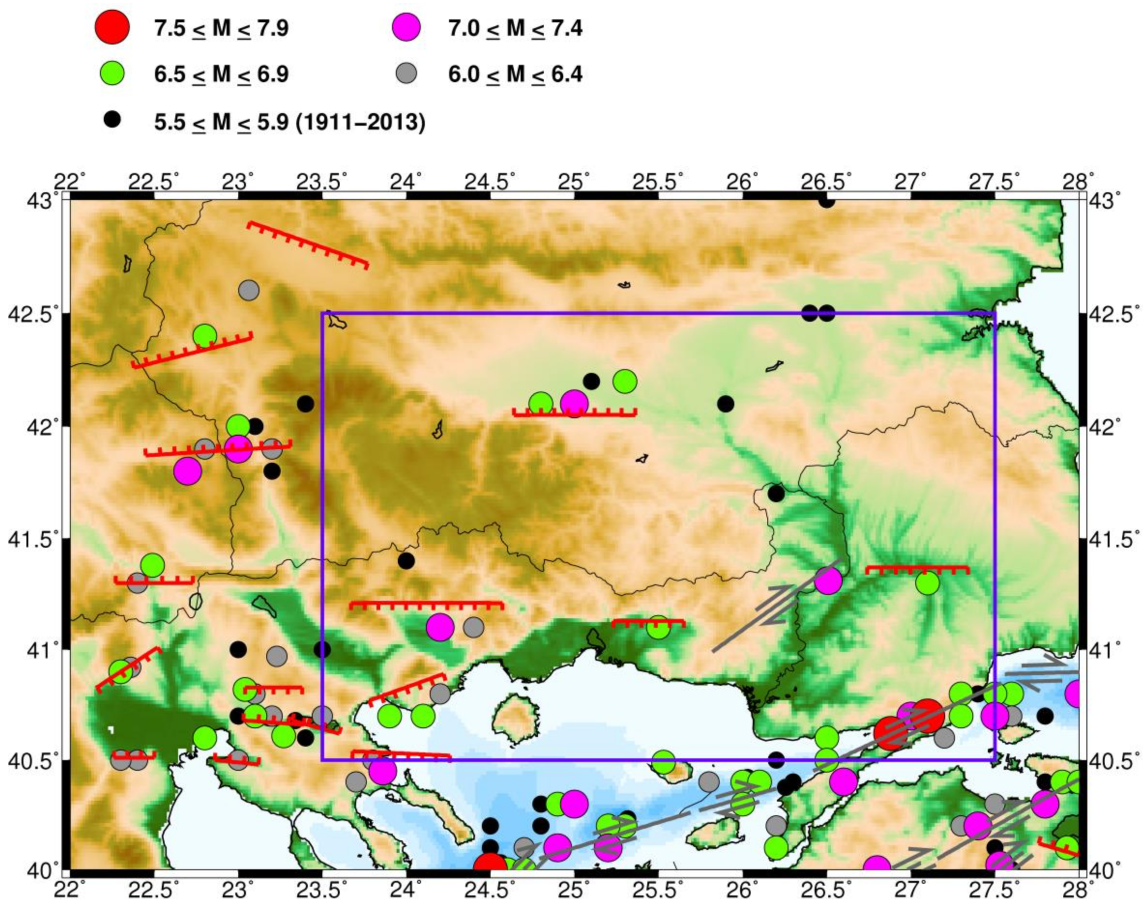


Fig. 50. Geographical distribution of strong earthquakes within the investigated area shown by a rectangular. The faults are after Papazachos et al. (2001).

The map in Fig. 51 shows the distribution of the moderate-to-small magnitude (3.5≤ M_W≤5.4) earthquakes during the instrumental era according to the legend.

From the maps in Fig. 50 and Fig. 51 one can conclude that the area is a low seismicity region with considerable activity of moderate magnitude events and nucleation of strong earthquakes mainly at the borders. The highest activity is related to the Servomacedonian zone, the north Aegean trough and the north Anatolia fault, the Kresna and Plovdiv fault areas. The activity at the area of the July 29, 1752 Havsa earthquake (41.41N 26.61E, M=7.5) and the November 6, 1784 Komotini earthquake (41.10N 25.30E, M6.7) is very low.

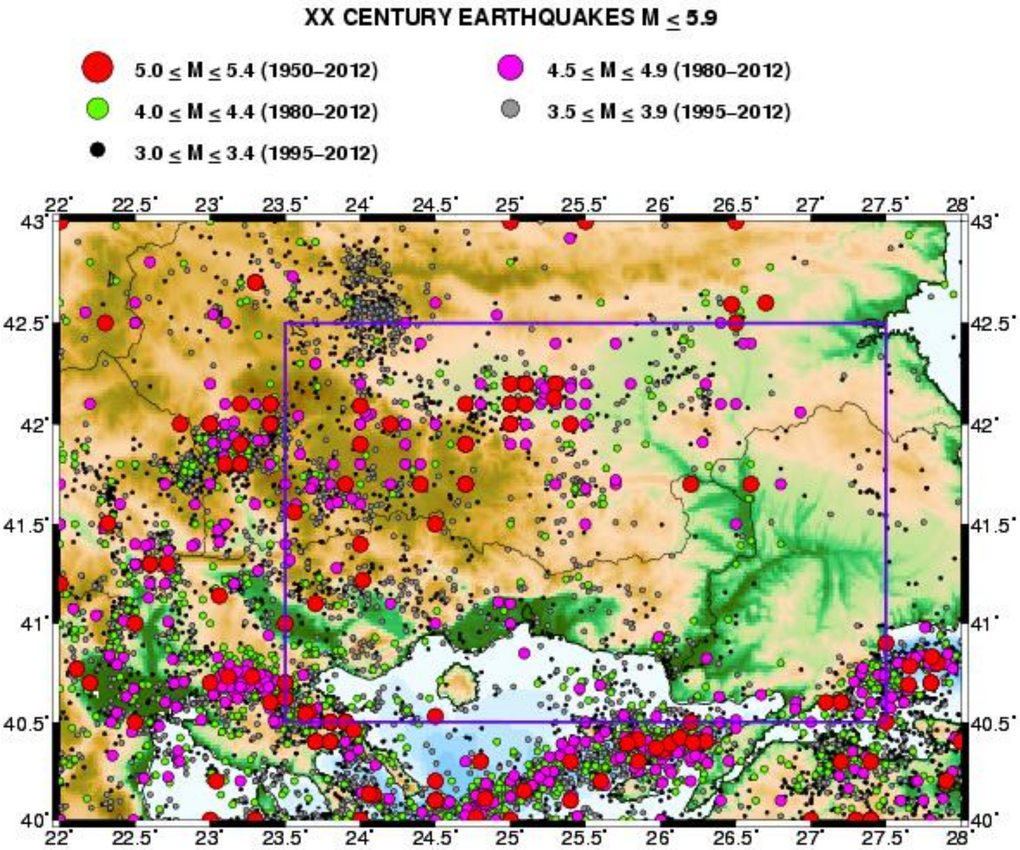


Fig. 51. Geographical distribution of moderate-to-small earthquakes within the investigated area shown by a rectangular. Information of the time period and size of the events are shown in the legend.

The map in Fig. 52 shows the location of the area type sources proposed by Papaioannou and Papazachos (2000) (blue polygons) and the epicenters of the earthquakes. Table (I) includes information on the seismicity parameters of the sources which mostly influences the results of the seismic hazard in the area.

Table 4.1: Information on the seismicity parameters of the sources which influence the examined area (Papaioannou and Papazachos (2000).

Name	b	a	Area Km^2	M_{max}	Rate M ≥5.0
Philipoupolis	0.79	3.23	14315	6.9	0.187
Kresna	0.83	3.44	20078	7.2	0.196
Drama	0.81	3.22	17305	7.0	0.158
Serres	0.82	3.54	9271	7.0	0.271
Athos	0.83	3.92	5249	7.3	0.595
Samothrace	0.82	3.76	10088	7.1	0.467
Hellispontos	0.80	3.74	19181	7.5	0.527

The map in Fig. 53 shows a hybrid model of line-type and area-type sources, which was proposed for the broader area (Papaioannou, 2002). In this model the strong (M≥6.0) earthquakes are associated with faults and the smaller events were considered that are located within the sources. This model takes into account the modern opinion on the distribution of strong events which is that the association of strong events with faults is more realistic than the view of having the same probability for the occurrence of a large magnitude event at every place within a seismic source. The faults are after Papazachos et al. (2001).

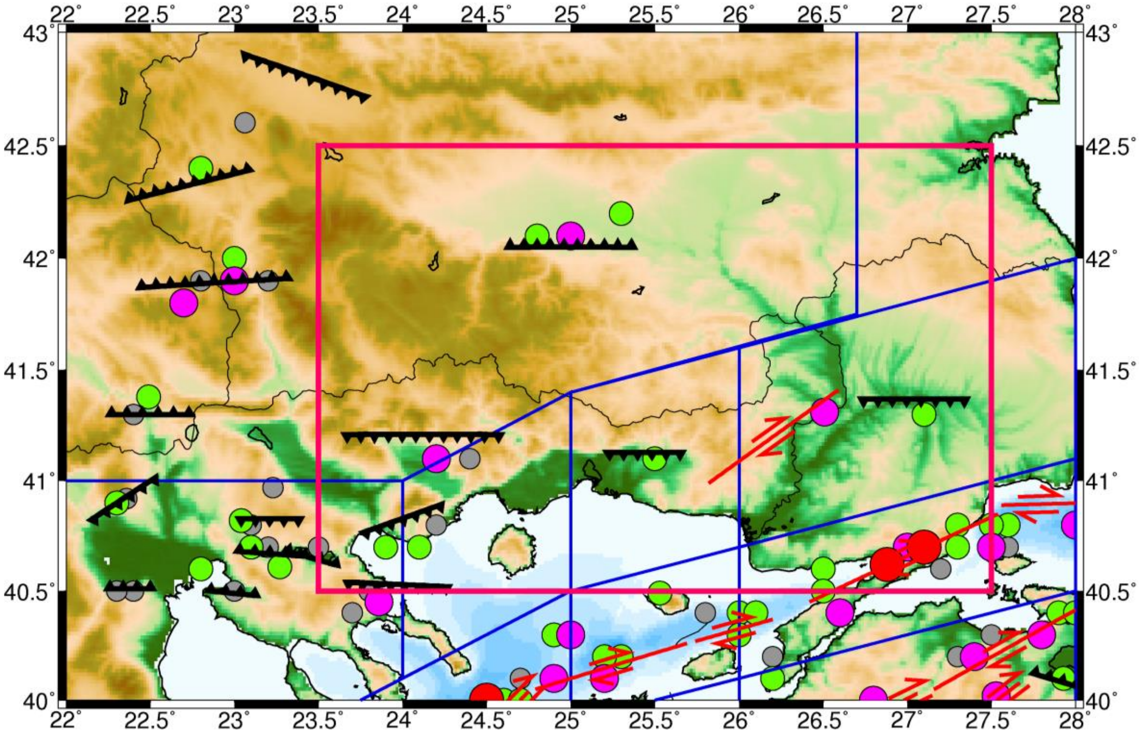
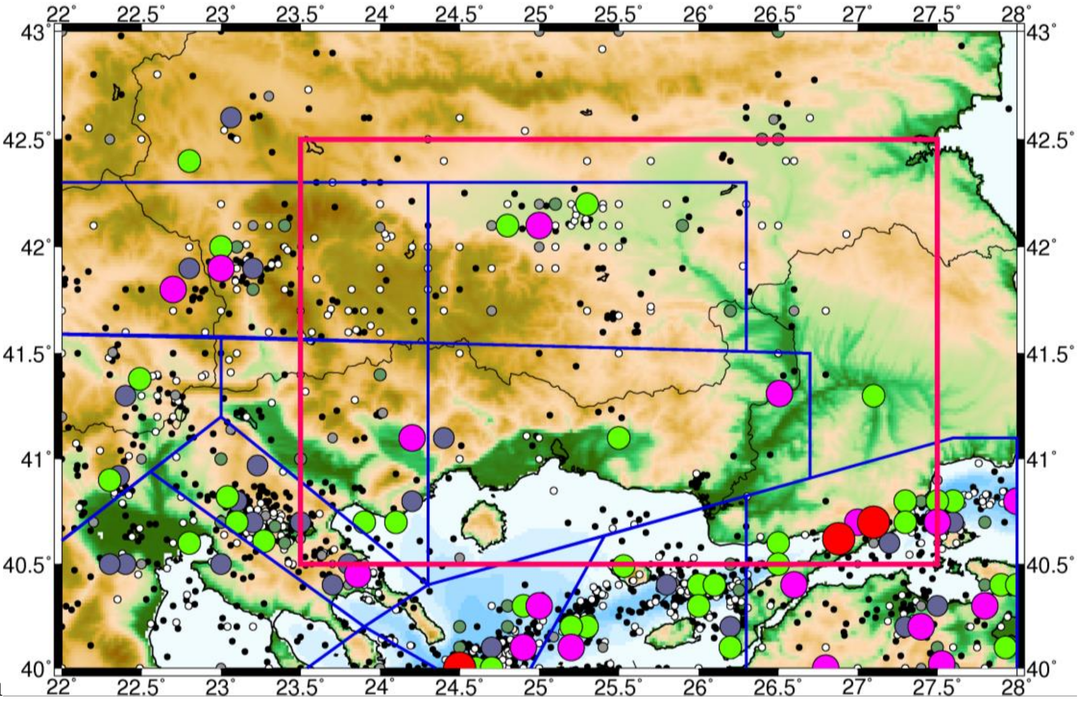


Fig. 52. Geographical distribution the epicenters of the known earthquakes at the broader area of the investigated area (shown by red rectangular). The blue polygons show the seismic sources proposed by Papaioannou and Papazachos (2000).



area

Fig. 53. A hybrid model of area-type and line-type (faults) in the area Papaioannou (2002). The faults are after Papazachos et al. (2001).

4.3.3 EMPIRICAL PREDICTIVE RELATIONS OF MACROSEISMIC INTENSITIES

In order to assess the seismic hazard at a site, it is necessary to adopt reliable relations describing the dependence of the seismic intensity measures as a function of the distance and source properties of the earthquakes in the area. The parameters which are usually used for these purposes are the macroseismic intensity and the peak values of the ground motion. In the present study the empirical relations for the macroseismic intensity and the peak ground acceleration were used.

The macroseismic intensities were used because the macroseismic intensity, effect of the earthquake. is the only procedure to investigate historical events and ink them with the current situation. Furthermore using scaling relations holding between the macroseismic intensity and instrumental parameters of the ground motion, we can define with acceptable uncertainties the distribution of the maximum values of instrumentally determined parameters as pga, pgv or pgd.

Several attenuation relations of macroseismic intensity as a function of magnitude and distance have been proposed for the Balkan area. Due to their simplicity such relations are used in seismic hazard assessment especially in the Cornell's (1968) method. During the last thirty years 356 macroseismic maps with more than 30.000 macroseismic intensity data points of shallow earthquakes in the Balkan area have been compiled (Papazachos and Papaioannou, 1997). Based on this large number of macroseismic observations a new attenuation relation has been proposed. This relations is,

$$I - I0 = -3.59 \log(\Delta+6) + 3.19 \qquad (73)$$

where Io is the epicentral intensity. The aforementioned authors have also proposed relations between epicentral intensity Io and magnitude M, applicable separately for every Balkan country independently. For Greece the proposed relation (Papazachos and Papaioannou, 1997) is,

$$I_o = 1.43M - 0.93 \qquad (74)$$

From the relations (1) and (2) the average macroseismic attenuation relation for the area of Greece is,

$$I_i = 2.26 + 1.45M - 3.59 * \log(\Delta + 6) \qquad (75)$$

Relation (3) was used for the seismic hazard assessment calculations considering the macroseismic intensity as a parameter of the seismic hazard.

Fig. 54 shows a comparison of attenuation relations as a function of the macroseismic intensity for various areas of the world (Papazachos and Papaioannou, 1997). It is clear that regions with high seismic activity (Balkans, W. USA, Italy) show high attenuation compared with less active areas as E.USA, NW Europe and Scandinavia.

Poardi firstly used Macroseismic data in 1627 in an attempt to measure the size of the earthquakes. Since the beginning of the 19th century macroseismic observations were routinely reported in the bulletins of the Observatory of Athens. Until 1934 the Rossi-Forell intensity scale was used, while since 1950 an intensity scale equivalent to the Modified Mercalli scale has been being used (Shebalin, 1974).

In Greece, macroseismic observations were firstly used for the definition of isoseismals of shallow and intermediate depth earthquakes by several authors. It has to be mentioned that substantial work has been done during the time period 1936-1949 when no bulletins were published by the Observatory of Athens (Galanopoulos, 1941, 1944, 1949, 1950, 1953, 1954; Ambraseys, 1988; Ambraseys and Jackson, 1990). Moreover, the study of individual earthquakes included, among other topics, the study of their macroseismic fields.

The Geophysical Laboratory of the Aristotle University of Thessaloniki, recognizing the importance of the study of the macroseismic observations on Earthquake Engineering, started to collect macroseismic data in the beginning of ‘80. Papazachos and Papazachou (1989) presented a catalogue of strong (M≥6.0) earthquakes, which occurred in the Aegean and surrounding area during 550BC-1986. Papazachos et al. (1997a, b), used an updated and more complete catalogue of strong earthquakes occurred in the Aegean area during 550BC-

1996 (Papazachos and Papazachou, 1997), and after extracting macroseismic data from the bulletins of the Observatory of Athens (1900-1939 and 1950-1996), compiled a data base consisting of 37,000 macroseismic observations of 900 earthquakes, which occurred in this area. This data base can be used for the determination of attenuation relations for every site in Greece, for the compilation of synthetic isoseismals and the definition of rupture zones. It can also be used to test the results of probabilistic seismic hazard studies (Papazachos and Papaioannou, 1998; Papazachos et al., 1998).

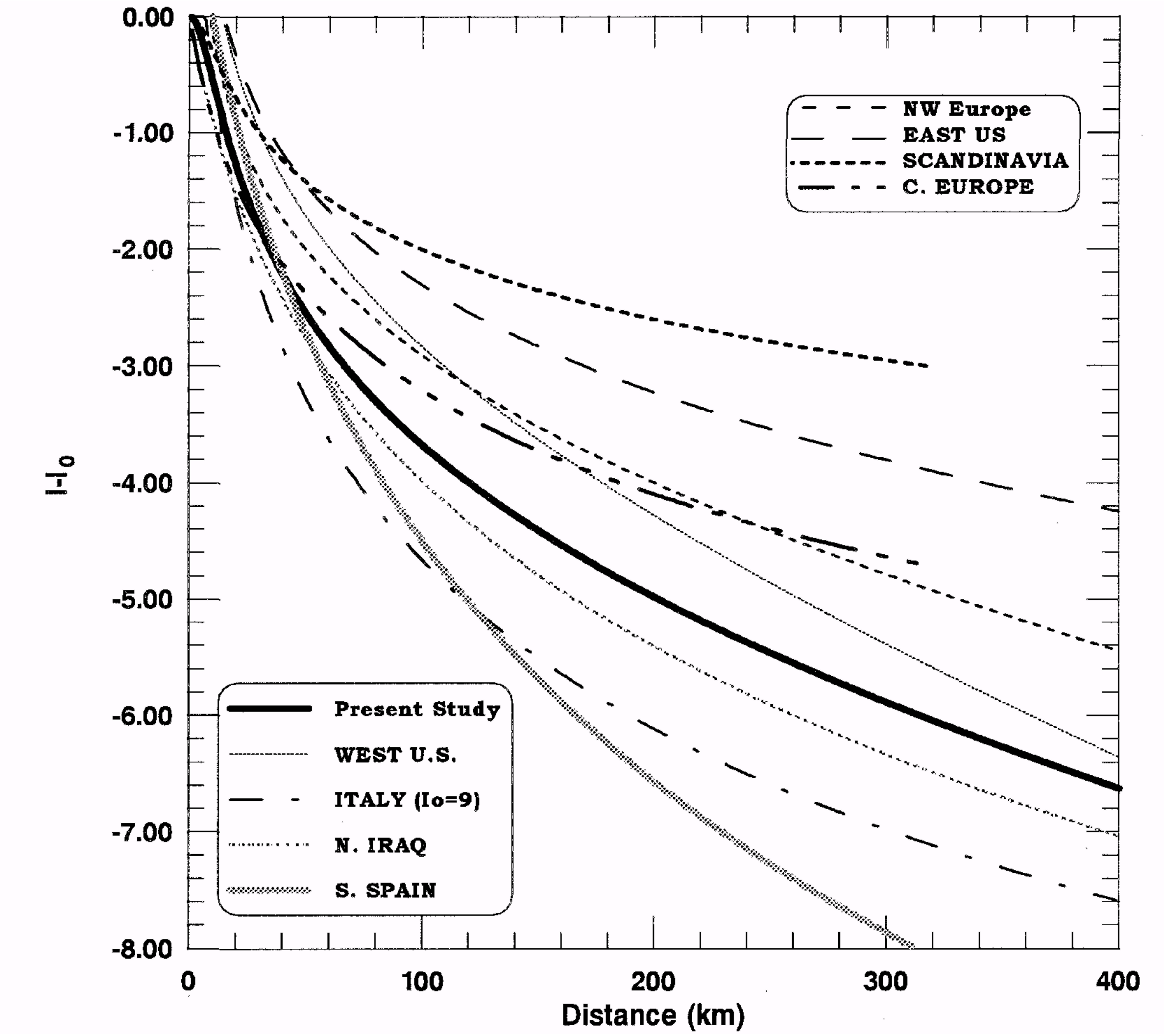


Fig. 54. Comparison between various attenuation relations holding for different areas of the world. The continuous black line stands for the Aegean area (Papazachos and Papaioannou, 1997).

The maps in Fig. 55, Fig. 56, Fig. 57, Fig. 58, Fig. 59 and Fig. 60 show the macroseismic field of strong earthquakes in the examined area.

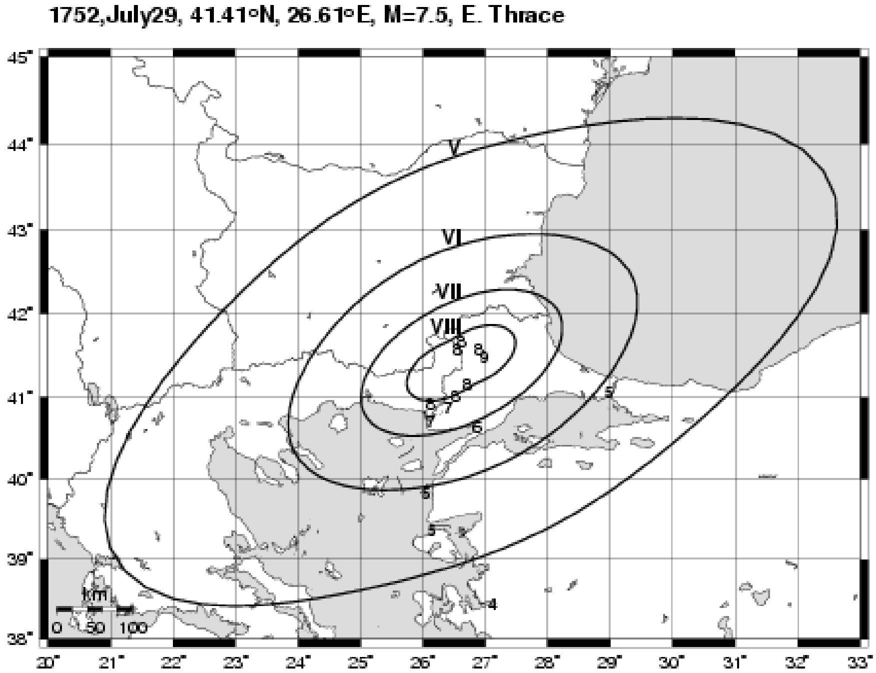


Fig. 55. Isoseismal map of the earthquake of 1752 in Thrace (Papazachos et al., 1997a).

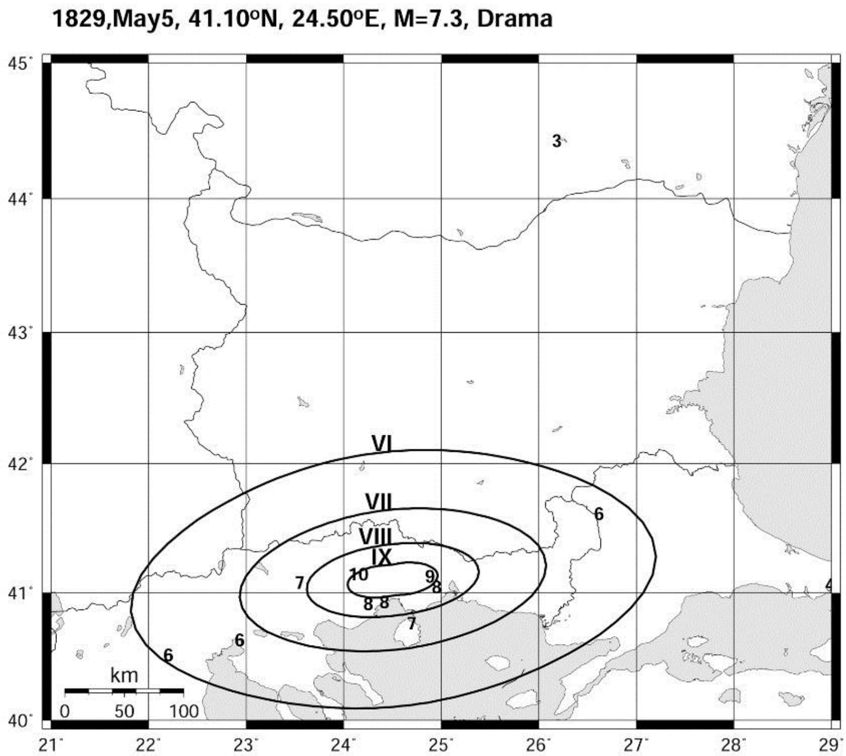


Fig. 56. Isoseismal map of the earthquake of May 5, 1829 M=7.3 (Papazachos et al., 1997a).

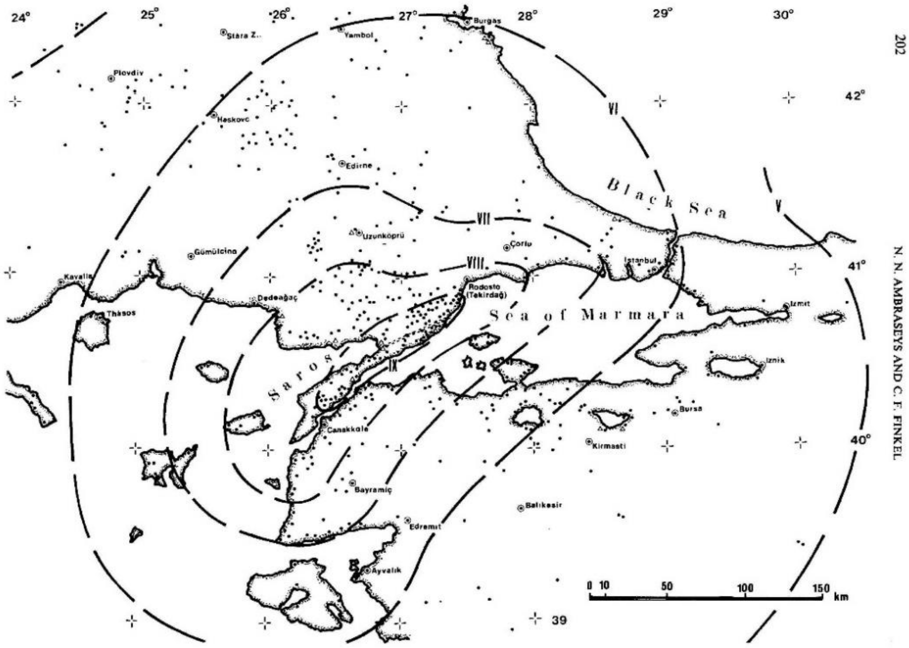


Fig. 57. Isoseismal map of the earthquake of August 9, 1912 M7.6 earthquake (Ambraseys and Finkel 1987).

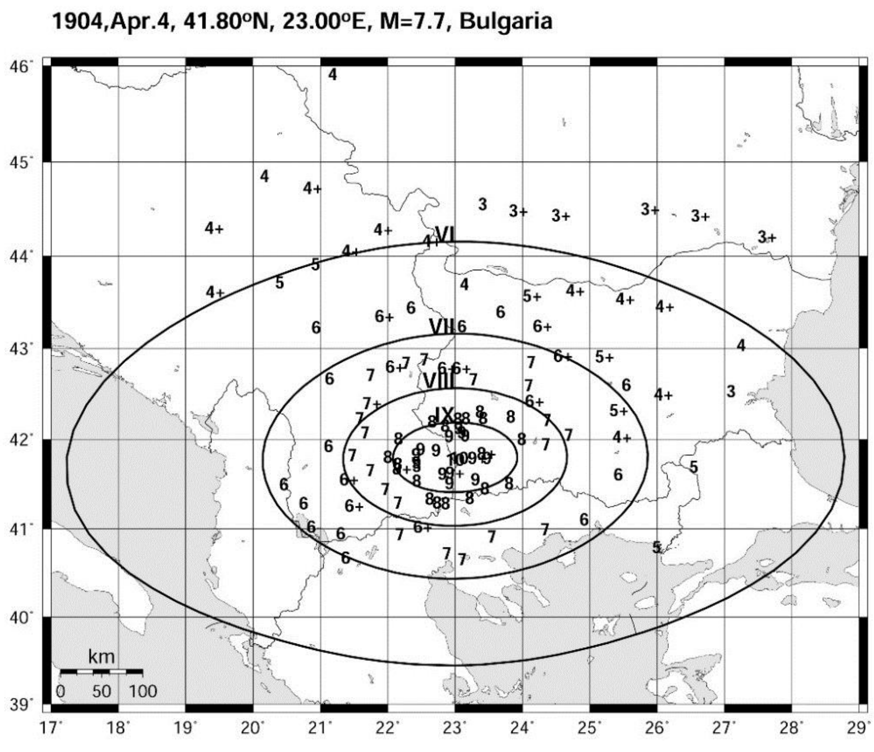


Fig. 58. Isoseismal map of the earthquake of April 4, 1904 M=7.7 Kresna mainshock. (Papazachos et al., 1997a).

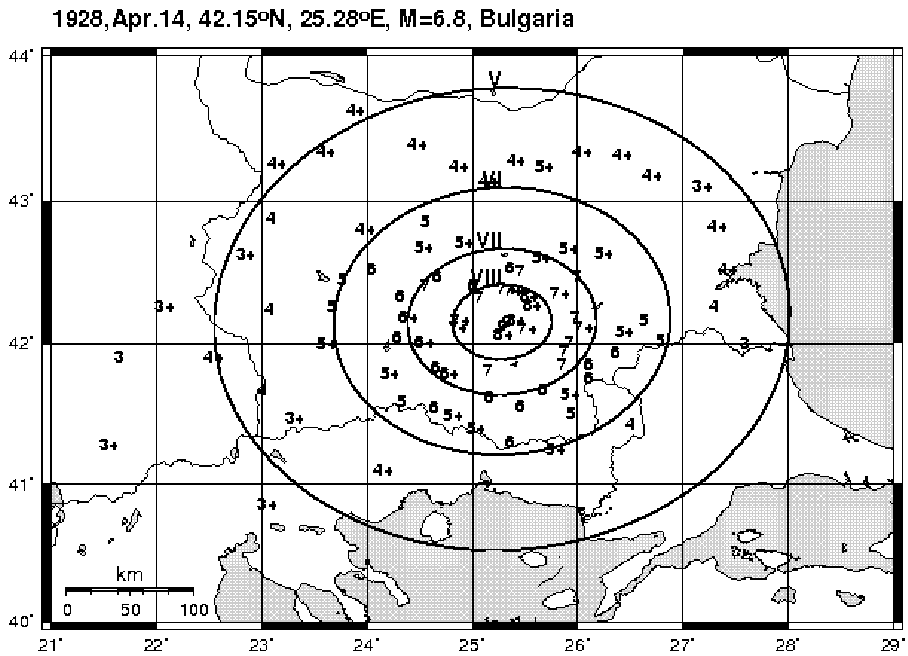


Fig. 59. Isoseismal map of the earthquake of April 14, 1928 M=6.8 Plovdiv earthquake. (Papazachos et al., 1997a).

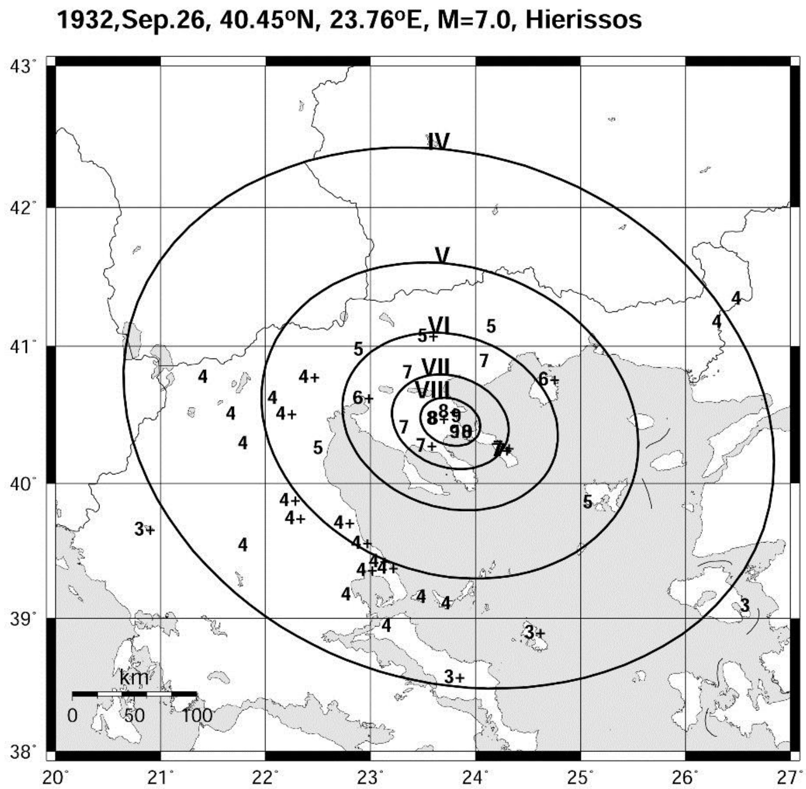


Fig. 60. Isoseismal map of the earthquake of September 26, 1932 M=7.0 Ierissos earthquake. (Papazachos et al., 1997a).

Ii is obvious the influence of the NE-SW striking strike slip strong earthquakes at the eastern part and the EW striking normal faults on the pattern of macroseismic field in the area.

4.3.4 DISTRIBUTION OF MAXIMUM MACROSEISMIC INTENSITIES IN THE STUDY AREA

For the estimation of the maximum macroseismic intensities that have been observed at the area of study, it is necessary to have a set of macroseismic observations for the study area covering a long time window. Although a large number of observations is available for the study area, the use only of observed macroseismic intensity values is problematic. The main limitation of the observed intensity data set is that frequently no observations are available for the site under study, either due to the absence of important cities or towns, or due to the lack of information concerning the damage distribution from certain strong events. For this reason, it was initially considered appropriate to use deterministically computed macroseismic intensities for the broader study area.

For these estimations, the earthquakes that had the most significant impact on the broader area of the study were used.

For the modeling of the macroseismic field of the previous earthquakes the formulation of Papazachos (1992) was used. This formulation assumes that the main energy source for each event can be represented by a point source and therefore the Kovesligethy relation can be used:

$$\mathrm{I} - \mathrm{I}_0 = \mathrm{n}\log\sqrt{1+\frac{\Delta^2}{\mathrm{h}^2}} + \mathrm{c}(\sqrt{\Delta^2+\mathrm{h}^2} - \mathrm{h}) \tag{76}$$

where I_0 is the epicentral intensity, I is the observed intensity at distance Δ, h is the source depth, n is the geometrical spreading factor and c is the anelastic attenuation coefficient. The main modification in the applied formulation is that the isoseismals are assumed to have an elliptical shape, due to the anisotropic radiation of the seismic energy at the source. Therefore, equation (6) is modified to:

$$I - I_{0_{\min}} = n\log\left(S^{1/2}\sqrt{1+\frac{\Delta^2}{h^2}}\right) + c(\sqrt{\Delta^2+h^2} - h) \tag{77}$$

where $I_{0_{min}}$ defines the apparent epicentral intensity at the direction of the minimum energy radiation (small axis of the elliptical isoseismals), and S is a factor which determines the azimuthal variation of the intensity and which is given by:

$$S = 1 - \varepsilon^2 \cos^2(\zeta - \phi) \tag{78}$$

where ε is the ellipticity of the isoseismals, ζ is the azimuth of the major axis of the elliptical isoseismals and φ is the azimuth of each site/direction we are studying. It can be shown (Papazachos, 1992) that at each direction equation (6) still applies with an "equivalent" epicentral intensity at each direction which is given by:

$$I_0(\phi) = I_{0_{\min}} + \frac{n}{2}\log S \tag{79}$$

Using the previous methodology and the values n=-3.227 and c=-0.0033 estimated by Papazachos and Papaioannou (1997), we computed the intensity values for the earthquakes using a grid with a spacing of 2 km which covered the broader study area. For every point we combined the results that are based on estimations, with the observed macroseismic intensities, which were extracted from the data bank of macroseismic information (Papazachos et al., 1998). The final results (in MM scale) are presented in the map of Fig. 61, which shows the distribution of the maximum intensities based on the overlapping of the above mentioned results.

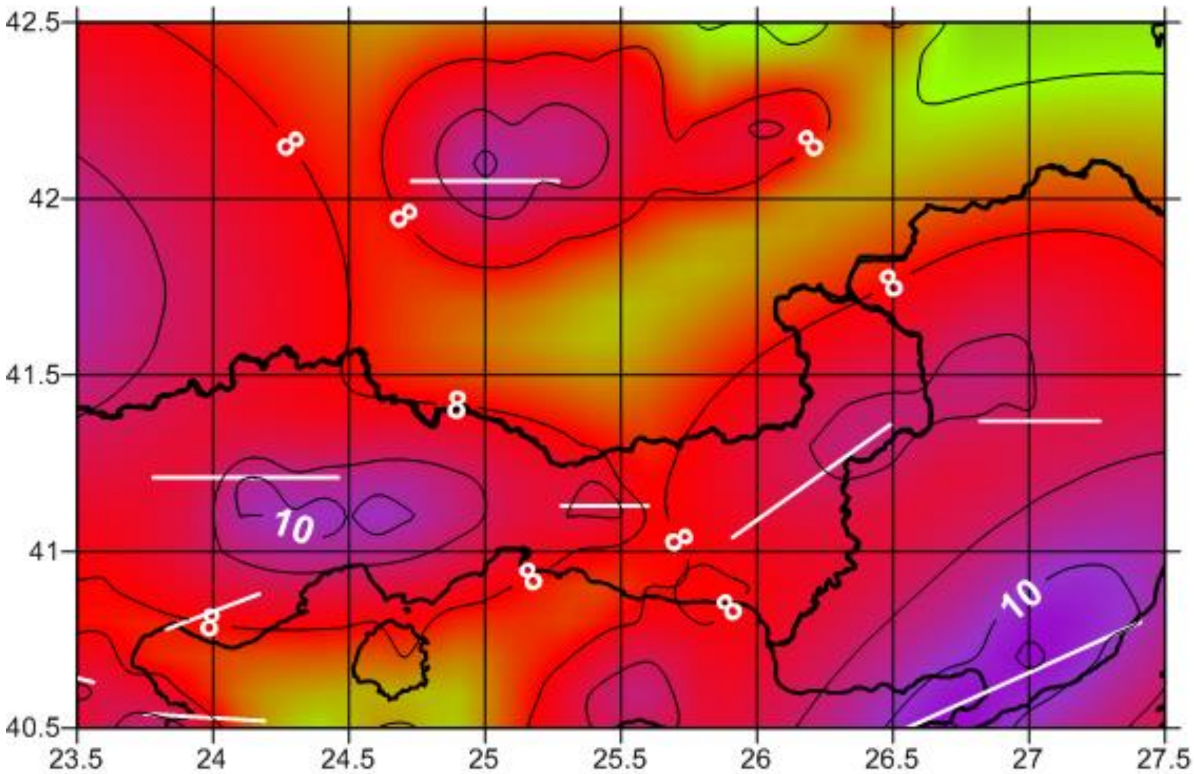


Fig. 61. Map depicting the geographical distribution of the maximum macroseismic intensities in the examined. The main faults of strong earthquakes (Papazachos et al., 2001) in the area are also shown.

4.3.5 INFORMATION OF EMPIRICAL PREDICTIVE RELATIONS OF HORIZONTAL PEAK GROUND ACCELERATION

Seismic hazard assessment is commonly based on empirical predictive attenuation relations. Such relations are generally expressed as mathematical functions relating a dependent variable to parameters characterising the earthquake source, propagation path and local site conditions. To date many attenuation relations for peak ground acceleration, velocity and displacement have been published based on ever increasing number strong motion data from the Circum Pacific region as well as from Europe and Middle East region.

Attenuation of strong ground motion in Greece in terms of peak ground acceleration, velocity and spectral pseudovelocity has been studied and relevant empirical models have been proposed for shallow earthquakes (Theodulidis and Papazachos 1992, 1994; Margaris et al. 2001, 2002, Tselentis and Danciu, 2008, 2010).

Recently, Skarlatoudis et al. (2003) proposed predictive relations for the attenuation of peak ground acceleration (PGA in cm/sec2), velocity (PGV in cm/sec) and displacement (PGD in cm) for shallow earthquakes in Greece of the general type:

$$\log Y = c_0 + c_1 M_w + c_2 \log\left(R^2 + h^2\right)^{1/2} + c_3 F + c_5 S \qquad (80)$$

$$\log Y = c_0 + c_1 M_w + c_2 \log\left(R + c_4\right) + c_3 F + c_5 S \qquad (81)$$

where Y is the strong motion parameter to be predicted, **M** is the moment magnitude, R is the epicentral distance, h is the focal depth of each earthquake, S is the variable accounting for the local site conditions and F is the variable referring to the effect of the faulting mechanism of the earthquakes in the predicting relations. Scaling coefficients c_0, c_1, c_2, c_3 and c_5 are to be determined from regression analysis. Coefficient c_4 in equation (11) accounts for saturation in the near field and is difficult to be determined directly by regression analysis on the available data given its strong correlation with scaling coefficient c_2, as it was shown using appropriate Monte-Carlo simulations (Papazachos and Papaioannou, 1997, 1998). For this reason value of c_4=6km was adopted from Margaris et al. (2002), that roughly corresponds to the average focal depth of the events used in the present study.

$$\ln Y = c_0 + c_1 M_W + c_2 \ln(R + r_0) + c_3 S + c_4 * F$$

and (82)

$$\ln Y = c_0 + c_1 M_W + c_2 \ln\sqrt{(R^2 + h_0^2)} + c_3 S + c_4 * F$$

where Y is the strong motion parameter to be predicted, M_w is the moment magnitude, R is the epicentral distance, S is a variable which takes the value 0 for the soil category B, 1 for the C and 2 for the D and F is a variable which is related to the faulting mechanism. Scaling coefficients c_0 , c_1 , c_2 , c_3, c_4 are to be determined from regression analysis. Coefficient r_0

accounts for saturation in the near field, while h_0 is known as “effective” depth of an event, that is, depth where seismic energy is released. Both equations are practically similar apart from the fact that the first has a simple term for distance and in the near field they give slightly different results.

The following pairs of attenuation relations were defined for horizontal PGA (cm/sec^2) and PGV (cm/sec):

ln PGA = 4.16+0.69Mw - 1.24 ln(R+6)+0.12*S+ 0.70 (83)

ln PGA = 3.52+0.70Mw - 1.14 ln (R2+72)1/2 +0.12*S+ 0.70 (84)

The last term gives the ±1 standard deviation of each relation.

The data set used consist of 1000 strong motion recordings, corresponding to 225, mainly normal and strike-slip faulting, shallow earthquakes in Greece. This data set was selected from the entire database of the available accelerograms in Greece (ITSAK: www.itsak.gr and NOA: www.noa.gr) that spans the period 1973-1999. The selected records satisfy at least one of the following criteria: (a) The earthquake which triggered the instrument should have a moment magnitude of **M**≥4.5, (b) The strong motion record should have a peak ground acceleration PGA≥0.05g, independent of the earthquake magnitude or, (c) The record can have PGA<0.05g but another record with PGA≥0.05g should be available from the same earthquake.

In Fig. 62 comparison of the horizontal PGA relations with those proposed by Ambraseys et al., (1996), for “rock” (S=0) soil conditions, is shown. For distances up to about 30km a good agreement is observed whereas for longer distances the latter relations give higher PGA values. Such a deviation may be due to different data sets used in regression analyses. For instance, Ambraseys used data from various seismotectonic environments that extend to long site-to-source distances.

Sabetta and Pugliese (1996) based on strong motion data from normal and thrust faulting-type earthquakes occurred in Italy, proposed horizontal PGA and PGV attenuation relations. In **Fig. 63** comparison of their horizontal PGA attenuation relation with those presented in this study, for “rock”(S=0) soil conditions, shows systematically higher values of the former. This difference may be due to the fact that Italian data come from both normal and thrust faulting events while the Greek data mainly from normal faulting. Spudich et al (1993) based on strong motion data from normal faulting earthquakes proposed horizontal PGA attenuation relation, that is compared with PGA attenuation relation of this study, for “rock”(S=0) soil conditions (Fig. 64). For magnitude Mw=6.5 there is good agreement between the two relations while for Mw=5.5 divergence mainly in long distances is observed.

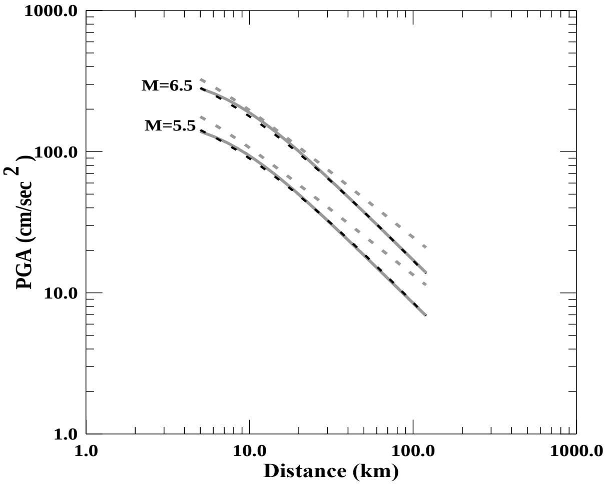


Fig. 62. Comparison of the PGA empirical relations, (11a) (grey continuous line) and (B) (black dashed line) with those proposed by Ambraseys et al (1996) (grey dashed line) for M=5.5 and 6.5 and rock soil conditions.

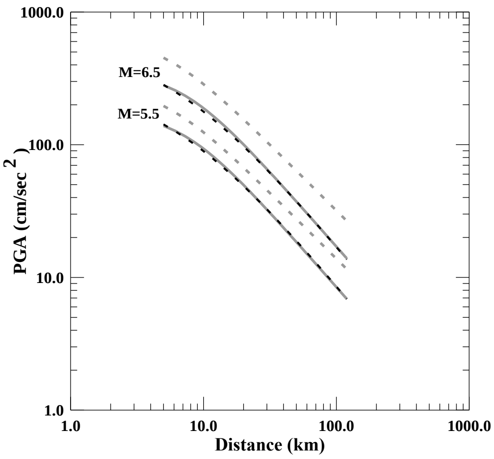


Fig. 63: Comparison of the PGA empirical relations Eqs. (A) (grey continuous line) and (B) (black dashed line) with those proposed by Sabetta and Pugliese (1996), (grey dashed line) for M=5.5 and 6.5 and rock soil conditions.

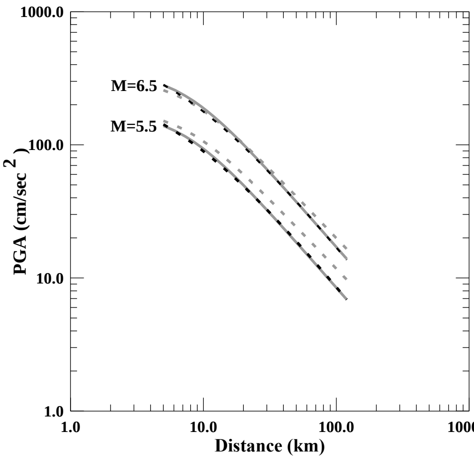


Fig. 64: Comparison of the PGA empirical relations Eqs. (A) (grey continuous line) and (B) (black dashed line) with those proposed by Spudich et al (1993), (grey dashed line) for M=5.5 and 6.5 and rock soil conditions.

Recently Skarlatoudis et al (2004) found that the attenuation of the small-to-moderate magnitude earthquakes in Greece show different pattern in comparison with the strong earthquakes. This observation must be taken into account especially in seismic hazard studies for areas affected by strong earthquakes with large mean return periods, where the adoption of one attenuation relation may result in overestimation of the results.

Fig. 65 shows a comparison of the predictive relations defined by Skarlatoudis et al (2004), with those proposed by Campbell (1989), Theodulidis and Papazachos (1992).and Skarlatoudis et al. (2003). All relations are scaled at the epicentral distance of 20 Km and plotted against magnitude. Skarlatoudis (2004) relation is plotted for site category C, using the classification proposed by NEHRP and UBC. Plotting against magnitude would reveal a proper definition of the scaling law that rules the predictive relations in low magnitude range. The expected results from this kind of comparison would be continuous curves for the entire range of magnitudes. On the contrary, they observed the existence of a "step" in the predicted levels of PGA around the magnitude of **M**=4.5, as can be seen in Fig. 65.

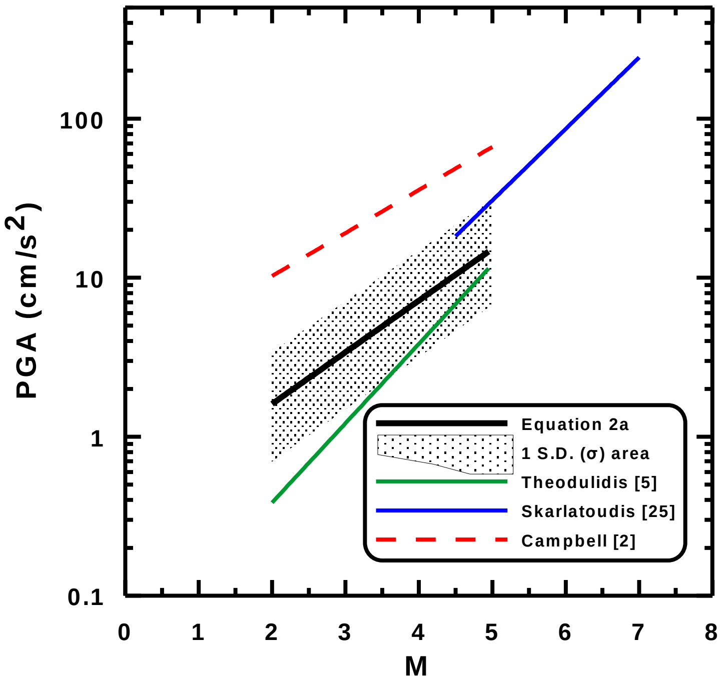


Fig. 65. Comparison of the PGA empirical relations (black continuous line), with those proposed by Campbell (1989) (red dashed line), Theodulidis and Papazachos (1992) (light green dashed) and Skarlatoudis et al (2003) (light blue continuous line) for epicentral distance R=20 Km.

This observation was taken into account in the calculations of the present work by modification of the computer codes used.

4.3.6 SEISMIC HAZARD ASSESSMENT

Every important decision concerning the evaluation of seismic loads imposed on manmade facilities is made using some form of seismic hazard analysis. In some cases, these analyses are informally conducted, with probability and likelihood assessed intuitively with subjective expert opinion. In instances involving complicated assessments of effects derived from various geo-science and engineering disciplines, decision makers often prefer formal assessments of probabilities of earthquake occurrences and associated natural effects that may produce damage to facilities and injury or life-loss to people. Such formal assessments are usually most appropriate for recommendations on regional or national seismic design requirements, earthquake evaluation of important facilities whose loss would imply substantial financial hardship to owners, estimation of earthquake damage and losses for emergency preparedness purposes and decision making regarding seismic safety of critical facilities.

There are two main approaches to assess seismic hazard, the deterministic and the probabilistic one. Recent efforts have considered five types of analyses that reflect the current usage. In the *type I, purely deterministic seismic hazard analysis,* one or more earthquakes are selected with only implicit consideration of their probabilities of occurrence. As example, it could be mentioned, the assignment of a maximum credible earthquake with specified magnitude and distance or the identification of a "characteristic" earthquake on a specified fault segment with specified source parameters. Probabilistic concepts enter in this analysis only in a simple form, such as scatter about an average ground-motion estimation curve. The *type II analysis, a semi-probabilistic seismic hazard analysis* takes into account one or more specific earthquakes, but, however the probability of occurrence is an explicit consideration in the selection of the earthquake. The *type III analysis, a single model of probabilistic seismic hazard assessment (PSHA),* differs sharply from type I and type II analysis techniques because in this case no specific earthquake is identified. In this case, a seismic hazard curve is produced that presents the annual probability that given levels of a ground-motion parameter will be exceeded at the site of structure. The *type III is called single model PSHA* because it employs only one model for the distribution of earthquake locations and magnitudes, and one attenuation model of the ground-motion parameter (Algermissen et al., 1982). Due to the uncertainty concerning the appropriate model to use for the spatial distribution and occurrence rates of earthquakes and for the attenuation of ground-motion with distance, an appropriate procedure is to consider alternative models and to calculate the hazard curve for each of these models. The variability of results illustrates the range of uncertainty on the hazard and this is the *type IV, multiple model of PSHA* (EPRI, 1986; Bernreuter et al., 1985a, b). Combinations of techniques might be desirable in a given situation. A hybrid method uses a type III and/or IV PSHA to characterize ground-motion probabilities and identify individual earthquakes that contribute the most to the seismic hazard. Then uses deterministic procedures to derive more detailed characteristics of the seismic hazard, including time histories of ground motion, that are available from a typical PSHA. This hybrid procedure can more effectively take advantage of recent advances in geological and seismological observations and physical modelling of the seismic source, wave propagation and site effects.

The results of PSHA are used by engineers, decision-makers, code-writers, risk managers and insurance entities, for a variety of purposes. To design and estimate damage to buildings, residences, and standard commercial facilities, a scalar characterization of ground motion and a minimum representation of uncertainty are often sufficient. A standard spectral shape can be anchored to the chosen scalar to obtain approximate, equivalent results for a range of structural periods of interest. Typically, ground motions with annual probabilities in the range of 10^{-1} to 10^{-3} are of interest to these facilities. For critical facilities (nuclear power plants, large dams, tunnels, etc.), a vector representation of ground motion is often required, including ground motion energy characteristics (Koliopoulos et al., 1998) at multiple frequencies and duration of strong shaking (Margaris et al., 1990; Papazachos et al., 1992; Koutrakis et al., 1999). For these critical systems, nonlinear models of structures may be used; appropriate realistic input motions for these models are required, and the PSHA must give sufficient information so that realistic motions can be derived for annual probability levels of 10^{-3} to 10^{-4} or lower.

In order to accomplish the main target of this report which s a reliable seismic hazard assessment of the examined area For this reason, an accurate definition of seismic sources is indispensable in order to estimate seismic hazard at the site, which is threatened by earthquakes generated in these seismic sources. Analytical works concerning seismicity and active tectonics have been accomplished in Greece and surrounding area that has been separated in seismogenic sources of shallow and intermediate depth earthquakes (Papazachos and Papaioannou, 1993; Papaioannou and Papazachos, 2000). Papazachos et al., (2001) defined the faults which are related to the nucleation of strong ($M \geq 6.0$) earthquakes since antiquity. Papaioannou (2001) proposed a hybrid model for the Aegean and surrounding area consisting of fault type sources according to Papazachos et al., (2001) and area type sources for the earthquakes with magnitude $4.0 \leq M \leq 5.9$. This model is useful for a reliable seismic hazard assessment at the examined site by the application of the method proposed by Cornell (1968) using the computer code FRISK88M (1996) properly modified. Using the aforementioned geographical distribution of the seismogenic sources in the area studied, the seismicity parameters of each source, the attenuation model of strong ground motion proposed the seismic hazard assessment was assessed for two mean return periods 476 and 952 years. The results are shown in Fig. 66and Fig. 67 and were made for "ROCK" site conditions.

The relation holding between the lifetime of a structure, t and the probability P_t. of occurrence of a given value of a seismic hazard parameter and the mean return period, T_m, is given by the relation:

$$T_m = -\frac{t}{\ln(1-P_t)} \tag{85}$$

For the Greek Seismic Code the calculations were performed for T_m = 475 years (which corresponds to lifetime, t=50 years and probability of exceedance P_t. =10%). This is valid also for the hazard maps of the EC8.

The maps in the Fig. 68 and Fig. 69 depict the geographical distribution of the mean PGA and the standard deviation values for the two return periods.

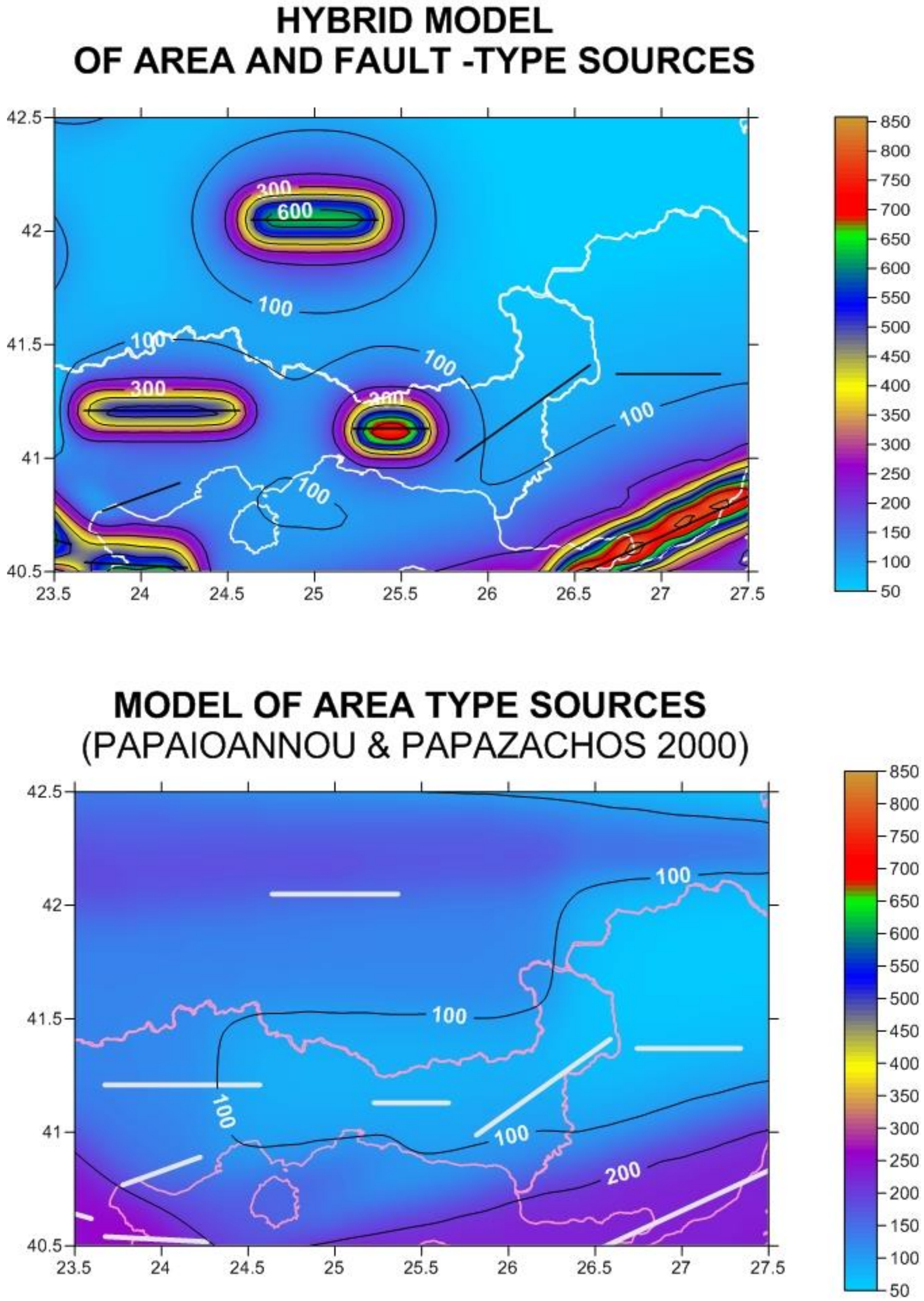


Fig. 66. Distribution of the PGA values (in cm/sec2) using the hybrid model of faults and area sources (upper map) and the area-type model of sources Papaioannou and Papazachos (2000) (bottom) for mean return period of 476 years.

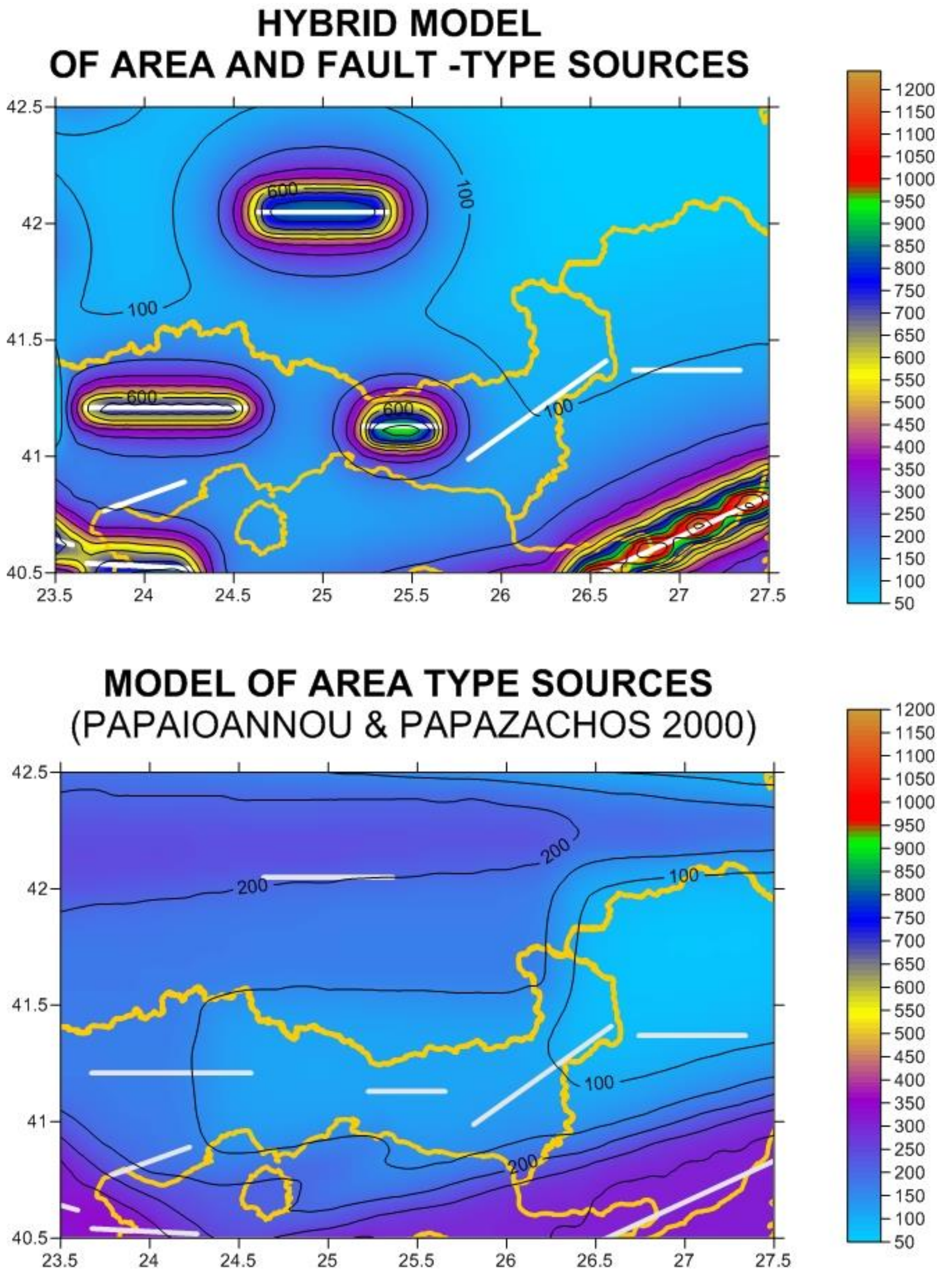
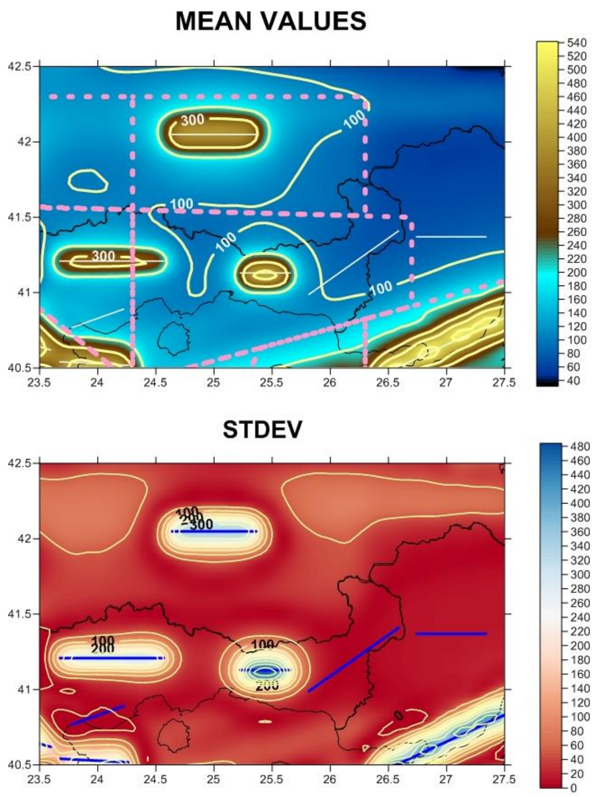


Fig. 67. Distribution of the PGA values (in cm/sec2) using the hybrid model of faults and area sources (upper map) and the area-type model of sources Papaioannou and Papazachos (2000) (bottom) for mean return period of 952 years.



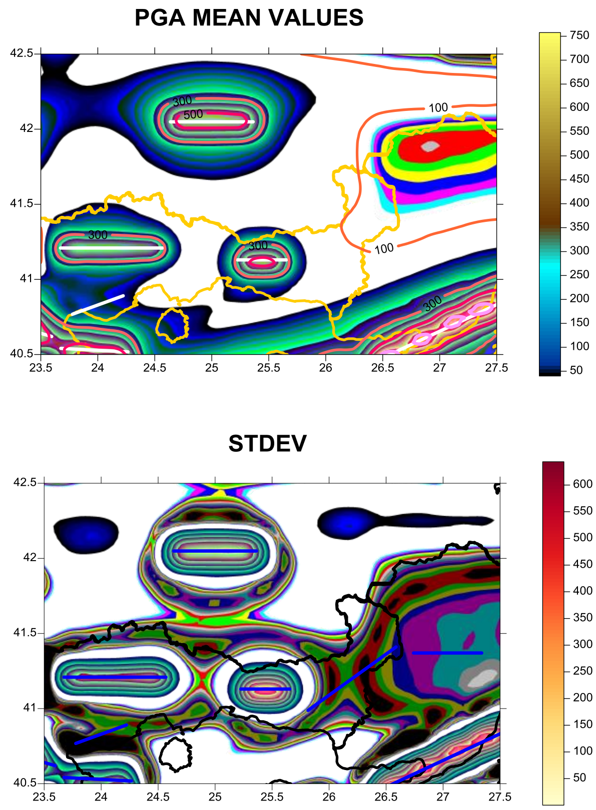


Fig. 68: Distribution of the mean PGA and standard deviation values for TM=476 years.

Fig. 69: Distribution of the mean PGA and standard deviation values for TM=952 years

All the maps were compiled using the licenced software SURFER and applying the Modified Shepard's Method. The calculation were made on a grid of points spaced 0.025^{O} x 0.025 ^{O} and considering a search radius of 0.50 $^{O.}$ The Modified Shepard's Method uses an inverse distance weighted least squares method, which results in the elimination or reduction of "bull's-eye" appearance of the generated contours. Modified Shepard's Method may extrapolate values beyond initial data's Z range.

Even though the application of the Papaioannou and Papazachos (2000) model (: PP2000 model) results in smoothed results compared the application of the Papaioannou (2002) (Pap2002 model), as it is clear from the maps in Fig. 66 and Fig. 67, however the latest seems to be more realistic. The high hazard values for sites located in the vicinity of faults influence the results appeared in the maps of Fig. 68 and Fig. 69 depicting the geographical distribution of the mean results .

Another approach for the seismic hazard is based on the statistical treatment of observed intensities. An example of this approach for the area is shown for the town of Alexandroupolis.

In order to apply this procedure is necessary to use a complete sample of macroseismic intensities which cover a long time window. The graphs in Fig. 70 show the intensity rate for

Alexandroupolis. We can assign various data completeness depending on the intensity level.

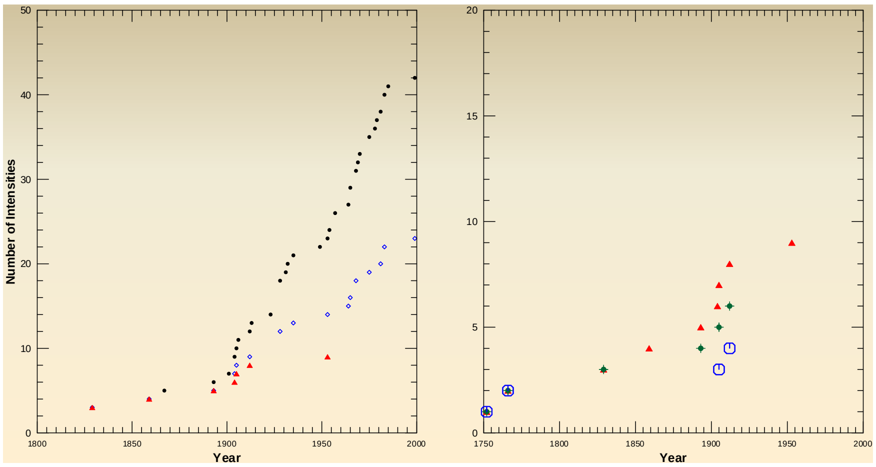


Fig. 70. Intensity rates for Alexandroupolis.

Using the complete sample of data we can examine the distribution of intensities as it is shown in Fig. 71

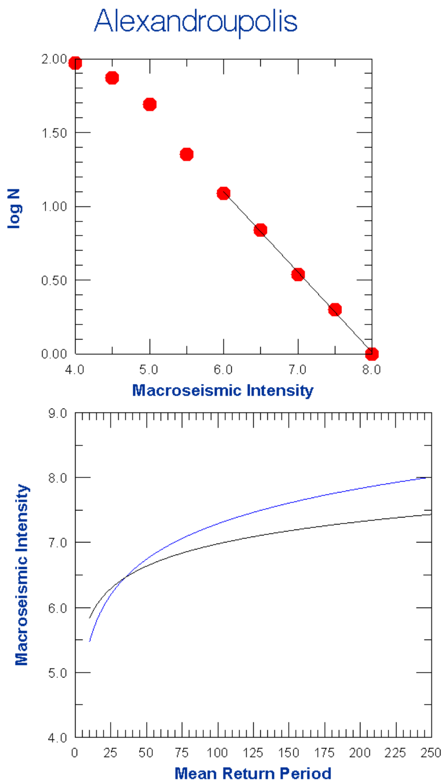


Fig. 71. Distribution of intensities and seismic hazard curve based on probabilistic approach of McGuire and statistical treatment of observed intensities

The comparison of the two hazard curves in Fig. 71 supports the idea that if a good complete sample of intensity values is used the results have no significant differences and these are within the errors of the intensity values.

The idea of using macroseismic intensity as another measure of the seismic hazard results is based on the approximation that the *Macroseismic Intensity* reflects the result of the overall all content of the seismic motion. This is shown in Fig. 72 by Anderson and Naeim (1984). The displacement of the model structure found to be much larger due to the 1979 Imperial Valley record compared to that of the 1940 El Centro record. The peak ground acceleration is the same 0.36g however the existence of a large pulse resulted in much greater displacements.

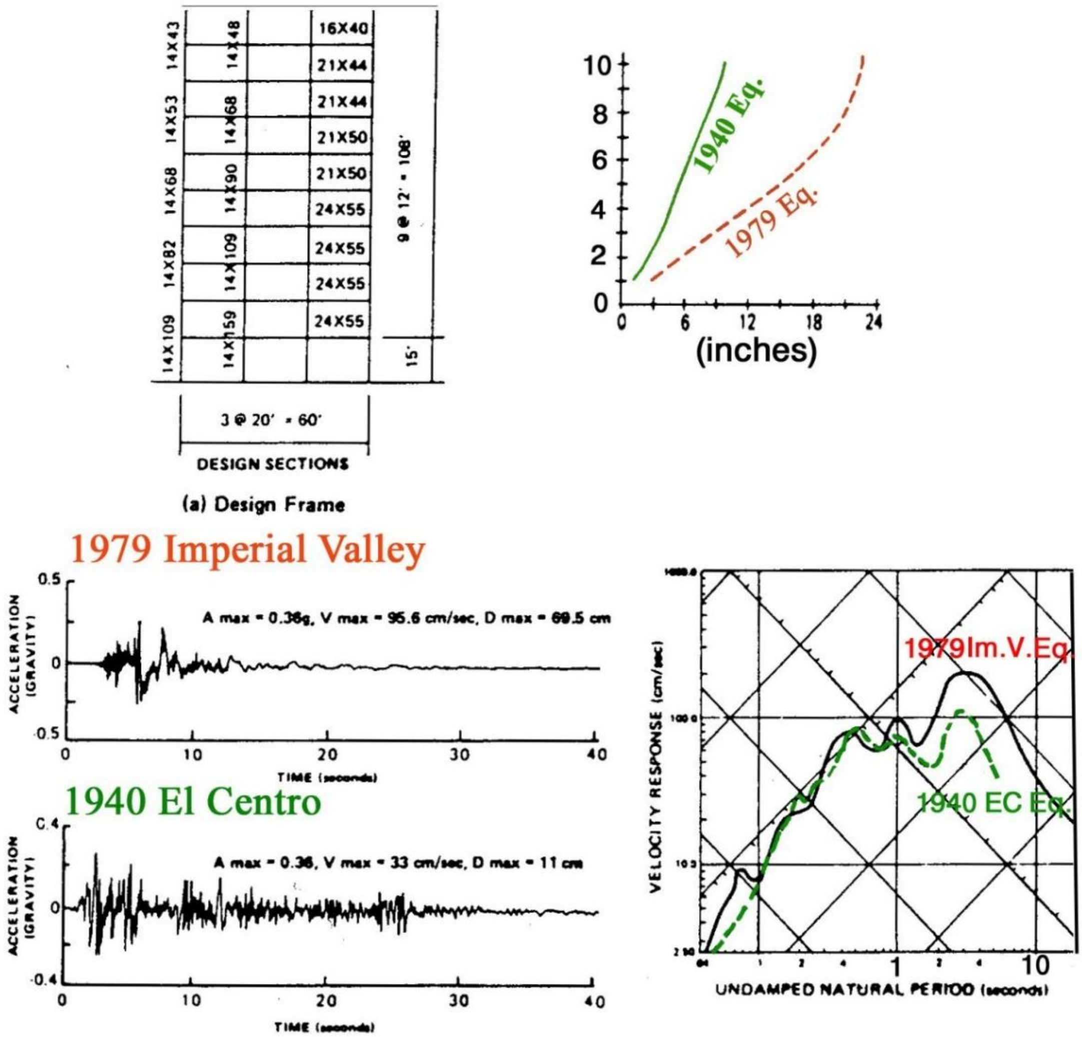


Fig. 72. Distribution of intensities and seismic hazard curve based on probabilistic approach of McGuire and statistical treatment of observed intensities

4.3.7 DISTRIBUTION OF MAXIMUM VALUES OF GROUND MOTION PARAMETERS

Another use of the elaboration of the macroseismic data is the complilation of maps depicting the maximum values of PGA or PGV on the basis of scalling relations holding between the macroseismic intensity and these parameters. For Greece relation of the type :

$$lnY = c_1 + c_2 I_{MM} + c_3 S + \sigma_{lnY} P \tag{86}$$

where holding between the parameter Y of the strong ground motion (PGA, PGV, PGD), as a function of the macroseismic intensity, I_{MM} and the site effect facctor, S. Relations of this type were proposed by Theodulidis (1991), Koliopoulos et al (1998) and Tselentis and Danciu (2008).

In order to compile these maps the scalling relations:

$$\begin{aligned} ln\, a_g &= 0.28 + 0.67 I_{MM} + 0.42S + 0.59P \\ ln\, v_g &= -3.02 + 0.79 I_{MM} - 0.04S + 0.70P \end{aligned} \tag{87}$$

proposed by Theodulidis (1991) were applied for PGA and PGV for the convertion of the values of the grid of map in Fig. 61 for “ROCK” type site conditions. The results for the mean values and the mean+1σ are presented in the maps of Fig. 73 and Fig. 74

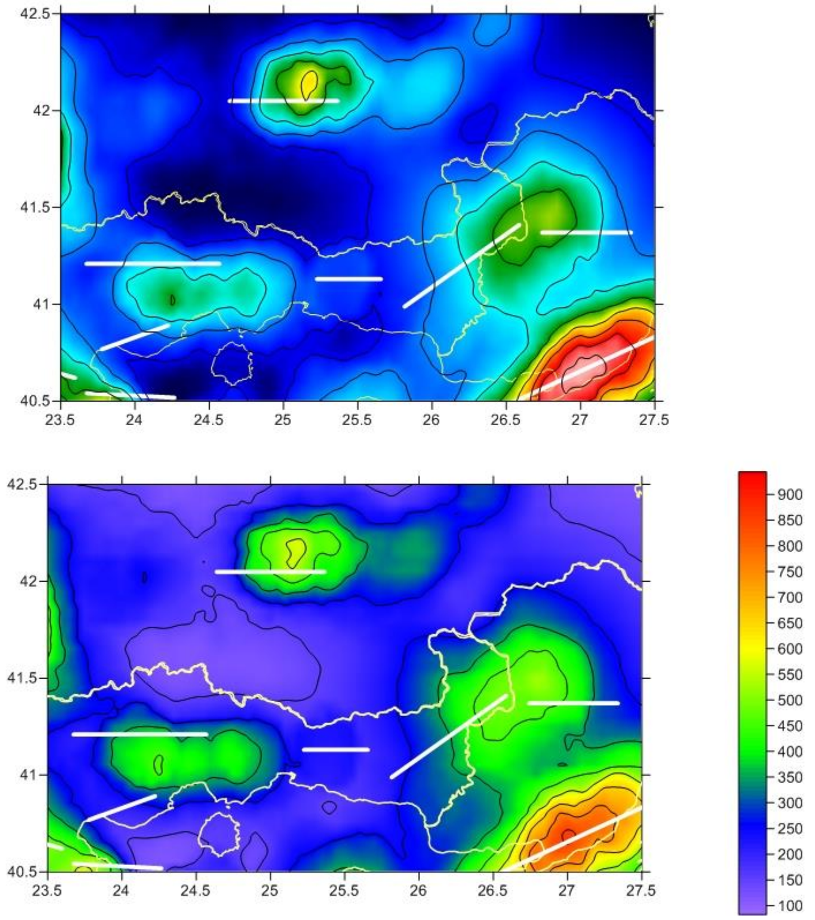


Fig. 73. Geographical distribution of mean and mean+1σ maximum PGA values from the conversion of known maximum intensities.

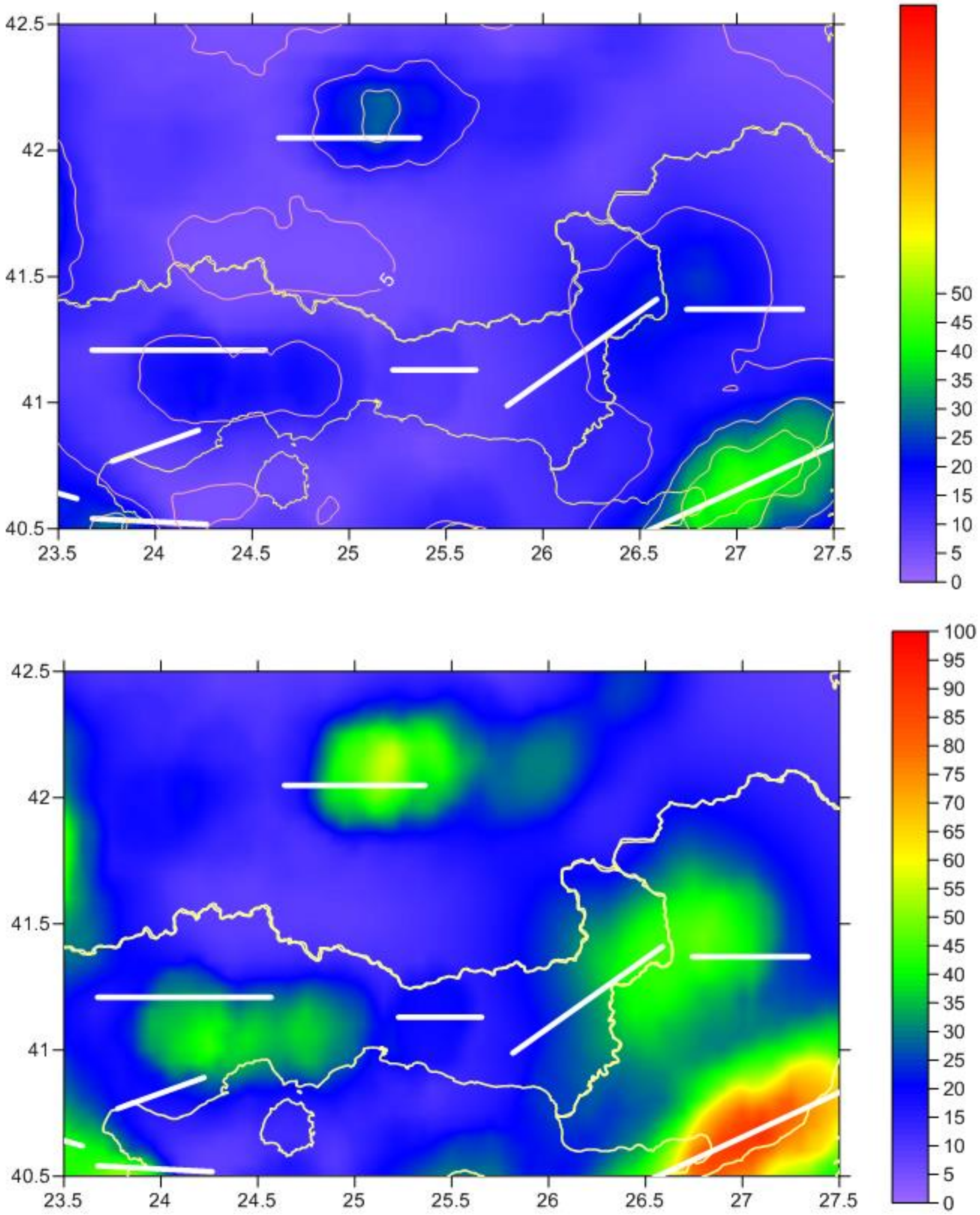


Fig. 74. Geographical ddistribution of mean and mean+1σ maximum PGV values using scalling relations for the conversion of known maximum intensities.

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4.4 TURKEY

In this activity, seismic hazard assessment at regional scale will be evaluated for the broader area of Samsun (Turkey), Tekirdağ and Istanbul (Marmara Region, Turkey) based on the selected methodology from GA1.

Samsun (Fig. 75.) is located on the Black Sea coast of Turkey with a population of 1,252,693 (2010). Its adjacent provinces are Sinop on the northwest, Çorum on the west, Amasya on the south, Tokat on the southeast, and Ordu on the east.

Fig. 75. Location of Samsun

Tekirdağ (Fig. 76) is located at the northern shores of the Marmara Sea , and approximately 10 km NNE of a large and well-developed geological structure peculiar to the strike-slip faulting.

The Istanbul-Marmara region of northwestern Turkey with a population of more than 15 million faces a high probability of being exposed to an earthquake of magnitude 7 or more.

Fig. 76. Location of Tekirdağ, and Istanbul

4.4.1 INTRODUCTION

Probabilistic seismic hazard analysis (PSHA) is a method used to evaluate seismic hazard by computing the probability of a specified level of ground motion being exceeded at a site or area of interest. In the most general sense, seismic hazard analysis aims to estimate the expected earthquake ground motion at a given site. This estimation can either be made in a deterministic or probabilistic manner.

The deterministic approach (properly, Deterministic Seismic Hazard Assessment – DSHA) is essentially based on the estimation of ground motion that would result from the so-called "scenario" earthquake(s), i.e., for the earthquakes that are estimated to produce most severe ground motion at a site. The probabilistic approach (properly, Probabilistic Seismic Hazard Assessment – PSHA), on the other hand, aim at assessing the probability that the ground motion parameter at a site due to the earthquakes from potential seismic sources will exceed a certain value in a given time period.

These basic steps of DSHA and PSHA are illustrated in Fig.77 and Fig. 78 for the determination of design basis response spectrum in terms of peak ground acceleration (PGA) only, and in terms several spectral acceleration amplitudes. For PSHA the latter case represents the so-called equi-hazard spectrum, where all the spectral acceleration amplitudes used in the construction of the spectrum have the same probability of exceedance.

The developments of the earthquake hazard assessment methodologies and accuracy have improved in parallel with growth in geo-tectonics and strong earthquake ground motion. However, the lack of data in these input parameters necessitates the use of assumptions and/or extrapolations especially for long return periods. These assumptions are important since they directly influence the uncertainty of the PSHA. To reflect the effect of the uncertainties on the PSHA the so-called "logic tree" analysis is used, where different alternative assumptions are combined with appropriate weights.

The earthquake hazard assessment is generally conducted for the free-field reference soil sites, generally chosen as the so-called "engineering bedrock" where the average shear wave propagation velocity in the upper 30m is less than about 750m/s (in US practice NEHRP Site Class B/C boundary). Site dependence of the response spectrum found through such an hazard assessment can be accomplished by using of site-dependent ground motion prediction equations, modifying on the basis of spectral modification factors (generally used in the earthquake resistant design codes) or by conducting rigorous site response analysis using a suite of spectrum compatible ground motion.

It has been an essential ingredient of collecting essentially involve information on neo-tectonics and seismicity of the region to enable the identification of seismic sources and distribution of earthquakes magnitudes in each source including the "maximum" earthquake potentials.

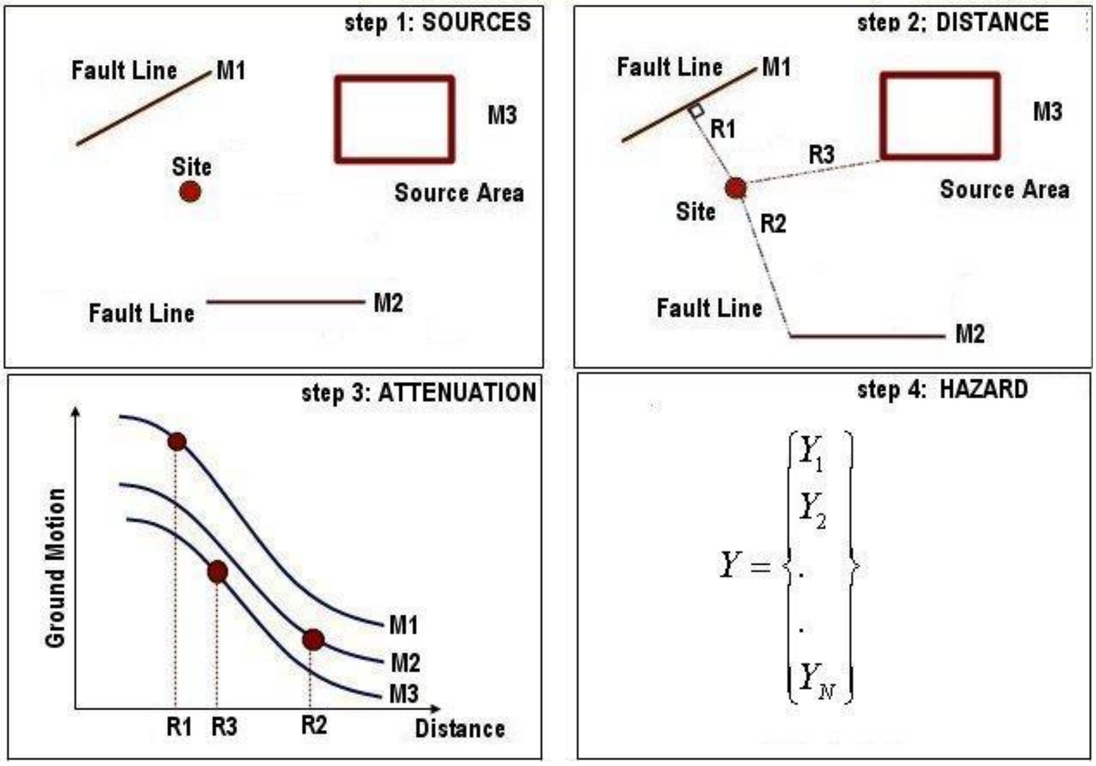

Fig.77. Basic steps of a deterministic seismic hazard analysis.

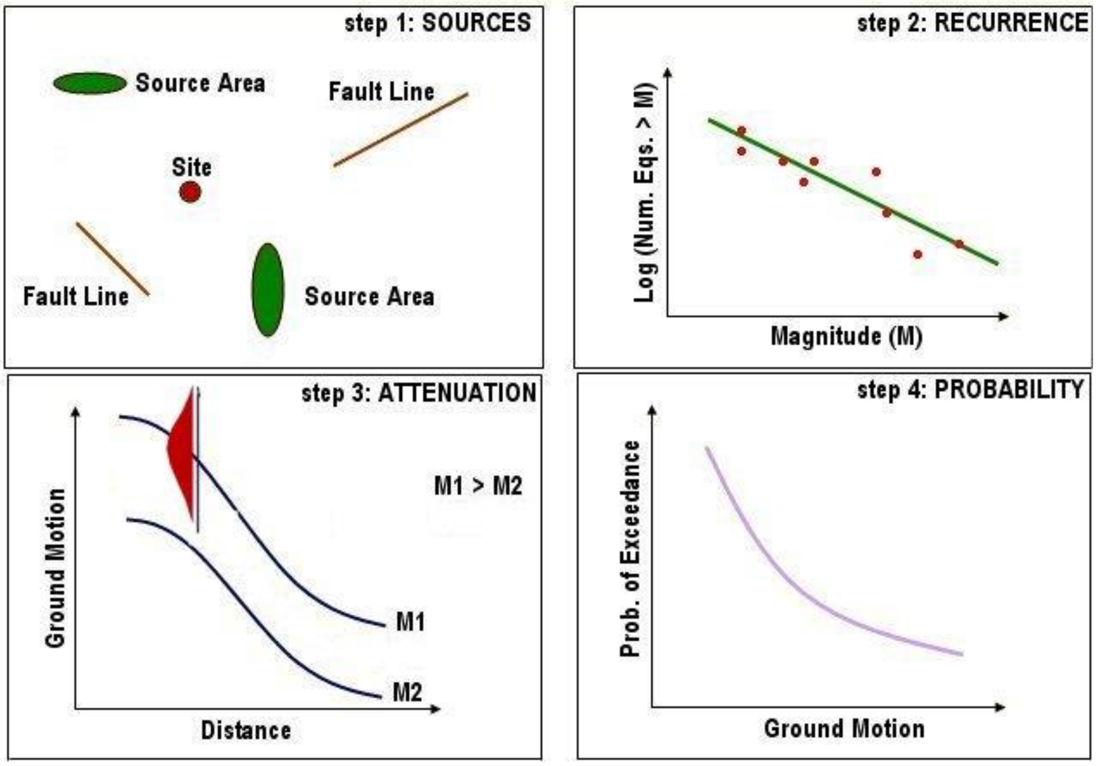

Fig. 78: Basic steps of a probabilistic seismic hazard analysis.

4.4.2 SEISMICITY

Data on the historical and instrumental seismicity of the region in question generally consist of the time of occurrence, source coordinates and magnitudes given in for several definitions. For large earthquakes these data are generally complemented by the so-called "macro seismic" data where information on the intensity distribution, damage and casualties are provided.

Attention should be paid to the cross-correlation of instrumental and historical earthquake data with the macroseismic information available. Uniformity in magnitude is generally implemented by converting all magnitudes to moment magnitude since the use of moment magnitude avoids the "saturation" of the more traditional band-limited magnitude measures at large seismic moments.

The data may be biased with respect to the reporting periods and magnitude ranges, and can only be considered to be homogenous for small magnitudes for the last several decades.

In the traditional probabilistic seismic hazard assessment (Cornell, 1968) only independent events are to be considered. To satisfiy this requirement earthquakes in the study region needs to be de-clustered by removing foreshocks and aftershocks from the seismicity databases in order to obtain a Poissonian distribution.

The seismicity distribution (i.e. epicentral maps) between 1000 and 2007 years time period for Turkey is given in Fig. 79.

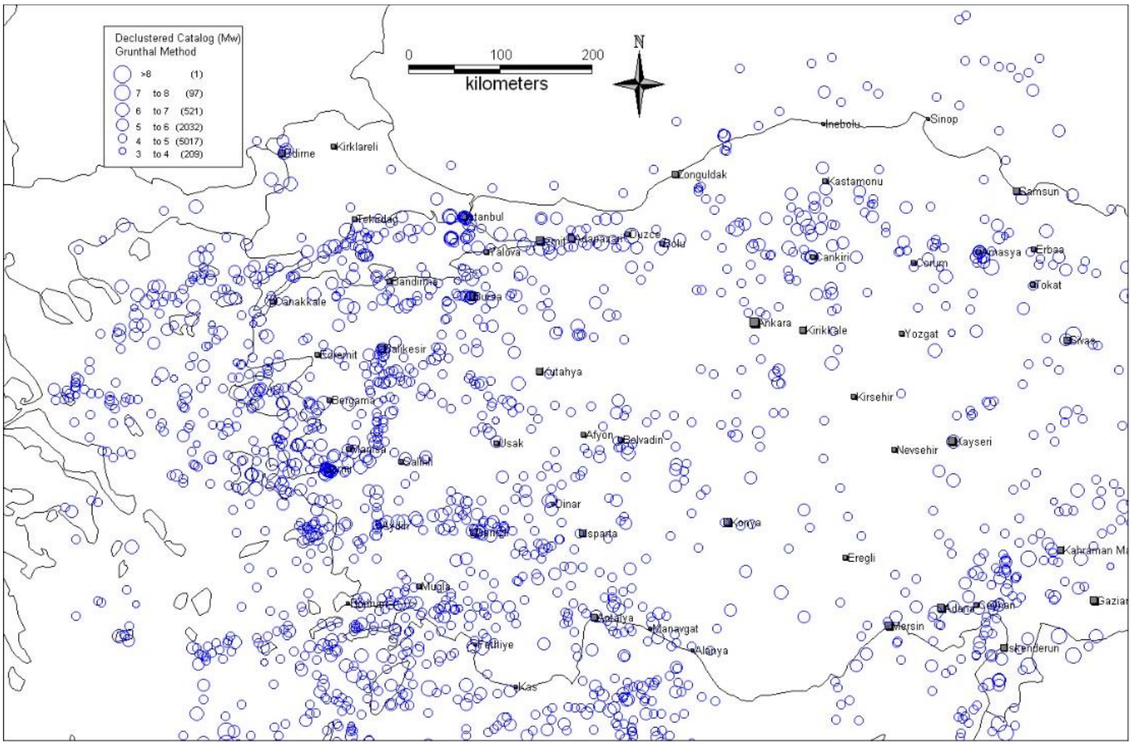

Fig. 79: Instrumental seismicity distribution for Turkey

4.4.3 TECTONICS OF THE REGION

Turkey is a tectonically active region that experiences frequent destructive earthquakes. In a tectonic map, Turkey lies within the Mediterranean sector of the Alpine-Himalayan orogenic system, which runs west east from the Mediterranean to Asia. Turkey is surrounded by three major plates: African, Eurasian, and Arabian, and is located on two generally acknowledged minor plates: Aegean and Anatolian, as shown in Fig. 80 (McKenzie, 1970). The relative motion between Eurasian, Arabian plates and the westward motion of the Anatolian-Aegean block is also illustrated in Fig. 81 (Armijo et al., 1999).

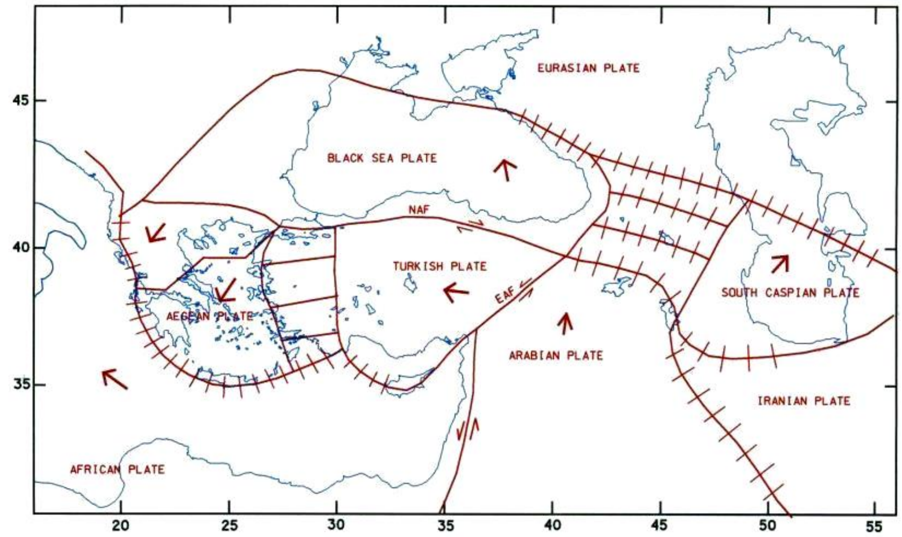

Fig. 80: Plate tectonics of the Eastern Mediterranean and Caucasus regions (after McKenzie, 1970)

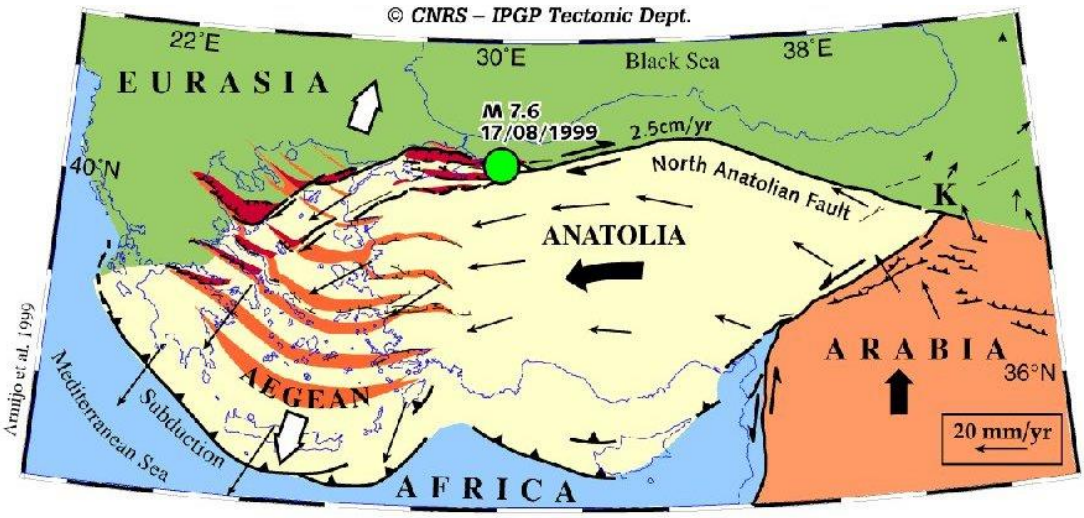

Fig. 81: The relative motion between Eurasian and Arabian plates and the westward motion of the Anatolian and Aegean blocks (Armijo et al., 1999)

GPS measurements carried out in Turkey during the period of 1988-1994 reveal valuable information about the rate of motion of the plates relative to one another in the region along major faults (Barka et. al., 1997; Barka & Reilinger, 1997). The results can be summarized as follows:

- Central Anatolia behaves as a rigid block and moves westward relative to Eurasia at about 15 mm/yr.
- Western Anatolia moves in a southwest direction at about 30 mm/yr.
- The Arabian plate moves northward with respect to Eurasia at a rate of 23±1 mm/yr, 10 mm/yr of this rate is taken up by shortening in the Caucasus The internal deformation in Eastern Anatolia caused by conjugate strike-slip faulting and E-W trending thrusts, including the Bitlis frontal thrust, accommodates approximately a 15 mm/yr slip rate.
- The Western Anatolian grabens take up a total of 15 mm/yr of the NE-SW extension.
- The African plate is moving in a northerly direction relative to Eurasia, at a rate of about 10 mm/yr.

4.4.3.1 Tectonic Setting of the Marmara Region

North Anatolian Fault Zone (NAFZ) extending in the Sea of Marmara have a more complex structure. Several researches have developed different tectonic models for NAF Marmara Sea region.

Le Pichon *et al.* (2001, 2003), Aksu *et al.* (2000), Imren *et al.* (2001), Gokasan *et al.* (2001), Kuscu *et al*. (2002), Alpar and Yaltirak (2002), and Demirbag *et al.* (2003) proposed that the NAF was composed of a pure right-lateral fault system along the trough of the Northern Marmara Sea. However, Armijo *et al.* (1999, 2002), Barka and Kadinsky-Cade (1988), Barka (1992), Stein *et al.* (1997), Okay *et al.* (2004), Parke *et al.* (2002), Flerit *et al.* (2003) and Polonia *et al*. (2004) proposed that the Sea of Marmara was a pull-apart basin formed by the right step-over between the strike-slip faults of Ganos and Izmit, further the normal faults in the Cinarcik Basin and the Central Marmara Sea were also active. Another alternative structural model is defined that NAF was composed of a pull a part system produced by fault segmentation, oversteps and slip partitioning (Armijo *et al.,* 1999; Armijo *et al.,* 2002; Barka and Kadisky-Cade, 1988; Barka, 1992; Stein e*t al.,* 1997; Okay *et al.,* 2000; Parke *et al*., 2002; Flerit *et al.,* 2003; Polonia *et al.,* 2004).

The North Marmara Basin is located by the conspicuous 70-km-wide step-over between two strike-slip faults, well-known on land, which have ruptured with purely right-lateral motion during recent earthquakes, both with similar magnitude (M 7.4) and clear surface rupture. One is the 1912 Ganos Earthquake that ruptured the Dardanelles region to the west of the

Marmara Sea; the second is the Izmit Earthquake that ruptured in 1999 east of the Marmara Sea. Pinar (1943) had previously drawn a single fault, bisecting the Gulf of Izmit and the three Marmara deeps. Thus, this fault was named "the Main Marmara Fault", which is located as an arc of great radius, going from Ganos to the entry of the Gulf of Izmit". Based on the recent high resolution bathymetric and deep-tower seismic reflection data set acquired by the MARMARASCARPS CRUISE in 2000, Armijo *et al*. (2005) found out that the surface ruptures formed by the 1912 Ganos (Sarkoy-Murefte) Earthquake reached the eastern end of Central Basin, and also the fault scarps associated with the 1894 earthquake could be estimated in the southern edge of the Cinarcik Basin Fig. 82.

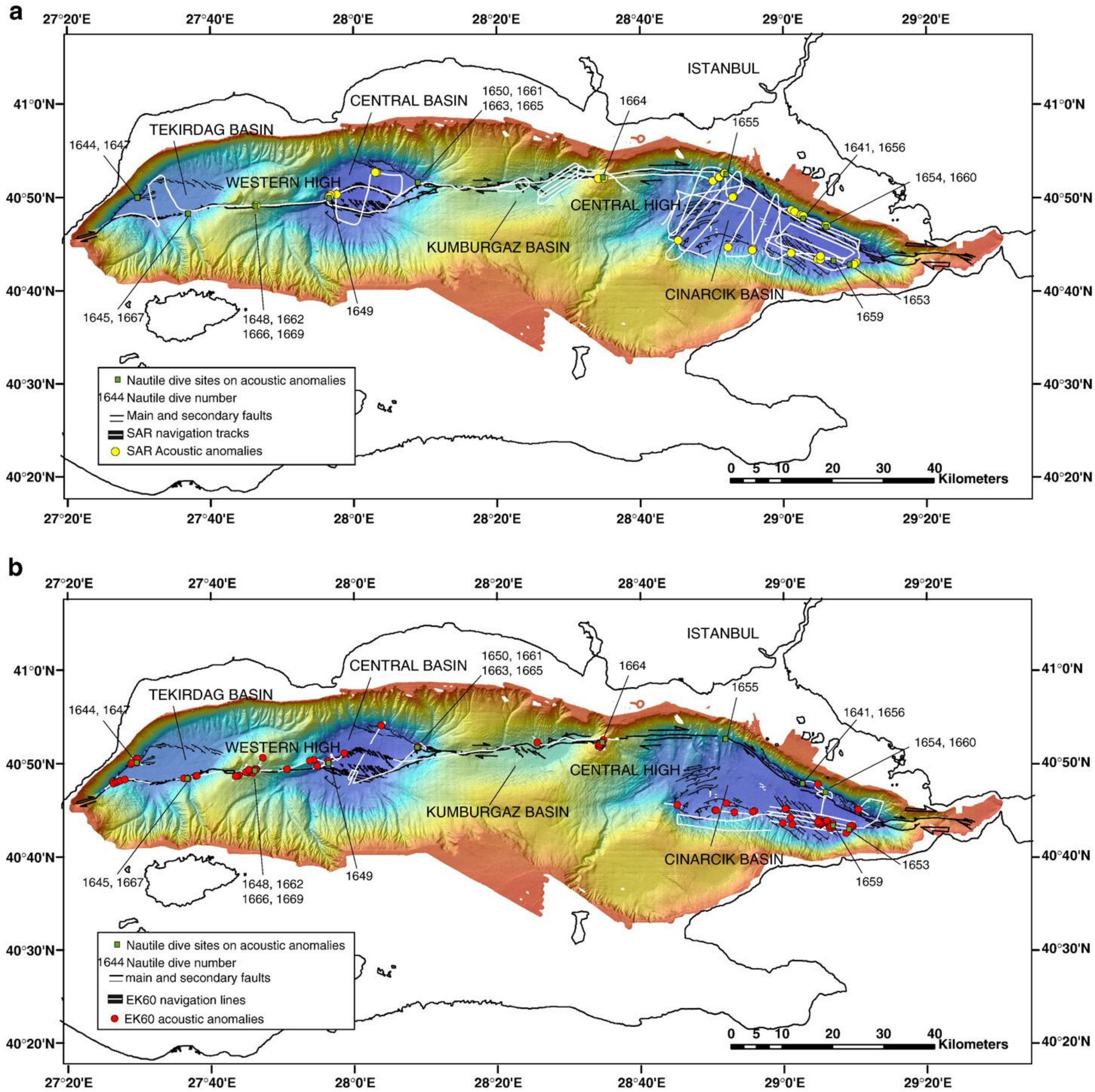

Fig. 82: Distribution of acoustic anomalies, superimposed on the bathymetric map (Rangin *et al*., 2001, Armijo *et al.*, 2002; 2005; Imren *et al*., 2001, Le Pichon *et al*., 2001) of the deeper parts of the Marmara Sea

In this study, we have used the fault segmentation model for the Marmara Sea region as shown in Fig. 89 (Erdik et al., 2004). This model is based on the tectonic model of the Marmara Sea, defining the Main Marmara fault, a thoroughgoing dextral strike-slip fault system, as the most significant tectonic element in the region. The segmentation provided relies on Le Pichon et al. (2001)'s discussion of several portions of the Main Marmara Fault based on bathymetric, sparker and deep-towed seismic reflection data and interprets it in terms of fault segments identifiable for different structural, tectonic and geometrical features. From east to west the Main Marmara fault cuts through Çınarcık, Central and Tekirdağ basins, which are connected by higher lying elements. The fault follows the northern margin of the basin when going through the Çınarcık trough in the northwesterly sense, makes a sharp bend towards west to the south of Yesilkoy, entering central highs, cuts through the Central basin and alternates in this manner until it reaches the 1912 Murefte-Şarköy rupture. All these features are interpreted as different fault segments in the model. The remaining segments of the model (e.g. for the eastern and southern Marmara regions) are compiled from various studies (Barka and Kadinsky-Cade, 1988; Şaroğlu et al., 1992; Akyuz et al., 2000; Yaltirak, 2002).

4.4.3.2 Tectonic Setting of Black Sea Region

The Black Sea is located between Ukraine, Russia, Georgia, Turkey, Bulgaria and Romania. It is a semi-isolated extensional basin surrounded by thrust belts. The structure of the basin is known mainly through the acquisition and interpretation of seismic data (Tugolesov *et al.*, 1985; Finetti *et al.*, 1988; Beloussov and Volvovsky, 1989). In terms of crustal structure, The Black Sea is formed of two deep basins Fig. 83. The western Black Sea Basin is underlain by oceanic to sub-oceanic crust and contains a sedimentary cover of up to 19 km thick. On the other side, the eastern Black Sea Basin is underlained by thinned continental crust approximately 10 km in thickness and up to 12 km thickness of sediments (Nikishin *et al.*, 2003). These basins are seperated by the Mid Black Sea Ridge which consists of the Andrusov Ridge in the north and the Archangelsky Ridge in the south (Fig. 84 & Fig. 85). The Andrusov Ridge is formed from continental crust and overlain by 5.–6. km thickness of sedimentary cover (Tugolesov *et al.*, 1985; Finetti *et al.*, 1988; Beloussov and Volvovsky, 1989; Robinson, 1997). The Archangelsky Ridge is bound to the south by the eastern Pontide belt, a complex terrane formed by a sequence of orogenic events during the Mesozoic and Cenozoic.

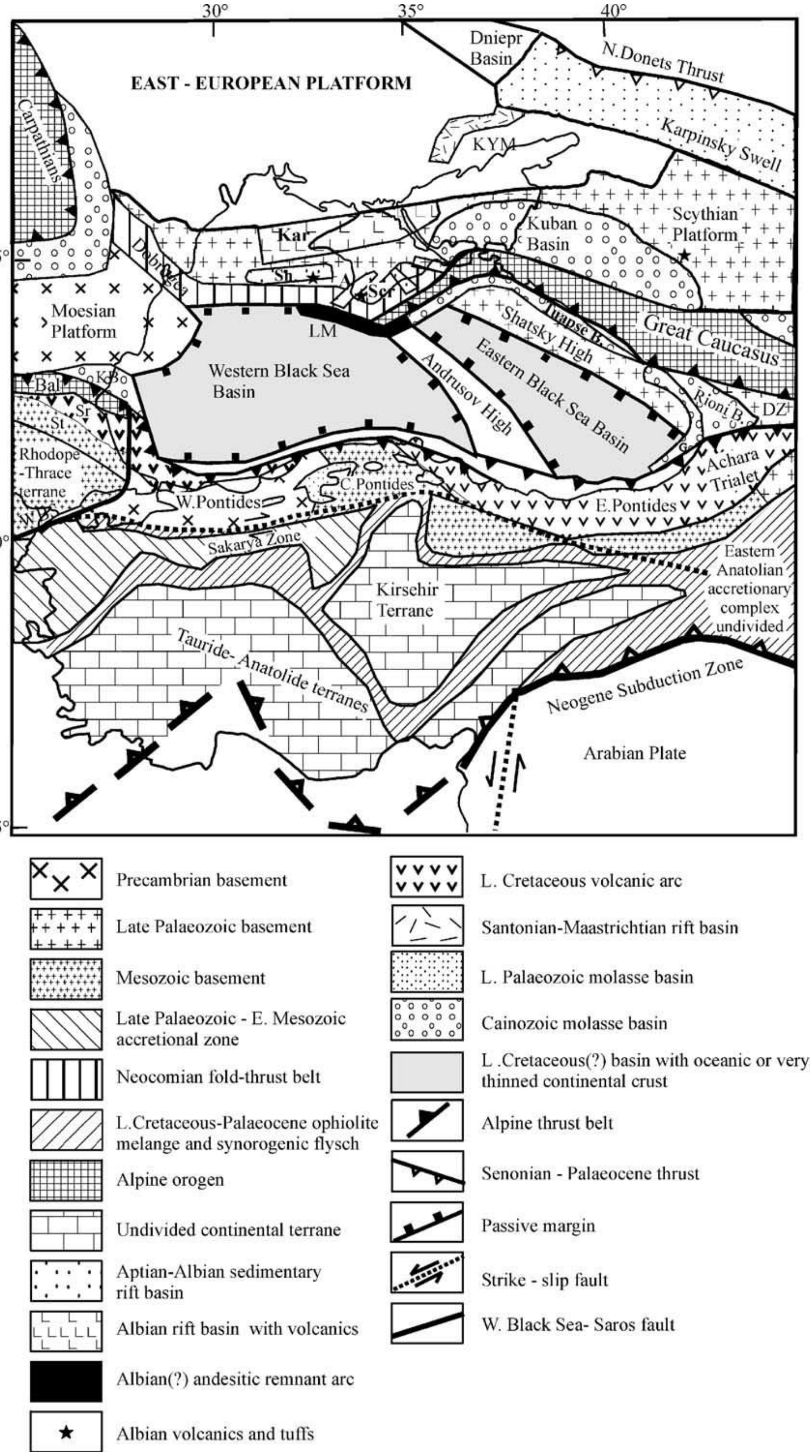

Fig. 83. Tectonic setting of the Black Sea Basin (Nikishin *et al.*, 2003)

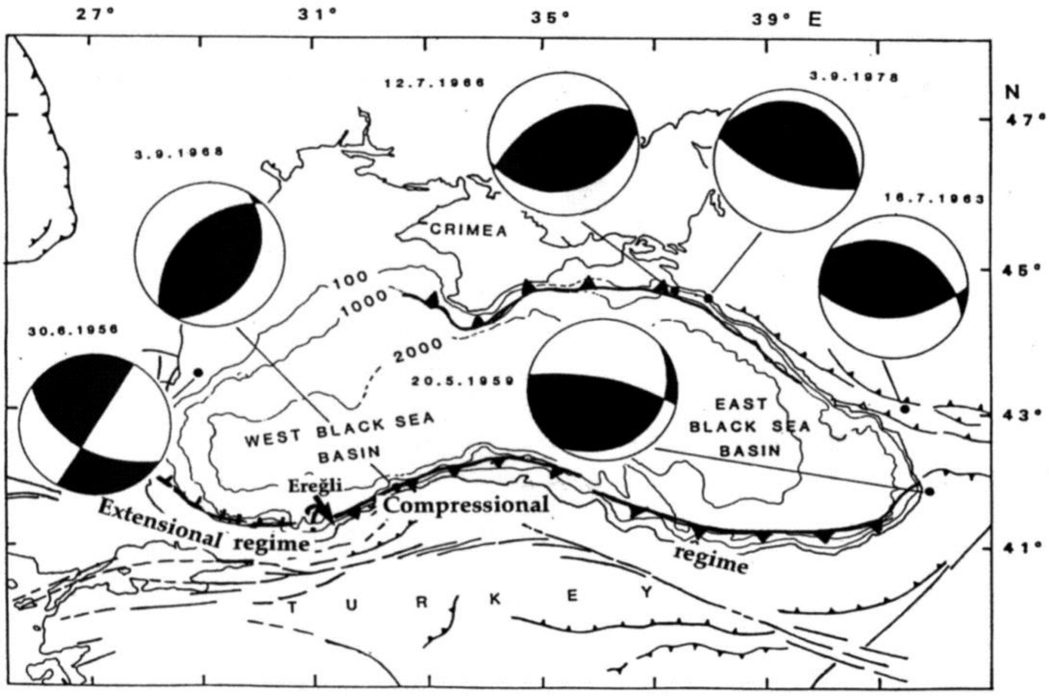

Fig. 84: Tectonics of the Black Sea (from Barka and Reilinger, 1997)

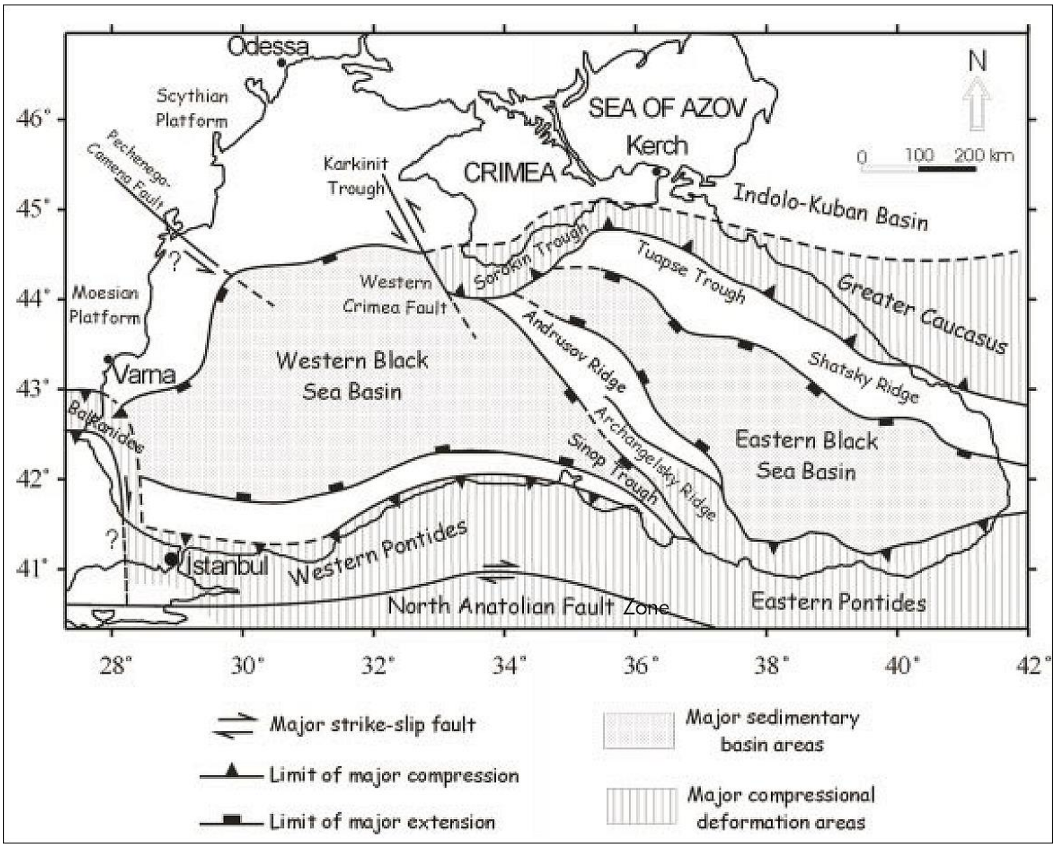

Fig. 85: Tectonic framework of the Black Sea region (after Temel and Ciftci, 2002)

The Black Sea region is known to be an area of active tectonics and seismicity Fig. 86 after Chekunov *et al.*, 1994). The central, deepest part of the Black Sea depression is believed to be relatively aseismic. Thus, when estimating seismic hazard, only continental slope and on-shore tectonic structures are considered as zones of strong earthquake generation (Medvedev, 1968). The seismic activity within the circum Black Sea is assumed as low-moderate for this century. The seismic activity is influenced by the extensional tectonics in the Western Anatolia. There is also a speculation that the lithosphere of the Black Sea and Caspian Sea form a resistant "backstop" diverting the impinging Anatolian Plate to the west and "funneling" the continental lithosphere of Eastern Turkey and the Caucasus around the eastern side of the Black Sea (McClusky *et al.*, 2000).

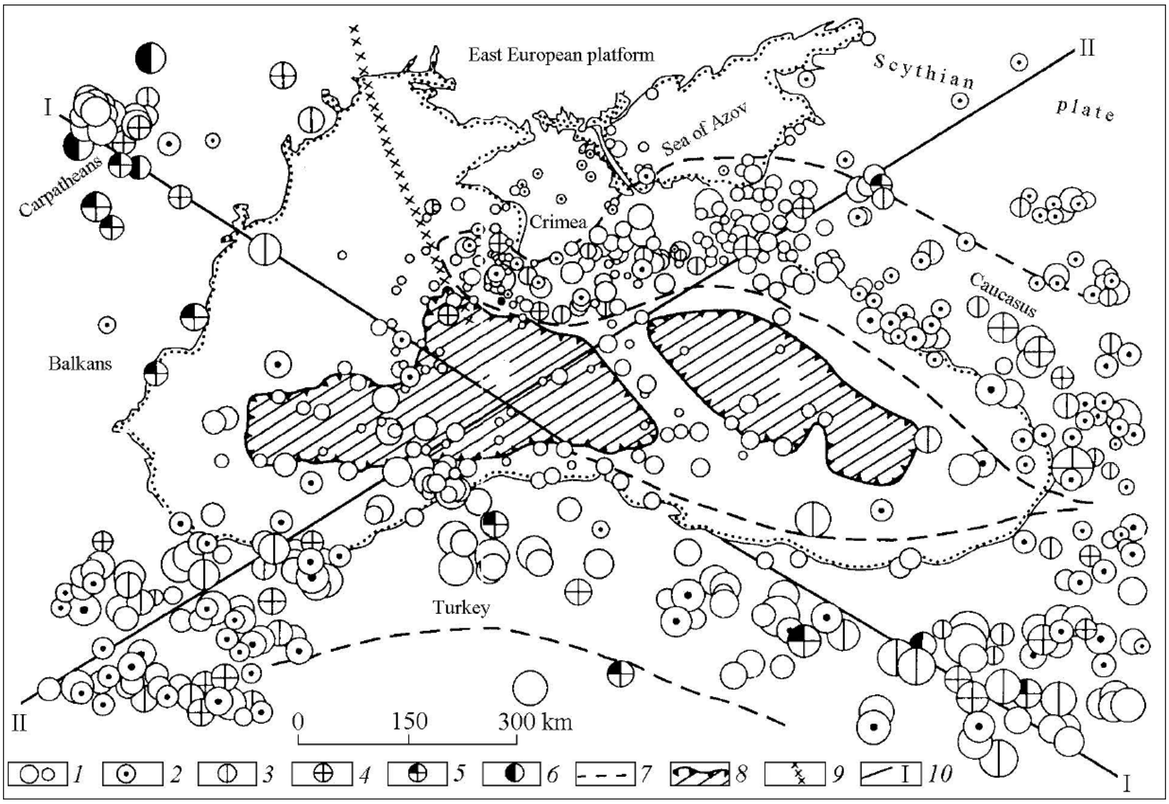

Fig. 86: Map of the Black Sea region and seismic zones (after Chekunov, 1994).

Meredith and Egan (2002) showed that deeper parts of southern margin of the Black Sea are dominated by extensional faults (Fig. 87Fig. 87). The Sinop Basin is located between the Archangelsky Ridge and the Turkish coastline and has been affected by normal faults along the Turkish margin and the Archangelsky Ridge (Rangin *et al.*, 2002).

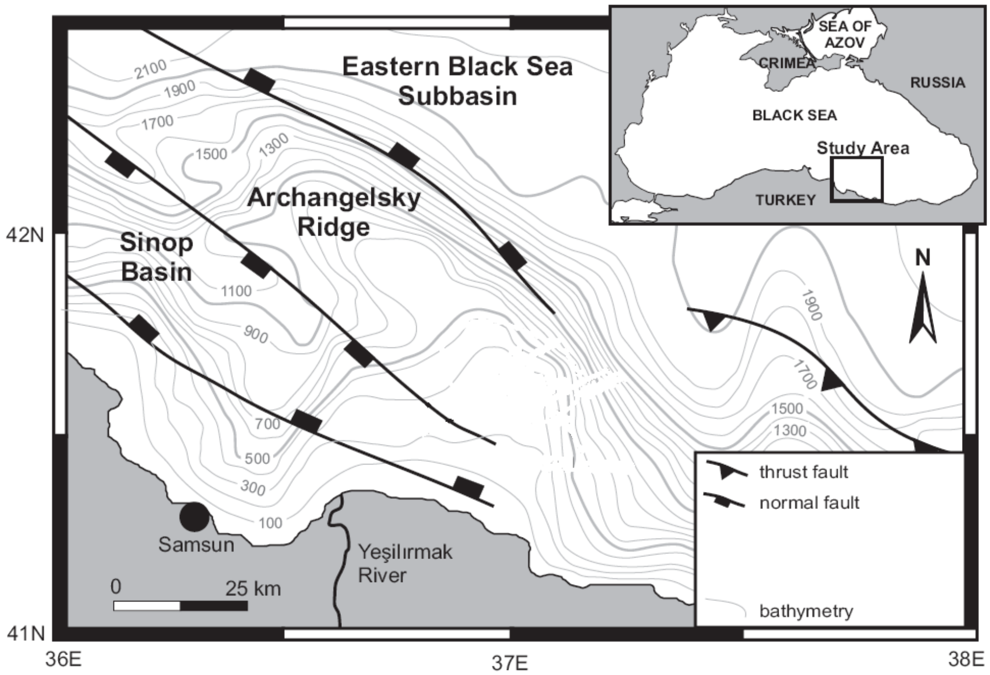

Fig. 87: Offshore faulting associated with the Black Sea Escarpment (after Dondurur, 2009).

The tectonic features of the Eastern Black Sea are indicated on Fig. 88The geological cross section along the profile A-A' is indicated on Fig. 88. These figures indicate the prominence of faulting in the Southern margin of the Black Sea.

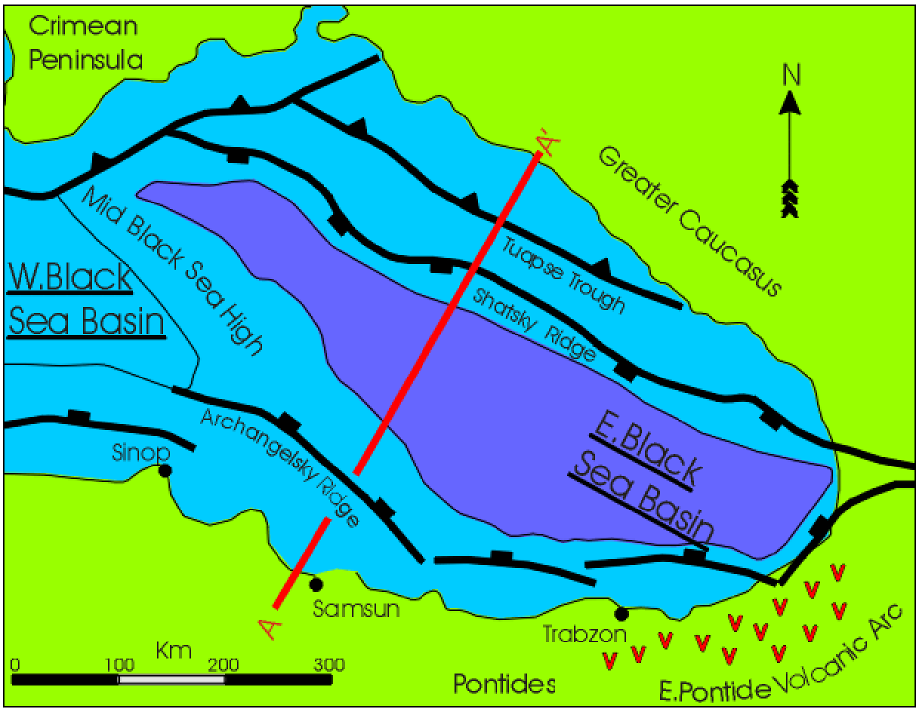

Fig. 88: Tectonic features of the Eastern Black Sea (after Egan, 2006)

4.4.4 SEISMIC SOURCE ZONATION

The first step in seismic hazard assessment (probabilistic and/or deterministic) is the identification and the delineation of earthquake sources (seismic source zonation) where the future events will take place. The seismicity-related source zone parameters are the appropriate earthquake recurrence model, recurrence rate (the so-called b value) and the maximum earthquake size.

Portrayal of the seismicity and the tectonics of a region provide the essential information towards the assessment of seismic source zones and the correlation of seismicity with the tectonic elements (seismo-tectonics) constitutes an important phase of the earthquake hazard assessment. Using geologic evidence of fault activity, macro-seismic locations of historic earthquakes and reliable instrumental locations of the more recent earthquakes assist in the modeling of seismic sources. The delineation of the individual source boundaries is generally based on boundaries of the neo-tectonic elements and sudden variations in the homogeneity of the seismicity. However, it is not always possible to compile detailed information in all these fields for the majority of the world. Thus, frequently, seismic source zones are determined with two fundamental tools: a seismicity profile and the tectonic regime of the region under consideration.

The earthquake sources may be characterized as discrete faults in tectonically active regions (fault sources) or as areal zones with uniform seismicity (areal sources). The geometric source zone parameters for areal and fault sources include the location, geometry, and for faults dip and width. Fault sources can be line sources (two dimensional) or planar sources (three dimensional) modeling the distribution of seismicity over the fault plane. Areal source zones are used to model spatial distribution of seismicity that cannot be specifically associated with major faults, background seismicity areas or in regions with unspecified faults. An areal seismic source zone is defined as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicenter of a future earthquake. Background seismic zones are areal sources that can be defined to account for floating earthquakes not accounted by these sources and also to delineate zones where no significant earthquake has taken place for centuries.

4.4.4.1 Seismic Source Zonation for Istanbul and Tekirdag (Marmara Region)

The earthquake hazard in the region is assumed to be the result of the contributions, computed in following two steps:

(1) Ground motions that would result from the earthquakes in the magnitude range from 5.0 to 6.9

(2) Ground motion that would result from larger events in the magnitude range 7.0 and higher.

Step (1) is termed as 'background source activity', i.e. the activity not associated with the main segmented tectonic entities. In this study, undelineated fault sources and small areal sources based on spatially smoothed historic seismicity are used as the background earthquake source.

Step (2) is related to the seismic energy release along well-defined and segmented faults. For this part the fault segmentation model that we used in the paper of Erdik et al. (2004) Fig. 89.

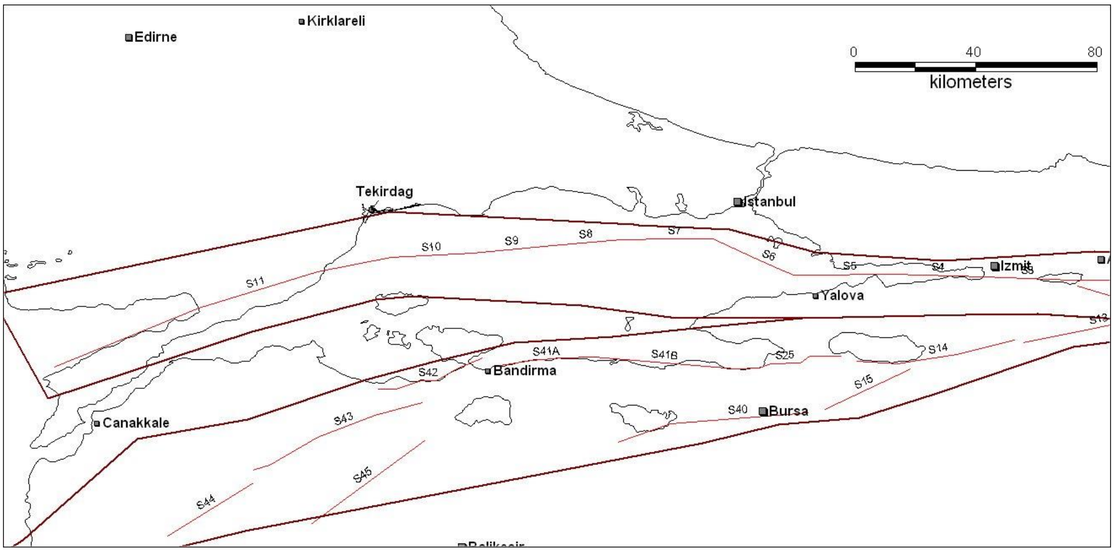

Fig. 89: Fault segmentation model proposed for the Marmara region (Erdik et al., 2004)

4.4.4.2 Seismic Source Zonation for Samsun Province (Turkey)

The seismic source zonation for Samsun province (Turkey) used in this study is essentially based on the seismic source zonation model of Turkey developed within the context of a project conducted for the Ministry of Transportion Turkey, DLH, aiming for the preparation of an earthquake resistant design code for the construction of railways, seaports and airports. The main improvement of this model when compared to previous studies (e.g., GHSAP, TEFER, Baku-Ceyhan Crude Oil Pipeline Projects) is the representation of main fault traces (such as the North Anatolian and the East Anatolian Faults) with linear sources. Previous models used only areal zones to define seismic sources. In order to account for the spatially more diffuse moderate size seismicity around these faults, widths of at least several kilometers were assigned to the zones even if the associated faults were well expressed on the surface. In the new model however, earthquakes with magnitude > 6.5 are assumed to take place on the linear zones, whereas the smaller magnitude events associated with the same fault are allowed to take place in the surrounding larger areal zone. In addition to linear and areal source zones background seismicity zones are defined to model the floating earthquakes that are located outside these distinctly defined source zones and to delineate zones where no significant earthquake has taken place Fig. 90.

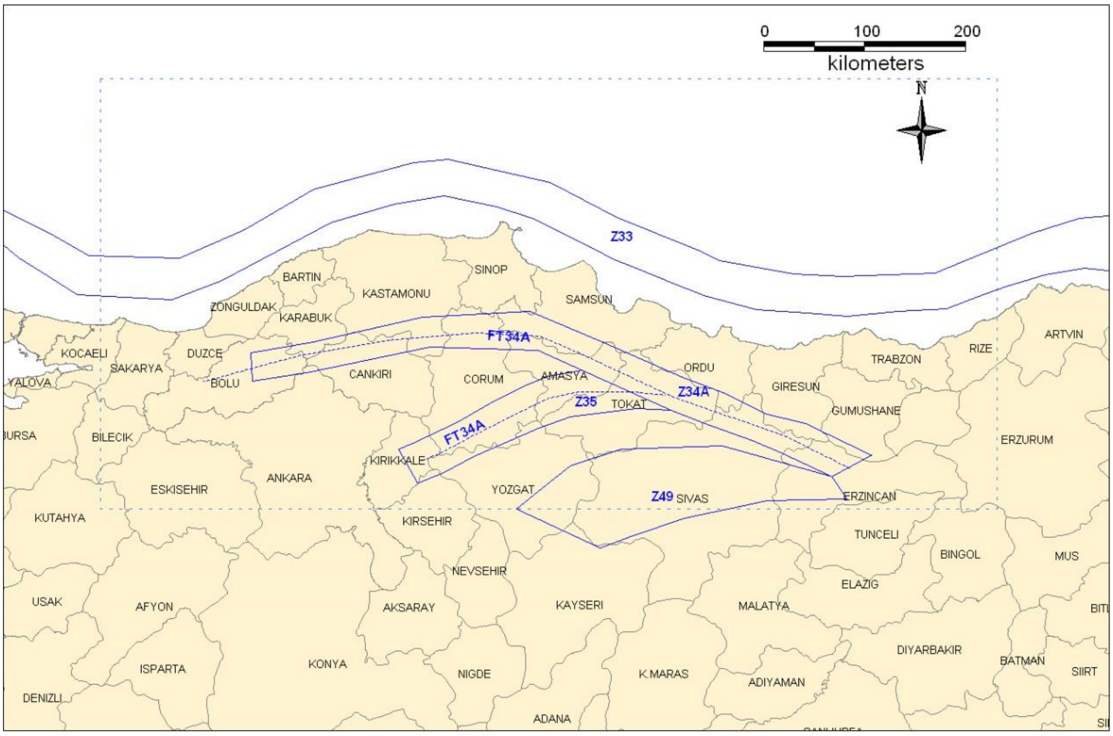

Fig. 90: A seismic source zonation for Samsun province (Turkey)

4.4.5 METHODOLOGY OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT

Two different methodologies have been used to compute the probabilistic hazard for Samsun (Turkey), and Istanbul, Tekirdag (Marmara Region). These are:

1. Time-dependent and Poisson approaches for the Marmara region
2. Poisson approach for Samsun Province (Turkey)

The study of Erdik et al (2004) forms the basis of the time dependent hazard model for the Marmara region. Earthquake occurrence and fault segmentation data in the Marmara region are adequate to constrain a time dependent characteristic model for the region. The results of the study indicate a lower future hazard for the region of the 1999 earthquake and a higher hazard for the Central Marmara Sea region corresponding to the unruptured segments of the Main Marmara Fault in the Marmara Sea, when compared to Poisson, so-called memory-less models. This finding is also in accordance with (Parsons et al, 2000) indicating heightened probabilities for a major earthquake in the Marmara Sea region based on stress transfer approach.

4.4.5.1 Time-Dependent Approach Used for Marmara Region

The use of a time-dependent probabilistic seismic-hazard model is felt to be needed for the assessment of probabilistic hazard in the Marmara region. In time-dependent models, the probability of earthquake occurrence increases with the elapsed time since the last major (or characteristic) earthquake on the fault that controls the regional earthquake hazard. In the case of the main Marmara Fault this earthquake is the 1999 Kocaeli event. This model is characterized by the recurrence-interval probability-density function of the characteristic earthquakes. Extensive paleoseismic and historical seismicity investigations on individual strike-slip faults (especially in California and Northwestern Turkey) indicate a quasi-periodic occurrence of characteristic earthquakes favoring the use of "time dependent" (or "renewal") stochastic models.

The methodology, elaborated in Erdik et al. (2003), is essentially very similar to the one developed and used by United States Geological Survey - WGCEP (http://geohazards.cr.usgs.gov/eq/index.html) for the preparation of US National Seismic Hazard Maps. The main physical ingredients of seismic hazard assessment are the tectonic setting of the region, the earthquake occurrences and the local site conditions. These regional physical features, the applicable attenuation relationships and the appropriate stochastic model for probabilistic hazard analysis will be discussed in the following sections

The time-dependent (renewal) model

While the Poisson process seems to be applicable in a global sense in a regional scale, extensive paleoseismic and historical seismicity investigations on individual faults indicate a somewhat periodic occurrence of large (characteristic) magnitude earthquakes that necessitate the use of "time dependent" (or "renewal") stochastic models (Schwartz and Coppersmith, 1984). The time dependent model is based on the assumption that the occurrence of large (characteristic) earthquakes has some periodicity. The conditional probability that an earthquake occurs in the next ΔT years, given that it has not occurred in the last T years is given by:

$$P(T,\Delta T)=\frac{\int_{T}^{T+\Delta T} f(t)dt}{\int_{T}^{\infty} f(t)dt} \tag{88}$$

where $f(t)$ is the probability density function for the earthquake recurrence intervals, T is the elapsed time since the last major earthquake and ΔT is the exposure period (taken as 50 years). Various statistical models have been proposed for the computation of the probability density function, such as Gaussian, log-normal, Weibull, Gamma and Brownian. Among those, the log-normal distribution is the most commonly used in the engineering practice. The Brownian Passage Time model is a more recently proposed model and is also assumed to adequately represent the earthquake distribution (Ellsworth et al., 1999). The log-normal and Brownian Passage Time models are compared in the following sections.

For the renewal model, the conditional probabilities for each fault segment are calculated. These probabilities are said to be conditional since they change as a function of the time elapsed since the last earthquake. A lognormal distribution with a covariance of 0.5 is assumed to represent the earthquake probability density distribution. The 50 year conditional probabilities thus calculated are converted to effective Poissonian annual probabilities by the use of the following expression (WGCEP, 1995):

$$R_{eff} = -\ln(1 - P_{cond}) / T \tag{89}$$

Earthquake recurrence parameters for the fault segmentation model

The association of historical earthquakes with the segments of the model is accomplished by a critical review of the literature on the historical seismicity of the Marmara region. The sesimicity information from two of these studies, Ambraseys and Finkel (1991) and Hubert-Ferrari (2000) are presented in Fig. 91 and Fig. 92 respectively.

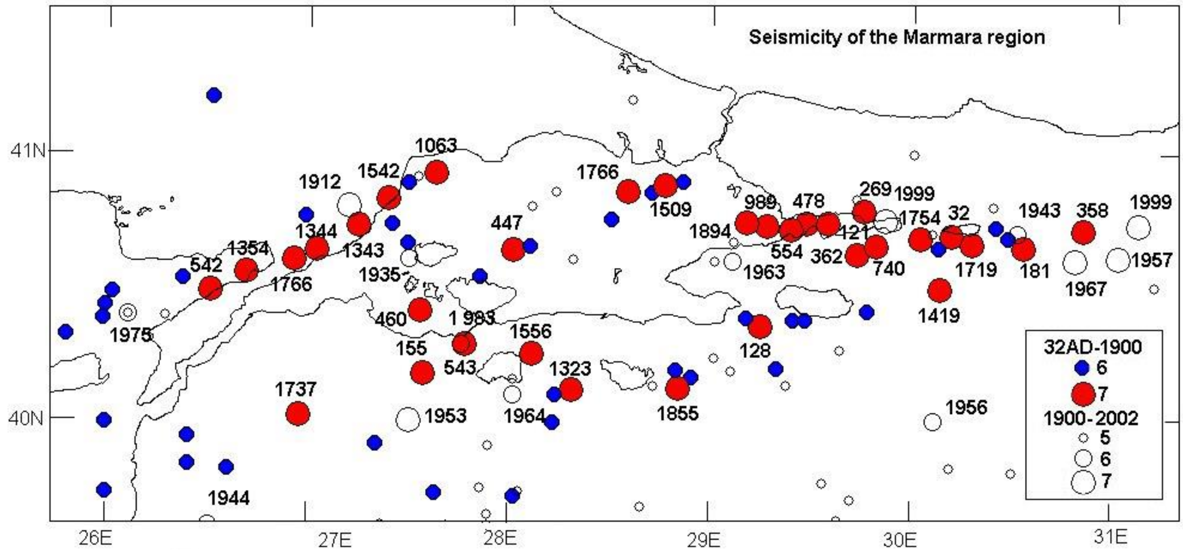

Fig. 91: The long-term seismicity of the Marmara region (Seismicity between 32 AD –1983 taken from Ambraseys and Finkel, 1991).

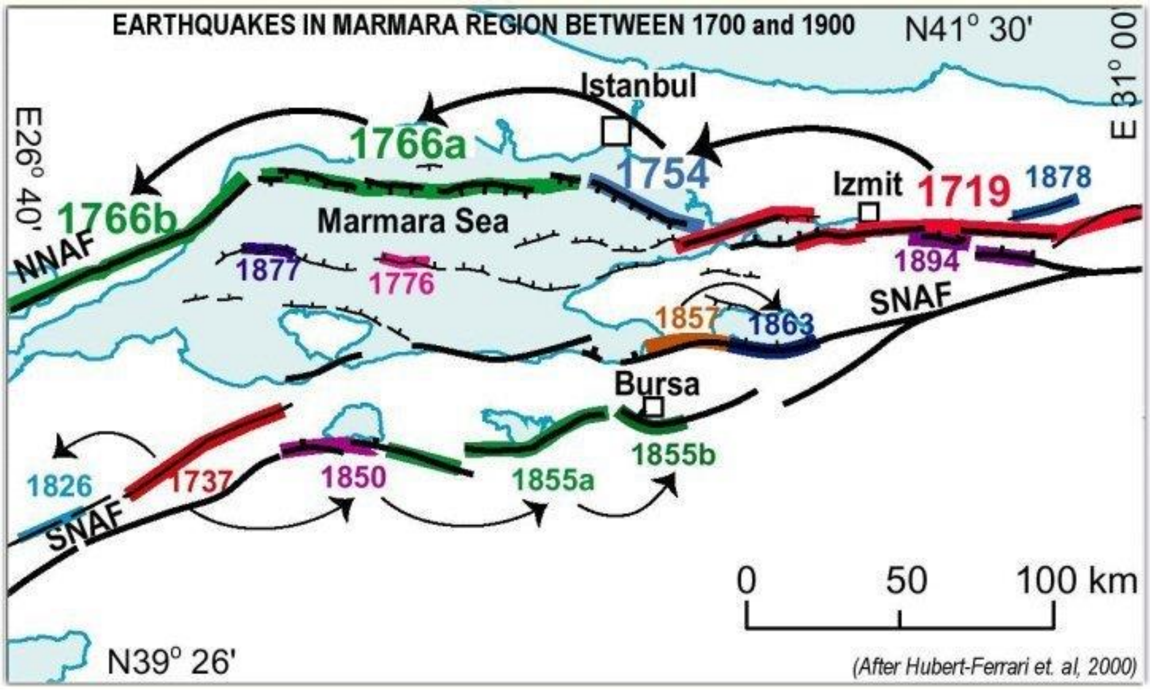

Fig. 92: The sequence of earthquakes in the 18th century around Marmara region (after Hubert-Ferrari, 2000).

4.4.5.2 The Time-Independent (Poisson) Approach Used for Samsun Province (Turkey)

The time-independent probabilistic (simple Homogeneous Poissonian) model was used to assess the seismic hazard in the remaining regions of the Turkish territory. For the earthquake events to follow that model, the following assumptions are in order:

1. Earthquakes are spatially independent;
2. Earthquakes are temporally independent;
3. Probability that two seismic events will take place at the same time and at the same place approaches zero.

The historical and instrumental seismicity, tectonic models and the known slip rates along the faults constitute the main ingredients of the hazard analysis. Seismic zonation has been implemented in three levels. The first level consists of linear faults representing the North Anatolian Fault (NAF), the north and east branches of NAF in the Marmara region, Bitlis – Zagros Suture Zone, Hatay Fault, Ezinepazari Fault, East-Anatolian Fault, Goksun Fault, Ecemis Fault, Tuzgolu Fault, Eskisehir Fault Zone, Simav-Sultandağ Fault Zone, Fethiye-Burdur Fault Zone, Gokova Fault Zone, Menderes Fault Zone, Gediz Fault Zone and Bergama Fault Zone. It is assumed that seismic energy along the line-segments is released by characteristic earthquakes, therefore the earthquakes with magnitude Mw≥ 6.5 are associated with these line sources. The second level consists of limited areal zones around these linear segments assuming that earthquakes with magnitude Mw< 6.5 may take place within this zone. Smaller en-echelon and/or diffused faults were assumed to be encompassed in these zones. The third level considers the background seismicity, which represents the diffused seismicity that cannot be associated with known faults.

The recurrence relationship of the events is expressed with the help of the empirical relationship first defined by Gutenberg - Richter: $\log N = A - bM$ where N is the number of shocks with magnitude greater or equal to M per unit time and unit area, and A and b are constants for any given region. The source regions may be described as lines representing the known faults or areas of diffuse seismicity, so that M may be related to unit length or unit area. The value of N will also generally be found assuming that M has upper and lower bounds M1 and Mo.

Using an application of the total probability theorem the probability per unit time that that ground motion amplitude a* is exceeded can be expressed as follows (McGuire, 1993):

$$P[A > a^* \text{in time t}]/t = \sum_i v_i \int\int G_A\big|_{m,r}(a^*) f_m(m) f_r(r|m) dmdr \tag{90}$$

where $P[I \le i|m,r]$ is the probability that the maximum effect I is less than i. Given m and r, $f_m(m)$ is the probability density function for magnitude, and $f_r(r|m)$ is the probability distribution function for distance. $f_r(r|m)$ is dependent on the geometric nature of the source.

The seismic zonation model developed in accordance with the Poisson approach is given in Fig. 78.

4.4.5.3 Earthquake Recurrence Models for Marmara Region

The earthquake recurrence parameters for each fault segment Fig. 89 are calculated by the procedures described in the previous section and presented in Table 4.2. All these parameters that used in the paper of Erdik et al, (2004) are updated based on the current year.

Table 4.2. Poisson and renewal model characteristic earthquake parameters associated with the segments

Segment	Last Char. Eq.	“cov”	Mean Recurrence Time	Char. Magnitude	Time since Last Char. Eq.	Time dependent (Renewal) 50year Prob.	Time dependent (Renewal) Annual Rate	Poissonian Annual Rate
1	1999	0.5	140	7.2	15	0.08260	0.00172	0.0071
2	1999	0.5	140	7.2	15	0.08260	0.00172	0.0071
3	1999	0.5	140	7.2	15	0.08260	0.00172	0.0071
4	1999	0.5	140	7.2	15	0.08260	0.00172	0.0071
5	1894	0.5	175	7.2	120	0.39620	0.01009	0.0057
6	1754	0.5	210	7.2	260	0.41200	0.01062	0.0048
7	1766	0.5	250	7.2	248	0.34280	0.00840	0.0040
8	1766	0.5	250	7.2	248	0.34280	0.00840	0.0040
9	1556	0.5	200	7.2	458	0.41730	0.01080	0.0050
10	-	0.5	200	7.2	1012	0.33250	0.00808	0.0050
11	1912	0.5	150	7.5	102	0.44960	0.01194	0.0067
12	1967	0.5	250	7.2	47	0.03810	0.00078	0.0040
13	-	0.5	600	7.2	1012	0.17200	0.00377	0.0017
14	-	0.5	600	7.2	1012	0.17200	0.00377	0.0017
15	-	0.5	1000	7.2	1012	0.09790	0.00206	0.0010
19	1944	0.5	250	7.5	70	0.08750	0.00183	0.0040
21	1999	0.5	250	7.2	15	0.00450	0.00009	0.0040
22	1957	0.5	250	7.2	57	0.05750	0.00118	0.0040
25	-	0.5	1000	7.2	1012	0.09790	0.00206	0.0010

						Time dependent (Renewal)		Poissonian
Segment	Last Char. Eq.	"cov"	Mean Recurrence Time	Char. Magnitude	Time since Last Char. Eq.	50year Prob.	Annual Rate	Annual Rate
40	1855	0.5	1000	7.2	159	0.00092	0.00002	0.0010
41	-	0.5	1000	7.2	1012	0.09790	0.00206	0.0010
42	-	0.5	1000	7.2	1012	0.09790	0.00206	0.0010
43	1737	0.5	1000	7.2	277	0.01010	0.00020	0.0010
44	-	0.5	1000	7.2	1012	0.09790	0.00206	0.0010
45	1953	0.5	1000	7.2	61	-	-	0.0010
				Mmin - Mmax	**alpha**	**Beta**		
BCK Z16	-	-	-	5.0 - 6.9	1.2078	1.767	-	
Z17	-	-	-	5.0-6.6	1.5136	2.0954	-	

4.4.5.4 Earthquake Recurrence Model for Turkey

The earthquake recurrence parameters for each fault segment (Fig. 89) are calculated by the procedures described in the previous section and presented in Table 4.3. computed recurrence parameters as well as the maximum magnitudes associated with the source zones are presented in Table 4.3

Table 4.3. Poisson model earthquake parameters associated with the segments

Source Zone No	**Associated Fault**	**a**	**b**	**M_{min} - M_{max}**
Z33	Black Sea Fault	3.8	0.9	5.0 - 7.3
Z34 Outside Zone	North Anatolian Fault Zone (NAF)	5	0.8	5.0 - 6.7
Z34 Inside Zone				6.8 - 7.9

Source Zone No	Associated Fault	a	b	M_{min} - M_{max}
Z35 Outside Zone	Alaca Ezine Pazari Fault	3.2	0.8	5.0 – 6.7
Z35 Inside Zone				6.8 – 7.9
Z49	Deliler Fault Zone	4.4	1	5.0 - 7.3
ZBK1	Background	5.13	1	5.0-6.5

4.4.6 GROUND MOTION PREDICTION EQUATIONS

Assessment of the seismic hazard requires an appropriate strong-motion attenuation relationship, which depicts the propagation and modification of strong ground motion as a function of earthquake size (magnitude) and the distance between the source and the site of interest. The traditional approach in estimating ground motions in seismic hazard analysis uses attenuation relationships, derived from the empirical strong motion data. Attenuation is defined as the change (decrease) in amplitude (peak ground acceleration, velocity, and displacement; response spectral accelerations or velocities) of earthquake ground motion with distance for given earthquake size, source mechanism, distance and local soil conditions. Several factors, such as: source physics, source distance, propagation path characteristics and site factors, control the earthquake ground motion. Other specific factors, such as: footwall/hanging-wall, basin and directivity effects also influence the ground motion characteristics.

The current understanding in the attenuation relationships is that the differentiation in the ground motion attenuation relationships is related to the major geo-tectonic regimes (such as shallow crustal, extensional and subduction) rather than with political boundaries or geographic regions.

The Next Generation Attenuation (NGA) project developed a series of GMPEs intended for application to geographically diverse regions (including Turkey); the only constraint is that the region be tectonically active with earthquakes occurring in the shallow crust. The NGA GMPEs are presented by Abrahamson and Silva (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008), Chiou and Youngs (2008), and Idriss (2008). The database used to develop the NGA GMPEs is large (3551 recordings from 173 earthquakes; with most recordings derived from Taiwan, California, and Europe/Turkey relative to those developed for relatively local regions, as is common in Europe.

For the PSHA investigations we will consider the following GMPEs for "active shallow region" with equal weights in the fault tree combination:

Ground motion models for active shallow regions:

- Akkar and Bommer (2009, rev:2010)
- Boore and Atkinson (2008)
- Chiou and Youngs (2008)
- Campbell and Bozorgnia (2008)
- Abrahamson and Silva (2008)

The reason for this selection limited to global and pan-european and most recent GMPEs was simply the broad database to fully account the aleatoric variability. Various characteristics of the selected GMPEs are given in Table 4.4 (Delavaud et al., 2012).

Akkar and Bommer (2010) predicts spectral ordinates at response periods of up to 3 seconds as a function of moment magnitudes from Mw 5 to 7.6, style-of-faulting, R_{JB} distances up to 100 km, and site class, the geometric mean values of 5%-damped horizontal pseudo-spectral acceleration, PSA (in $cm^{/}s^{2}$) in Europe and the Middle East.

Boore and Atkinson (2008) used data from the PEER Next Generation Attenuation (NGA) Flatfile supplemented with additional data from three small events (2001 Anza M4.92, 2003 Big Bear City M4.92 and 2002 Yorba Linda M4.27) and the 2004 Parkfield earthquake, which were used only for a study of distance attenuation function but not the final regression (due to rules of NGA project); three faulting mechanism using P and T axes; focal depths between 2 and 31 km. This paper excludes singly-recorded earthquakes and aftershock records.

Chiou and Youngs (2008) model is based on PEER Next Generation Attenuation (NGA) database; characterizes sites using V_{S30}; l is applicable for 150≤ VS30 ≤ 1500 m/s; is included data from aftershocks; is excluded data from more than 70 km to remove the effects of bias in sample.

Campbell and Bozorgnia (2008) used data from PEER NGA Flatfile and three faulting mechanism types based on rake angle; characterize sites using V_{S30}; included dip of rupture plane.

Abrahamson and Silva (2008) model is applicable for 5≤Mw≤8.5 (strike-slip) and 5≤Mw≤8.0 (dip-slip) and 0≤dr≤200 km; selected data from the Next Generation Attenuation (NGA) database and included data from all earthquakes, including aftershocks, from shallow crustal earthquakes in active tectonic regions under assumption that median ground motions from shallow crustal earthquakes at dr < 100 km are similar. This assumes that median stress-drops are similar between shallow crustal events in: California, Alaska, Taiwan, Japan, Turkey, Italy, Greece, New Zealand and NW China.

Table 4.4. Characteristics of the selected GMPEs for active shallow regions (Delavaud et al., 2012)

Model	Area	Magnitude Range	Distance Range (km)	Period Range (s)	Site	Mechanism	Component
Abrahamson and Silva (2008)	California, Taiwan and other regions	Mw=5.0-8.0	Rrup = 0 – 200	0.01 – 10.0, PGA, PGV	Function of Vs30	N, R/T, S	GMRot150
Boore and Atkinson (2008)	California, Taiwan and other regions	Mw=4.27 – 7.9	Rjb = 0 – 280	0.01 – 10.0, PGA, PGV	Function of Vs30	N, R, S, U	GMRot150
Chiou and Youns (2008)	California, Taiwan and other regions	Mw=4.27 – 7.9	Rrup = 0.2 – 70	0.01 – 10.0, PGA, PGV	Function of Vs30	N, R, S	GMRot150
Campbell and Bozorgnia (2008)	California, Taiwan and other regions	Mw=4.27 – 7.9	Rrup = 0.07 – 199.27	0.01 – 10.0, PGA, PGV	Function of Vs30	N, R, S	GMRot150
Akkar and Bommer (2010)	European and Middle East	Mw=5.0-7.6	Rrup = 0 – 99	0.05-3.0, PGA,PGV	3 classes	N,R/T,S	GMEAN

4.4.7 HAZARD MAPS

4.4.7.1 Hazard Maps for Marmara Region

For regional hazard maps it becomes essential to quantify seismic hazard associated with a certain ground condition, so-called the "reference ground", from which the ground motion for other types of ground condition can be inferred. In this study NEHRP B/C Boundary (characterized with a 30m average shear wave propagation velocity of 760m/s) is used as the reference ground, similar to the seismic hazard maps prepared by USGS. The results obtained for 10% and 2% probabilities of exceedence in 50 years for PGA for the Poisson and renewal models are presented in Fig. 93Fig. 93 through Fig. 96, respectively.

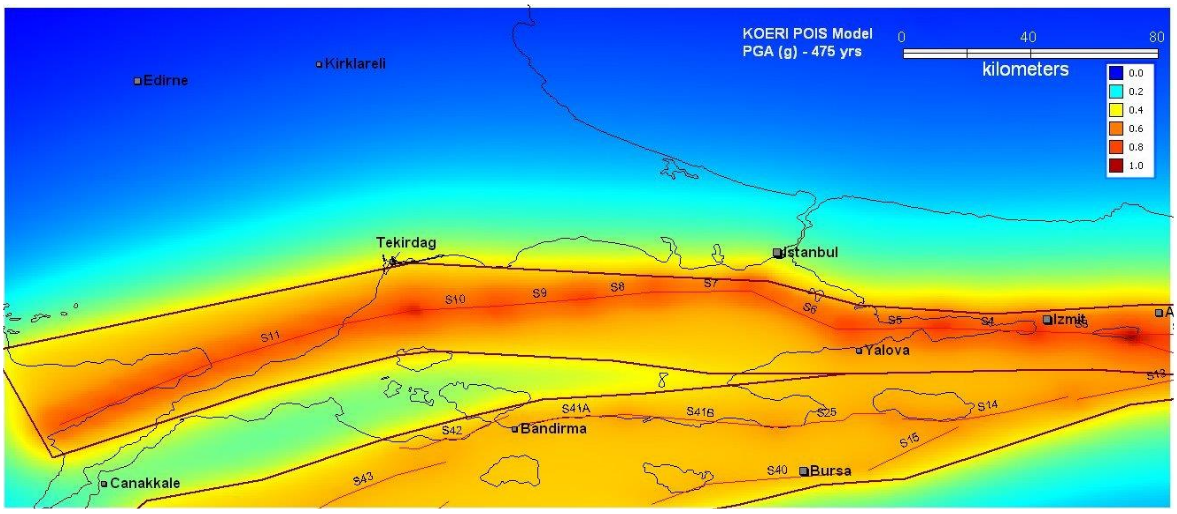

Fig. 93: PGA map at NEHRP B/C boundary site class for 10% probability of exceedence in 50 yr (poisson model).

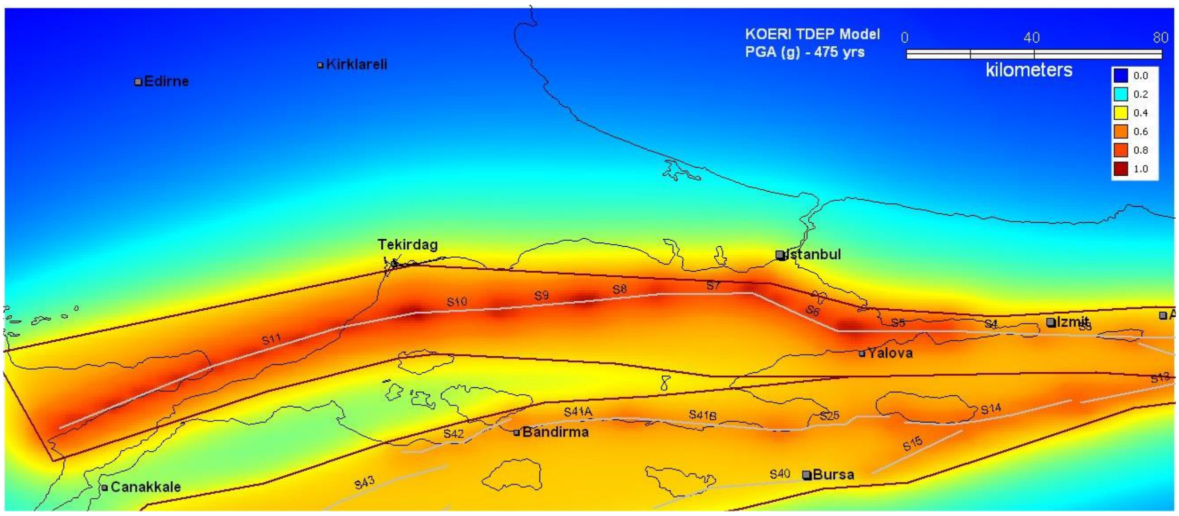

Fig. 94: PGA map at NEHRP B/C boundary site class for 10% probability of exceedence in 50 yr (renewal model).

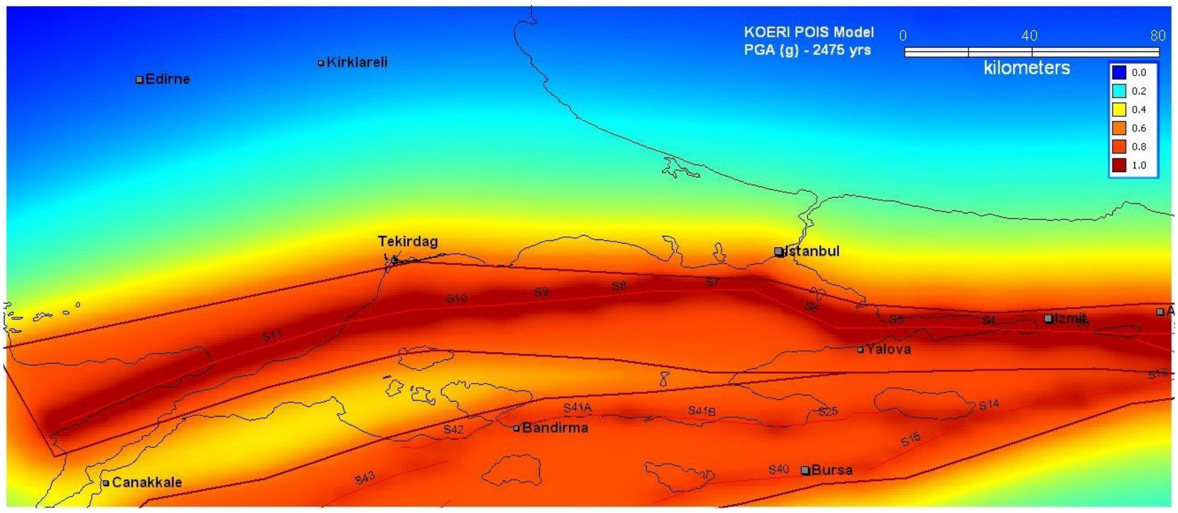

Fig. 95: PGA map at NEHRP B/C boundary site class for 2% probability of exceedence in 50 yr (poisson model)

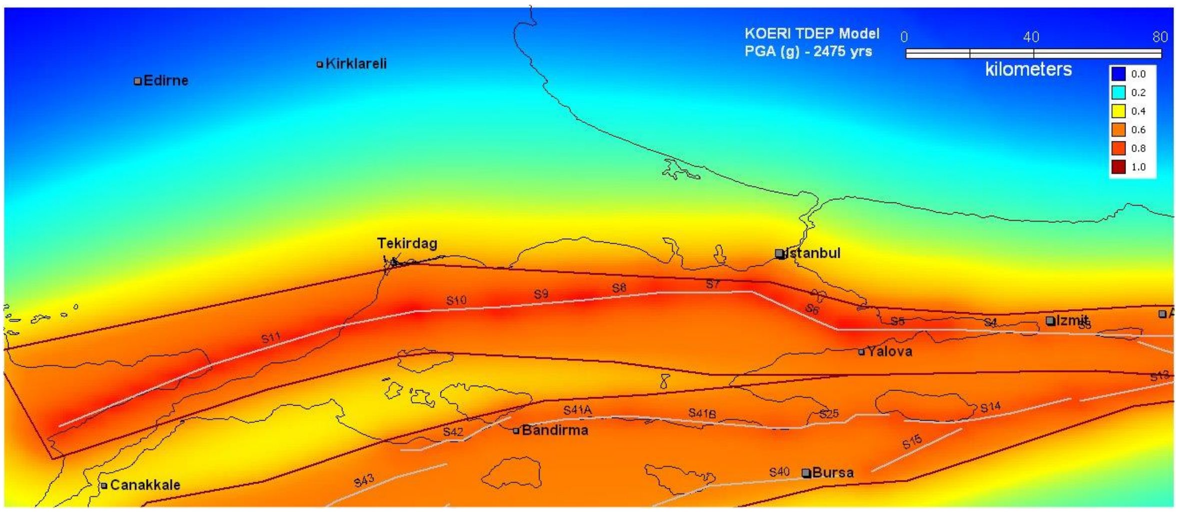

Fig. 96: PGA map at NEHRP B/C boundary site class for 2% probability of exceedence in 50 yr (renewal model).

4.4.7.2 Hazard Maps for the Samsun Province (Turkey)

The results for Samsun province obtained for 10% and 2% probabilities of exceedence in 50 years for PGA for the Poisson and renewal models are presented in Fig. 97 and Fig. 98, respectively

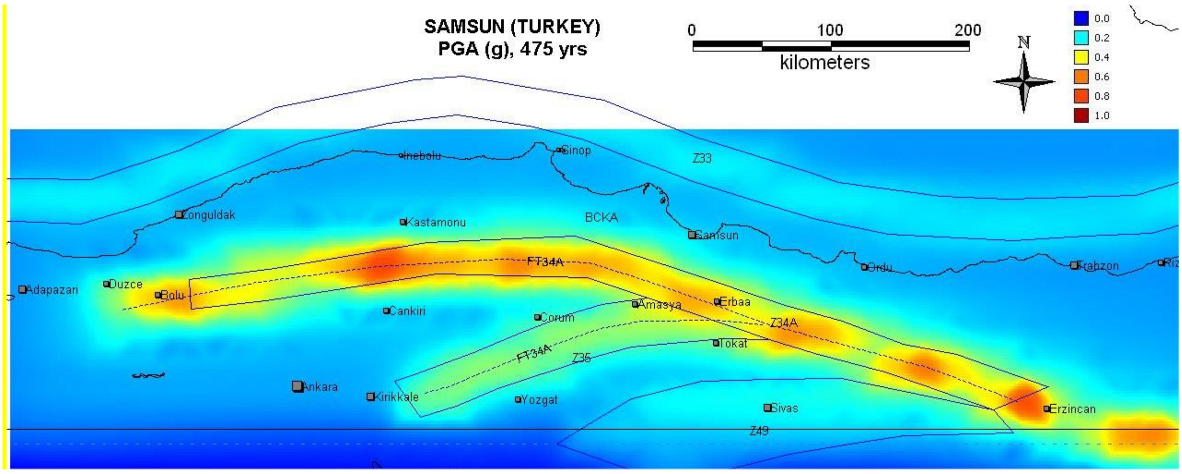

Fig. 97: PGA map at NEHRP B/C boundary site class for 10% probability of exceedence in 50 yr (poisson model).

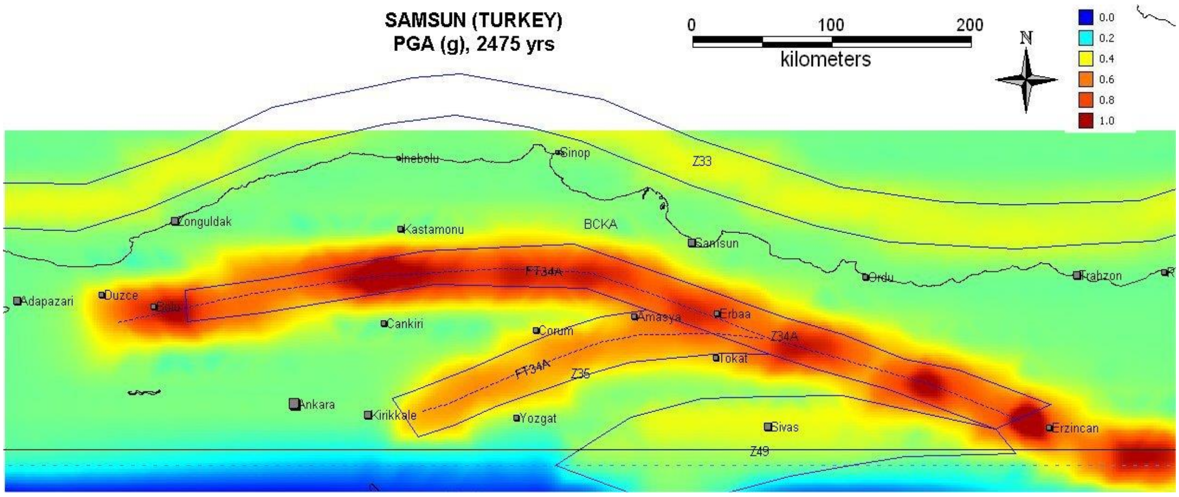

Fig. 98: PGA map at NEHRP B/C boundary site class for 2% probability of exceedence in 50 yr (poisson model).

4.4.8 DETERMINISTIC SEISMIC HAZARD ASSESSMENT (DSHA)

4.4.8.1 Introduction

The DSHA can also be called as the "scenario" earthquake hazard assessment method. Scenario ground motions are estimated from a single or a set of the possible scenario earthquakes, generally the maximum magnitude earthquakes associated with seismic source zones. In routine DSHA applications "maximum" earthquake scenarios are assumed in each seismic source at locations closest to the site and the appropriately selected attenuation relationship is applied with a probability level of 0 or 1 standard deviations above the median. The ground motion parameter associated with a 0 and 1 level of standard deviation above the median has respectively 50% and 84% chance of not being exceeded if the scenario earthquake occurs.

The DSHA approach can be also aimed at finding those earthquakes that will not necessarily produce the largest possible ground motion at a site in a region, but which will *contribute most* to the seismic hazard that has been estimated (for the considered site) by the PSHA approach. This is accompolished therogh a de-aggregation process where an inverse process of decomposition of PSHA estimates into the respective contributions of different seismic events is made. Beside the size and the location of the hazard-consistent earthquakes, by the deaggregation process yields also the uncertainty, measured by the number of standard deviations from the median ground motion as predicted by the related ground motion prediction equations.

4.4.8.2 Earthquake Scenario

The Center district of the Samsun province is located at the northernmost region of Turkey and it is 40 kilometers away from the North Anatolian Fault Zone (NAFZ). It has a population of 1,252,693 people according to the 2010 data. . The most important seismic activity which could affect the area is right directional North Anatolian Fault Zone (NAFZ). NAF which is one of the most important strike-slip fault systems known in the world has close resemblance with San Andreas Fault at California, USA.

As it is well known the 20th century is marked with a chain of earthquakes (Fig. 99) that ruptured the North Anatolian Fault along its whole length. Among those, 1942 Erbaa Niksar, 1943 Ladik earthquakes have also affected at large area of Samsun province. Brief descriptions of these events are given below.

Fig. 99: Scenario earthquakes that affected in the vicinity of Samsun province

1942, DECEMBER 20, ERBAA - NİKSAR EARTHQUAKE

Earthquake parameters: Ms = 7.1, Io = X, epicenter: 40.7 N, 36.6 E. This is the second event of the chain of earthquakes that broke the North Anatolian Fault along its length. The destructive earthquake ruined all villages between Niksar and the confluence of Kelkit and Yeşilırmak rivers and killed thousands of people. The surface rupture caused by the event reached 50 km with horizontal displacements of 1.5 – 1.7 km. Damage extended to a zone of 100 km length. The intensity distribution is given in Fig. 100.

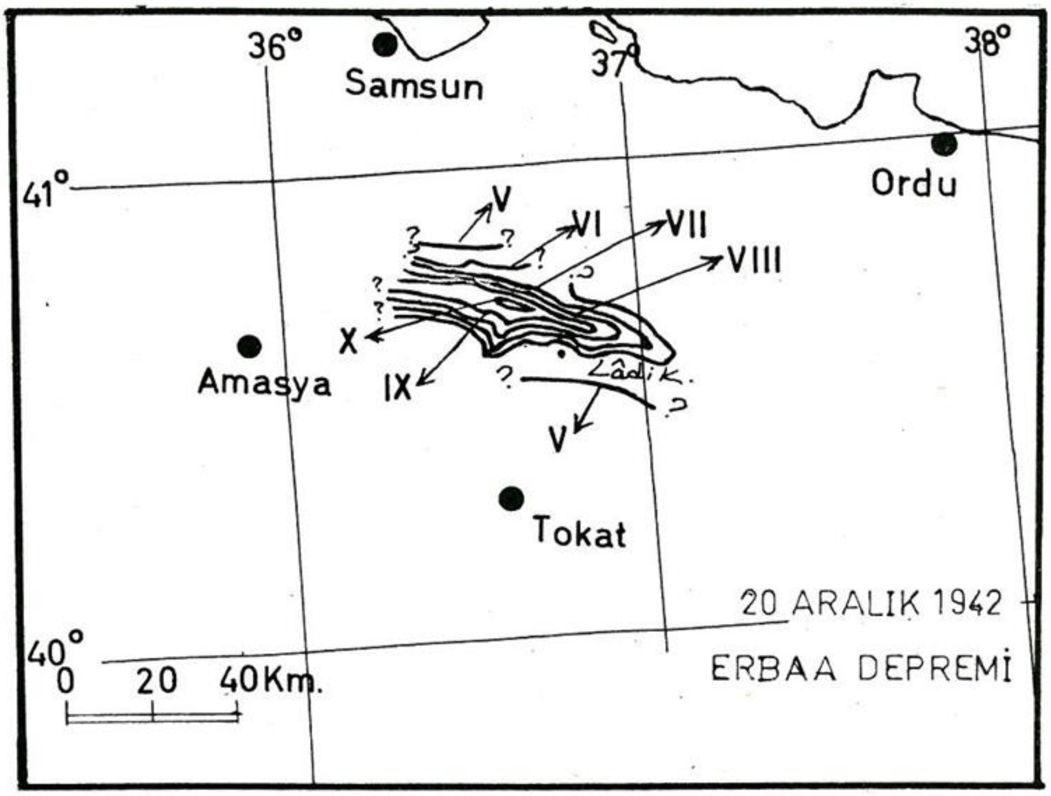

Fig. 100: Intensity distribution of 1942 Erbaa – Niksar earthquake

1943 NOVEMBER 26, LADIK EARTHQUAKE

Earthquake parameters: Ms = 7.3, Io = XI, epicenter: 40.5 N, 34.0 E. The earthquake occurring on the North Anatolian Fault devastated a longitudinal zone of 300km long and 20 km wide along the ruptured segment. The damaged area extends from Ilgaz to Erbaa. The shock was associated with a 265 km surface rupture. The eastern end of the rupture coincides with the western termination of the 1942 rupture. The intensity distribution is given in Fig. 101.

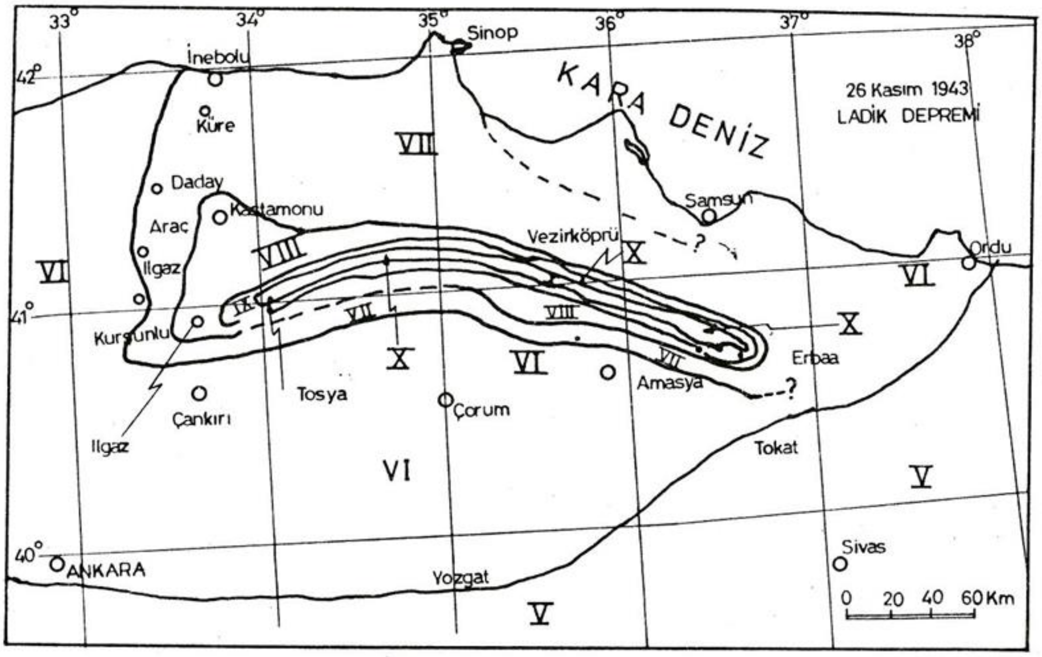

Fig. 101. Intensity distribution of 1943 Ladik earthquake

The selected scenario earthquakes, showing in Fig. 102, are given in the following items:

1) Scenario I – Southern Samsun (similar to the Ladik, and Erbaa-Niksar events)

   M7.6

   Depth 10.0km

   Lat: 40.91, Lon: 35.89

2) Scenario II – Northern Samsun

   M6.6

   Depth 5.0km

   Lat: 41.3086, Lon: 36.3998

Fig. 102: Location of Scenario I and II events

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4.5 BULGARIA

4.5.1 COUNTRY, PROJECT AREA IN THE COUNTRY

Bulgaria is situated in the eastern part of the Balkan Peninsula and is bounded on the east with Black sea. The Bulgarian project area includes North-East and South-East regions (Severoiztochen and Yugoiztochen) of the country. These two regions consist of 8 districts (Fig. 103) – Burgas, Sliven, Yambol, Stara Zagora, Varna, Dobrich, Shumen and Targoviste. The total area of the these two regions is 33678 km^2 or more of 30% of the territory of Bulgaria. The population is 2131570 or more than 25% of the population of Bulgaria.

4.5.1.1 Economy

South-East region (Yugoiztochen - districts Burgas, Sliven, Yambol, Stara Zagora) is the second richest Bulgarian region. Most important are tourism, electric power generation, and services. Burgas isthe second largest Bulgarian port, big tourist centers are Sunny beach, Sozopol, Pomorie, Primorsko, Ravda and Kiten. Main industrial centers are the big cities and towns of Radnevo and Galabovo - electric power generation and mining.

One of richest regions of Bulgaria is North-East region (Severoiztochen - districts Varna, Dobrich, Shumen and Targoviste. It is important for the national economy. Its economy is service-oriented and includes tourism. Severoiztochen is the second most-visited region by foreign tourists after Yugoiztochen. Notable resorts include Golden Sands, Albena, SS Constantine and Helena. Interesting places are the towns of Balchik, Kavarna, Cape Kaliakra - on the sea, Madara - nearby Shumen; Shumen boasts the Monument to 1300 Years of Bulgaria. Dobrich Province form Southern Dobruja - the Bulgarian breadbasket. The port of Varna is the largest port in Bulgaria and the third largest on the Black Sea. The port of Balchik is a small fishing town. Varna is Bulgaria's second financial capital after Sofia; the city produces electronics, ships, food and other goods. Other important industrial centers in the region are Shumen - production and repair of trucks; Dobrich - big food-producing city, unofficial capital of Dobruja; Devnya - big chemical center (cement and nitric fertilizer).

4.5.1.2 Seismic Activity, Strong Earthquakes

Earthquakes are the most deadly of the natural disasters affecting the human environment, indeed catastrophic earthquakes have marked the whole human history, accounting for 60% of worldwide casualties associated with natural disasters. Earthquakes are the expression of the continuing evolution of the Earth planet and its surface. Earthquakes adversely affect large parts of the Earth. Global seismic hazard and vulnerability to earthquakes are increasing steadily as urbanization and development occupy more areas that a prone to effects of strong earthquakes; the uncontrolled growth of megacities in highly seismic areas around the world is often associated with the construction of seismically unsafe buildings and infrastructures, and undertaken with an insufficient knowledge of the regional seismicity peculiarities and seismic hazard. The assessment of seismic hazard is the first link in the prevention chain and the first step in the evaluation of the seismic risk. The implementation of the seismic hazard estimates into the policies for seismic risk reduction will allow focusing on the prevention of earthquake effects rather than on intervention following the disasters.

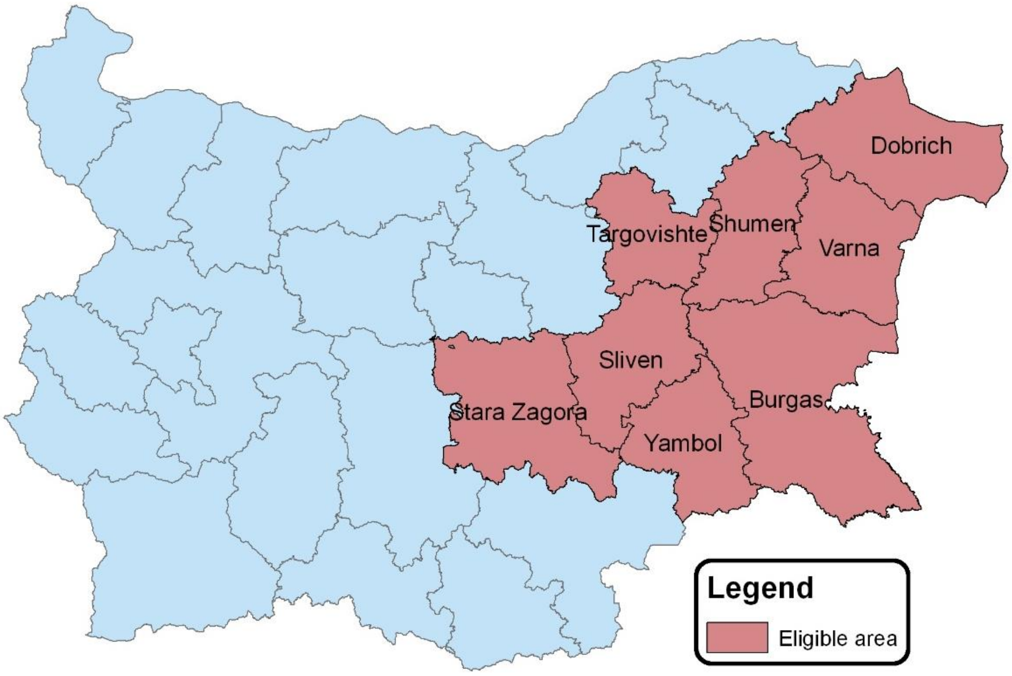

Fig. 103: ESNET Bulgarian eligible area.

The territory of Bulgaria represents a typical example of high seismic risk area in the eastern part of the Balkan Peninsula. The Balkan Peninsula, from plate-tectonic point of view, is an element of the continental margin of Eurasia that is located between the stable part of the European continent to the north and ophiolitic sutures (Vardar and Izmir-Ankara) to the South. South of the satures, fragments of the passive continental margin of Africa crop out (Boyanov et al., 1989). The neotectonic movements on the Balkan Peninsula were controlled by extensional collapse of the Late Alpin orogen, and were influenced by extension behind the Aegean arc and by the complicated vertical and horizontal movements in the Pannonian region (Zagorcev, 1992).

Bulgaria contains important industrial areas that face considerable earthquake risk, though less than its neighboring countries: Greece, Turkey and Romania. Over the past centuries, Bulgaria has experienced strong earthquakes. The first well documented earthquake on the territory of Bulgaria is the 1 c BC quake occurred in the Black Sea near the town of Kavarna. In historical aspect, it is worth to mention the 1818 (VIII-IX MSK) and the 1858 (M_S=6.3,

I_0=IX MSK) earthquakes occurred near the town of Sofia. The 1858 earthquake caused heavy destruction to the city of Sofia and the appearance of thermal springs in the western part of the town. Some of the Europe′s strongest earthquakes 20-th century occurred in Bulgaria (at the beginning of the 20th century from 1901 to 1928 on the territory of Bulgaria occurred 5 earthquakes with magnitude larger than or equal to 7.0). Impressive seismic activity developed in the SW Bulgaria during 1904-1906. The seismic sequence started on 4 of April 1904 with two catastrophic earthquakes within 23 minutes (the first quake at 10^h 05^{min} with M_S=7.1 considered as a foreshock and the second one at 10^h 26^{min} with M_S=7.8 and I_0=X-the main shock). The main shock was felt in a very large are (up to Budapest, Hungary) and some eye-witnesses have seen waves on the surface in the town of Sofia. The surface outcrop caused by the 1904 earthquake still can be seen in the Kresna gorge. This earthquake was followed by a well expressed long-lasting aftershock activity. Along the Maritca valley (central part of Bulgaria), in 1928 a sequence of three destructive earthquakes occurred. The towns Plovdiv, Chirpan, Parvomay suffered great damage. Many other towns and villages were strongly affected. 74000 buildings were completely destroyed and 114 people killed. They caused two surface coseismic ruptures, each of them several tens of kilometers in length. That is the one of few cases (quoted in Richter, 1958) when before and after a strong earthquake detailed geodetic surveys have been performed (presented in Yankov, 1935). On some places the ground displacement reaches up to 1.5-2 m.

Moreover, the seismicity of the neighboring countries, like Greece, Turkey, former Yugoslavia and Romania (especially Vrancea-Romania intermediate earthquakes involving the non-crustal lithosphere), influences the seismic hazard in Bulgaria.

The strongest and most destructive earthquakes in Bulgarian occurred after 1900 are listed in Table 4.5.

The thickness of the earth crust varies from 30 km close to the Black sea up to 51 km in the southwestern part of Bulgaria. From the analysis of the depth distribution (as for example Sokerova et al., 1992; Dacev et al., 1995: Simeonova et al., 2006) it was recognized that most of earthquakes in Bulgaria and near surroundings occurred in the Earth's crust up to 50 km. The hypocenters are mainly located in the upper crust, and only a few events are related to the lower crust. The maximum density of seismicity involves the layer between 5 and 25 km.

Table 4.5. Strong and destructive earthquakes occurred in Bulgaria after 1900 year (bold and red – earthquakes in or close to eligible area)

Date d. m. y.	Time GMT h. m. s.	Epicenter coordinates φ°N	 λ°E	h km	M	I_0
31.03.1901	**07 10 22**	**43.37**	**28.70**	**14**	**7.2**	**10**

04 04 1904	10 02 34	41.77 23.05	15	7.3	9-10
04 04 1904	10 25 55	41.85 23.08	18	7.8	10
08 10 1905	07 27 30	41.86 23.08	19	6.4	8-9
15 02 1909	**09 33 40**	**42.52 26.48**	**4-8**	**6.0**	**8**
23 02 1910	07 52 14	41.70 23.55	10	5.4	7-8
14 06 1913	**09 33 13**	**43.10 25.70**	**15**	**7.0**	**9-10**
18 10 1917	18 57 40	42.70 23.33	6	5.2	7-8
14 04 1928	**09 00 01**	**42.21 25.36**	**10**	**6.8**	**9**
18 04 1928	**19 22 48**	**42.20 25.06**	**16**	**7.1**	**9-10**
25 04 1928	**09 25 46**	**42.08 25.89**	**13**	**5.7**	**8**
23 08 1942	**15 41 25**	**43.47 26.60**	**10**	**5.1**	**7**
30 06 1956	**01 50 22**	**43.55 28.68**	**20**	**5.5**	**7**
03 11 1977	02 22 58	42.08 24.08	8	5.3	7
21 02 1986	**05 39 56**	**43.21 26.01**	**8**	**5.1**	**7-8**
07 12 1986	**14 17 09**	**43.19 26.01**	**10**	**5.7**	**8**
22 05 2012	00 00 32	42.58 23.00	9	5.8	7-8

The spatial pattern of seismicity in and near Bulgaria is shown in Fig. 104. The figure represents the epicentral map of the earthquakes with magnitude: larger than or equal to 6.0 (M≥6.0) occurred before 1900; M≥4.0 after 1900; and with M≥3.0 occurred after 1980 in and near Bulgaria. Seismicity (all instrumentally recorded seismic events after 1980) in and near the country project area is presented in Fig. 104.

Both epicentral maps (Fig. 104. and Fig. 105.) show that seismicity is not uniformly distributed in space. Therefore the seismicity is described in distributed geographical zones (seismic source zones). Each source is characterized by its own specific seismicity, geological and tectonic development.

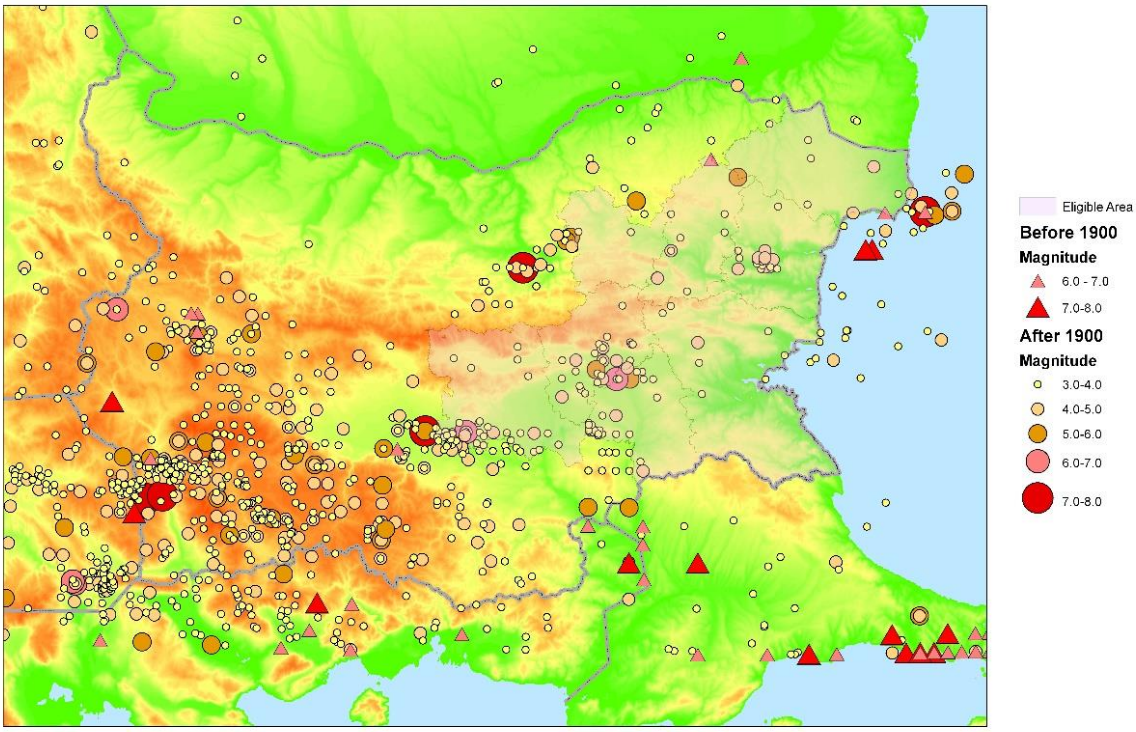

Fig. 104: Epicentral map for Bulgaria and surroundings (M≥3.0)

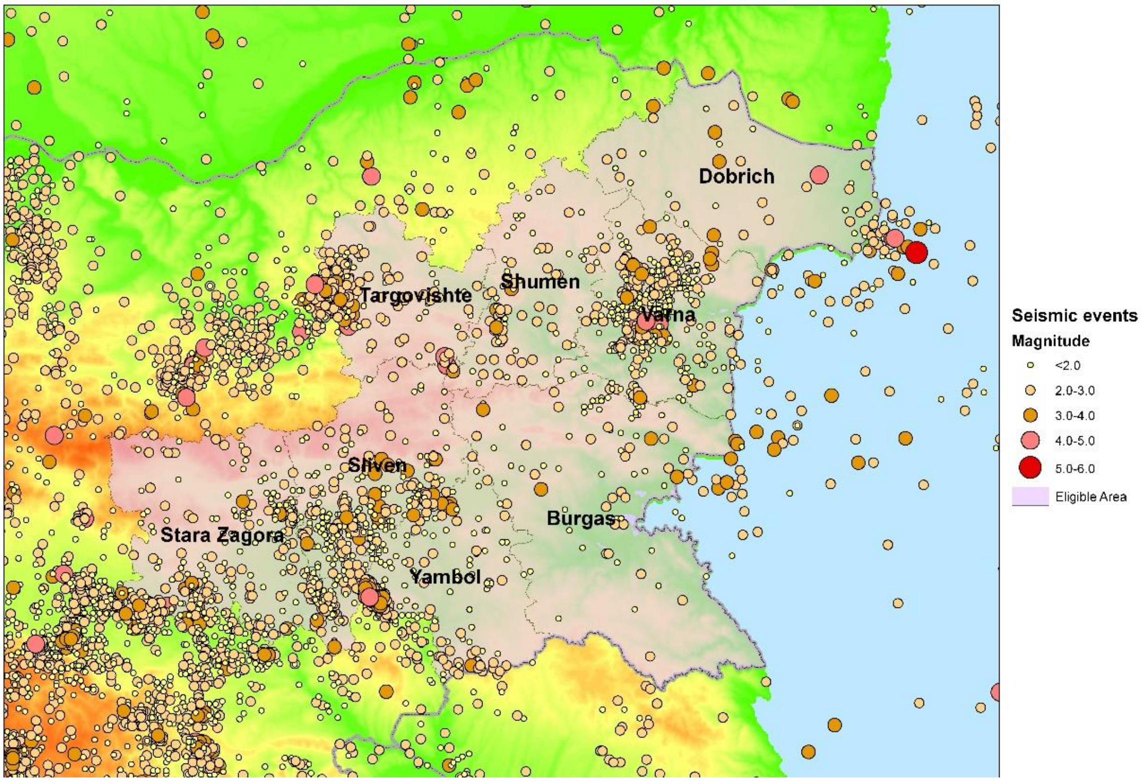

Fig. 105: Epicentral map for Bulgaria and surroundings (after 1980, all recorded events)

From the seismotectonics analysis of the considered parts of the Balkans this modeling seems more appropriate than to use specific linear fault structures or three-dimensional fault planes. The main seismic source zones that are defined (as presented in Sokerova et al., 1992; Dachev et al.' 1995; Simeonova at al., 2006; Solakov et al., 2009) within and near the country project area are as follows:

Shabla seismic zone The eastern periphery of the Moesian platform is marked by a fault system in NNE-SSW direction, separating the platform from deep part of the West Black Sea back-arch marginal riftogenic basin. Strong earthquakes manifest the Neotectonic/Quaternary activity of this fault system. The strongest seismic events (543 earthquake with M=7.6, 1444 earthquake with M=7.5, 1901 earthquake with M=7.2) are associated with Kaliakra fault system defined by numerous seismic profiling undertaken in the Black Sea. The hypocentre distribution involves the surficial 20 km. The maximum earthquake potential M_{max} associated with Shabla seismic zone is M_{max}= 8.0 (Boncev et al., 1982).

North-East Bulgaria seismic zone The seismic source is situated in the broad transitional zone where the Moesian platform succession has been down faulted to the east during the Middle Cretaceous opening of the Western Black Sea Basin (Tari et all. 1997). That is an area with not expressed contemporary tectonic activity. The southern part of the seismic source zone is characterized with low to moderate seismic activity while in the northern part sporadic moderate to strong earthquakes occurred. The strongest earthquakes generated in the zone is the 1892 Dulovo quake (I_o=8, M_S≈7.0) located in the northern part of the zone.

Close to the eligible area are located two active seismic zones Gorna Orjahovitca (North Bulgaria) and Marica (South Bulgaria). These zones have significant impact to the seismic hazard in the area. In these zones have been realized earthquakes with magnitudes of 7.0 at the beginning of previous century. The macroseismic intensities from these earthquakes reach VIII-IX for some parts of eligible area.

Gorna Orjahovitza seismic zone The main tectonic structure in this area is the E-W extended Resenski trough, which is formed during the Quaternary period. Two sublatitudinal faults, which are reactivated segments of the Fore Balkan fault, and an oblique fault in NE-SW direction marks the boundaries of the Resenski trough . The strongest event here occurred in 1913 (M_s=7.0), followed by seismic quiescence until 1986 when the two moderate Strazhitza earthquakes occurred (M_S=5.3 on February 21 and M_s=5.7 on December 7). The macroseismic effects caused by 1986 earthquakes are of intensity VII-VIII (MSK) in the western part of Targoviste district. The seismicity in the zone is shallow, concentrated mainly in the surficial 15 km, with rare events down to the 25-30 km depth. The maximum 7.0 earthquake is expected in Gorna Orjahovitza seismic zone (M_{max}=7.0, Boncev et al., 1982).

Maritsa seismic zone The contemporary tectonic activity of the area is associated with Maritsa fault system with WNW-ESE direction. The Maritsa fault with its satellites belongs to structures with a longlasting development, which continues in the neotectonic period. The largest of its segments, which is with well-expressed Neogene-Quaternary activity, reaches the length of about 70 km (Dachev et al., 1995). The strongest earthquakes occurred on the fault system are those in 1928 (the Chirpan earthquake of April 14, 1928 with M_S=6.8 and the Plovdiv earthquake of April 18, 1928 with M_S=7.0, I =9-10 MSK). 74000 buildings were completely destroyed and 114 people killed. The earthquakes caused two surface coseismic ruptures, each of them several tens of kilometers in length. Ground displacement reached the length of 1.5-2 m (Yankov, 1935). The hypocenter distribution involves the surficial 20 km, with sporadic events down to 45 km. The highest density of foci is observed at 5-10 km depth. The maximum 7.5 earthquake is expected in Maritsatza seismic zone (M_{max}=7.5, Boncev et al., 1982).

The Northern part of the region is strongly influenced by the intermediate Vrancea earthquakes. The Southern part is influenced by strongest earthquakes on Turkish and Greece territory.

In the region of Provadia are located a lot of earthquakes with magnitudes between 4.0 and 5.0 last 30 years with maximal macroseismic ntensity up to VI-VII (MSK).

Several earthquakes with magnitudes between 5 and 6 have been realized near the town of Yambol. The maximal observed intensity from these earthquakes is VIII (MSK).

4.5.2 SEISMIC MONITORING NETWORK

The beginning of Bulgarian seismology dates back to 1891. At that time Spas Watzof, the director of Central Meteorological Station in Sofia, organized network of correspondents for observation of felt earthquakes in Bulgaria (Watzof, 1902). Watzof formed a proto-type of macroseismic bulletin containing: time of perceived shaking, locality, intensity, direction of impact, and observed effects. The first bulletin including data for Central Balkan earthquakes occurred in the 19^{th} century was published in 1902 (Watzof, 1902). The initial data on earthquakes felt in Bulgaria were published in 17 volumes edited by Spas Watzof (1902-1923). Over more than 6 decades, reports on earthquakes affected the territory of Bulgaria (occurred in the Balkans) have been annually and/or periodically (at several years) published till 1964 (Glavcheva, 2004).

The period of Bulgarian historical era ends in 1905 when the seismograph of Omorri-Boch type was installed in the firs Seismological Station in the town of Sofia. The same year four seismoscopes of Agamenonne type were installed in Sofia, Petrohan, Rila monastery and the town of Kazanlak.

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At present NIGGG-BAS runs the Bulgarian seismological network-NOTSSI (National Operative Telemetric System for Seismological Information). NOTSSI was founded at the end of 1980. The overall objective for the NOTSSI is continuous monitoring of seismicity on the territory of Bulgaria and surroundings. NIGGG, respectively NOTSSI, is responsible for rapid earthquake determination, public information trough media, and information of responsible governmental authorities if necessary urgent activities to be undertaken. The institute also operates two local seismic networks deployed around the Kozloduy Nuclear Power Plant and the town of Provadia in Northeastern Bulgaria. In 2005, the institute performed overall modernization of the NOTSSI. The upgraded Bulgarian National Digital Seismological Network (BNDSN) consists of a National Data Center (NDC), 15 stations equipped with RefTek High Resolution Broadband Seismic Recorders – model DAS 130-01/3. Configuration of BNDSN is presented in Fig. 106.

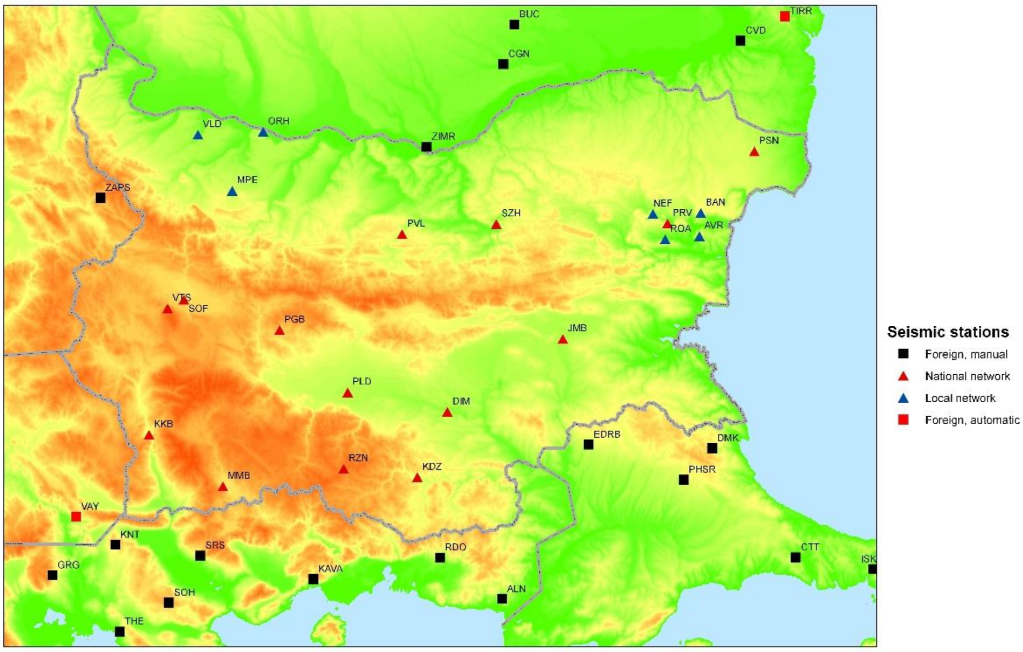


Fig. 106: Bulgarian seismic network and foreign stations used in epicenter location

Real-time data transfer was realized via Virtual Private Network (VPN) of the Bulgarian Telecommunication Company (BTC). The data acquisition and processing hardware redundancy at the National Data Center was achieved by two clustered SUN Fire 5400 servers and two Blade 1500 Workstations. To secure the acquisition, processing and data storage processes a three layer network was designed at the NDC.

Real-time data acquisition was performed using REFTEK’s full duplex errorcorrection protocol RTPD. For data archiving two formats are used: PASSCAL (PASSCAL Data Center) and wildly used for seismological data miniSEED.

Data processing was performed by the Seismic Network Data Processor (SNDP) software package running on both Servers. SNDP includes two subsystems:

• *Real-time subsystem (RTS)* – for signal detection; evaluation of the signal parameters; phase identification and association; source estimation.

• *Seismic analysis subsystem (SNDA)* – for interactive data processing.

The signal detection process is performed by traditional STA/LTA detection algorithm. The filter parameters of the detectors are defined on the base of previously evaluated ambient noise at the seismic stations.

Currently, the BNDC and BNDSN allow reliable automatic localization of low magnitude events MS>1.5 within the network, and MS≥3.0 at regional distances. Since 2005-2006, real-time data exchange between Bulgaria and Greece, Romania, Serbia, Macedonia, Slovakia, Slovenia, Austria and other regional and national seismological data centers was implemented.

4.5.3 PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA)

Seismic hazard is the probability that various levels of strong ground motion will be exceeded during a specified time period at a site. The ground motion levels may be expressed in terms of peak ground acceleration (velocity, displacement) and/or peak response spectral amplitudes for a range of frequencies.

PSHA was developed in the late 1960s and early 1970s at the Universidad National Autonoma de Mexico (UNAM) and the Massachusetts Institute of Technology (MIT) and PSHA has now become the most widely used approach for estimating seismic-design loads (Bommer and Abrahamson, 2006). Probabilistic techniques utilize all the details and parameters of the seismotectonic model. Modern techniques allow uncertainties in the seismic input to be included in the analysis.

The main steps involved in the seismic hazard analysis are the following:

1. construction of seismic source model - each element of the model is represented as a seismic source (areal, volume, linear or point) with defined geometry and depth;
2. determination of the seimicity parameters such as magnitude frequency relationship, minimum magnitude, maximum magnitude and their uncertainties for each seismic source;
3. designation of a ground motion attenuation relationship for each seismic source;

4. selection of appropriate stochastic model of earthquake occurrence (Poisson, Markov, etc);
5. computation of seismic hazard curves with appropriate confidence levels such as to demonstrate the scatter of data.
6. Sensitive analisys

In Fig. 107, a Flow Chart for main stages in probabilistic seismic hazard analysis is presented.

4.5.4 MATHEMATICAL FORMULATION

The formal procedure for probabilistic calculations taking account of spatial and temporal uncertainty in the future seismicity was presented by Esteva (1967, 1968) and Cornell (1968). The probabilistic method of seismic hazard analysis, as it is currently understood, was presented by Cornell (1971), and by Merz and Cornell (1973).

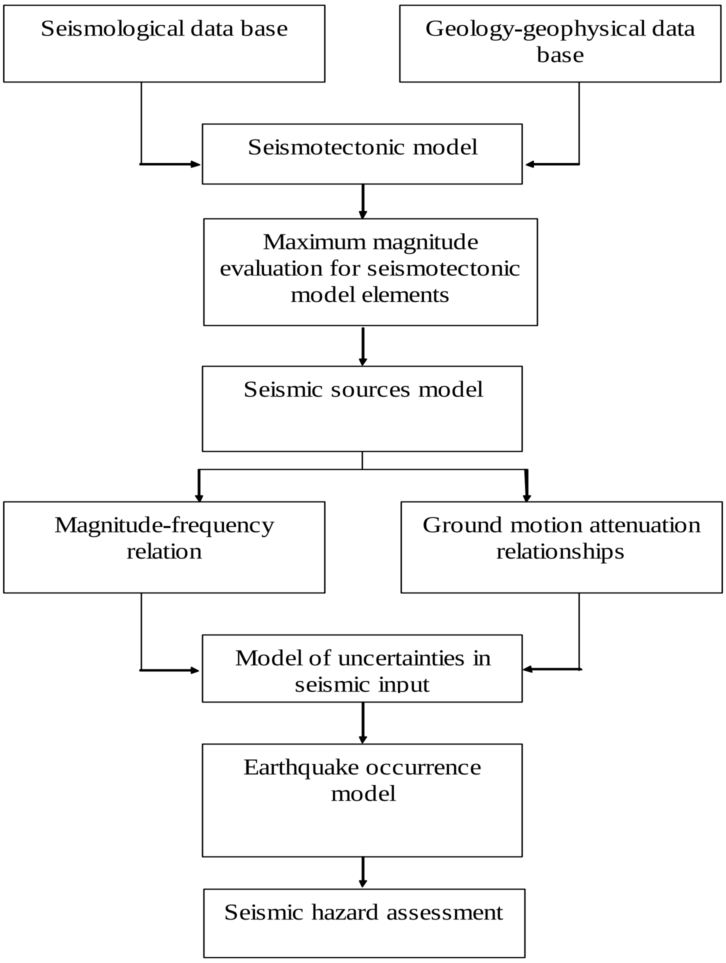


Fig. 107: Flow chart for seismic hazard assessment

It is commonly assumed that the occurrence of individual event can be represented as a Poisson process. The probability that at a given site a ground motion parameter, Z, will exceed a specified level, z, during a given time period, t, is given by the expression:

$$P(Z \geq z \mid t) = 1 - e^{-\nu(z)t} \leq \nu(z) \tag{91}$$

where ν(z) is the average frequency during time period t at which the level of ground motion parameter Z exceeds z at the site resulting from earthquakes in all sources in the region.

The “return period” of z is defined as:

$$R_Z(z) = \frac{1}{\nu(Z \geq z)} = \frac{-t}{\ln(1 - P(Z \geq z))} \tag{92}$$

The inequality at the right side of above equation (4.1) is valid regardless of the appropriate probability model for earthquake occurrence and ν(z)t provides an accurate and slightly conservative estimate for probabilities less than 0.1.

The frequency of exceedance, ν(z), is a function of the uncertainty in the time, size and location of future earthquakes and uncertainty in the level of ground motions they may produce at the site.

It is computed by expression:

$$\nu(z) = \sum_n \alpha_n(m^0) \int_{m^0}^{m^u} \int_0^{\infty} f(m) f(r \mid m) P(Z \geq z \mid m,r) dr dm \qquad (93)$$

where $\alpha_n(m^o)$ is the frequency of earthquakes on source n above a minimum magnitude of engineering significance m^o; f(m) is the probability density function for event size between m^o and maximal event for the source m^u; f(r|m) is the probability density function for distance to the earthquake rupture which is usually conditional on the earthquake size; and P(Z<z | m,r) is the probability that for a given magnitude m earthquake at a distance r from the site, the ground motion exceeds level z. The average frequency ν(z) is evaluated by three probability functions: magnitude distribution, conditional distance distribution and conditional exceedance probability distribution.

4.5.5 DEVELOPMENT OF THE PSHA MODELS

The constituent models of the Probabilistic Seismic Hazard Methodology are models of: 1) seismic sources; 2) earthquake recurrence frequency; 3) ground motion attenuation; and 4) ground motion occurrence probability at a site (Thenhaus and Campbell, 2003).

4.5.5.1 Seismic sources

Description of the geometry of a seismic source is necessary for evaluation of site-source distances.

Seismic sources are identified on the base of geological, seismological and geophysical data. An understanding of the regional tectonics, local Quaternary history and seismicity of an area leads to the identification of geological structures that may be seismic sources. The association of geological structure with historic or instrumental seismicity clarifies their role in the present tectonic stress regime.

The limiting size earthquake that can occur on each seismic source is a very important parameter in seismic hazard analysis, especially at low probability levels. For sources defined as faults, the maximum earthquake magnitude is related to the fault geometry and fault behavior through an assessment of the maximum dimensions of a single rupture. For area sources maximum magnitude is usually estimated to be the maximum historic event plus an increment.

4.5.5.2 Earthquake recurrence

Earthquake recurrence is represented in terms of the rate of the seismic activity and the relative frequency of various magnitude earthquakes. To determine earthquake recurrence frequency two sources of data are used: observed seismicity (historical and instrumental and geological (geology, geomorphology, tectonics and neotectonics). For sources defined as individual faults historic seismicity and geological data can be used to characterize the earthquake recurrence. For large area sources, only historical seismicity is usually used to estimate the earthquake recurrence rate.

4.5.5.3 Ground motion attenuation

Ground motion attenuation relationships define the values of a ground motion parameter, such as peak ground acceleration or response spectral values, as a function of earthquake size (magnitude M) and the distance in terms of both the expected values and the dispersion of the expected values. Attenuation relationships are developed usually from statistical analysis of strong motion data or from peak ground motion parameters inferred from reported shaking intensity. The ground motion attenuation relationships and their uncertainties are of substantial importance in hazard analysis. Estimates of parameters (coefficients and standard deviation) of an attenuation equation depend on quantity and quality of input data (magnitude range, homogeneity of the available data sample etc.).

4.5.5.4 Ground motion probability

The probability model widely used in hazard analysis is that earthquakes occur as a Poisson process in a time. The probabilistic methodology quantifies the hazard at a site from all earthquakes of all possible magnitudes, at all distances from the site as probability of exceeding some amplitudes of shaking at a site in periods of interest (Thenhaus and Campbell, 2003).

4.5.6 TREATMENT OF UNCERTAINTIES (RANDOM AND EPISTEMIC)

Handling uncertainties is a key element of Probabilistic Seismic hazard Analysis. Two types of uncertainty are defined in seismic hazard analysis-random and modeling (McGuire, 1993). Distinction between the two types of uncertainty has emerged as an important issue in the proper estimation of seismic hazard. The first type uncertainty (aleatory) represents the randomness inherent in the natural phenomena of earthquake generation and seismic wave propagation. The probability functions contained in the basic analysis model represent the random uncertainties. Specification of standard deviation (σ) of a mean ground attenuation relationship is a representation of aleatory variability. Aleatory variability is included directly in the PSHA calculations by means of mathematical formulation. Modeling (epistemic) uncertainties comes from statistical or modeling variations. The large uncertainties in seismic hazard result from lack of knowledge about earthquake cause, characteristics, ground motions, i.e. from uncertainties in the inputs. There are many epistemic uncertainties in any seismic hazard assessment, including the configuration and characteristics of the seismic source zones, the model for earthquake recurrence frequency, and the maximum earthquake magnitude.

In PSHA, the established procedure is to incorporate the epistemic uncertainty into the calculation through the use of logic tree. Logic tree was first introduce into PSHA by Kulkarni et al, (1984) as a tool to model and quantify the uncertainties in the inputs required for such analysis, and the have since become a part of PSHA (Coppersmith&Youngs, 1986). The logic tree is to handle epistemic uncertainties and not random variabilities (aleatory) of known distribution (e.g. Bommer et al., 2005). The logic tree allows a formal characterization of uncertainty in the analysis by explicitly including alternative interpretations, models, and parameters that are weighted in the analysis according to their probability of being correct. Logic tree models may be evaluated, or adequately sample through Monte Carlo simulation (introduced by Bungumen et al., 1986), which is computationally a more efficient procedure (Thenhaus and Campbell, 2003). An important principle to follow in setting up a logic tree (as defined in Bommer et al., 2005), is that the options represented by the branches extending from a single node should encompass the complete range of physical possibilities that particular parameter could be expected to take. The branches should be set up so that, as knowledge improves revised estimates for the parameters should fall within the bounds expressed by the logic tree branches. However, physically unrealizable scenarios should not be included in the logic tree. The use of a logic tree does not relieved the analyst from the responsibility of judging if the specified value of a particular parameter could be expected to occur in nature (Bommer et al., 2005).

Nowadays it has become established practice that the ground motion variability is an integral and indispensable part of PSHA (McGuire, 2004; Bommer and Abrahamson, 2006). Modern methods of seismic hazard analysis incorporate uncertainties into the analysis to assess their impact on the estimate of the expected level of seismic hazard as well as the uncertainty in that estimate.

4.5.7 PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA)

A key milestone in the development of PSHA was the computer program EQRISK, written by McGuire (1976). Nowadays there are a number of PSHA computer codes available to the analyst. The most widely used in practice are those developed by McGuire (1976, 1978) and Bender and Perkins (1982, 1986). A version of machine code EQRISK (McGuire, 1976) was developed and used in practice for probabilistic hazard assessment in Bulgaria. The main difference from the original code consists in using calculation procedures for coordinate transformation and distance integration presented in Bender, Perkins (1982).

Bulgarian version of PSHA computer code offers the following possibilities:

- Usage of different types of attenuation models, including arbitrary functions of M, R and h and some NGA models;
- Allows different types of laws for different sources;
- Depth is included as a random uncertainty (each source is described with its own depth distribution – up to 10 depths with their probabilities);
- Source mechanism is included as a random uncertainty (each source is described with its own SM distribution SM - probability);
- Additionally allows point and circle sources as well as sources between 2 circles with a common center;
- Allows non continuous sources and fault sources (as in SEISRISK);
- Allows Monte-Carlo sensitive analysis;
- Computation of hazard in terms of PGA and SA could be performed with one run of the program.

4.5.8 DE-AGGREGATION OF PSHA

Probabilistic seismic hazard analysis considers a multitude of earthquake occurrence and ground motion, and produces an integrated description on seismic hazard representing all events. The PSHA is able to quantify and account for the random uncertainties associated with estimation of the seismicity and the attenuation characteristics of the region. For physical interpretation of the results from PSHA and to take certain engineering decisions, it is desirable to have a representative earthquake which is compatible with the results of the PSHA method. This could be achieved through the de-aggregation of the probabilistic seismic hazard. A procedure called de-aggregation was applied to examine the spatial and magnitude dependence of PSHA results.

For physical interpretation of the PSHA results and to take certain engineering decisions, it is desirable to have a representative earthquake which is compatible with the results of the PSHA method. This could be achieved through the de-aggregation of the probabilistic seismic hazard (MCGuire, 1995). A procedure called de-aggregation (or disaggregation) has been developed to examine the spatial and magnitude dependence of PSHA results. The aim is to determine the magnitudes and distances that contribute to the calculated exceedance frequencies at a given return period and at a structural period of engineering interest (Thenhaus and Campbell, 2003). De-aggregating PSHA results two important goals are achieved (McGuire, 1995): 1) a relation between the calculated hazard and the specified seismic sources; 2) the loop between scientists performing hazard assessment and users of hazard studies is closed. As a result the seismic hazard philosophy is better understood and more reliable decisions on seismic design, analysis, and retrofit are undertaken.

4.5.9 PSHA RESULTS FOR THE IMPLEMENTATION AREA

A seismic source model is developed for PSHA for the territory of Bulgaria. The model is based on complex geodetic, geological, geophysical and seismological data and is presented in Fig. 108. For each source are defined the all parameters describing the seismicity in the source. Two cases are considered:

1. All sources are areal sources – earthquakes are randomly distributed in the corresponding source
2. Smaller earthquakes are randomly distributed in the source while stronger earthquakes are happened only on the faults defined in the source.

The final result is a mean of the two considered cases.

The ground motion attenuation relationship presented in Ambraseys et al. (1996) is used for hazard assessment.

The seismic hazard for the country in different return periods have been evaluated applying the above described methodology, the compiled seismic source model and selected attenuation model. In Fig. 109. are presented the obtained results for the eligible area for return period of 475 years (probability of exceedance of 10% in 50 years).

Large parts of the area are with expected acceleration between 0.09g and 0.13g and between 0.13g and 0.18g. Small parts (North-East and South-West) fall in territories with expected acceleration between 0.18g and 0.26g and larger than 0.26g.

In Fig. 110. is presented the influence of the intermediate Vrancea earthquakes on the seismic hazard. As seen in the figure almost all Northern part of the eligible area is strongly (more than 50 %) influenced by intermediate Vrancea earthquakes.

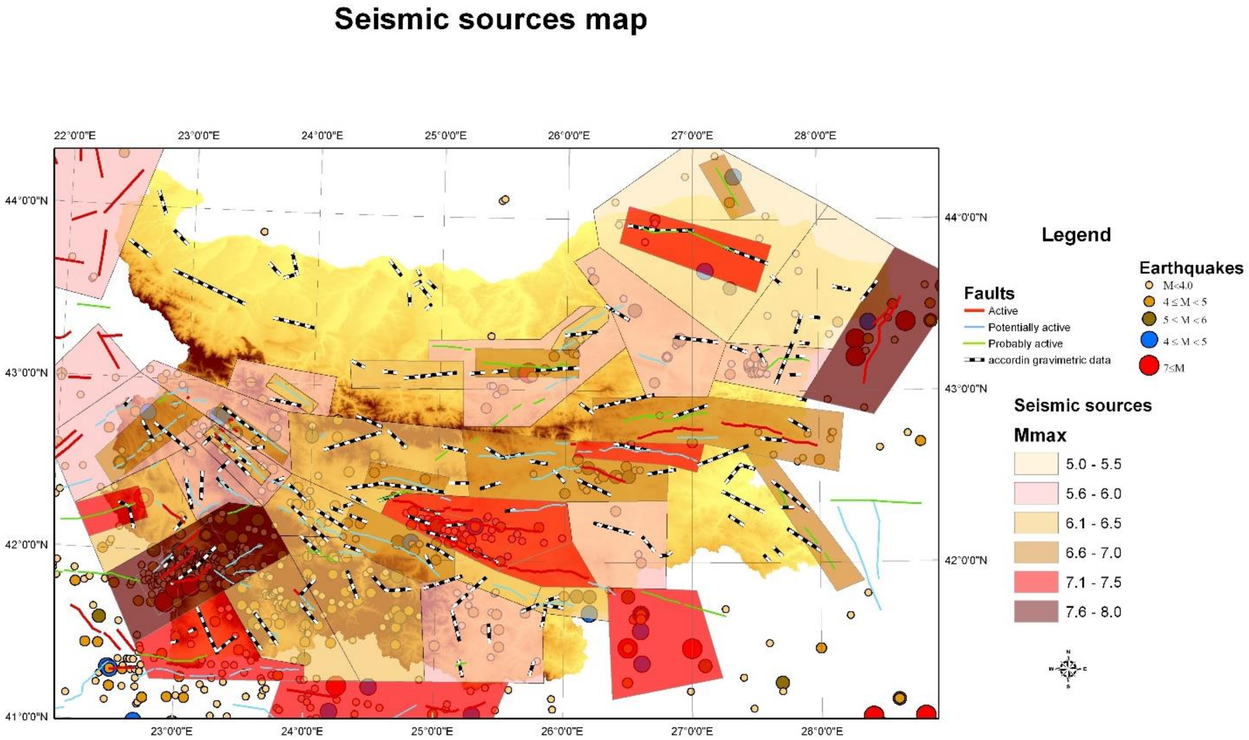


Fig. 108. Map of seismic sources used for seismic hazard assessment

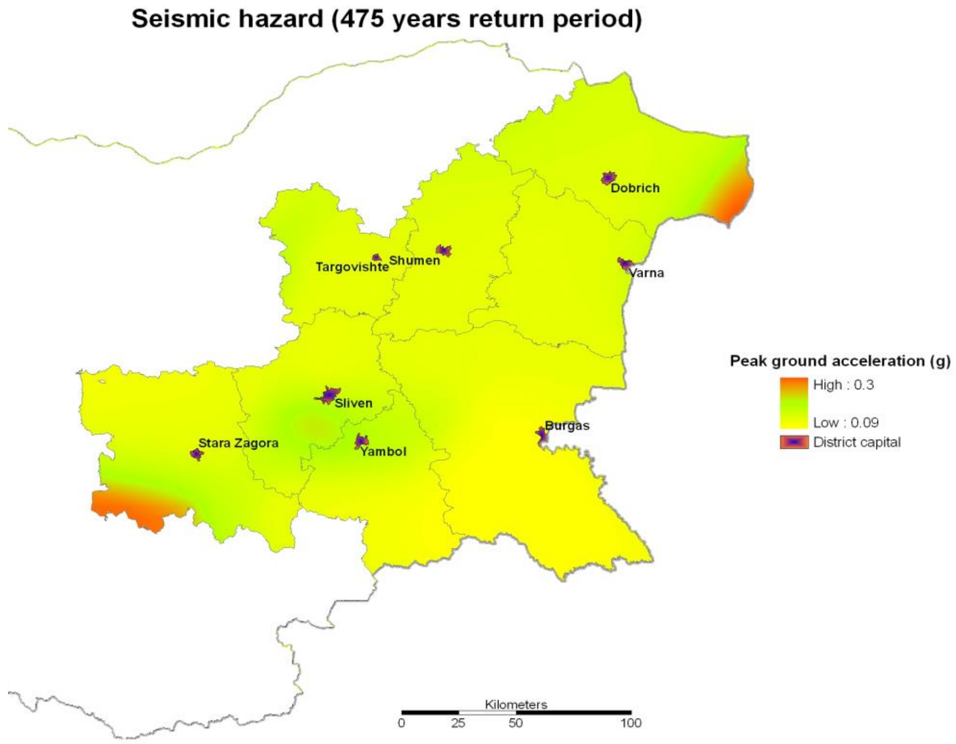


Fig. 109: Proposed map for seismic code (eligible area)

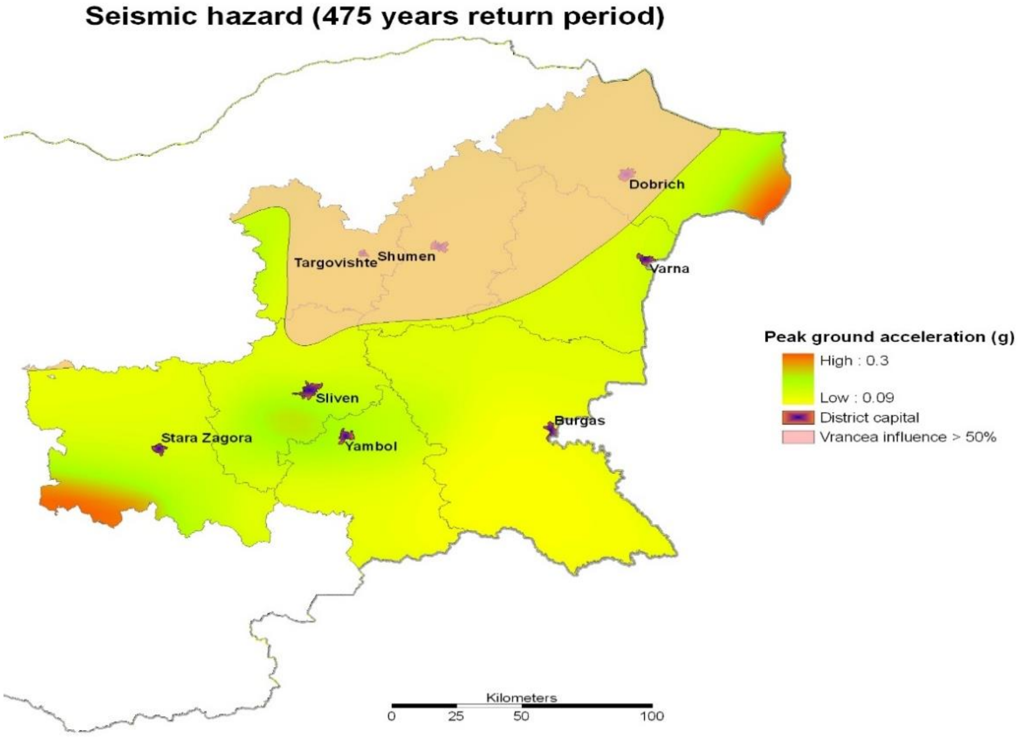


Fig. 110: Influence of the intermediate Vrancea earthquakes on the seismic hazard

4.5.10 DE-AGGREGATION OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR BULGARIAN ELIGIBLE AREA (MAIN DISTRICT TOWNS).

De-aggregation of the seismic hazard for a return period of 475 years (probability of exceedance of 10% in 50 years) for PGA was performed for 8 cities (administrative centres) on the territory of ESNET Bulgarian eligible area (Fig. 111 – Fig. 114)

The de-aggregation results show existence of both unimodal and bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA.

PSHA de-aggregation plots for PGA show the following peculiarities:

1. Unimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is observed. The mode of the distribution is for magnitude 5.0-7.5 earthquake at a distance of 5 to 20 km from the city of Yambol. The strongest contributor to the hazard is the near regional seismicity (Fig. 111).
2. PSHA disaggregation plots show a slight bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is observed for PGA (Fig.10). The primary mode in Fig.10 (well expressed) is a magnitude 5.0 to 6.0 earthquake at 10 to 20 km from the cities of Sliven and Stara Zagora (effect of the near regional seismicity). The secondary mode (not well expressed) is for magnitude greater or equal to 7.5 earthquakes

at a large distance (effect of Vrancea intermediate earthquakes). The strongest contributor to the hazard is the near regional seismicity.

3. PSHA disaggregation plots show a slight bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is observed for PGA (Fig.11). The primary mode in Fig. 113 is for magnitude greater or equal to 7.5 earthquakes at a distance of more than 200 km from the cities of Targovishte, Shumen, Dobrich and Burgas (effect of Vrancea intermediate earthquakes). The secondary mode is a magnitude 5.0 to 6.0 earthquake at 10 to 20 km from the cities (effect of the near regional seismicity). The strongest contributor to the hazard is the Vrancea intermediate source.
4. PSHA disaggregation plots show a bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency (Fig. 114). The primary mode of the distribution is for magnitude greater or equal to 7.0 earthquakes at a distance 10 to 20 km from the city of Varna (effect of the near regional seismicity). The secondary mode is a magnitude 7.5 or larger earthquake at a distance of more than 250 km from the city of Varna (effect of Vrancea intermediate earthquakes).

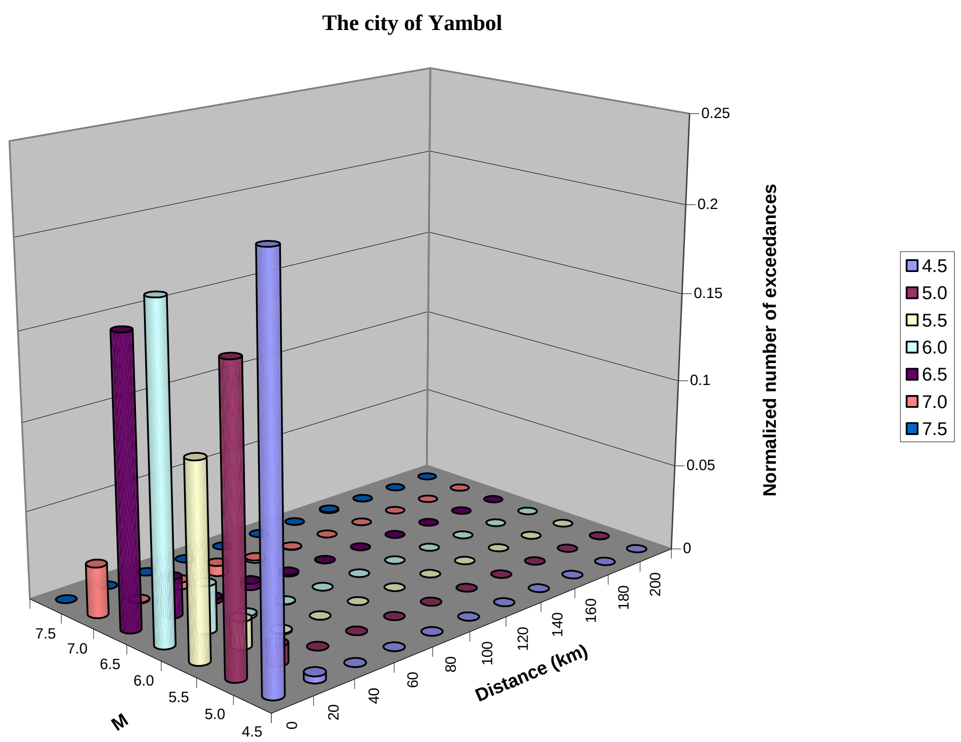
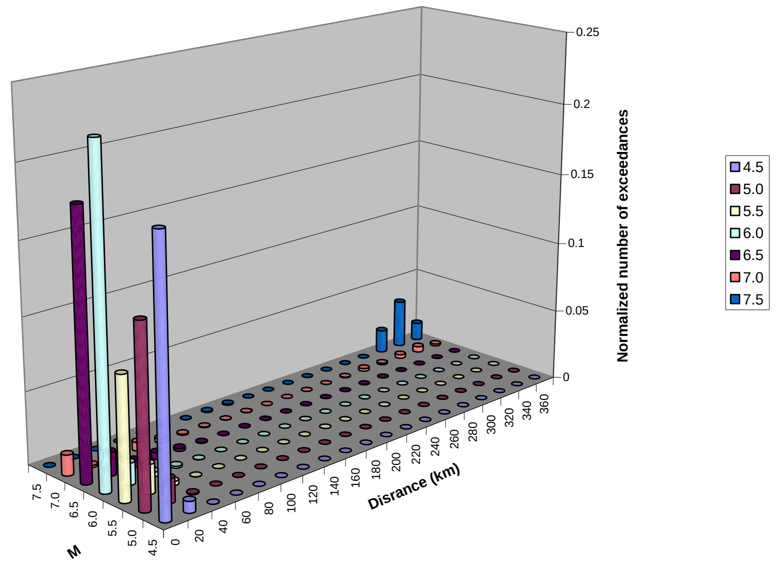


Fig. 111: Unimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency - the strongest contributor to the hazard for the cities is the near regional seismicity

The city of Sliven



The city of Stara Zagora

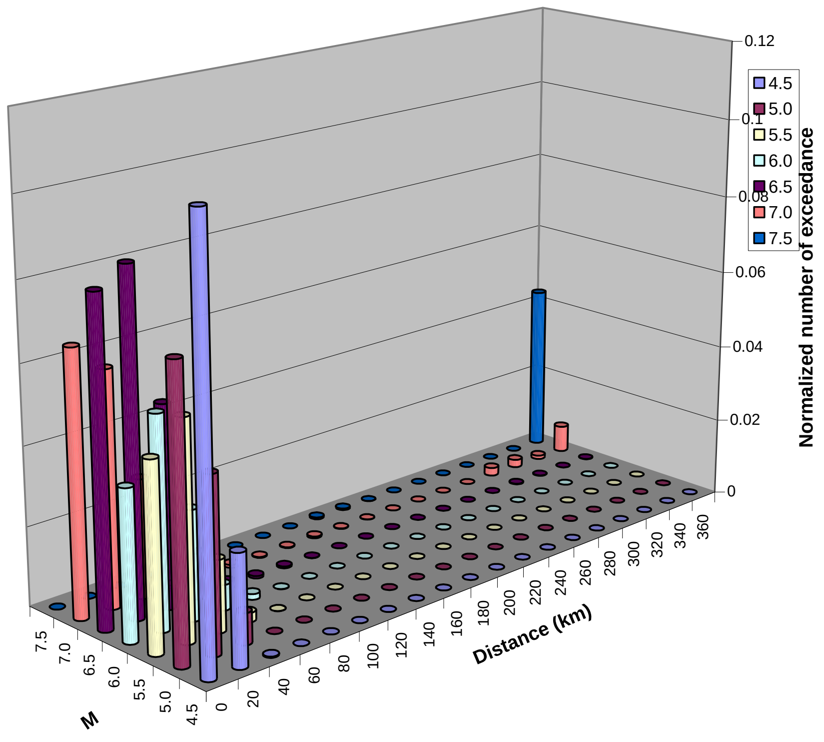


Fig. 112: Slight bimodal distribution of earthquake magnitude and distance - stronger contributor to the hazard for the cities is the near regional seismicity

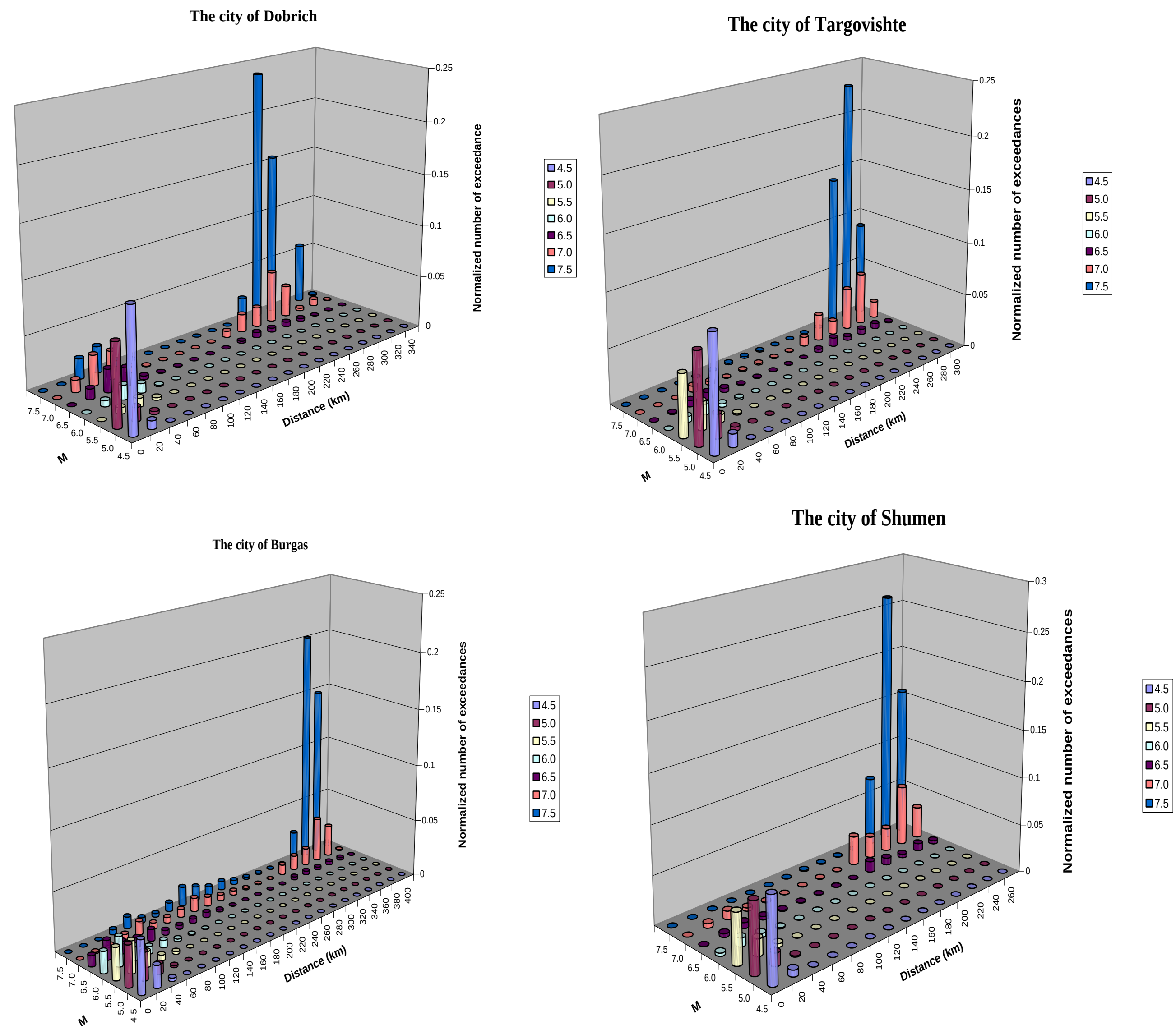


Fig. 113: Slight bimodal distribution of earthquake magnitude and distance - stronger contributor to the hazard for the cities is the Vrancea intermediate source

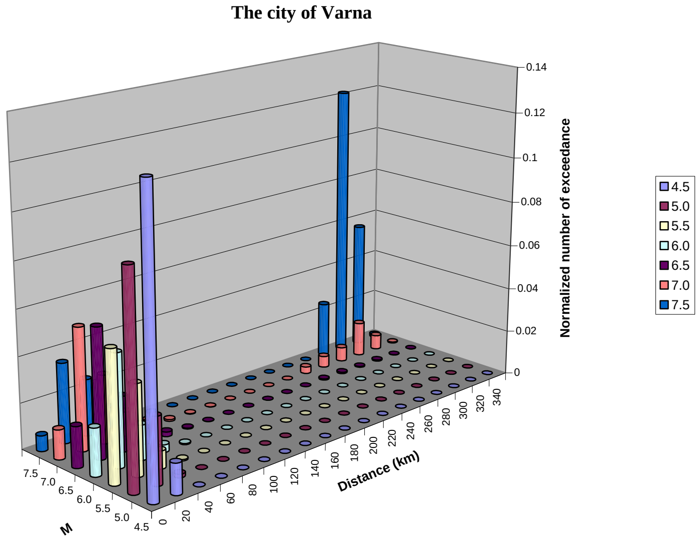


Fig. 114:A bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency.

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4.6 UKRAINE

4.6.1 SEISMICITY AND SEISMIC ZONING OF UKRAINIAN TERRITORY

Seismicity of Ukrainian Black Sea region is defined with territorial effect of seismic active zones, as follows:

1. Seismically active zone of Vrancha, Romania (connection region of Eastern and Southern Carpathian mountains);
2. seismically active zone of Crimea - Black Sea region;
3. Seismically active zone Dobrudja (delta region of Danube river);
4. Black Sea depression;
5. Platform part of Ukraine.

4.6.2 SEISMIC HAZARD IN UKRAINE

120 000 km^2 of Ukrainian territory (about 20%) – seismically dangerous.

Intensity of earthquakes - 6-9 points according to scale MSK-64

There are about 10.9 millions of people reside on seismic territories (about 22% of population):

- in zone of 6-scale earthquakes - 7,98 millions of people (15.5%),
- in zone of 7-scale earthquakes - 2,23 millions of people (4,3%),
- in zone of 8-9-scale earthquakes - 0,79 millions of people (1,5%).

The Complete Set of general seismic zoning maps (GSZ) of Ukrainian territory is used in Ukraine (GSZ-2004, A, B, C). The scale of maps is 1:2 500 000 (authors: Pustovitenko B.G., Kulchitsky V.E., Pustovitenko A.A.). The Complete Set has probable periods of earthquakes repeatability as 1 time in 500, 1000 and 5000 years. Maps of the Complete Set show estimated prognostic intensity of seismic impacts in accordance with scale MSK-64, that are expected at this territory with defined probability (%) during defined (selected) time period.[1]

Map GSZ-2004-A Fig. 115 corresponds to 10% exceedance probability of estimated intensity for proximate 50 years period, probable period of earthquakes repeatability is 1 time in 500 years.

[1] http://www.seism.org.ua/seism04-03.pdf

Application: for designing and constructing facilities and buildings with civilian and industrial purposes; for different habitable structures and object at towns and countryside.

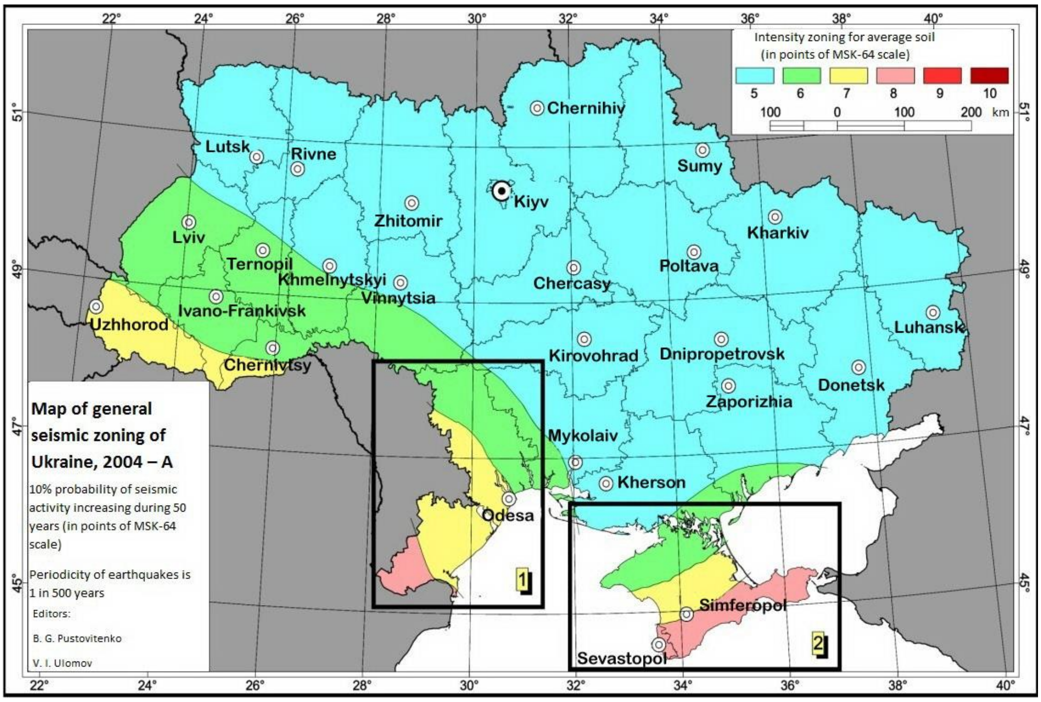

Fig. 115: Map GSZ-2004-A [2]

Map GSZ-2004-B (Fig. 116**)** corresponds to 5% exceedance probability of estimated intensity for proximate 50 years period, probable period of earthquakes repeatability is 1 time in 1000 years.

Application: for designing and constructing facilities and buildings with increased level of responsibility (oil tanks V=1000 m^3, arterial pipelines, industrial facilities with spans bigger than 100 meters, communications facilities higher than 100 meters, unique buildings and facilities, etc.), destruction of which in time of powerful earthquakes can cause local-level emergency situation.

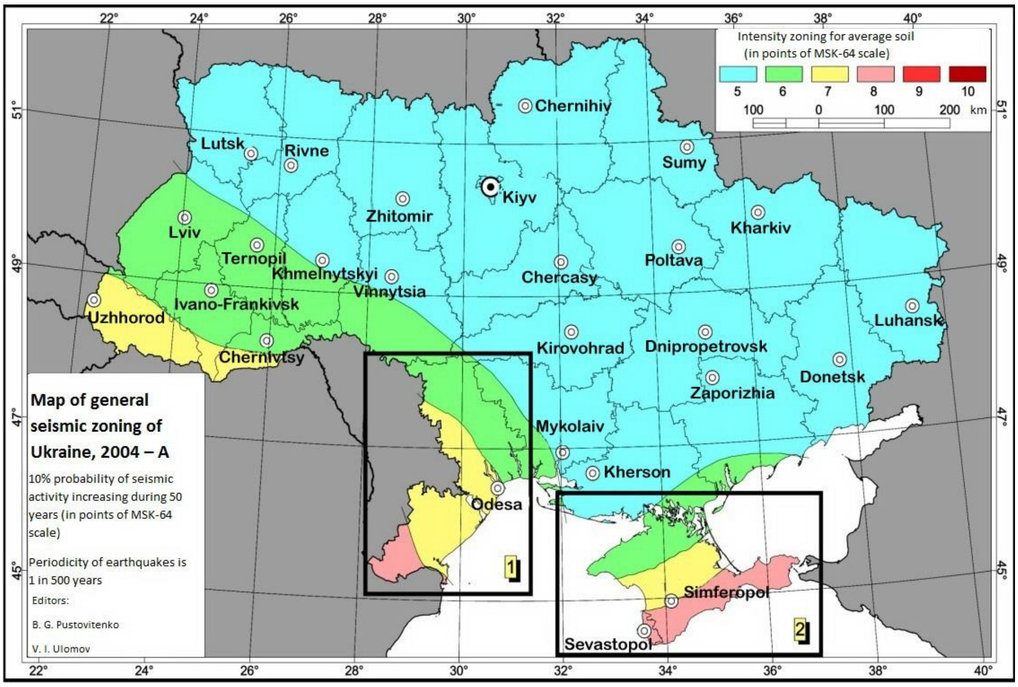

Fig. 116: Map GSZ-2004-B [2]

Map GSZ-2004-C (Fig. 117**)** corresponds to 1% exceedance probability of estimated intensity for proximate 50 years period, probable period of earthquakes repeatability is 1 time in 1000 years.

Application: for designing and constructing facilities and buildings with extreme level of responsibility that have reliability index under responsibility not lower than 1,2 (large hydrofacilities, nuclear power plant, large chemical plants, different ecologically dangerous facilities, etc.), destruction of which in time of powerful earthquakes can cause state-level emergency situation.

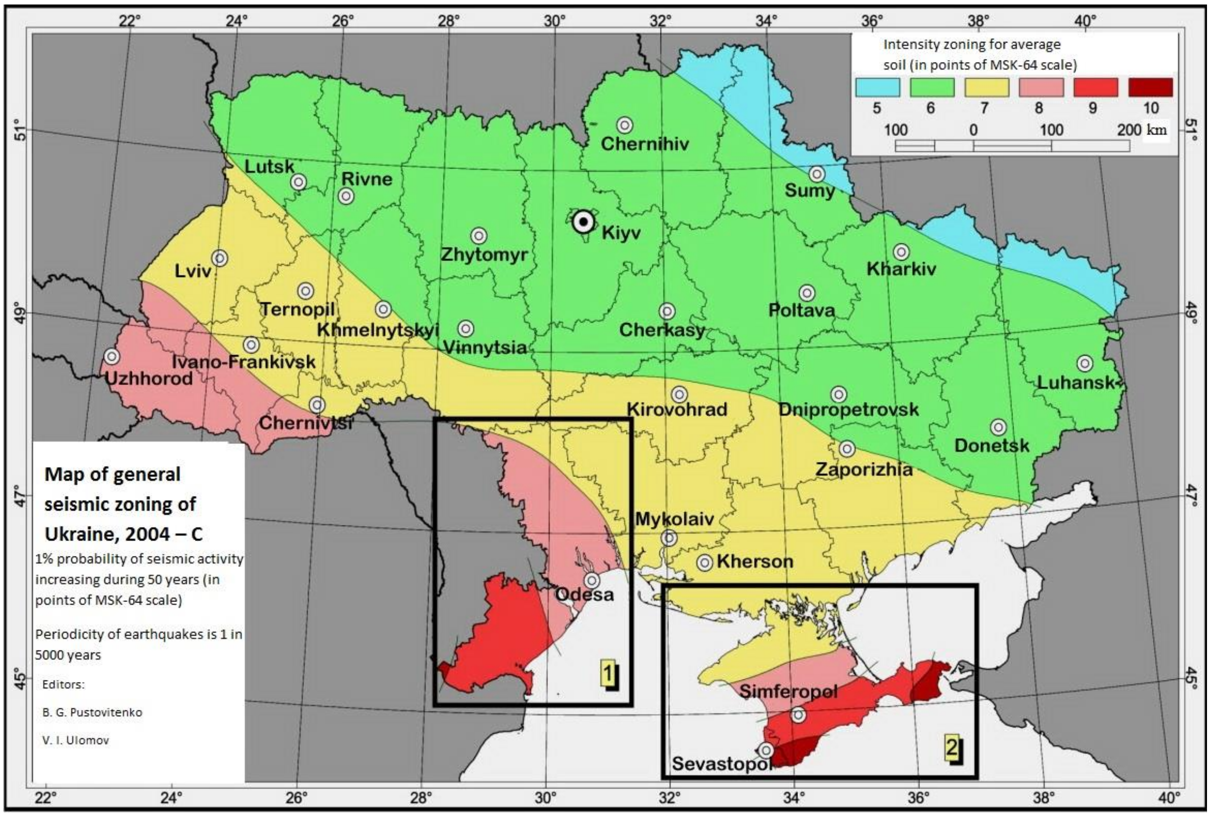

Fig. 117: Map GSZ-2004-C [2]

4.6.3 SEISMIC HAZARD ESTIMATING PROCEDURE

Generalized characteristic (intensity) of earthquake damaging effect at defined geographical point is estimated with points of seismic scale MSK-64. Normal amplitude characteristics of ground oscillations at regions with seismic level about 7, 8, 9 and 10 point of scale MSK-64 are the next [1]:

- by seismic-level about 7 points normal acceleration amplitudes (also named as PGA – peak ground acceleration) - 100 cm/s^2, normal velocity amplitudes (also named as PGV – peak ground velocity) - 8,0 cm/s, normal displacement amplitudes - 4,0 cm;

- by seismic-level about 8 points normal acceleration amplitudes (also named as PGA – peak ground acceleration) - 200 cm/s^2, normal velocity amplitudes (also named as PGV – peak ground velocity) - 16,0 cm/s, normal displacement amplitudes - 4,0 cm:

- by seismic-level about 9 points normal acceleration amplitudes (also named as PGA – peak ground acceleration) - 400 cm/s^2, normal velocity amplitudes (also named as PGV – peak ground velocity) - 32,0 cm/s, normal displacement amplitudes - 16,0 cm:

- by seismic-level about 10 points normal acceleration amplitudes (also named as PGA – peak ground acceleration) - 800 cm/s^2, normal velocity amplitudes (also named as PGV – peak ground velocity) - 64,0 cm/s, normal displacement amplitudes - 32,0 cm

4.6.4 METHODOLOGICAL APPROACHES TO INITIAL SEISMIC REFINEMENT AT BUILDING SITE

Equation of seismic regime at building site is used for initial seismic refinement. To set-up correct equation of seismic regime it is necessary to find time periods (periods of repeatability) T_i that correspond to seismic events with integer-valued power I_i at building site. Using founded number pares (I_i, T_i) it is possible to define indexes of correlated seismic regime equation at building site [1]

$$I = a + b\lg T \qquad (94)$$

where a, b - empirical coefficients of seismic regime equation;

T - average period of time (measured in years) between earthquakes with power I at building point.

Clarified earthquake intensity I is calculated by using relation (1). Founded intensity corresponds to specified time period T = 500, 1000 or 5000 years between earthquakes with calculated intensity, or correspond to allowed risk-level about 90 %, 95 % or 99 % of non-exceeding of estimated seismic load during 50 years of facility (building) exploitation.

There is positive or negative difference δI between earthquake intensity (that was taken from map GSZ-2004) and specified earthquake intensity (that was calculated with the help of the equation (1)). Anyway, for subsequent calculations it is accepted that the module I does not exceed value = 1.0.

Seismic regime correction is calculated by using increment of intensity I. Correction factor is defined by Eq.$K_{\text{c.p}} = 2^I$ (95)

$$K_{\text{c.p}} = 2^I \qquad (95)$$

where I - increment of intensity (measured in tenth of point).

Mapping of potentially dangerous seismic-genegraded structures (SGS) is done by the complex of geological, geomorphological, geophysical, geochemical and other features. On this basis and with regard to the seismic data (observable and historical seismic activity) zones of possible earthquakes (zones of PA) are determined. These zones are used for calculation of seismic impact on average soils and flat areas at the construction site.

The analysis of stock and literature sources of geological-geophysical and seismic content is conducted for characteristic of seismic-generating structures.

At the same time ancient and modern ruptural structures are examined with purpose to find the most agile regional and local snaps, deep structure and modern crust movement, seismic regime of polygon, magnitude and deep of focuses, parameters of macro-seismic field and others. Preliminary data analysis is complemented with results of field observations at key sites, materials of aerial- and space-photos decoding.

Usually, only two scales of research - 1:500 000 and 1:100 000 – are used to estimate seismic-tectonic situation. More detailed scale is used to analyze seismic-tectonic situation in object near-zone (radium less than 50 km), less detailed scale is used to analyze seismic-tectonic situation in object far-zone (radium from 50 km to 100 km) [1].

For estimating seismicity of objects with the increased level of potential hazard it is recommended to conduct engineering-seismic observations (using network of temporary station) for confirming data about pre-selected earthquakes focuses with the help of instrumentally-fixed weak shocks and for receiving information about deep distribution of f hypocenters. For estimating amount of seismic activity increasing different methods are used: instrumental-seismic, seismic methods and also theoretical and empirical engineering-geological approaches.

4.6.5 METHODOLOGICAL APPROACHES OF SEISMIC MICRO-ZONING SUBJECT TO ENGINEERING-GEOLOGICAL AND GEOMORPHOLOGICAL CONDITIONS.

Numerous observations made by scientists who explore effect or earthquakes showed us that local manifestation of seismic effect is closely connected with engineering-geological, hydro-geological and geomorphological conditions. Thus, objective estimation of seismic hazard can be done only as a result of integgraded application of different procedures designed for exploring engineering-seismic conditions of defined site or territory.

It is proved with multiple scientific studies that *seismic intensity* on earth surface may vary from *+2 to -2 scale points* by different engineering-geological conditions. The most dangerous in point of seismicity are the areas with widely-spread mellow watered soils.

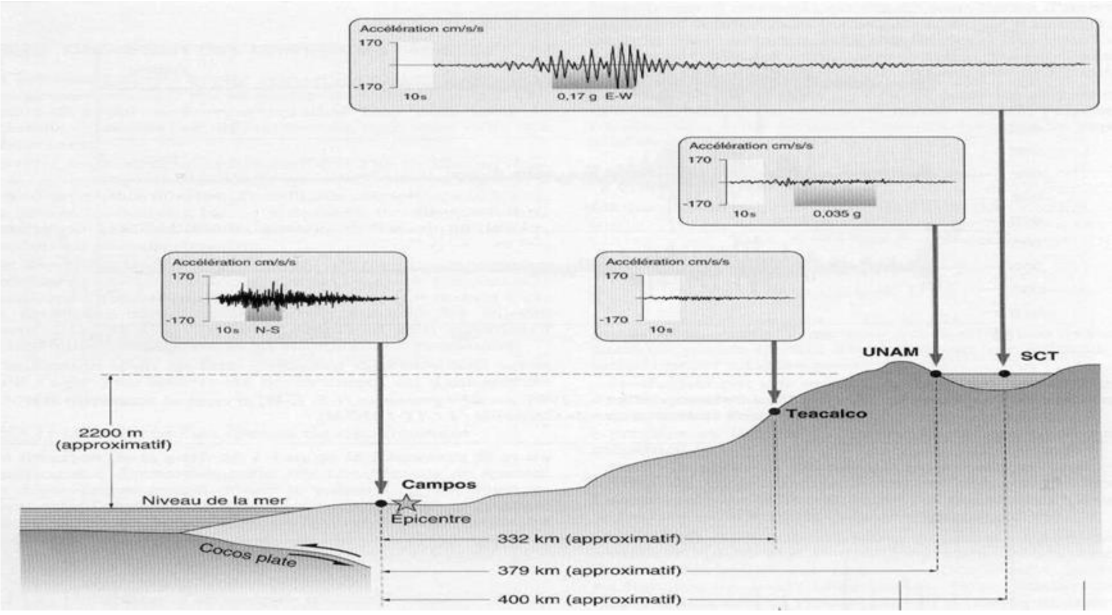

Fig. 118: Changing characteristics of seismic impact in impound area

Within the site of construction seismicity of micro-zones is determined as a result of seismic micro-zoning procedure (SMP). Working materials of SMP have to contain quantitative assessment of layers bedding character impact-effect, seismic properties of designed strata soils and topography of earth surface (the last in case of strongly rough terrain), and also have contain data about buried ruptures in point of amplitude and spectral characteristics of seismic impact (

Fig. 118).

It is recommended to determine dynamical properties index of soil strata (its seismic rigidity) by using formula Eq. $K_{\text{гр}} = 2^{1,67\lg\left(\frac{655}{\rho V_s}\right)}$, (96)

$$K_{\text{гр}} = 2^{1,67\lg\left(\frac{655}{\rho V_s}\right)}, \tag{96}$$

where ρV_s - seismic rigidity of the designed strata soil, t/m^{2}s;

ρ - consistency of the soil, t/m^3;
V_s - velocity of cross-cut seismic waves into the designed series, m/s.

If designed soil strata consists of several layers, then weight averaged seismic rigidity of layer package is taken into account. The weight averaged seismic rigidity is calculated with Eq. (97)

$$\rho V_s = \frac{\sum(\rho_i V_{si}) h_i}{\sum h_i}, \tag{97}$$

where: h_i– thickness of i-layer of the package, m;

$\rho_i V_{si}$ – seismic rigidity of the *i*-layer of the package, t/m^2*sec, regard to cross-cut seismic waves.

For preliminary assessment of ground-conditions impact on seismicity of construction sites with increased level of responsibility it is allowed to set the correction index of dynamical properties of homogenous soil strata $K_{гр}$ at value:

0,5 – for slightly-weathered rocks and non-weathered rocks;

1,0 - for weathered rocks and strong-weathered rocks, macro-fragmental blanket, sand and clay soils with provisional axis compression resistance R_o>0,25 MPa (2,5 kgf/cm^2);

2,0 – for sand and clay soils with provisional axis compression resistance $R_o \leq$ 0,25 MPa (2,5 kgf/cm^2).

In those cases when designed soil strata has non-homogenous structure, the index $K_{гр}$ is calculated as average value of random amount with formula [5]

$$K_{гр} = \frac{\sum K_{гр,i} h_i}{\sum h_i}, \qquad (98)$$

Where: h_i– thickness of *i*-layer of non-homogenous designed soil strata;

$K_{гр,I}$ – index considering seismic properties of *i*-layer.

4.6.6 SPECIFICS OF APPLICATION OF SEISMIC HAZARD ESTIMATING PROCEDURE FOR SPECIFIC TERRITORY (AS EXAMPLE – NORTH-WESTERN BLACK SEA REGION (UKRAINE))

Proposed procedure of seismic hazard estimating was designed for territory of Eastern Carpathians and North-Western Black Sea Region and tested at Odessa-city (Ukraine). It is proposed for application at regions with similar engineering-geological and seismic conditions. This procedure includes:

1) method of regional seismic conditions analysis;
2) method of engineering-geological conditions analysis;
3) method of local seismic hazard engineering-geological assessment.

For the territory of Odessa-city (Ukraine) designed engineering-geological basics for conducting of seismic micro-zoning, and also previously estimated grade of local seismic hazard in point of engineering-geological conditions changing. The final purpose of the detailed seismic zoning and micro-zoning is assessment of seismic impact at specific construction site.

The territory of Odessa-city is located in zone of possible earthquakes with intensity about 6-7 point. The most of territory is located onto non-coherent quaternary (loessial) soils. Significant rising of underground water level occurred in the last 30 years. Development of filled soils widely spreads, engineering-geological properties of ground change. All of this makes territory of the city unfavorable in point of seismic hazard.

4.6.7 METHOD OF ANALYSIS OF SEISMIC CONDITIONS

The research and analysis of regional seismic conditions in order to specify the level of regional seismic danger includes:

Research of edited and fund materials:

- the creation of a database (in accordance with historical data and the data given by seismological stations) concerning the sources of earthquakes within a territory (the coordinates of the source, its depth, its magnitude and the intensity in surface ground zero);
- the creation of an electronic map of sources of earthquakes and seismic events based on geo informational technologies;
- the building up of a 3-D model of the subterranean structure of the region in accordance with geological and geophysical data that will include the soleplate of the Earth crust, the Conrad discontinuity, the surface of the outer mantle, the Moho-discontinuity;
- the building up of digital space models that will characterize in 3-D the variety of parameters of seismic influence;
- the pointing out of regions which are similar in accordance to characteristics of seismic influence;
- the determination of links between the pointed out areas and the geological zones (in accordance to depth, the Earth crust, the outer mantle and the asthenosphere);
- the unification of seism generating areas, their generalization and smoothening of borders (in a radius up to 1 km), the outlining of areas with seism linear structure;
- the verification of every outlined seism generating area of the standard statistic indicators of characteristics under research;
- the adding to every outlined seism generating area data concerning the sources of earthquakes within its borders;
- the calculation in accordance with equation of the macro seismic field (based on the model of attenuation) of maximum intensity of seismic influence from every source of earthquake and from every outlined seismic active area for the territory under research and in many of its parts;
- the outlining from the seism active areas the most seism dangerous ones (in accordance with the maximum calculated intensities of influence and the observed magnitudes, the frequency of earthquakes and others) for the territory of research;
- the calculations for the territory under research the angles of approach of seismic waves (2D and 3D) from every seismic active area.
- the evaluation of value of the angles of approach of seismic waves on the change

of intensity of seismic influence due to geo morphological factors;

- the correction of law of dissemination of quantities, of characteristics of influence as a result of taking into account the influence of soil conditions and terrain.

EXAMPLE: Under different distances, energetic levels and mechanisms of earthquakes the intensity of seismic influx can be influenced by engineering – geological factors. For example within the city of Odessa under the level of seismic influence more than 7-8 points the dissolution of forest grounds is possible, in this case the level of local seismic danger will not be determined by the intensity of the influence itself, but by magnitude of seismic deformations and seismic collapse which can be calculated through such characteristics as coupling and the angle of internal friction.

The way to determinate the intensity of tremor. As a result of analyses of macro seismic data there's the empirical correlation that connects the macro seismic intensity, measured in points of a seismic scale MSK-64, with the magnitude of an earthquake, the depth of the source and the distance to ground zero.

These interrelations are described with an equation of a macro seismic field. In accordance with this equation the evaluation of intensity of earthquakes has been carried out for the city of Odessa (for the period from 1000 b C till 2003 M<3) on the distance # from the ground zero of the magnitude M, the depth of the source of earthquake h:

$$I_i = bM - v \cdot \lg \; + c \qquad (99)$$

As multipliers the regional meanings of the Eastern-Carpathian region were used: b=1.5, v=3.5, c= 3.0

The calculation could also be carried out with the help of the Vutkov formula (Vutkov, 1985)

$$I_i = \; - v \cdot \lg \qquad (100)$$

(the values are the same).

In the majority of cases the value of points calculated with the help of this formula coincides with the intensity of the tremor on soil that is mediocre in accordance to its seismic characteristics.

The analyses concerning the data on the sources of earthquakes has been carried out on the territory of the Eastern Carpathian Mountains, The Moldavian Highlands and the North-West Black Sea region with a magnitude more than 3 for the period from 984 till the year 2003.

This method allows with the appropriate level of accuracy to periphery the aseismic and seismic areas. The outlining of areas with the most probable sources of strong earthquakes (the PSE areas), the demarcation of the borders of these areas and their differentiation in accordance with the magnitude of maximum crunches (Mmax) has an important meaning for seismic positioning and the detailed evaluation of the seismic danger of the region. The areas of probable sources of earthquakes are parts of the Earth crust or the outer mantle that has accumulated a huge energy potential of resilient tensions.

The outlining of seismic active areas is carried out on the basis of the following geological and geophysical characteristics:

Specific density of the sources of earthquakes, maximum magnitudes, the depth of the source of earthquakes, the frequency of earthquakes and the depth structure of the lithosphere.For the geological and geophysical interpretation of the characteristics of the seism generating areas the data concerning the earth crust volume, the Moho-dicontinuity and the surface of the asthenosphere is used. The changes (strengthening or weakening) of the intensity of seismic influence due to changes of the engineering-geological conditions are also to be considered.

4.6.8 METHOD OF ENGINEERING-GEOLOGICAL CONDITIONS ANALYSIS

For analysis of *engineering-geological conditions* of this territory were used next methods of regional researching: geological mapping, geological-structure and geomorphological methods, methods of analytical and mathematical engineering-geological modeling, engineering-geological hydrogeological zoning) [4].

The development of engineering-geological basics of seismic micro-zoning includes:

1) The researching of existing methods and engineering-geological criteria of local seismic hazard grade assessment.
2) The comparative analysis of accuracy of previous engineering-geological researches materials concerning concrete territory.
3) The designing of actual electronic maps on basis of regional and prospecting studies (descriptions of chinks, bore pits, wells and exposures).
4) The creation of data base using initial materials of regional and prospecting studies (geological-mapping chinks, engineering-geological chinks and bore pits, exposures).
5) The creation of electronic topographical basics.
6) The integrating data base of initial material and electronic map of actual material for creating layer of geo-spaced data base.
7) The designing and building-up (using topographical base) digital models of relief of earth surface in scale 1 : 25 000 and 1 : 10 000 in format ArclnfoGrid with resolution ability about 10 meters in plan for following using by building-up models of geological structure, geomorphological and engineering-geological conditions.
8) The creation geo-spaced data base (GDB) about levels of underground waters (LUW) on the territory based on materials of regime observations.
9) The designing of geomorphological base.
4) The designing of geological base.
5) The designing of engineering-geological base of territory, including data about levels of underground waters, physical-mechanical properties indicators of engineering-geological elements, as well as density, porosity, index of plasticity, nature humidity,

collapsibility and other.

Geomorphological zoning allows to allocate geomorphologically homogenous elements and then may be used in special engineering-geological zoning. Parameters, studied under designing of geomorphological base, geological base and engineering-geological base, then may be used for assessment of local seismic hazard grade. For determination of complexity and degree of variability of engineering-geological conditions, as factors of modification of local seismic hazard, the *method of special complex engineering-geological zoning (SCEGZ)* is proposed [4].

Special complex engineering-geological zoning – this is the type of regional engineering-geological zoning for determination complexity and grade of modification of engineering-geological conditions as factors of changing of local seismic hazard.

Objects of researching under SCEGZ are engineering-geological taxonomic elements – districts, sub-districts and sites (seismic micro-districts). Final elements of SCEGZ are engineering-geological sub-districts and sites – “*engineering-geological micro-districts*”.

Special engineering-geological zoning is made using scales 1:50 000 – 1:10 000 for the territory of cities or large populated clusters.

Using of the mentioned complex of methods allows to efficiently estimate space and space-temporal variability of probable values of amount of increasing of seismic intensity (1) by geostatic methods. Thus, space variability of value 1 in limits of Odessa’s territory is about -0.5 - (+1.5 point), by average time variability 0,25 – 0,5 point for each 10 years (from 1960 year till 2000 year) [4].

Special complex engineering-geological zoning is conducted according to substantial-morphological engineering-geological features.

For example: according to structure-tectonic features territory of Odessa-city is belong to northern wing of Black Sea depression that is overlaid on southern slope of Ukrainian shield. But according to geomorphological features (rank - *region*) territory of Odessa-city is belong to Dniestr-Bug loessial accumulative plain. Engineering-geological zoning of territory of Odessa starts from *sub-regions* that are selected according to complex of regional geomorphological characteristics (age and genetic types of relief elements, their high-levels and other).

Using selected engineering-geological elements the average engineering-geological characteristics of conditions are calculated.

Geo-informational and digital modeling technologies (Arclnfo 8.3, Erdas Imagine 8.6, TNTMips 6.6) are used for building-up maps of engineering-geological conditions and zoning

4.6.9 METHOD OF LOCAL SEISMIC HAZARD ENGINEERING-GEOLOGICAL ASSESSMENT

The main *estimation criteria of grade seismic intensity* on concrete territory are: spread specifics of geological-genetic complexes of rocks; capacity of quaternary sediments strata (including capacity of watered strata); engineering-geological properties of different geological-genetic rock complexes; dissemination of underground openings; deep of burial of half-rock layers; presence of discrete violating; grade of cleavage of half-rock layers; grade of decompaction of crumbly layers (depth to 20 meters); engineering-geodynamic conditions; gradient of earth surface.

The main hydrogeological criteria of estimation of seismic intensity increasing (on territory of Odessa) are: presence of water-bearing horizon (depth to 20 meters), level of water-bearing horizon and parameters of its dynamic.

Assessment value of seismic intensity increasing is made on basis of existing theoretical ideas and empiric data about correlation between value of seismic intensity increasing and engineering-geological (and also seismic) properties of the geological environment. For mentioned assessment the following methods are used:

- the approximated assessment of seismic intensity increasing for category of soil by seismic properties, by levels of underground waters and capacity of quaternary sediments on basis of qualified assessment of seismic hazard grade of territory;
- the estimation of seismic intensity increasing on the basis of method of seismic rigidity in accordance with the formula of Medvedev and with regard to the level of underground waters (LUW);
- the quantitative assessment of possible seismic intensity increasing with regard to the seismic rigidity of rocks, depth of burial of the LUW, capacity of the quaternary sediments, geomorphological factors (depth of vertical dismemberment of the relief) and the angle of approach of surface seismic wave to the earth surface.

Initial data for calculations are engineering-geological properties that are selected with correction to the LUW.

Formula of Medvedev estimates seismic hazard modification of explored soil in towards the etalon soil. For non-watered soils values of acoustic rigidity are compared: of etalon ($\rho_E V_E$) and explored ($\rho_i V_i$) soil (in upper 10-20 meters zone of section), according to the formula [4]:

$$\Delta I = 1.67 \lg (\rho_E V_E / \rho_i V_i) \qquad (101)$$

For highly-watered (flooded) loessial and sand soils to the mentioned formula increasing h_{UGV} (that takes into account depth of burial of the LUW) is added:

$$\Delta I_B = \exp(-0.04h^2_{UGV}), \tag{102}$$

considered on

Fig. 119.

Estimation of possible values of seismic intensity increasing according to the scale MSK-64 in regard to capacity modification of the sedentary-aeolian-diluvian sediment strata is conducted upon empiric graph of Casimov, than is considered on

Fig. 120. The formula is:

$$\Delta I = \log(mQ - 0.67) \tag{103}$$

where *mQ* – capacity of loessial sediments strata.

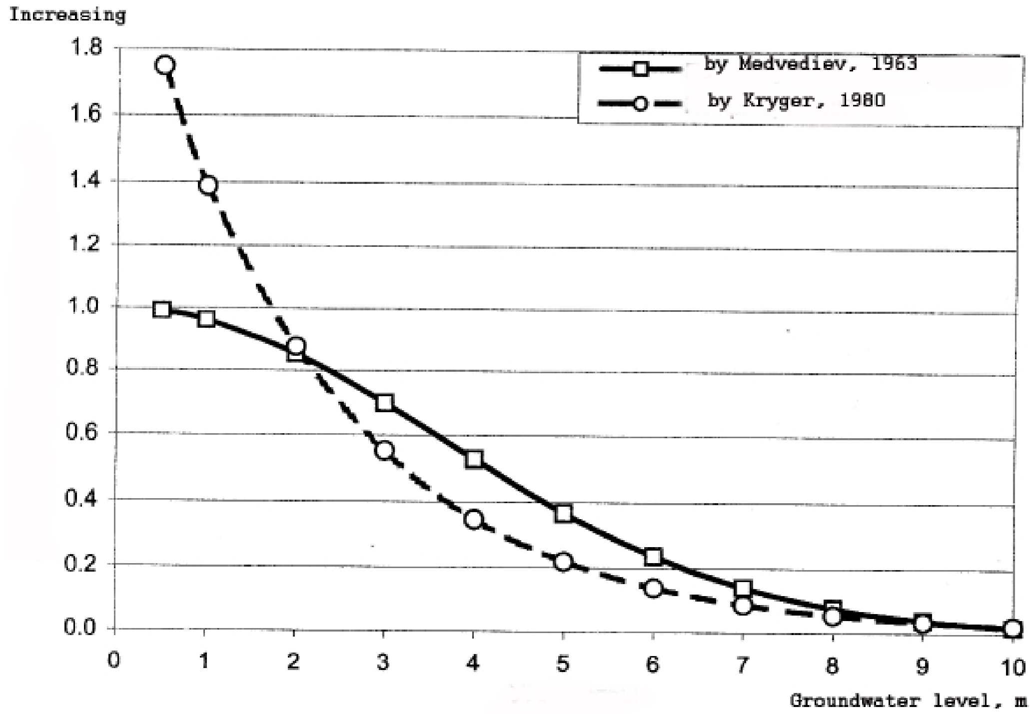

Fig. 119: Increasing of seismic intensity according to the scale MSK-64 in dependence from variation of depth of burial of underground water level [4].

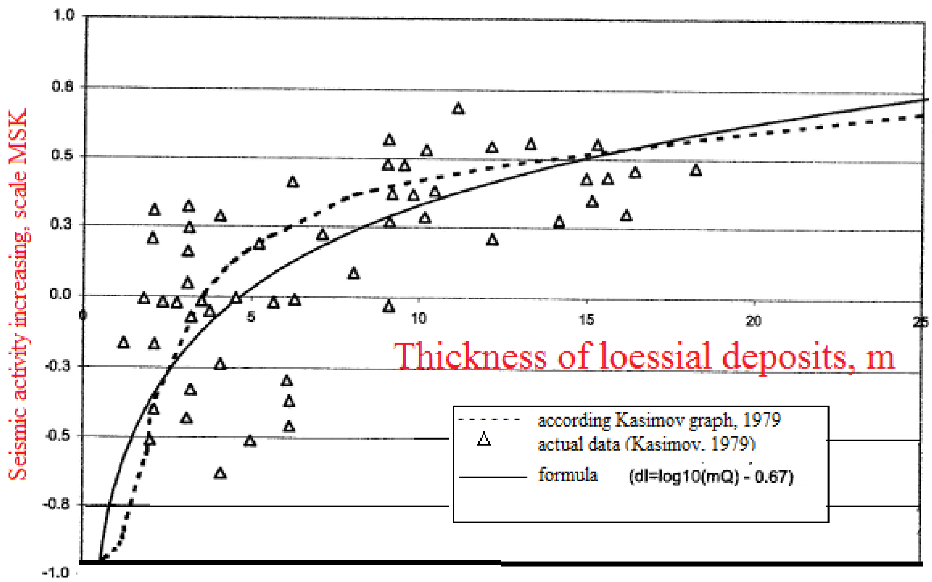

Fig. 120: Dependency between capacity of loessial sediments and increasing of seismic intensity [4].

Theoretical and empiric components of possible modifications of seismic intensity on the earth surface are used for assessment of geomorphological conditions:

a) angle of inclination of earth surface;

b) possible angle of approach of surface seismic wave to an element of the relief (relatively about concrete seismic active area);

c) depth of vertical dismemberment of relief, or high of slope (Fig. 121).

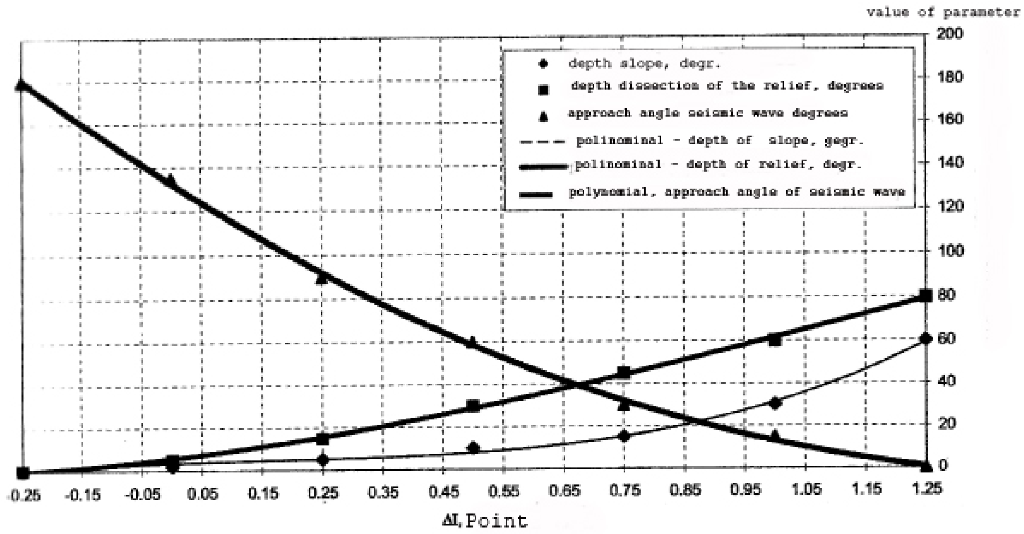

Fig. 121: Schematic graph of correlation between depth of vertical dismemberment of relief, slope angle, angle of approach of surface seismic wave to an element of relief, and possible value of seismic intensity increasing according to the scale MSK-64 (on base of theoretical and empirical data) [4].

The mentioned method is tested on the territory of North-Western Black Sea region and Odessa-city, maps-schemes of possible increasing of seismic intensity (according to the scale MSK-64) are created and for Odessa-city map-scheme (Fig.122) of estimated value of seismic intensity increasing in regard to 4 (four) engineering-geological parameters (seismic rigidity, depth of underground water level, slopes angle, capacity of the quaternary sediments (Fig.123).

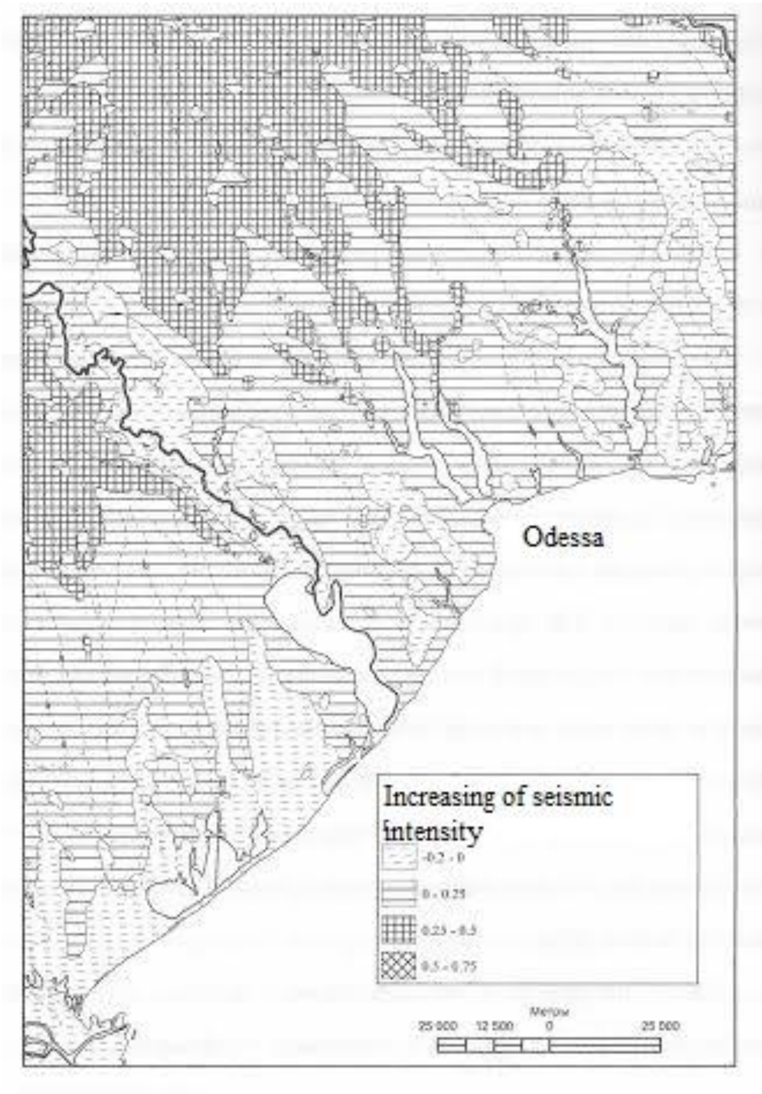

Fig. 122: Map-scheme of possible seismic intensity increasing according to the scale MSK-64 in dependence from geomorphological factors, North-Western Black Sea region [4]

Mentioned methodical approaches to assessment of regional seismic hazard and determination possible seismic impact increasing in terms of local engineering-geological conditions on specific sites allows us to estimate more accurately seismic hazard on specific sites and in complex with economical assessments – to determine grade of seismic risk. This by-turn, gives possibility to apply economically profitable and scientifically grounded approaches for prevention consequences and damage caused by earthquakes.

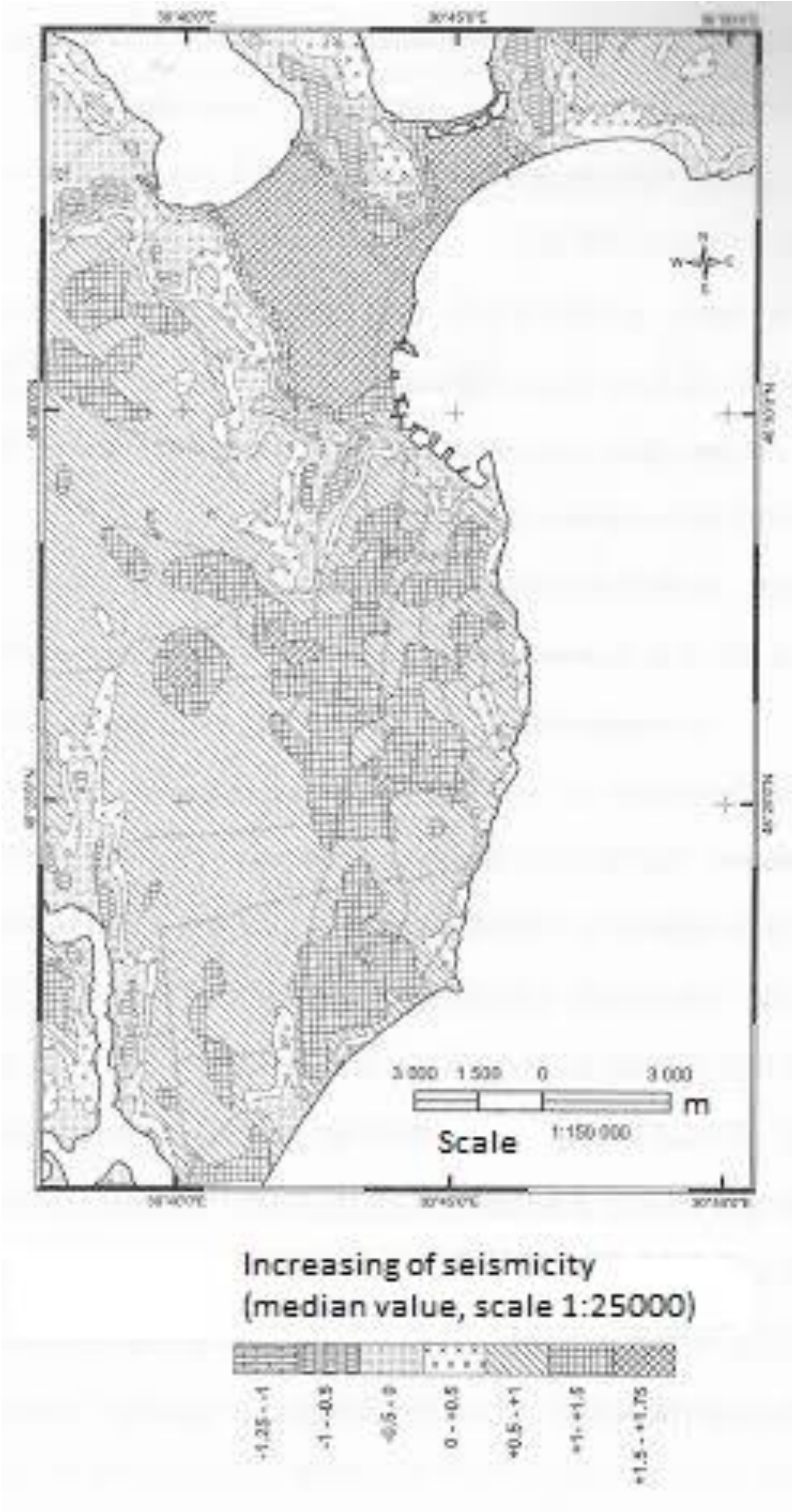

Fig. 123: Map-scheme of estimated value of seismic intensity increasing on the territory of Odessa-city [4].

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4.7 ROMANIA

4.7.1 SEISMICITY OF ROMANIA

Distribution of the seismic activity in Romania (according to Romplus catalogue, Oncescu et al., 1999, updated) is plotted in Fig. 124. A main feature is the concentration of earthquakes in the Vrancea region, at the Carpathians arc bend, at intermediate depths. The seismicity in the crust shows some alignments along the South Carpathians and along the active faults developed in front of the Carpathians arc bend to south-east (Peceneaga-Camena fault, Intramoesian fault, Sf. Gheorghe fault, etc.). Am enhancement of seismicity in the crust is recorded in the western part of Romania (Banat and Crişana-Maramureş). The crustal seismic activity is small to moderate with the maximum observed shocks below magnitude 6, except Câmpulung-Făgăraş region (M_{max} = 6.5).

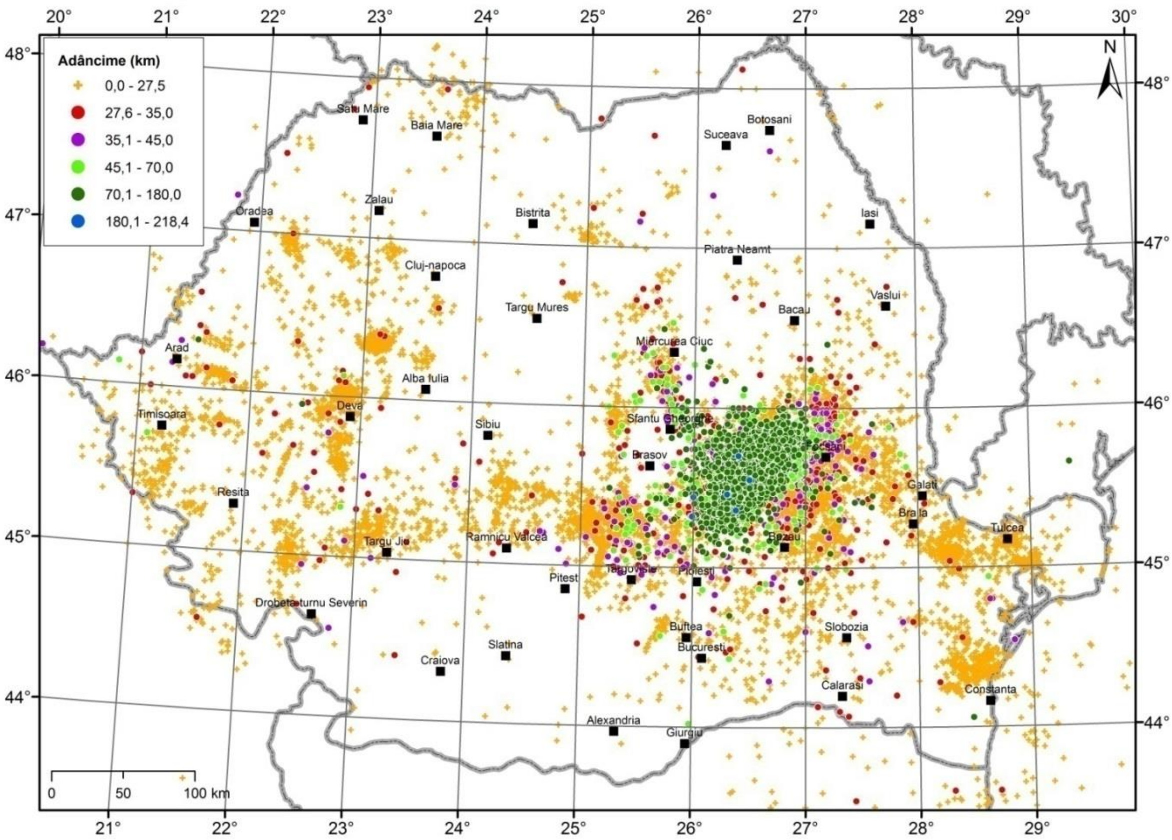

Fig. 124: Distribution of seismicity in Romania according to Romplus catalogue (Oncescu et al., 1999, updated)

Placed at the contact of three major tectonic units, Moesian Plate, East-European Plate and Tisza- Dacia Plate, Vrancea zone is an intra-continental seismic area. It is the most concentrated seismic area in Europe. The moment release rate here is as high as the moment release rate of Southern California (Wenzel et al., 1998).

Major earthquakes occurred during the last century:

October 6th 1908 (Mw = 7.1),

November 10th 1940 (M_W = 7.7),

March 4th 1977 (M_W = 7.4),

August 30th 1986 (M_W = 7.1),

May 30th 1990 (M_W = 6.9).

The largest shock since 1990: October 27th 2004 (M_W = 6.0).

Tomography images (Fig. 125 and Fig. 126) show well-resolved structures in the upper mantle beneath the Carpathian-Pannonian system and provide important clues to the geodynamic processes that have shaped this region. The high-velocity body at intermediate depths (60 – 170 km) in Vrancea is well delimited from the surrounding asthenosphere material and matches precisely the seismogenic volume. The sharp contrast between the seismic active body and the astenospheric material suggests the presence of specific critical mechanisms, like phase transitions, melting or geochemical processes, which facilitate repeated faulting processes generating earthquakes.

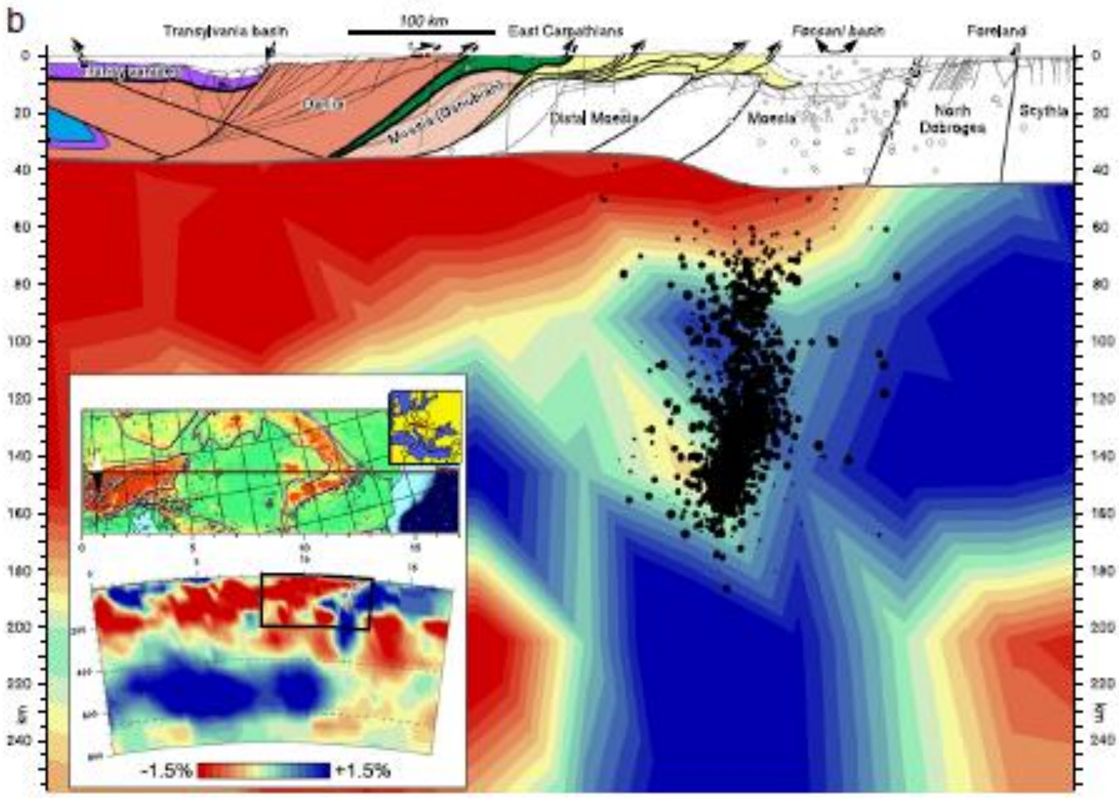

Fig. 125: Vertical cross section across the Transylvanian Basin, SE Carpathians and their foreland (after Matenco et al., 2007) overlaid over regional P-wave tomography (Bijwaard and Spakman, 2000; Wortel and Spakman, 2000).

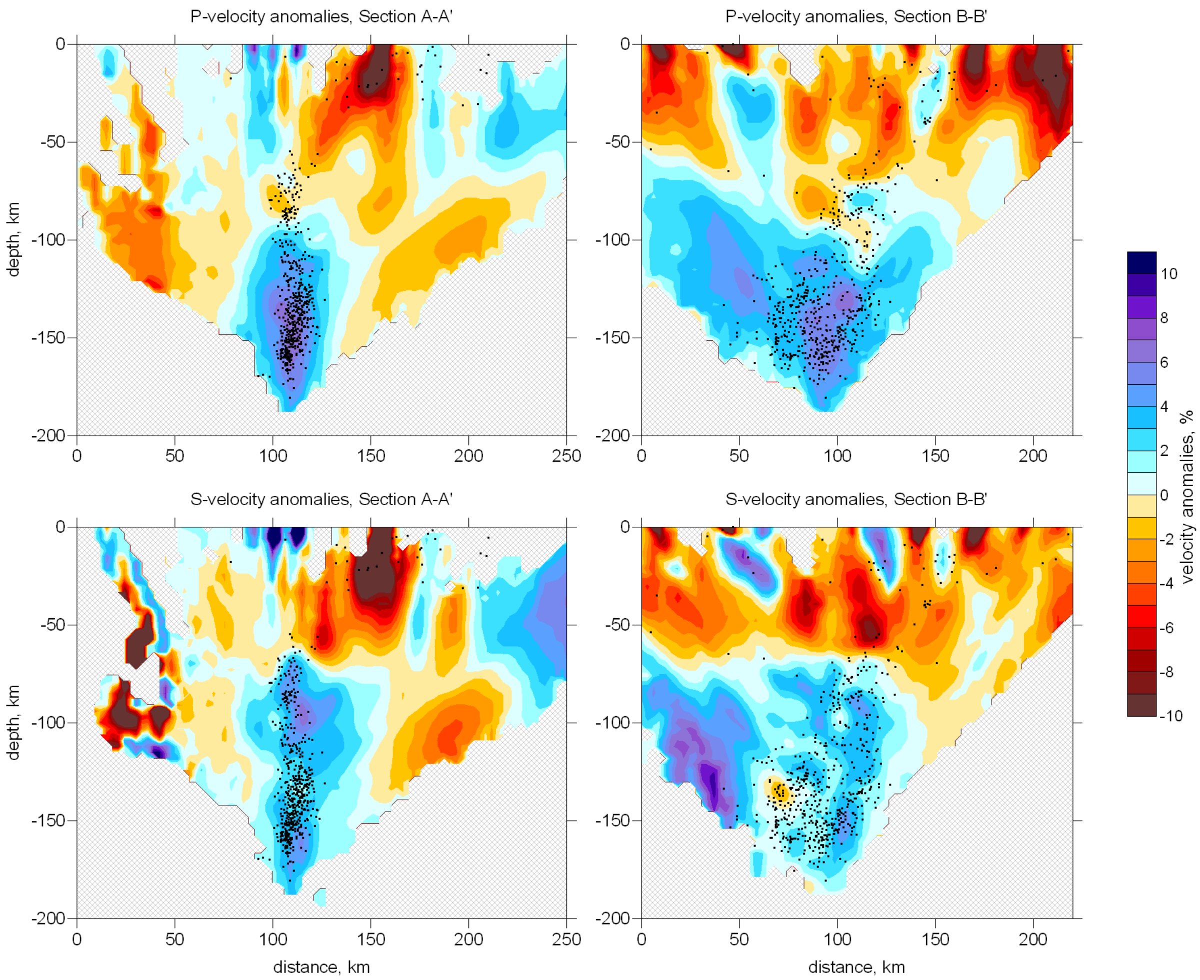

Fig. 126: Geometry of the high-velocity body and seismicity (after *Koulakov et al., 2009*).

The seismic hazard in Romania is dominated by the intermediate-depth earthquakes in the Vrancea source, located at the Eastern Carpathians arc bend. The seismic radiation generated by the Vrancea major shocks causes damage over extended areas, including about half of the Romania surface, northern Bulgaria, Republic of Moldavia and southern Ukraine.

4.7.2 SEISMIC SURVEY IN ROMANIA

The seismic survey of the territory of Romania is mainly performed by the seismic network operated by the National Institute for Earth Physics of Bucharest (NIEP).

The network consists at present of 121 permanent high quality digital stations (102 real time and 19 off-line stations), which cover the whole territory of the country (Fig. 127). All stations are equipped with 3-component accelerometers, while most of the real time stations comprise in addition broadband or short period velocity sensors. The network has digital seismic stations equipped with different high quality digitizers (Kinemetrics K2, Quanterra

Q330, Quanterra Q330HR, PS6-26, Basalt), broadband and short period seismometers (CMG3ESP, CMG40T, KS2000, KS54000, KS2000, CMG3T, STS2, SH-1, S13, Mark l4c, Ranger, gs21, Mark l22) and acceleration sensors Episensor Kinemetrics.

The real time data transmission is performed using several communication systems: internet connection, a line through General Packet Radio Service (GPRS), a dedicated line through satellite, and a dedicated line provided by the Romanian Special Telecommunication service (STS). A detailed description is given in Neagoe and Ionescu (2009) and Neagoe et al. (2011).

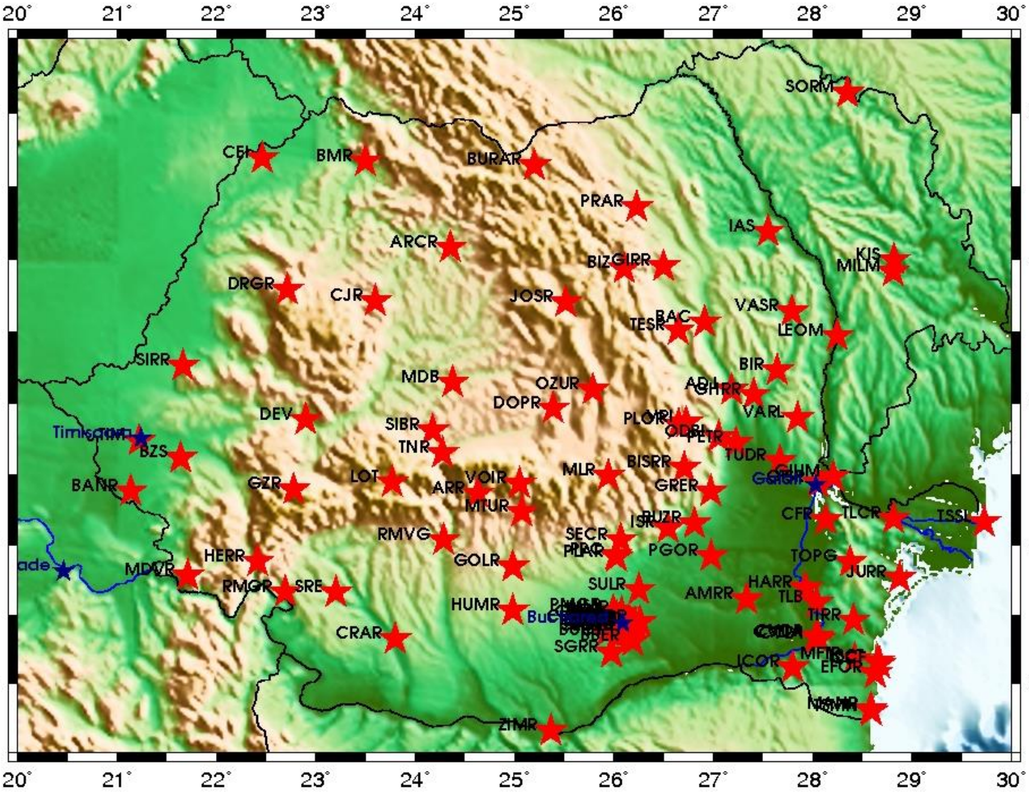

Fig. 127: The real time stations of the Romanian seismic network, in operation at resent.

In the framework of the recent project DACEA 29 stations were installed along Danube river region, in Romania and Bulgaria (Fig. 128). The youngest seismological observatory belonging to NIEP was installed in 2008 at Eforie, close to the Black Sea shore (Fig. 129).

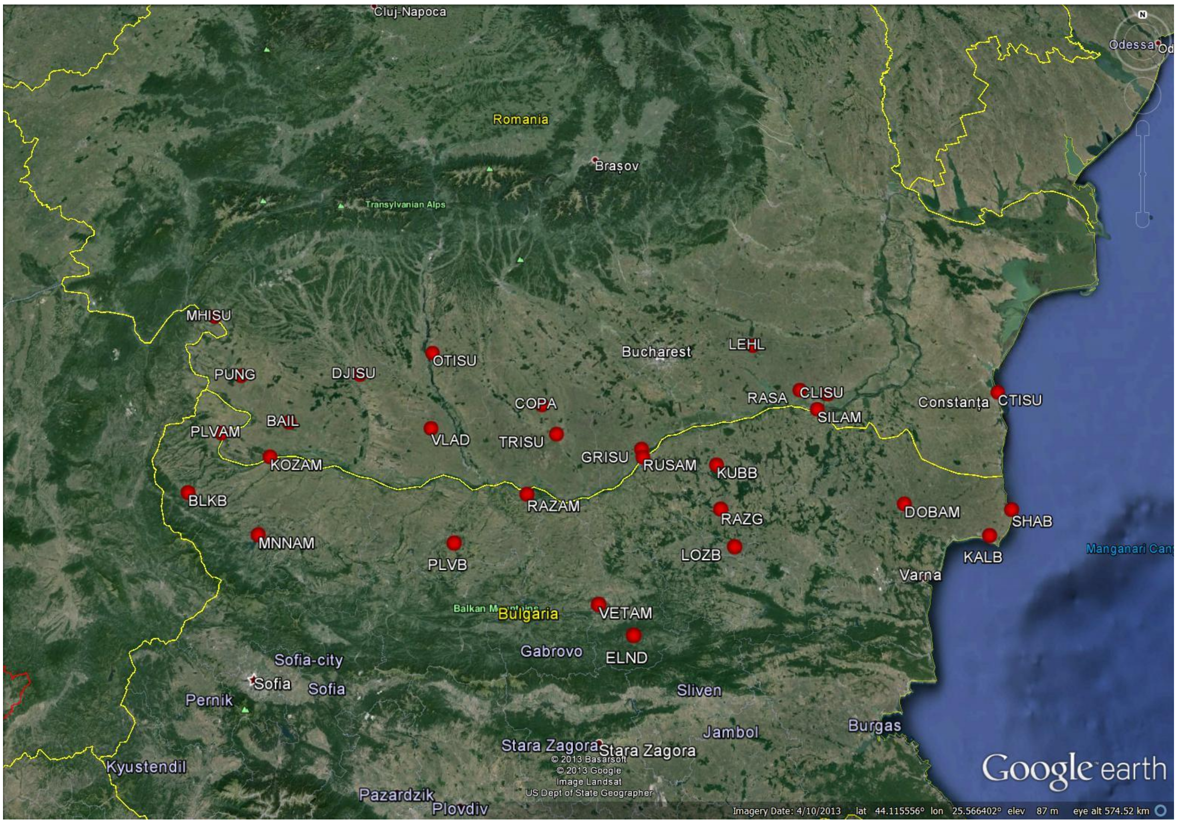

Fig. 128: Seismic stations installed in 2009 in the framework of the DACEA cross-border project.

Fig. 129: Seismological observatories of NIEP. The Dobrogea observatory, installed at Eforie, is the back-up for the National Data Center in Bucharest and the monitoring center for Black Sea tsunami events.

There are several earthquake catalogues for the Romanian earthquakes. The official catalogue of NIEP, continuously compiled and released is the ROMPLUS catalogue (Oncescu et al. 1999, updated), which uses moment magnitudes M_w. The authors claim that the catalogue is complete between 1411 and 1800 for $M_w \geq 7.0$, between 1801 and 1900 for $M_w \geq 6.5$, between 1901 and 1935 for $M_w \geq 5.5$, between 1936 and 1977 for $M_w \geq 4.5$, between 1978 and 1997 (2003) for $M_w \geq 3.0$. However, the magnitude estimates before about 1800 are affected by large errors. The maximum magnitude for the Vrancea zone was accepted to be M = 8 after Lungu et al. (1999), Mantyniemi et al. (2003), and Marza et al. (1991).

4.7.3 SEISMOGENIC SOURCES

The first step in seismic hazard assessment is the identification of potentially dangerous earthquake sources. This implies complex investigations on geotectonic and seismicity data. The map of the active faults identified on the Romania territory is given in Fig. 130.

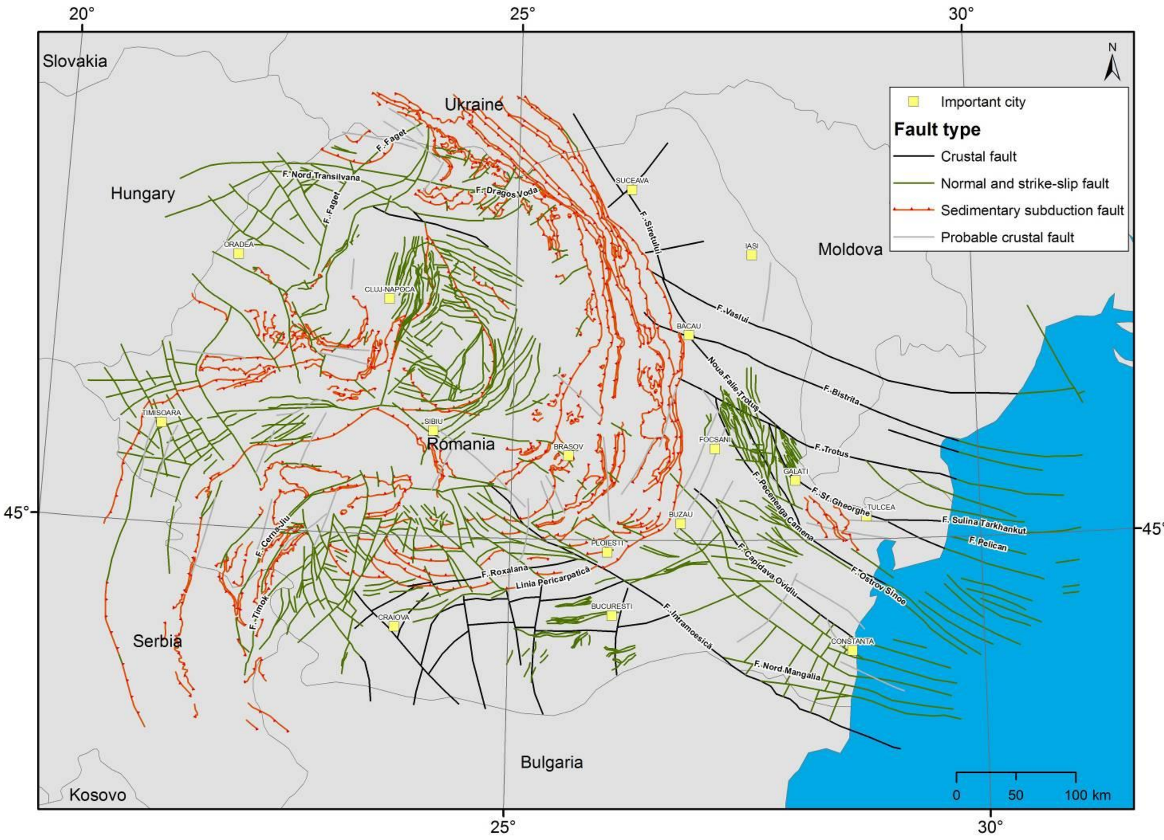

Fig. 130: Active faults identified on the Romania territory (after Dinu et al., 2009; Răileanu et al., 2009)

The seismogenic sources are defined on the basis of geotectonic and seismicity data. They represent areas of homogeneous seismic activity at regional scale defined by simple polygons (Fig. 131).

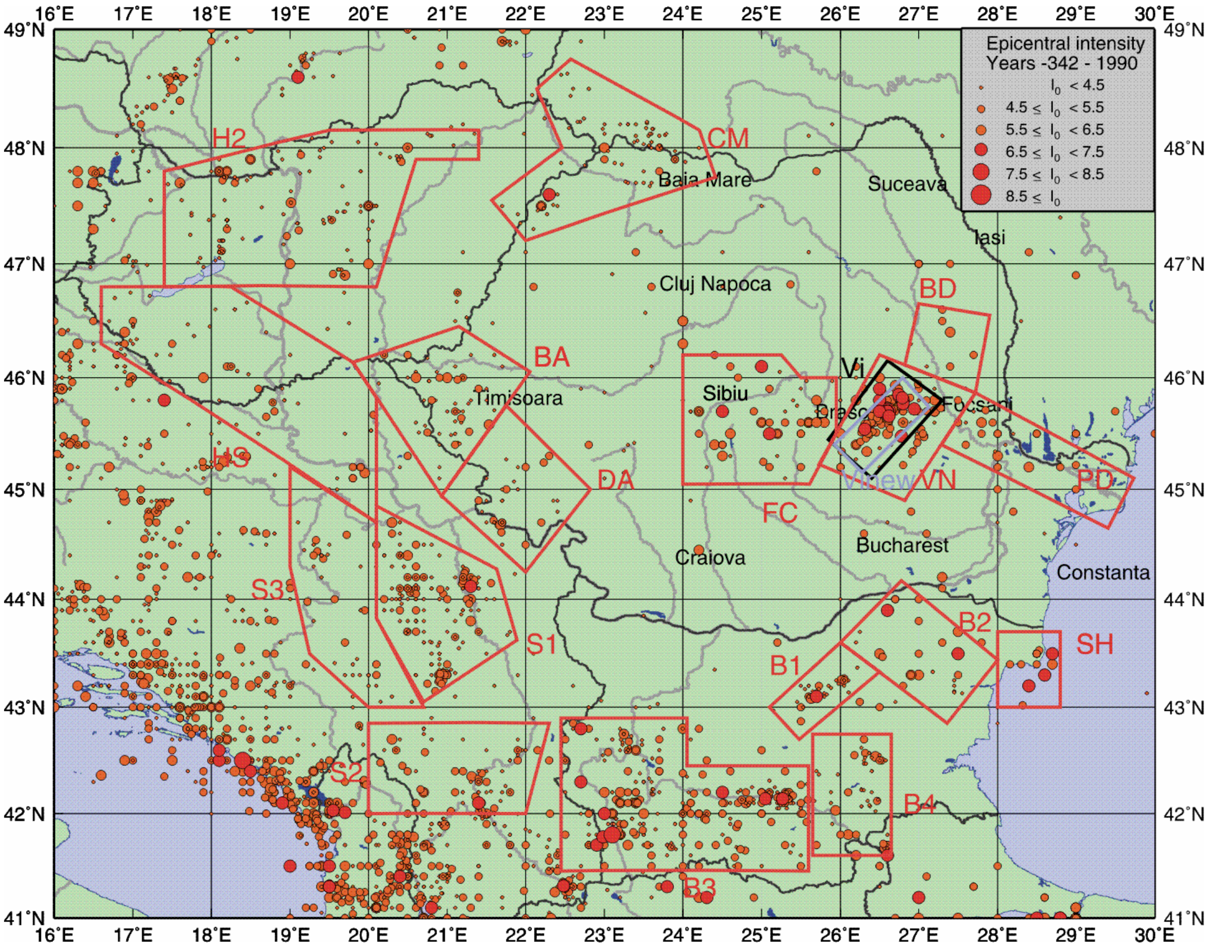

Fig. 131: Seismogenic zones in Romania and at the cross-border areas (after Leydecker et al., 2008)

The seismic sources contributing to the seismic hazard of the south-eastern part of Romania (Dobrogea region) are:

1. Vrancea intermediate-depth source (**VI**, in Fig. 131)
2. North Dobrogea source (**PD**, in Fig. 131)
3. Shabla source (**SH**, in Fig. 131)

Romania and the neighboring countries are affected episodically by the Vrancea earthquakes. The earthquakes occur at depths of 70-200 km (subcrustal / intermediate), high energy, experienced widespread 2-3 such events per century, with 7-7.5 magnitude, destructive character, the last two occurring on November 10, 1940 (M_w = 7.7) and March 4, 1977 (M_w = 7.4). The strongest Vrancea earthquake ever occurred is accepted to be the October 26, 1802 event (M_w = 7.9). The earthquake was felt with the maximum intensity of X MSK and with intensity V over a huge area (Fig. 132).

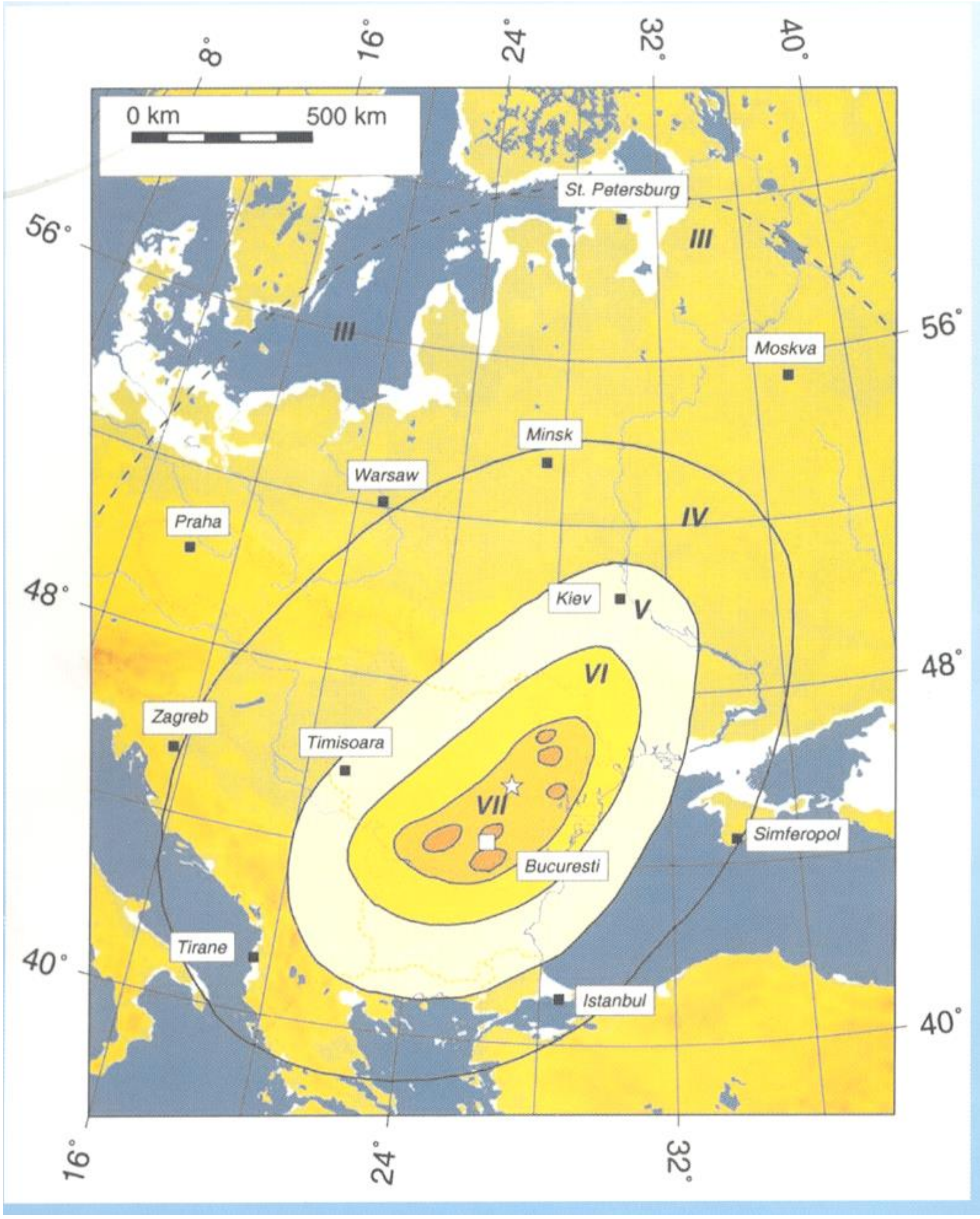

Fig. 132: Isoseismal map for the Vrancea strongest earthquake of 26 October 1802.The magnitude M_W=9.5 and the intensity in Bucharest was I=IX½ (MMI)

The distribution of effects is typically strongly elongated on NE-SW direction and sharply attenuated on NW-SE direction, especially in the back-arc side (Transylvania). Examples of distributions for the last strongest events are presented in the Fig. 133.

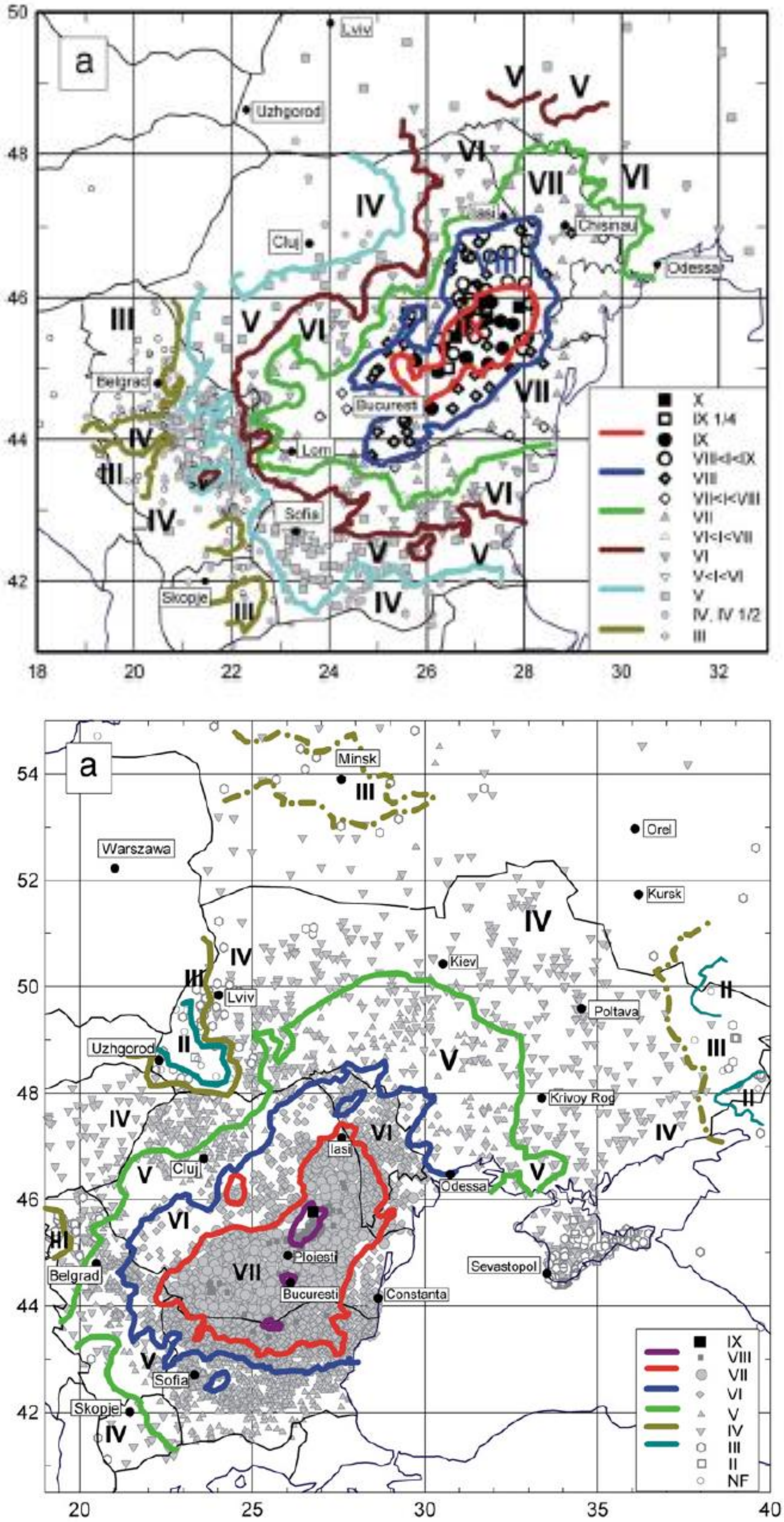

Fig. 133: Distribution of macroseismic effects for Vrancea earthquakes of 1940 (top) and 1977 (bottom). After Kronrod et al. (2013)

4.7.4 GROUND MOTION MODELLING

Analysis of the seismic intensity and instrumental data from the intermediate-depth Vrancea earthquakes revealed several peculiarities of earthquake effects (e.g., Mândrescu and Radulian, 1999; Mândrescu et al., 1988; Moldovan et al., 2000).

- The earthquakes affect very large areas with a predominant NE-SW orientation;
- The local and regional geological conditions can control the variation of amplitudes of earthquake ground motion to a larger degree than magnitude or distance.
- The strong ground motion parameters exhibit a large variability.

The modelling of the ground motion parameters characterizing the Vrancea intermediate-depth earthquakes is more complicated than for the crustal earthquakes due to the complex patterns observed in the first case. A few studies proposed empirical azimuth-dependent attenuation equations for seismic intensity (e.g., Ivan et al. 1998; Mârza 1996; Mârza and Pântea 1994) and maximum peak ground acceleration (Lungu et al. 1995; 1997). The studies were based on the macroseismic data and the analog accelerograms of the strong Vrancea earthquakes of 1977, 1986 and 1990. In an another attempt, Sokolov et al. (2008) developed regional ground-motion prediction equations for Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Pseudo-Spectral Acceleration (PSA), and seismic intensity (MSK or MMI scale). They used to this purpose the Fourier Amplitude Spectrum (FAS), source scaling and attenuation models (Sokolov et al., 2005) and the generalised site amplification functions. The stochastic technique (Boore, 2003) based on the site-dependent spectra was used for the case of PGA, PGV, and PSA models. The equations for seismic intensity were evaluated using the recently developed relations between intensity and FAS (Chernov and Sokolov 1999; Sokolov 2002).

Following this approach seven regions are defined characterized by similar general geological and geomorphological conditions and azimuthal direction from the Vrancea zone (Fig. 134). The characteristics of the region-dependent site amplification were evaluated by averaging of all data, which were obtained for stations located within the given region. The amplification characteristics may vary significantly from one region to another depending on the frequency range. The regions "East" and "Focsani" are characterized by the highest amplification in the high frequency (> 10 Hz) range, while the region "South-West" exhibits the relatively high amplification for the intermediate frequencies (1-4 Hz). The regions "North" and "South" show almost the same amplification for frequencies more than 1 Hz. The increase of amplification amplitudes toward the lower frequencies (region "South-West") may be explained by the influence of surface waves generated within the deep sediments of the Moesian platform.

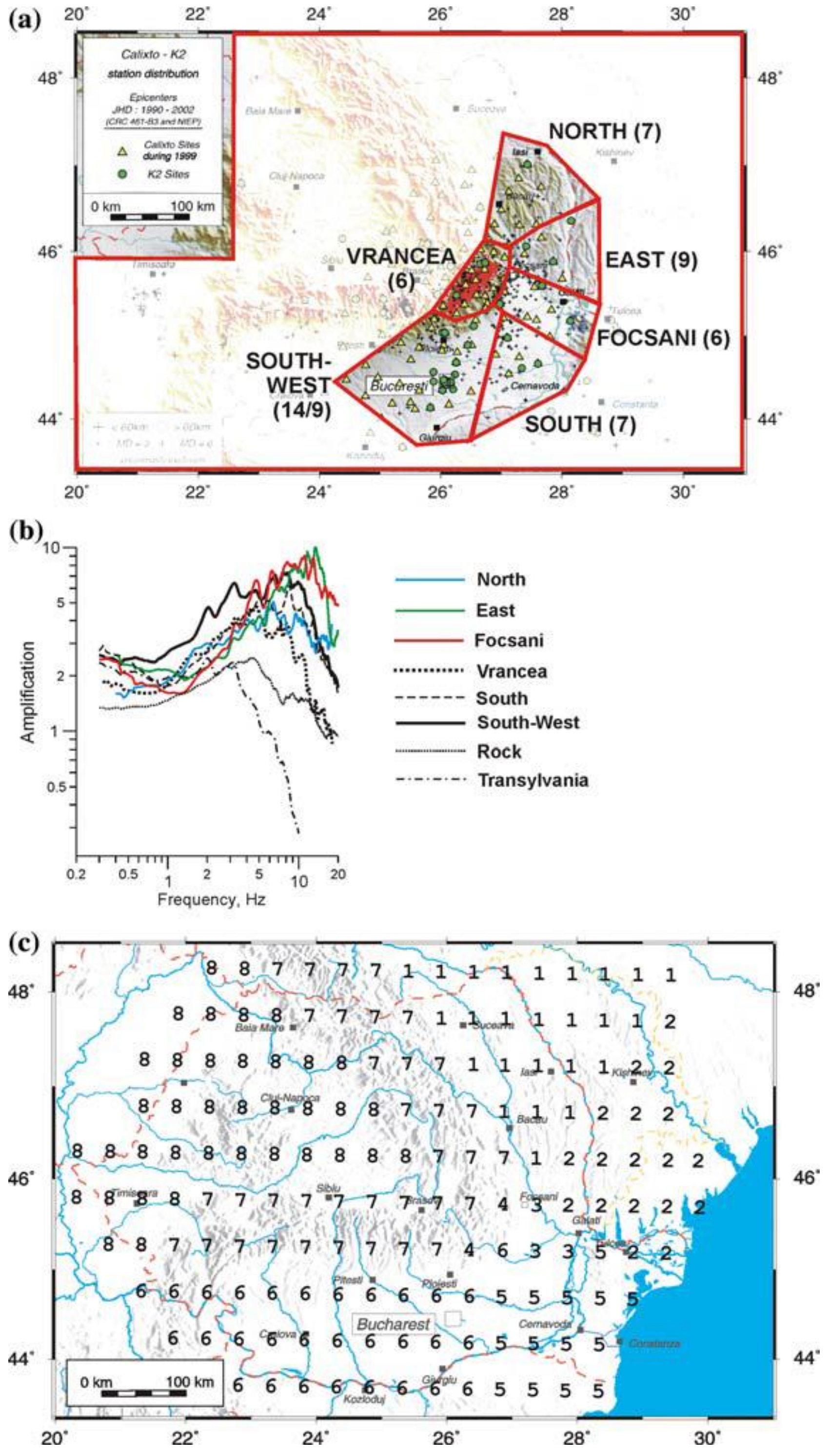

Fig. 134: (**a**) Scheme of the characteristic regions. Numbers in parentheses denote number of the stations within the region. For the South-West region, the numbers also show the number of stations (9) in the city of Bucharest. (**b**) The generalised region-dependent site amplifications (mean amplitude values) including amplification for the generalised "rock"

category. (**c**) Distribution of the generalised site amplification functions (regions) along the territory of Romania.

The "region-dependent" equations developed by Sokolov et al. (2008) are useful for the rapid estimation of seismic effect after strong earthquakes (Shakemap generation) and for seismic hazard assessment, both deterministic and probabilistic approaches.

4.7.5 PROBABILISTIC APPROACH

The fundamental hypothesis of the probabilistic seismic hazard assessment (Cornell, 1968) assumes that earthquake occurrence is a stationary random process. Events are supposed to be distributed in time like in a Poisson process (independently). The maximum credible earthquake for a given seismogenic zone is estimated with respect to seismicity, frequency of earthquakes, maximum observed intensity and quality of historical documents. A characteristic depth is ascribed for each seismogenic zone where the maximum of seismic energy is supposed to be released.

Probabilistic seismic hazard maps in terms of horizontal peak ground acceleration were published by Mârza et al. (1991), Musson (2000), Mäntyniemi et al. (2003), Mărmureanu et al. (2004), Enescu and Enescu (2007) and in terms of macroseismic intensity by Ardeleanu et al. (2005) and Leydecker et al. (2008). Musson (2000) presented maps for the Pannonian Basin (including Romania) for return periods of 100, 475, 1000 and 3000 years. For earthquakes in the intermediate-depth Vrancea seismic zone he used three different attenuation models depending on the direction from the source. Mäntyniemi et al. (2003) mapped for a return period of 475 years the specific seismic hazard for the Vrancea seismic zone using depth- and azimuth-dependent attenuation functions. On the other hand, Mărmureanu et al. (2004) solely investigated the seismic hazard from crustal earthquakes.

Enescu and Enescu (2007) proposed a procedure to compute isoseismals and isoacceleration maps for the Vrancea intermediate-depth earthquakes starting from instrumental data (acceleration and velocity). The authors defined an "etalon" earthquake matching the data recorded during the Vrancea event of 30 August 1986 (M_w = 7.1, depth = 131 km). Then they determined a family of azimuthally dependent attenuation relationships for the etalon earthquake based on 35 instrumental PGA recordings available for this event. The generalised isoseismals for 1986 event (Fig. 135) are conceived as a sort of reference matrix for any Vrancea strong event. The generalised macroseismic field (intensity as a function of epicentral distance and azimuth) is defined by three independent parameters: maximal intensity, I_0, focal depth, h and directivity factor, δ, of the rupture propagation. In the authors' opinion, this standardisation is justified because the fault plane solutions for the Vrancea strong events are very close to each other and the procedure practically removes undesirable site effects. In these circumstances, having at-hand attenuation relationships properly evaluated, the construction of isoseismal maps for other real or potential earthquakes, with given I_0, h and δ is possible. However, as shown by Kronrod et al. (2012), this procedure of generalisation of isoseismals has drawbacks because it is based on a small number of observations (approximately 10–15 times smaller than the amount of macroseismic data), which is concentrated near the epicentre.

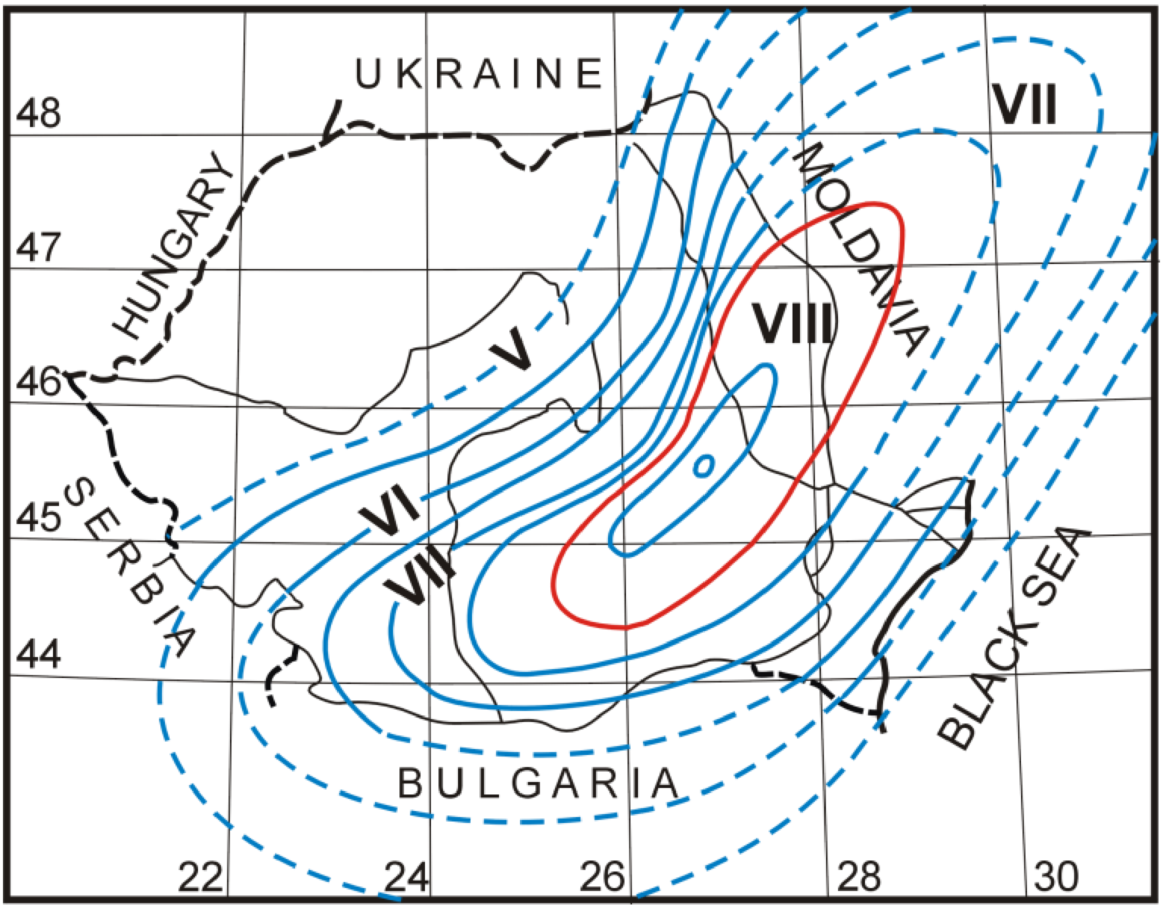

Fig. 135: Isoseismal map of the etalon earthquake (Enescu and Enescu, 2007) as modified by Mărmureanu et al. (2011).

Another approach based on instrumental observations and geological data is proposed in a series of publications by Sokolov and collaborators (Sokolov et al., 2005a; 2005b; Böse et al., 2009). The procedure is valid for Vrancea intermediate-depth earthquakes in a magnitude range from 5 to 8 and depth range from 70 to 160 km. The model includes the regional Fourier amplitude spectrum source scaling and attenuation model and generalised frequency-dependent amplification functions for specific local site conditions. The modelled space distribution of ground motion parameters (e.g., PGA) is in good agreement with the observed one.

Site-dependent seismic hazard (peak ground acceleration, response spectrum amplitudes, and seismic intensity) was estimated by Sokolov et al. (2004) for several points – stations of the strong motion array in Romania, for which the site-specific ground motion amplification functions were determined. Application of the unified approach for probabilistic seismic hazard assessment (PSHA) shows a good agreement with the general features of observed earthquake effects on the territory of Romania. Based on these results, the authors conclude that the influence of geological factors plays important, somewhere prevailing, role in distribution of earthquake ground-motion parameters along the territory of the country.

Leydecker et al. (2008) computed the seismic hazard for Romania using EQRISK algorithm developed by McGuire (1976) on the basis of the approach of Cornell (1968). Seismic hazard distribution is computed in terms of intensity values. For the crustal sources the intensity attenuation function of Sponheuer (1960) is applied. The attenuation dependence on distance and depth is expressed according to the relation proposed by Kövesligethy (1907):

$$I_{site} = I_{epic.} - 3\log(r/h) - 1.3\alpha * (r - h) \qquad (104)$$

where r is the hypocentral distance (km), h is the depth (km) and α is the absorption coefficient.

While the isoseismal shape of the crustal earthquakes can be treated as circular, due to extremely irregular isoseismals of the intermediate depth earthquakes (Fig. x), their effects on the seismic hazard have to be treated separately. An empirical approach is proposed to take into account the directionality of attenuation. A factor Ω is introduced to the attenuation law:

$$I_{site} = I_{epic.} - 3\log(r/h) - 1.3\alpha * \Omega * (r - h) \qquad (105)$$

The Ω parameter is estimated on the basis of detailed macroseismic maps of the three strong Vrancea intermediate depth earthquakes over the considered computation grid (a gridding of 0.5^0 in longitude and 0.25^0 in latitude).

The hazard map for a recurrence period of 475 years is given in Fig. 136. It was obtained by combining the hazard distribution for source zones of normal depth and that for Vrancea intermediate depth zone.

Description of development of the codes for earthquake resistance of buildings and structures in Romania during last 60 years, as well as the current standards for seismic zonation, and design provisions, was given by Lungu et al. (2003).

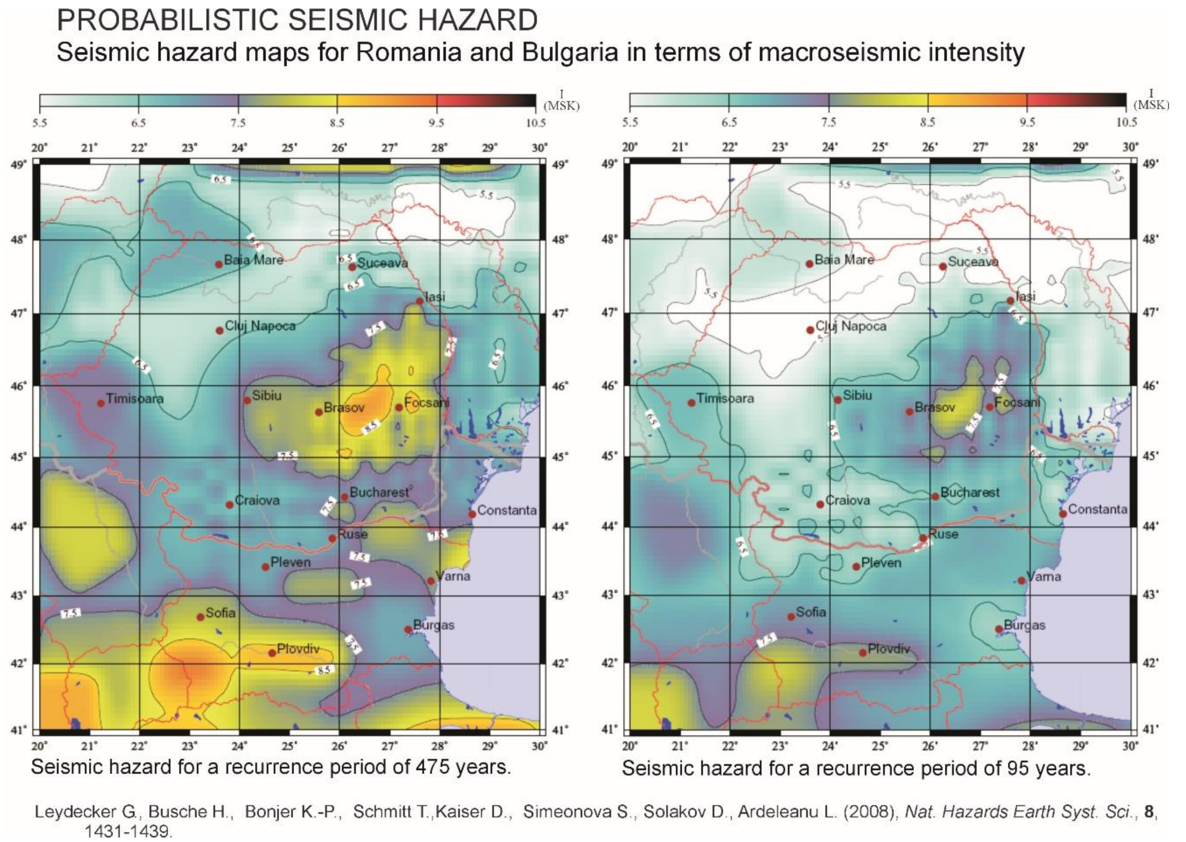

Fig. 136: Seismic hazard map for 475 years and 95 years recurrence periods as obtained by Leydecker et al. (2008).

4.7.6 DETERMINISTIC APPROACH

The seismic hazard evaluation, which is based on the traditional Probabilistic Seismic Hazard Analysis (PSHA) relies on the probabilistic analysis of earthquake catalogues and of ground motion, macroseismic observations and instrumental recordings. Recently PSHA showed its limitation in providing a reliable seismic hazard assessment, possibly due to insufficient information about historical seismicity, which can introduce relevant errors in the purely statistical approach mainly based on the seismic history. In contrast to the probabilistic approach which is a statistical one, the deterministic approach is a scenario-based approach. This scenario-based approach allows us to incorporate all available information collected in a geological, seismotectonic and geotechnical database of the site of interest as well as advanced physical modelling techniques providing a reliable and robust deterministic design basis for civil infrastructures.

At the same time a scenario-based seismic hazard analysis allows to develop the required input for probabilistic risk assessment (PRA), as required by safety analysts and insurance companies. The scenario-based approach removes the ambiguity in the results of probabilistic seismic hazard analysis (PSHA) which relies on the projections of the Gutenberg–Richter (G–R) equation. The problems in the validity of G–R projections, because of the incomplete to total absence of data for making the projections, are still unresolved. The scenario-based methodology is strictly based on observable facts and data and complemented by physical modelling techniques, which can be submitted to a formalized validation process. By means of sensitivity analysis, knowledge gaps related to lack of data can be dealt with easily, due to the limited amount of scenarios to be investigated (Klügel et al., 2006). The comparative analyses of the recently published results on regional seismic hazard assessments, obtained via PSHA and NDSHA (Panza et al., 2008; Peresan et al., 2008) have shown, as appropriate, the suggestion to limit the probabilistic analysis to the definition, for a given area, of the magnitude of the different scenario earthquakes: (a) disastrous (return period about 500 years); (b) very strong (return period about 250 years); (c) strong (return period about 125 years); (d) frequent (return period about 60 years) and to use them for deterministic computations (Peresan et al., 2008).

In the framework of the UNESCO-IUGS-IGCP Project 414 and taking the benefits of the existing CEI Network, neo-deterministic hazard computation for some CEI countries have been performed at national and regional scales. Using numerically simulated ground motion, a first-order deterministic evaluation of the seismic hazard of Romania has been proposed (Radulian et al., 2000). The distribution of the peak values numerically determined correlates with the values recorded in the areas situated eastwards and southward of the Carpathians arc (Fig. 137).

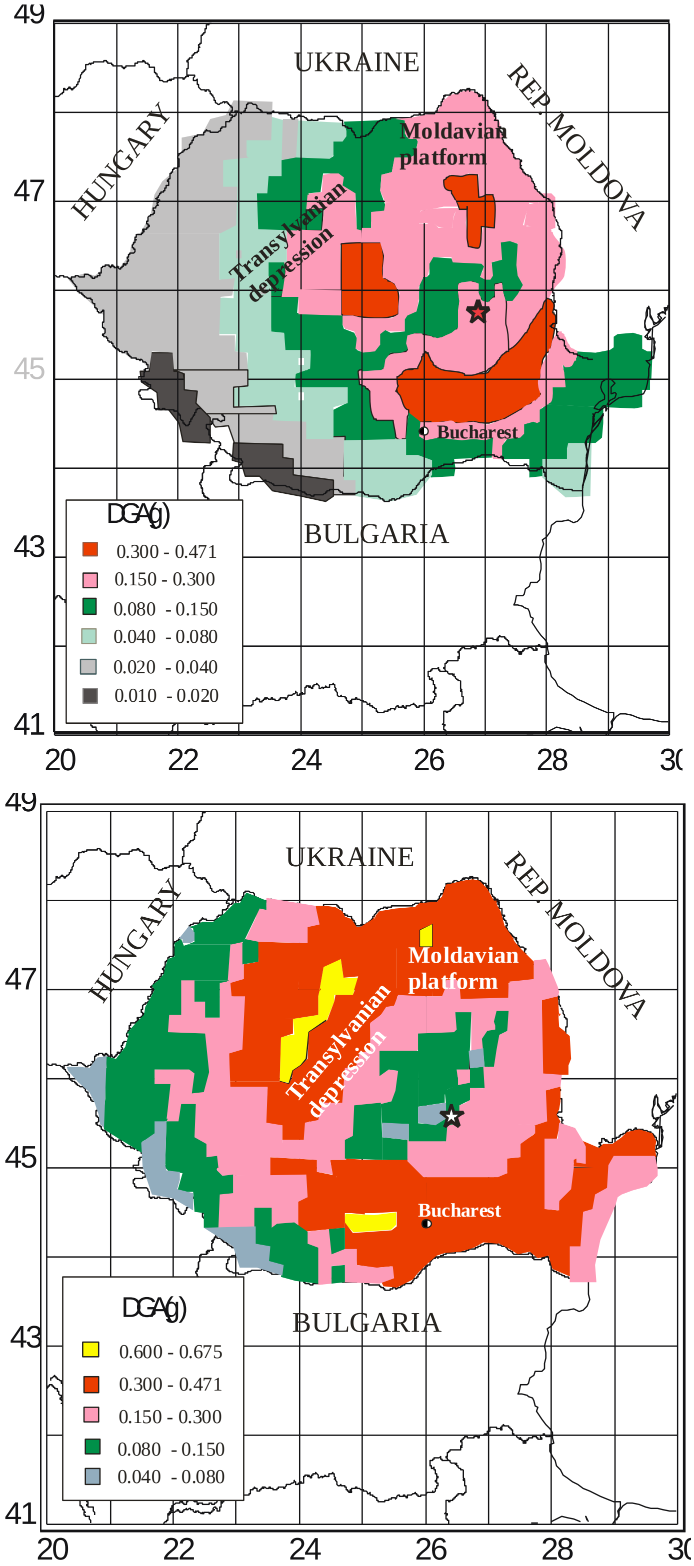

Fig. 137: Seismic hazard determination in terms of DGA values for two scenario earthquakes: 1977 (M_w = 7.4, depth = 90 km) – upper frame and 1940 (M_w = 7.7, depth = 150 km) – bottom frame (compiled after Radulian et al., 2000).

4.8 MOLDOVA

4.8.1 PAST EVENTS AND THEIR CONSEQUENCES

Seismic observations in Moldova on a regular basis started in 1949, when, on December 20, the first seismogram was recorded at the seismic station Kishinev. The year 1963 could be considered the starting point of the scientific investigations into earthquake engineering, when the first volume of scientific publications was issued dedicated to problems of tectonics and seismology of Moldova, prepared by the group of young scientists of the Institute of Geology and Mineral Resources of the Academy of Sciences of Moldavian Soviet Socialist Republic (MSSR).

The Institute of Geophysics and Geology (IGG) was founded in 1967 on the basis of the Institute of Geology and Minerals and the regional seismic station "Kishinev." The research priorities of the Institute are monitoring of seismicity of the Vrancea zone, seismic hazard and risk assessment, microzonation, GIS technologies, and mathematical models in earthquake engineering. The present director is Dr. Vasilii Alkaz. The staff has numbered from 100 to 120 in the 1970s and 1980s to 50 in the 1990s. Currently the staff consists of 22 seismologists (including staff of seismological stations), 8 of them with Ph.D. degrees. The seismological section consists of (1) Laboratory for Seismology, (2) Laboratory of Survey of Seismic Effects, and (3) the Center of Experimental Seismology.

The territory of the Republic of Moldova is influenced by earthquakes of intermediate depth from the Vrancea seismic zone,situated in Romania. The strongest of these earthquakes are distributed in the depth interval of 80-150 km, with maximum magnitude of 7.5-7.8. The most significant seismic effect, maximum intensity VIII-IX on the scale of XII, is observed in Romania and Moldova. Statistical information about seismic activity of the Vrancea zone is available since the year 1000. On average, strong earthquakes of magnitude M > 6 occur five times or more per century. Some of them (November 10, 1940, March 4, 1977, August 31, 1986) caused casualties and considerable damage.

The main mission of the seismological section is monitoring seismicity for the territory of Moldova, and conducting seismotectonic investigation, seismic hazard assessment, long-term earthquake prediction research, and engineering seismology. These investigations have resulted in maps of macro- and microzonation for seismic-resistant construction and are the basis for taking measures in reducing the consequences of strong earthquakes.

The seismic network of Moldova consists of five seismic stations, situated in Kishinev, Cahul, Leovo, Soroky, and Djurjuleshti. Kishinev is the base station for the network; the other four provide regional data. Station Kishinev was established in 1949 by the Institute for Earth Physics, USSR Academy of Sciences, to provide supplementary data on parameters of Carpathian earthquakes. Station Cahul started its observations in 1978 and provides additional information for studying of characteristics of earthquakes from the Vrancea zone. Stations

Leovo (1982) and Soroki (1983) were established in connection with structural changes in the Soviet network in 1979 for work on earthquake forecasts. Djurjuleshti was installed in 1988. Information about the location of the seismic stations is shown in Fig. 138.

In the last twenty years the Laboratory of Seismology performed the investigation of the horizontal discontinuities of the upper mantle for Moldova and neighboring Romania by analysis of teleseismic P-wave propagation. A database of the seismological information has been created in the Institute, including the catalog of the earthquakes and focal mechanisms of the studied region, macroseismic information. The statistical algorithms for interpretation of seismic intensity and seismic impact and alternative models of its assessment are considered in probabilistic representation of seismic hazard.

The Laboratory of Survey of Seismic Effects has launched a projects aimed at utilizing GIS technology for storing and processing of the available information. This projects allows constructing of seismic macrozonation maps in digital format, and certain advances in seismic risk and seismic microzonation studies.

Some results of these projects are shown in Fig. 138 Fig. 139- Fig. 143.

4.8.2 EXISTING LEGISLATION FRAMEWORK

Regulatory Documents which standardizes the activity in the domain of Seismology and Engineering Geology:

- Decision of Government of the Republic of Moldova on measures to optimize the infrastructure sphere of science and innovation no. 1326 of 14.12.2005, Official Monitor (Gazette) of the Republic of Moldova nr.168-171/1406 of 16.12.2005 regarding the reorganization and creation of organizations and institutions of science and innovation, including Institute of Geology and Seismology.
- SNIP 1.02.07-87. Engineering exploration for the construction. General definitions. (“Инженерные изыскания для строительства. Основные положения).
- SNIP II-7-81. Construction in seismic regions („Строительство в сейсмических районах”).
- SNIP 2.01.15-90 Engineering protection of territories, buildings and construction from dangerous geological processes. Principal regulations of designing. (“Инженерная защита территорий, зданий и сооружений от опасных геологических процессов. основные положения проектирования”).

Fig. 138: The location of the seismic stations in Republic of Moldova

- RSN 60-86 Engineering exploration for construction. Seismic microzoning. Norms of work realization ("Инженерные изыскания для строительства. Сейсмическое микрорайонирование. Нормы производства работ").
- RSN 65-87 Engineering exploration for construction. Seismic microzoning. Technical requirements of work realization Инженерные изыскания для строительства. Сейсмическое микрорайонирование. Технические требования к производству работ
- СП 11-105-97 Part 1 Engineer-geological study for the construction. General requirements for work realization ("Часть 1 Инженерно-геологические изыскания для строительства. Общие правила производства работ").

The Institute of Geology and Seismology made some special investigation in the field of seismic zonation and seismic microzonation which were adopted as normative documents in Moldova Republic. Fig. 139 illustrates a seismic zonation of Republic of Moldova. Fig. 140

illustrate a seismic microzonation of Chisinau city with the consideration of the local geological condition and soil properties. The seismic risk map for Chisinau city was elaborated on the base of seismic microzonation (Fig. 141).

Fig. 142 and Fig. 143 illustrate the seismic risk for Republic of Moldova in the damage and integral risks.

Fig. 139: The new seismic zoning map of Moldova Republic.

It was adopted by the Ministry of Regional Development and Construction in 2010, and approved for practical use (aseismic design and construction).

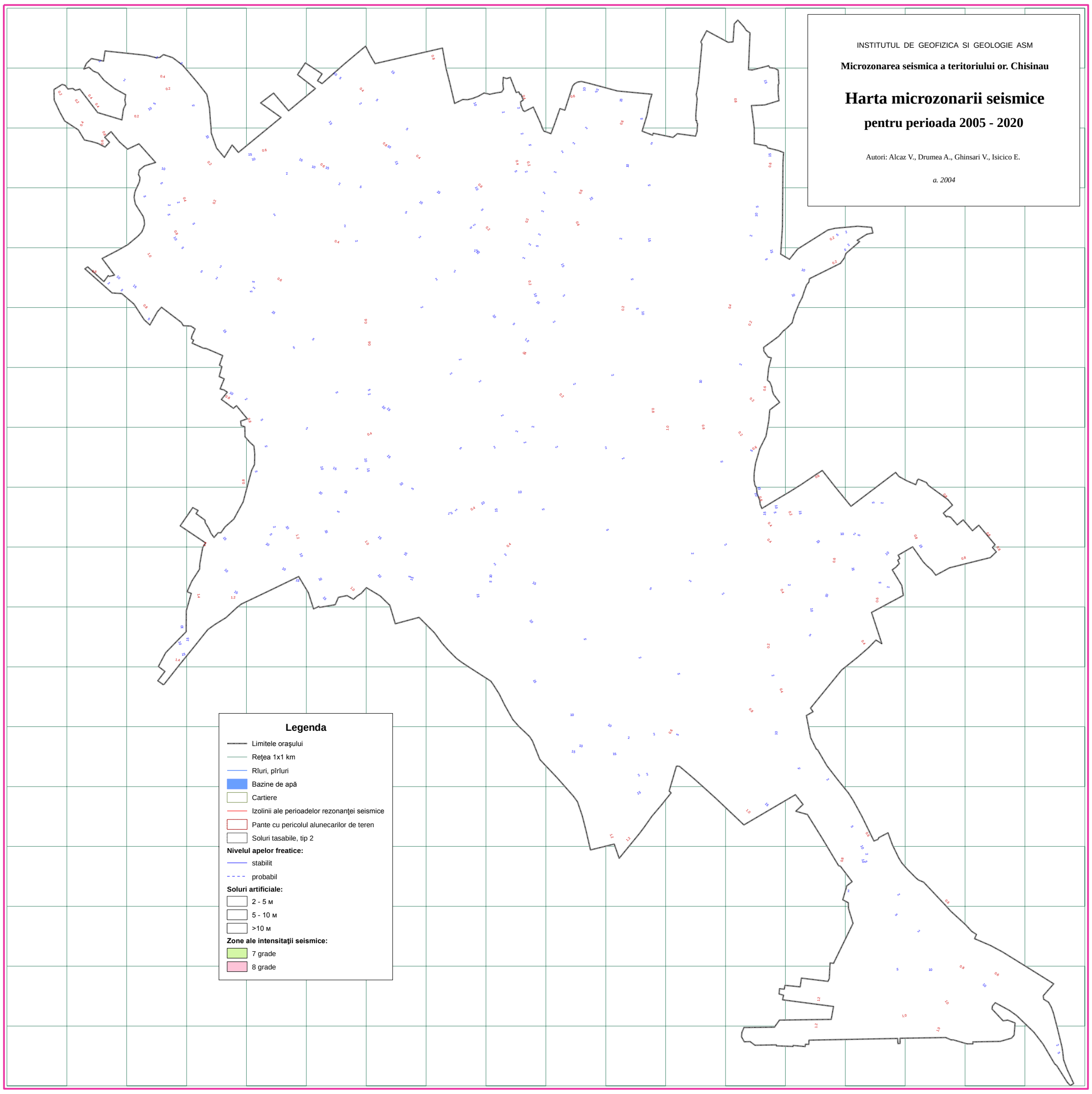

Fig. 140: The new seismic microzonation map of Chisinau city.

It was adopted as normative document for the construction project design in Chisinau city by the Ministry of Regional Development and Construction in 2013.

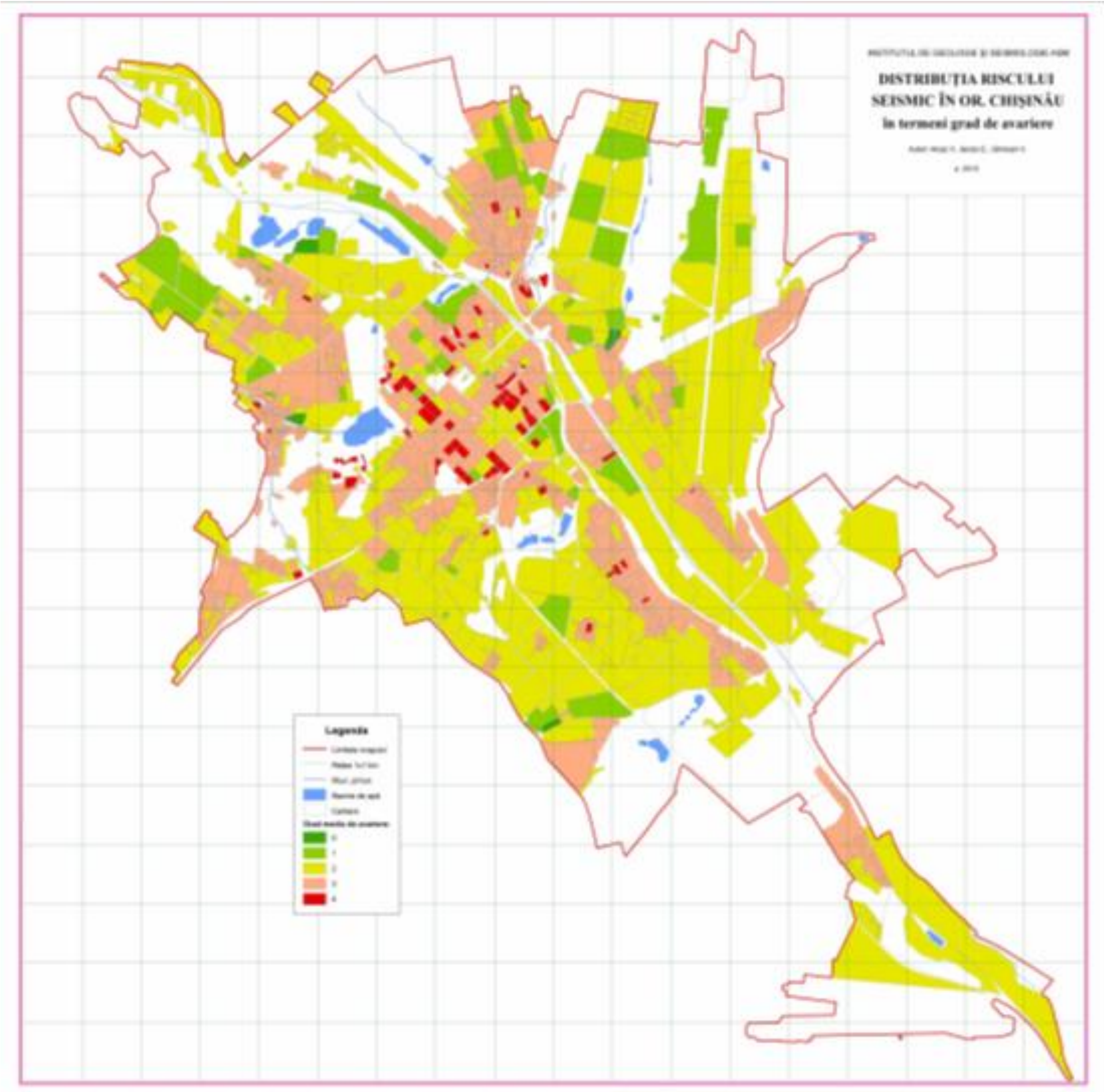

Fig. 141: Seismic risk map of Kishinev city.

It was elaborated in 2009 for scenario earthquake (like 10.11.1940) in terms of the average degree of damage for each quarter of the city.

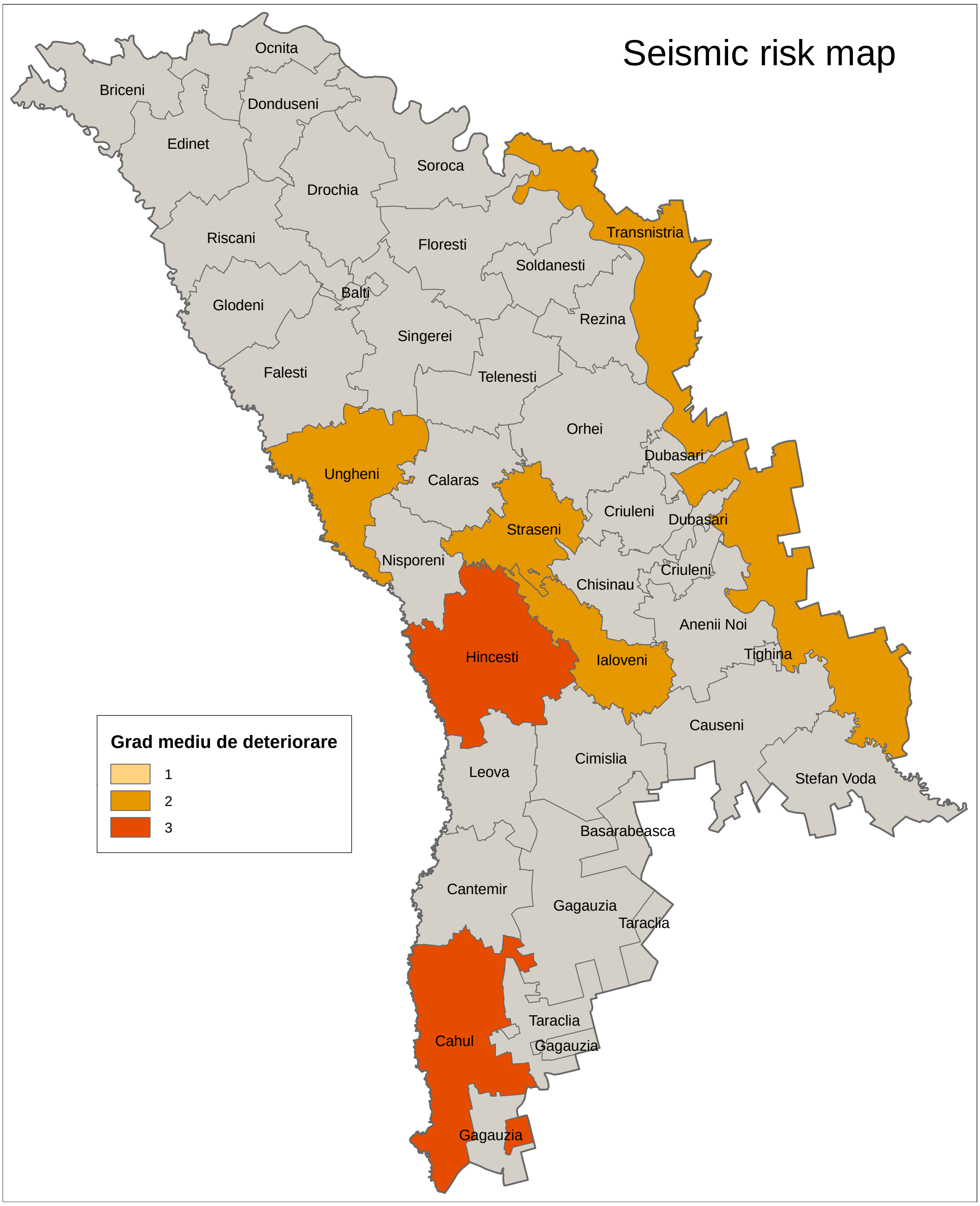

Fig. 142: Seismic risk map of Moldova Republic.

It was elaborated in 2012 for scenario earthquake (like 10.11.1940) in terms of the average degree of damage for each district.

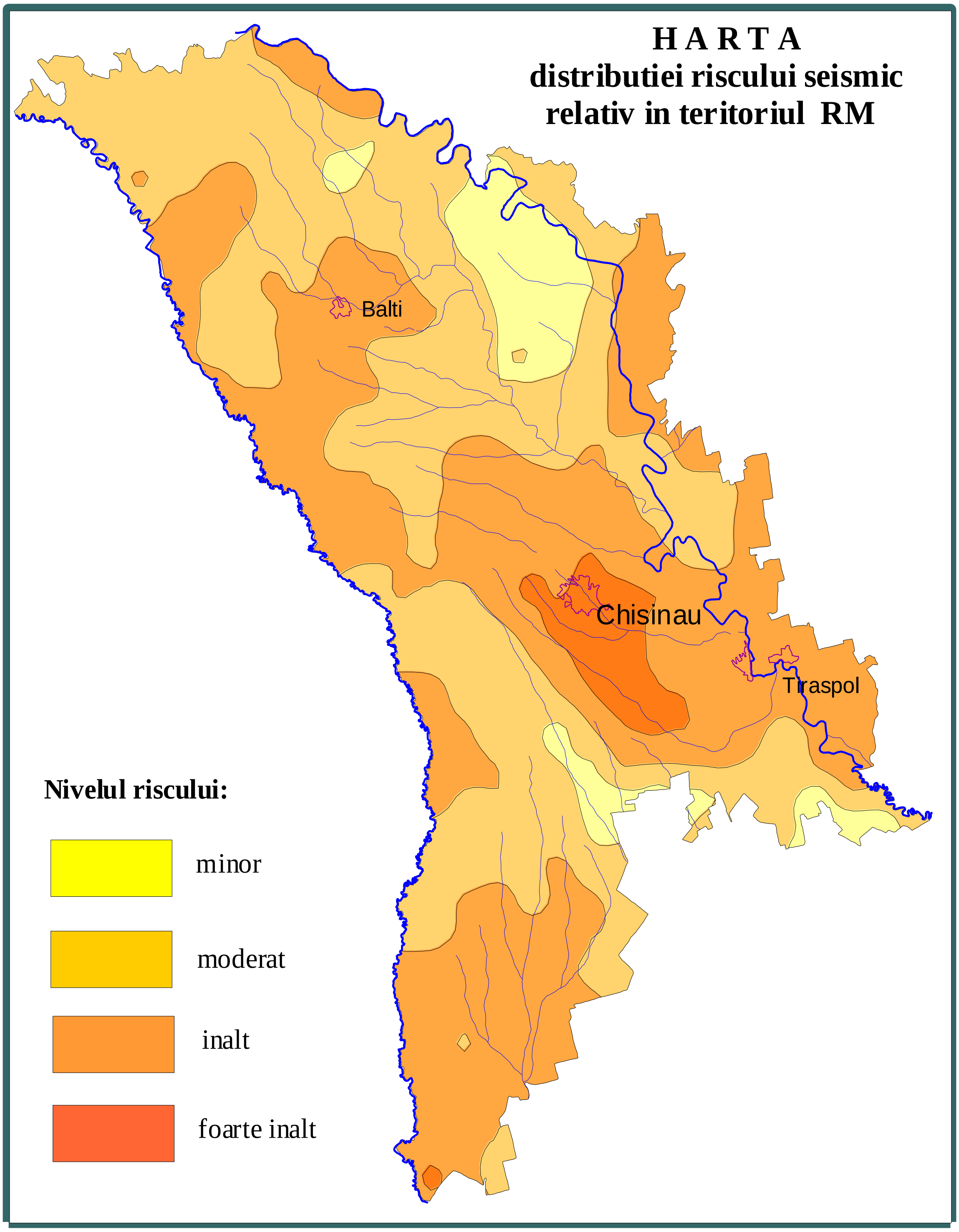

Fig. 143: Relative seismic risk map of Moldova Republic.

4.8.3 SYNTHESIS AND CONCLUSIONS

Efforts were spent to compile past events, existing legislation framework, and available bibliography in all of the participanting countries to establish a base for a scientific network regarding earthquake, landslide and flood hazard prevention.

The purpose of this Deliverable is to study the seismic hazard in the eligible area for scientific exchange and transfer of technical knowledge taking into account the seismicity in each particular country, various seismic hazard approaches combining the experience and expertise of each partner of the participating countries.

The seismic hazard assessment of the examined area is based on probabilistic and deterministic approaches and for various return periods dependended on the local seismic codes of each participating country of this project. Each country member describes and presents the adopted seismic hazard models which have been applied in each eligible area and the regional seismic hazard assessment is presented. The calculated results will be used in the next phases of the project. The aforementioned calculations will be a part of the uploaded data in the Web-based tool which is going to assist designers, planners and decision makers in the Black Sea and surrronding areas.

5 FLOOD HAZARD ASSESSMENT METHODS AND MODELING (ACTIVITY 1.8)

5.1 EXECUTIVE SUMMARY

Floods occur with a continuously increasing frequency due to climatic changes and cause serious damage every year in the wider Black Sea area endangering human life and property. As societies continuously expand, these phenomena are expected to play an increasingly important role, blocking sustainable development unless properly tackled.

The problem has been recognized by the EU Commission [1], [2] who has taken numerous actions towards flood hazard mitigation [3]. Flood hazard often present a cross border character so broadening the cross border cooperation among societies, is expected to greatly help mitigate those hazards. Problems already recognized towards that scope, have been already recognized by the EU [4], [5] and include the lack of a “common ground” in terms of assessing the level of Flood Hazard. This is due to the fact that even in the same country, different hazard assessment methodologies have being used making the comparison of results impossible. What seems to be needed is a scientific consensus on this matter, which is going to lead to the use of a common methodology in order to be able to cooperate and communicate on flood hazard issues, transparently. This is one of the SciNetNatHaz project’s scopes; the others being related to other problems also recognized by the EU Commission, as are the lack of data and metadata.

Selecting a methodology to apply to a vast area like the one around the Black Sea is not an easy task. It is in fact a matter of conciliation and compromise. “Conciliation” to achieve a scientific consensus where all involved scientists from all partners must agree upon the methodology to adopt, leaving aside the ones that they usually use; and “compromise” to finally select the methodology which gives reliable and accurate enough results, is flexible and can be adapted to local conditions, it’s data requirements are already met (and this is a problem considering that there are different countries involved with a different level of data availability, legal status etc) and finally, cheap to implement in terms of cost of software, additional data, expert services etc. Moreover, it is planned to share the methodologies proposed with the scientific community interested in those matters, in order to have a feedback and even discussions and to broaden the number of people involved in order to achieve the final project’s scope which is to establish a scientific network activated (also) in flood hazard prevention issues.

An additional problem to be faced comes from the fact that there are two types of floods occurring in the area and they affect in a different way the eligible areas of the countries involved. Riverine floods mostly affect Romania, Moldova and Ukraine whereas flash floods mostly affect Greece, Bulgaria and Turkey. So as it appears, the selection of common methodologies to use for FH assessment is similar to selecting “best practices” to apply in certain locations over the entire area in order to assess flood hazards.

To achieve that goal, a review of the current state of the art and state-of-practice in respect to used methodological approaches to assess FH in the countries involved, was carried out.

Best Practices as the implementation on the river Danube as shown in the Danube FloodRisk project were adopted in respect to riverine floods.

Considering flash floods, the state-of-practice review, with a broader overview of methodologies used worldwide, completed the image of the "candidate" methodologies, their requirements and outputs. Those methodologies were reviewed in detail, taking into consideration their data requirements as compared to data already collected during the previous stage of the project's implementation including new data that could be easily collected with a small cost.

The final selection was based on an evaluation scheme which took into account the methodologies' requirements, the cost of implementation and the outputs in terms of their reliability and accuracy. A two step approach was finally selected: i) locate the flood prone areas on a watershed/regional scale using readily available data and ii) apply hydraulic models in order to assess in detail the flood parameters in a site specific/local scale and accurately delineate the inundation area, depth and other flooding parameters.

Additionally, Open Source software was selected as the tool on which the implementation will be based. The selection of Open Source software implies a greater effort to support current and future users but the project partners are willing to undertake that effort, because the use of cost free Open Source software, will give the ability to anyone interested (scientists, people working in National and local state administration etc) to apply the methodologies, assess flood hazard and provide support to decision making regarding planning preventive measures. The project partners expect this solution to boost applied research in the wider area regarding flash flood hazard assessment, for the benefit of the stakeholders who include the scientific community, education, local and state administration and the public.

Scope of Activities "A 1.8" and "A 1.12" is to select the most appropriate and feasible methodologies to be further used for flood hazard assessment in the eligible areas of the countries involved in the project. A basic overview of the methodological approaches used in the participating countries to assess FH will reveal the current status and the potential common ground in terms of required outcomes. At the second stage (Action A 1.12), a methodological approach, which fits to the available data, budget and required outputs will be selected to be proposed as the universally applied by all partners in order to produce comparable and at the same time accurate and reliable, results.

The implementation is foreseen for a next stage of the project's implementation as described in Group of Actions GA.3 (pilot implementations), where the methodologies selected in this phase (GA.1) will be implemented, evaluated and calibrated in pilot areas, in order to be finally shared with the stakeholders. Moreover, tutorials and step-by-step guides will be provided along with software tools to stakeholders in order to disseminate the results of this research project regarding flood hazard assessment.

Within this scope, this document attempts to provide information on the methodological approaches used to assess Flood Hazard in order to effectively design disaster mitigation measures. As there are two basic types of floods occurring in the area of investigation, both riverine and flash floods, there is a respective classification of the overview of methodologies used to assess those types of flood hazards. Another issue is attempted to be investigated; in the wider area of the project’s implementation there are two major river systems: Danube and Evros/Maritsa/Meric rivers where a lot of effort has been spent on flood hazard assessment and disaster mitigation but with different outcomes as far as the disaster mitigation is concerned. The overview of both cases, attempts to reveal the reasons of that fact and investigate if the differences are due to the methodological approaches used to assess flood hazard or if there are other reasons for that.

5.2 INTRODUCTION

Flood occurrence and damage frequency in Europe, is continuously increasing due to climate changes and the expansion of societies. Floods pose a serious threat to human life, property and infrastructure and block sustainable development.

The problem has already been recognized by the EU who has shown a great interest evident by the numerous Organizations and Bodies formed, the legislation issued and the large number of research projects funded [3].

A large number of Research projects carried out so far and funded by the EU, cover riverine floods in respect to flood hazard (FH) assessment and early warning, while a couple of them attempt to cover a part of the "information gap" regarding data and methodologies harmonization. The implementation of those projects has led to the identification of Riverine Flood Hazard in large rivers of Europe and of the Black Sea area including Evros/Maritsa and Danube rivers. Solutions for the riverine problems have been proposed in most cases and even early warning systems have been developed.

The problems which still remain in respect to flood hazard are related to information gaps, comparability of assessment results and problems in dealing with cross-border issues [4], [5], [6], [7], [8], [9].

The incomparability of assessment results is related to the different methodological approaches used to assess the FH and this problem is widely spread as different methodologies are often used by researchers even within the same country.

To tackle the problem, the achievement of a consensus among the scientific community regarding data and methodologies used to assess ELF Hazards is absolutely necessary because it will help create a large network of potential partners and will give them the means to communicate transparently regarding related scientific problems.

An additional problem that has not been fully addressed as yet is related to flash floods which are typical in Mediterranean countries. They are sudden and violent phenomena causing heavy damage and losses and they are the most frequent type of flooding in the central and especially the southern part of the Black Sea area. The problem with modeling these types of floods is that water courses that cause flooding are usually ephemeral with very little or not at all water during most of the year. Moreover, the respective watersheds are usually of limited extent and with a steep morphology so, this type of flooding has to be addressed by implementing research on a local scale.

Selection of a common methodology to use can only be based on a strong scientific consensus where all involved scientists must agree upon the methodology to initially adopt, leaving aside the ones that they usually use. Additional compromises must be made regarding the anticipated results and the feasibility in terms of data availability and cost of implementation. The methodology to be finally selected must provide accurate enough results, must be flexible and adaptable to local conditions, it's data requirements must already be met (and this is a problem considering that there are different countries involved with a different level of data availability, legal status etc) and finally, it must be cheap to implement in terms of cost of software, additional data, expert services etc.

5.3 CURRENT STATUS IN TERMS OF METHODOLOGIES USED AND EU COMMISSION POLICIES

Selecting a methodology to apply for FH assessment is also connected to the anticipated results so EU policies in respect to the requirements they set, are the basis for any decision.

A review of already implemented EU funded projects can also help create a more complete image of the current status in terms of harmonization of methodologies to assess FH.

5.3.1 EU FUNDED PROJECTS RELATED TO FLOODS

Most EU countries have already started preparing the Flood Management plans according to the 2007/60/EC Directive. At this point, all countries have completed the Preliminary Flood Risk Assessment (Art. 4&5, deadline reporting 22.3.2012) [http://ec.europa.eu/environment/water/flood_risk/timetable.htm] and are proceeding to the next stage which is the "Flood Hazard & Flood Risk Maps" (Art. 6, deadline reporting 22.3.2014).

A series of Scientific Research Projects focusing on flood disaster mitigation has been funded by the EU Commission during the past years [13]. Their overview reveals the evolution in flood related research targets over the years to the current status formed especially regarding the development of FH assessment methodologies and some effort made towards harmonization.

Moreover, the results of those Research Projects can greatly help in avoiding duplicate work and increasing the positive effects, by establishing project synergies and linking the results of past projects with the basic necessary information of the current ones.

Synergies of the SciNetNatHaz project with relevant to flood Hazard assessment & management projects already carried out with EU funding, include (but are not limited to):

5.3.1.1 EVROS/MARITZA/MERIC river

1. The Project **"RIVERCROSS - Cross-border cooperation on flood basin River Evros / Maritza / Meric ",** includes partners from the Netherlands, Germany, Poland and Greece, and emphasizes the exchange of experience on trans-boundary water management, analysis of factors determine the success or failure of the CBC this field

and produce proposals for improvements and new methodologies. RIVERCROSS in particular tried to contribute to solutions for river-basin management in cross-border regions by facilitating reflection, information sharing, and policy learning about cultural and institutional barriers and opportunities. Areas of implementation included the Evros/Maritza/Meric river area. The outcomes were basically educative material including information about regions of interest, presentation of case studies, pictures, data, experiences, best practices, etc.

2. The Project "**Observation of quantitative and qualitative characteristics of rivers Erythropotamos**, **Ardas and Evros Region Eastern Macedonia and Thrace**", in the framework of the Community Initiative INTERREG IIIA / PHARE CBC GREECE-BULGARIA, implemented by the Department of Water Supply Directorate of Public Works, Region of Eastern Macedonia and Thrace, and funded by the European Regional Development Fund (ERDF) and by 75% National Funds 25%. The Project aims at creating a **flood forecasting system** to enhance defense against floods, to implementing key measures for the gradual incorporation of and compliance to the EC Directive 2000/60/EC and to designing a common approach between Greece and Bulgaria in order to achieve the common goals.
3. **Flood warning system establishment in Arda river basin for minimising the risk in the cross border area** (**ARDAFORECAST**). Greece-Bulgaria 2007-2013, Investing in our Future. Project start: 20 Mar. 2012; End: 19 Mar. 2014. [http://arda.hydro.bg/index.php], 28/04/2014. The Project's expected outputs include the establishment of hydro meteorological information system, the development of GIS database, the improvement of the density and frequency of the hydro-meteorological observation network through, the installation of additional automatic stations, a flood warning system operation manual, a set of hot points, a set of alert threshold for each hot points, a set of warning procedures, WEB based tools for information exchange and access of decision makers, stakeholders and large public to all the necessary data and forecasts.

   Precipitation and air temperature data were fused using the regional scale, short range ALADIN model which provides a 3 day forecast and for the Global scale model, the European Centre of Medium Range Forecast (ECMWF) with a 5 day forecast ability.

   The Hydrological aspect was covered using calculations of the surface runoff at "points of interest" or hot-spots assessed using morphometric parameters (topography). In particular, the ISBA scheme was used to calculate surface runoff and drainage per-unit area. The hydrological model was combined with TOPMODEL which is based on the basin topography. The methodology was developed in France for flash flood hazard assessment in the Mediterranean region and used in the Ardas (a tributary of Evros/Maritza/Meric river) area too.

The application involves the use of the TOPMODEL to locate "hot spots" at a regional scale and then the use of hydraulic models to assess the hazard at a local scale. In the implementation for the town of Smolyan, the HEC-RAS model and software was used to compute flood parameters for different return periods.

4. **Regional Strategy for Disaster Prevention- CivPro**. It's a Regional Initiative Project financed by the European Programme for Interregional Cooperation INTERREG IVC (Evros/Maritsa/Meric area included). In the frame of the project, regions from 11 European countries joined forces to share their experience and knowledge in order to establish modalities and strengthen the link between crisis management and disaster prevention http://www.territorialcooperation.eu/frontpage/show/793.

   As an outcome of the project partners develop a European Training Center in Greece. By sharing the knowledge and experience acquired in the frame of the project, they develop improved governance models to introduce cross-cutting thinking and approaches to disaster prevention, for the purpose of establishing comprehensive national and regional policy approaches in terms of structures and organization.

5. The Project SEE/A/118/2.2/X: Practical Use of MONITORing in Natural Disaster Management – Project "MONITOR II" [http://www.monitor2.org/index.php?option=com_content&view=frontpage&Itemid=1&ac45af24dc0db8131d6d3647bf3df4c7=b2a7a35180c18b667673e65384bc7324], 28/04/2014. Scope of the Project is to improve communication among Disaster Management Experts. This is going to be achieved, according to the project, by improving communication and accelerating the flow of information between risk experts, local stakeholders and civil protection services. Requirements include the harmonization of procedures, methodologies and standards. Evros/Maritsa/Meric area included in the investigated areas.

   There were different methodologies used to assess the flood hazard in different countries but there was also an interesting effort to link flood hazard to erosion processes by producing "Flood & Erosion Intensity" and "Flood & Erosion" maps. Flood Hazard assessment was based on HORA (Flood Hazard zonation for Austria) according to which, flood hazard assessment is based on 1-D model analysis and on a coarse DEM (topographic data), for return periods of 30, 100 and 200 years. At a more detailed approach of the following stage, hydrological data and flood protection facilities were incorporated from maps of a 1:5000 scale.

6. **Project FLAPP – Flood Prevention in Border Areas**: Common approach on the cross-border management of floods. INTERREG III. Implementation period: Jan 2005-Aug 2007. The Project was about the integrated river basin management in cross-border areas (Danube river was included). Aspect of the project include: flood prevention via construction and land use planning measures, sustainable management

of river basins, disaster management, cross-border cooperation for a holistic approach on flood management issues, raising public awareness on flood management issues (www.flapp.org), 28/04/2014.

7. **Turkey Earthquake and Flood Recovery Project -TEFER:** The purpose of the project is to investigate the Turkish Black Sea coast area in respect to floods and landslides and to develop a flood management programme to reduce or eliminate long-term risk and damage to people and their property. In the West Black Sea Flood Region the priority is laid on engineered flood defense works, mainly in the form of channel improvements. Tefer outcomes include a quantitative and qualitative evaluation of erosion processes in the river catchments affected by the floods and earthquakes of 1998/99 and the movements of sediments in the rivers was made and resulted in a set-up of general guidelines regarding the erosion processes in the respective basins as well as the sediment transport in the rivers. A provision was made of the required data regarding erosion and sediment transport for the flood damage repair component of the TEFER project. Main components of the project were:
    - **i.** Data collection of erosion and sediment transports in the various basins/project locations;
    - **ii.** Analysis of erosion and sediment transport mechanisms and amounts for both regular erosion, landslides, and flood or earthquake related events;
    - **iii.** Frequency analysis of floods in the various basins, both regular and extreme floods;
    - **iv.** Analysis and prediction of sediment transport capacity as related to sediment loads for the various rivers and project locations in the area;
    - **v.** Modeling studies in order to assess the impact of erosion and sediment transport on the flood carrying capacity of the rivers and at the various project locations;
    - **vi.** Conceptual design of river engineering measures to improve flood and sediment transport conveyance.

5.3.1.2 DANUBE river

1. **Integrated Management of the Danube ("Danube WATER integrated management").** The project aims to increase the capacity of border control cooperation and Romania - Bulgaria in terms of quality monitoring of environmental factors on the Danube and grounding joint response to emergencies (droughts, floods, pollution and contamination). http://www.danube-water.eu/
2. **Plan for Preventing Flood protection and mitigation**. Scope of the project is to develop plan of prevention, protection and flood mitigation in the hydrographic area Dobrogea Litoral (Danube river wider area). These maps can be used to support

decision making regarding flood hazard mitigation http://www.rowater.ro/dadobrogea/default.aspx

3. **DESWAT project (**Destructive Water Abatement and Control of Water Disasters) The Destructive Waters, or DESWAT, program is an initiative of the Romanian Ministry of Environment and Water Management (MMGA) to improve the water management authority National Administration Apele Romane (ANAR)'s flood monitoring capacity, as well as to improve its National Institute of Hydrology and Water Management flood modeling and prediction capabilities. The main objectives of the DESWAT project include: Upgrade of the hydrological monitoring system, consisting of 633 automatic hydrometrical stations (water level, air and water temperature and precipitation sensors); 247 supplemental raingauge automatic stations; and about 70 hydrometrical stations will also have water quality sensors (dissolved oxygen, conductivity, pH, turbidity, etc); and to Implement advance hydrological data integration, processing and modeling software systems. The Integration with SIMIN project (Romanian Integrated Meteorological System) is also a major target of the project. The basic idea is to adopt a hydrological modeling system similar to the National Weather Service River Forecasting System (USA-NWSRFS), which will be used to elaborate hydrological forecasts, in an interactive way, for medium and large scale basins (http://www.inhga.ro/), 28/04/2014.
4. **ROMANIAN FLASH FLOOD GUIDANCE (RO_FFG):** "*The objective of this technology transfer project is to design, develop and test the components of an operational flash flood guidance system for Romania. There are radar rainfall estimates for the area and a number of real time on-site precipitation sensors which would be used to provide input to the system. The flash flood guidance system will be implemented by HRC at the National Institute for Hydrology and Water Management (NIHWM) in Bucharest."* The RO_FFG is designed to provide real time information and guidance, regarding potential, upcoming or imminent small-scale flash flood *(http://www.hrc-lab.org/), 28/04/2014.*
5. **HYDRATE Project: "***The **HYDRATE** objective is to improve the scientific basis of flash flood forecasting by extending the understanding of past flash flood events, advancing and harmonising a European-wide innovative flash flood observation strategy and developing a coherent set of technologies and tools for effective early warning systems. To this end, the project includes actions on the organization of the existing flash flood data patrimony across Europe. The observation strategy proposed in **HYDRATE** has the objective to collect flash flood data by combining hydrometeorological monitoring and the acquisition of complementary information from post-event surveys.This will involve a network of existing Hydrometeorological Observatories; all placed in high flash flood potential regions. **HYDRATE** will develop a freely-accessible European Flash Flood Database to make available the collected hydrometeorological data to the international research community. The*

*final aim of **HYDRATE** is to enhance the capability of flash flood forecasting in ungauged basins by exploiting the extended availability of flash flood data and the improved process understanding…" (*http://www.hydrate.tesaf.unipd.it/), *28/04/2014.*

6. **The DANUBE FLOODRISK Project within the Southeast Europe Transnational Cooperation Programme which** focuses "*on the most cost-effective measures for flood risk reduction: risk assessment, risk mapping, involvement of stakeholders, risk reduction by adequate spatial planning*". The Danube FloodRisk project has achieved an essential goal for an effective flood hazard assessment and management, which is the consensus between participating countries and the flood hazard management on the entire river watershed basis. The later, considering the size of the Danube river basin and the number of involved countries, is a great achievement and has led to an effective FH assessment over the entire area. For those reasons it should be considered as a "Best Practices" project.

5.3.2 ADDITIONAL EU FUNDED PROJECTS REGARDING FLOOD DISASTER (FD) IN TERMS OF MODELING FLOOD HAZARD, PRODUCING FLOOD HAZARD MAPS AND INDICATING BEST FD MITIGATION PRACTICES

1. The "**FLINKMAN**" project [http://www.flinkman-project.eu/]. The basic scope of the project is the "development" of a suitable framework through the preparation of a flood management plan to ensure consistent and effective link, at each stage of the chain prevention - Readiness - Response - Recovery of floods. Moreover the project aims at: i) Developing supportive tools, based on Information Technologies (IT), which will promote the collection, evaluation and exchange of best practices. ii) Upgrading the current status of Civil Protection Units and iii) promoting international cooperation among the competent bodies in Europe.
2. **FLOODSite – Integrated Flood Risk Analysis and Management Methodologies.** FLOODsite was an "Integrated Project" in the Global Change and Ecosystems priority of the Sixth Framework Programme of the European Commission. It commenced in 2004 and ran to 2009. The FLOODsite consortium includes 37 of Europe's leading institutes and universities and the project involves managers, researchers and practitioners from a range of government, commercial and research organisations, specialising in aspects of flood risk management. **"***The FLOODsite project covers the physical, environmental, ecological and socio-economic aspects of floods from rivers, estuaries and the sea. The project is arranged into seven themes covering: 1) Risk analysis – hazard sources, pathways and vulnerability of receptors. 2) Risk management – pre-flood measures and flood emergency management. 3) Technological integration – decision support and uncertainty. 4) Pilot applications – for river, estuary and coastal sites. 5) Training and knowledge uptake – guidance for professionals, public information and educational material. 6) Networking, review*

and assessment. 7) Co-ordination and management." (http://www.floodsite.net/), 28/04/2014.

3. Project **FLoods and fIre Risk assessment – FLIRE**. The aim of the LIFE + FLIRE is the combinatorial and effective assessment and management of flood and fire risks using cutting-edge tools and technologies, taking into account the issues of prevention, adaptation and interaction. FLIRE includes the development of the following tools and actions: Management Tool of Meteorological Information (WIMT) that takes short term forecast, taking into account local conditions, and classifies the weather as favorable for potential flood or fire risk. A tool for the assessment and management of flood risk in nearly real time, which will include components for river basin modeling, urban modeling and a Flood Early Warning System. This tool takes the WIMT information on flood hazards and activates the corresponding early warning systems (EWS). (http://www.flire.eu/el/), 28/04/2014)
4. **FLOODRELIEF: REaL-tImE Flood Decision Support System Integrating Hydrological, Meteorological and Remote Sensing Technologies.** *"The main objective of FLOODRELIEF is to address the limitations of current flood predictions by developing and demonstrating a new generation of flood forecasting methodologies which will advance present capabilities and accuracies and making the results more readily accessible both to flood managers and those threatened by floods. This is achieved by exploiting and integrating different sources of forecast information, including improved hydrological and meteorological model systems and databases, radar, advanced data assimilation procedures and uncertainty estimation, into real-time flood management decision support tool designed to meet the needs of regional flood forecasting authorities."* *http://www.eugris.info/DisplayProject.asp?P=4598*
5. **ECOFLOOD: Towards Natural Flood Reduction Strategies. "***The long-term objective of the Ecoflood project is to stimulate creation of floodplains that both protect the environment against floods and provide opportunities for restoration and development of highly valuable ecosystems. This requires an integrated vision. However, there is a knowledge gap between research fields, and scientific output is often not appropriate for stakeholders. EcoFlood contributes to this long-term objective by compiling comprehensive guidelines for creation of natural flood defenses based on the present information. The guidelines will contain: a) scientific knowledge on wet and terrestrial floodplain ecosystems, b) practical problems that obstruct stakeholders in creating natural flood defenses, c) scientific gaps and insecurities. Gathering this information is the main deliverable of a scientific conference, a stakeholder workshop and a thinktank meeting. The various relevant research fields will be integrated in the Ecoflood project."* **http://levis.sggw.waw.pl/ecoflood/**

6. **ACTIF: Achieving Technology Innovation in Flood Forecasting.** *"ACTIF will actively consolidate and disseminate Fifth Framework research advances in Flood Forecasting through three scientific meetings and preparation of best European practice guidance. The ACTIF partners will compile best practice guides on three topics where significant research advances have been made in recent years and also on cataloguing specific data sets of long-term value to the research community. Thus ACTIF will facilitate the uptake by end-users of European research advances in flood forecasting, warning and dissemination."* [http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/scho0606bkys-e-e.pdf] (26/04/2014)
7. **VULMIN – Flood vulnerability of localities and the environment under the global modification.** Aim of this project was to evaluate the vulnerability of the potential flood-affected systems (human settlements, the communication network, arable lands etc.) in relation to their physical conditions and to social, economic and political contexts. (http://www.igar-vulmin.ro/obiective.html), 28/04/2014.

5.3.3 CONCLUSIONS

EU has spent a lot of effort towards flood disaster mitigation, evident by the legislation issued, the numerous Organizations and bodies formed and the Research projects funded over the past years. As far as the Flood Hazard assessment modeling is concerned, most of the Research projects carried out so far, cover riverine floods in terms of flood hazard assessment and early warning, while only a couple of them cover the part of data and methodologies homogenization.

Lessons learned as described in the outcomes and Best Practices from all the projects reviewed, were taken into consideration during the process towards the selection of Flood Hazard Assessment methodologies.

The implementation of those projects has led to the identification of Riverine Flood Hazard in large rivers of Europe and of the Black Sea area including Evros/Maritsa and Danube rivers. Solutions for the riverine flood problems have been proposed in most cases and even early warning systems have been developed.

Problems still remaining regarding floods in large rivers, are related to the cross-border character of those river systems. Danube river FloodRisk project is a good example of how these problems should be faced: harmonized management strategies, close cross-border cooperation and flood hazard/risk management on a river basin basis.

Widening the geographical area considered in planning flood prevention or mitigation measures on a "river basin" basis as in the case of the Danube FloodRisk project, offers the ability to select the more cost-effective mitigation strategies. The (existing) problems that arise when considering cross-border cooperation in flood hazard mitigation and management, are usually related to the lack of a legal framework for cooperation; to the lack of capacity and resources; to the lack of trust; to differing institutional structures; to the lack of political "will" and to the lack of public awareness and participation.

Problems regarding flash floods have not been adequately addressed. There have been serious efforts, especially by developing monitoring and early warning systems as in the cases of the DESWAT and the HYDRATE projects which were both carried out in Romania, but there have very little done regarding Flash flood Prevention. Prevention requires applied research on a local scale so that decisions can be made regarding the design of the appropriate and effective preventive measures.

A serious additional problem which plays a decisive role in Flood Hazard Assessment is due to the existing "information gap" and to the lack of using harmonized methodologies [4], [5], because data requirements always play a decisive and sometimes, restrictive role in selecting and applying the appropriate methodologies; and harmonization leads to comparable and "append-able" results which is an essential prerequisite when working in cross-border areas.

5.3.4 REFERENCES

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5.3.5 SELECTED LINKS

(Last time visited on 28/04/2014, 22:00)

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5. Council of Europe: European and Mediterranean Major Hazards Agreement
6. *http://www.coe.int/t/dg4/majorhazards/ressources/pub/default_en.asp*
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11. ECOFLOOD: Towards Natural Flood Reduction Strategies. *http://levis.sggw.waw.pl/ecoflood/*
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18. European Flood Awareness System –EFAS. *http://www.efas.eu/*
19. FLOODRELIEF: REaL-tImE Flood Decision Support System Integrating Hydrological, Meteorological and Remote Sensing Technologies. *http://www.eugris.info/DisplayProject.asp?P=4598*
20. Global Assessment Report on Disaster Risk Reduction 2013: From Shared Risk to Shared Value: the Global Disaster Alert & Coordination System *http://vosocc.unocha.org/*
21. HYDRATE: *http://www.hydrate.tesaf.unipd.it/index.asp?sezione=ProjectOverview&SubSez=ProjectOverview*
22. Joint Research Centre (JRC) *http://ec.europa.eu/dgs/jrc/*
23. Practical Use of MONITORing in Natural Disaster Management – Project "MONITOR II" *http://www.monitor2.org/index.php?option=com_content&view=frontpage&Itemid=1&ac45af24dc0db8131d6d3647bf3df4c7=b2a7a35180c18b667673e65384bc7324*
24. The Prevention Web: Serving the Information needs of the Disaster Reduction Community. *http://www.preventionweb.net/english/*
25. River basin modeling, management and flood mitigation: *http://databases.eucc-d.de/plugins/projectsdb/project.php?show=288*
26. Romanian Flash Flood Guidance system -ROFFG *http://www.boku.ac.at/diebodenkultur/volltexte/sondernummern/band-64/heft-3-4/matreata.pdf*
27. UN-HABITAT : RDMU (Risk and Disaster Management Unit): *http://www.unhabitat.org/programmes/rdmu*
28. UNDAC (United Nations Disaster Assessment and Coordination): *http://www.unocha.org/what-we-do/coordination-tools/undac/overview*

5.4 TURKEY

5.4.1 INTRODUCTION AND SCOPE

This document is the contribution of the IPA partner on the deliverable D1.02 of the *SciNetNatHaz* Project within the context of Flood Hazard Assessment (FHA) and intends to present the current status in terms of methodologies used in Turkey.

As it is mentioned in previous paragraphs, there have been many different projects within the Black Sea Basin wider area on FHA methods and strategies, yet there are two major aspects that should be pointed out once more. First of them is the insufficient scientific cross border collaboration which restricts the necessary awareness and prevents the development of a determined political will which could lead to a closer and transparent cooperation. The second one is the lack of a multinational common scientific and technical language, especially on *flash flood hazard* related issues, which could lead to simple, affordable, applicable and harmonized methodologies.

An evaluation of the existing flood hazard assessment models/methods that are applied in Turkey will be presented below with reference to certain example studies. Then, the general comparison will be made with particular remarks towards the objectives of the SciNetNatHazPrev project.

5.4.1.1 Classification of Flood Hazard Assessment Methods in Local Scale

In this section, a brief classification of flood hazard assessment methods will be presented which will presumably make it easier to compare different methods and models. Each flood hazard assessment method requires certain types of data with certain quality and quantity. The end-result of each method in terms of temporal/spatial resolution, accuracy and reliability is different than one another; depending on the time, effort and budget allocated on providing and processing the data. Thus, it is of great importance to state the objectives and expectations of the flood hazard assessment study and to thoroughly evaluate the alternative methodologies before deciding which model suits best for a certain need. The following classification of flood models is partially adapted from Olsen, 2004 [1] with the addition of concepts used in Turkish practice of flood hazard assessment. Fig. 144 provides a description of the aforementioned flood modeling practice in a schematic way.

5.4.1.2 Stochastic/Conceptual Flood Hazard Assessment Tools

The extreme events have a certain probabilistic pattern on spatial basis [2]. For instance, if several historical floods are recorded on a certain zone, it is likely that this kind of events will occur again on this particular zone. Hence, using the available extreme flood data recorded over a relatively long time interval (at least some ten years to be meaningful), it is possible to develop an extreme probability density function (i.e. Gumbel, FT-II, Frechet, Weibull, etc.) which would yield the yearly occurrence probability (or return period) of an extreme event at a given severity (magnitude). If this is done over an area, say within a basin, it may be possible to generate a flood map that shows the expected inundation levels for a given return period. The set of data necessary for such a tool is spatially well-distributed reliable flood data (showing water levels and flow rates), recorded over a sufficiently long time. This sort of a data is quite difficult and expensive to obtain and usually available only for particular sparse locations.

Other than statistical tools, or to be used in combination with them, there are also conceptual models, also called artificial intelligence methods, which could provide with a certain basis on data processing or improvement. These methods proved to be beneficial especially when there are temporal or spatial gaps in the available data [3].

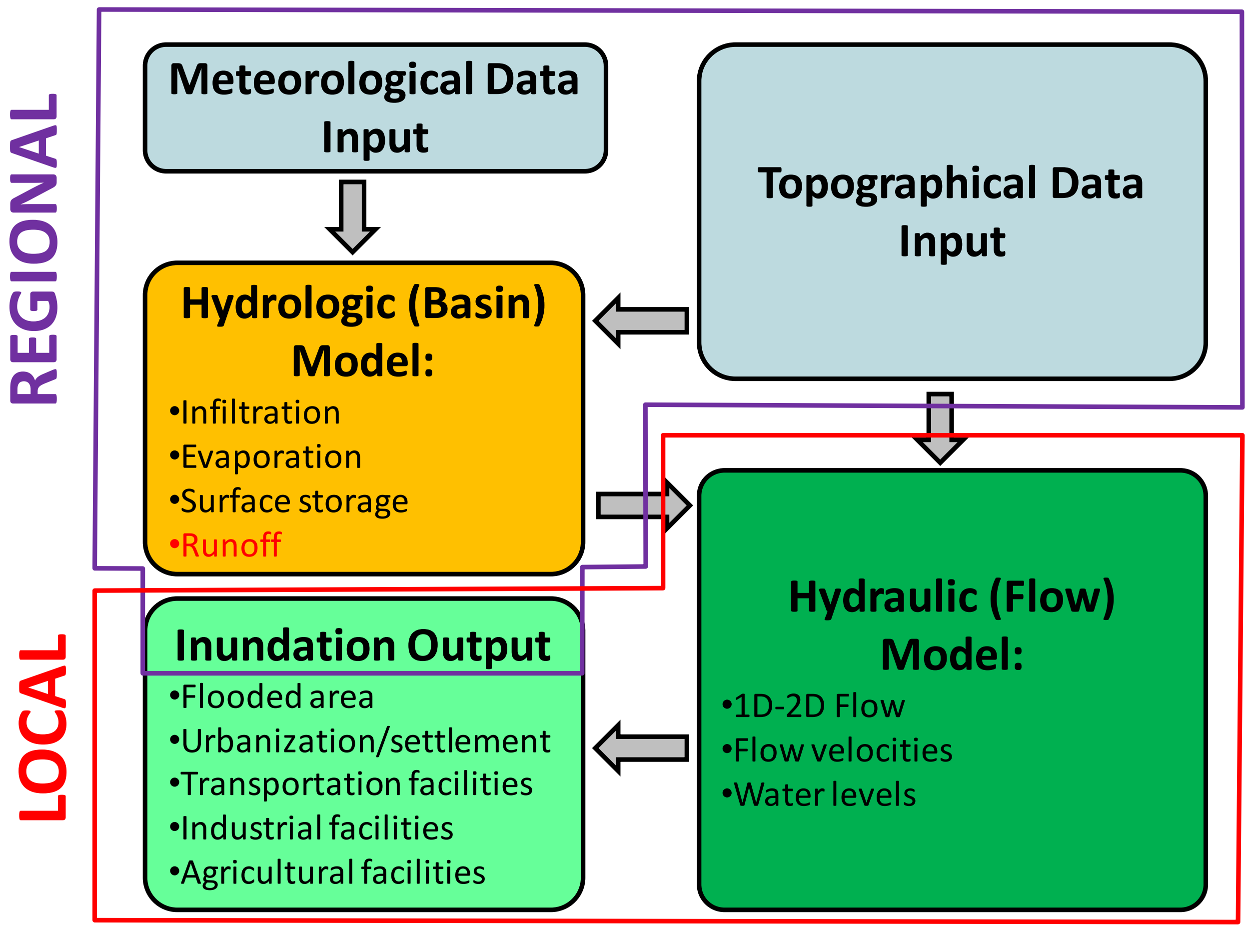

Fig. 144: Schematic description of a general flood modeling practice

In Turkey, State Hydraulics Works which is a directorate under the Ministry of Forest and Water is responsible for operation and maintenance of hydrological stations. There are roughly 2000 hydrological stations in Turkey, of which only 1114 are still under operation (http://en.dsi.gov.tr/land-water-resources, 01.04.2014). Considering that the total area of Turkey is over 780000 km^2, roughly 700 km^2 is represented by a hydrological station. Furthermore, flash floods usually occur on ephemeral or intermittent streams where there is no (or very limited) flow in most of the time, whereas the hydrological stations are typically located on perennial streams where there is always water. Hence, the data from these hydrological stations (and consecutively the statistical tools based on them) would not be satisfactorily representative as far as the flash flood hazard is concerned. Still, there are studies where ephemeral streams can also, to a certain extent, be modeled with stochastic approaches [4], [5].

5.4.1.3 Basin Based (Hydrological) Models

In hydrological analysis, a river basin generally is treated as a whole since it is the core unit in hydrology. The "basin based hydrological models" are the models that are based on the "water cycle", process the relationship between atmospheric, surface water and groundwater storage systems and basically run on the conservation of water. These models use simple conceptual relations which are usually tuned by field data, such as precipitation-to-runoff, unit/synthetic hydrographs, infiltration and percolation, evaporation, etc. The primary purpose of basin based models is to assess water allocation issues along with control of diffused pollution. Although flood hazard assessment is not the primary issue, these models can yield flood hydrographs (i.e. discharges) as "by-products" if fed by accurate meteorological data.

The output hydrographs obtained from basin based models are usually used as an input parameter to hydraulic models. The combined use of basin based models and hydraulic models, gives a higher resolution and much more accurate flood hazard assessment output. Some examples of most preferred software packages in Turkey are SWAT (http://swat.tamu.edu/, 01.04.2014), WEAP (http://www.weap21.org/, 01.04.2014), HEC-HMS (http://www.hec.usace.army.mil/software/hec-hms/, 01.04.2014) and MIKE-Basin (http://mikebydhi.com/Products/WaterResources/MIKEBASIN.aspx, 01.04.2014). Some of these models are GIS integrated (such as HEC-HMS and MIKE-Basin) whilst some of them are fully conceptual (such as SWAT).

5.4.1.4 1D Hydraulic Models

Hydraulic models, in general, are physically consistent models from the "conservation of mass" and "conservation of momentum" points of view. In a one dimensional domain, the former yields continuity equation, whereas the latter is characterized by the 1D Saint-Venant equation [1]. With these two differential equations discretized and solved over a river flow network, two unknown parameters, namely cross-sectional averaged velocity and flow depth, can be solved on any point. The sets of data needed are the topographic data (plan geometry of river flow network with nodes of calculation and the cross-sections at each node), land use data (the surface roughness characteristic of the bed in terms of Manning roughness, Chezy coefficient, etc.) and man-made structures along the river flow network which control, regulate or interfere in the water flow (such as culverts, weirs, reservoirs, bridges, etc.).

The flow can be solved for either steady (time independent) or unsteady (time dependent) cases. In these models, flow is always calculated in the streamwise direction and no lateral flow is allowed. Inflow with surface runoff per unit length of the river or seepage to groundwater per unit length can be defined. Many different boundary conditions for model run can be used, such as:

- Known upstream discharge, known downstream level, unknown upstream level,
- Known upstream discharge, known upstream level, unknown downstream level,
- Known upstream level, known downstream level, unknown upstream discharge, etc.

These models have been used for flood hazard assessment purposes for quite a long time, for almost five decades.

The necessary topographic data can usually be obtained from the combined use of satellite and orthophoto images, but usually backed up with field measurements of the cross-section geometry. When these models are incorporated with GIS, the flow depth output of the model can easily be converted to inundation area output.

The calculation load of the mode is usually quite bearable by medium-capacity PC's, which makes these models preferable for many cases such as realtime runs or hazard map assessment tools. These models are easily applicable.

The most popular 1D flow model that has been used in Turkey is, by far, HEC-RAS model, a public license software that has been developed by the US Army Corps of Engineers (http://www.hec.usace.army.mil/ software/hec-ras/, 01.04.2014). On the other hand, MIKE 11 by DHI is the most popular software among the paid license 1D flow models (http://www.mikebydhi.com/Products/WaterResources/ MIKE11.aspx, 01.04.2014).

When the flow covers a very wide area such that the lateral flow component cannot be neglected (i.e. the flow within an estuary or a lake), 1D flow models would not be sufficient to resolve the behaviour of the flow but that usually happens in large rivers. In such a case, 2D models are necessary.

5.4.1.5 2D Hydraulic Models and Hybrid (Quasi-2D) Models

In 2D hydraulic models, the computational domain is depth averaged and in two horizontal coordinates. Thus, although there is one equation for continuity, there are two components of the Saint-Venant equation, which altogether are solved for three unknowns, namely two velocity components and the flow depth. With this two dimensional spatial domain, it can be possible to quantify flow in large flow bodies. Some of the most preferred software packages in Turkey for 2D flow modeling are MIKE21C (http://www.mikebydhi.com/Products/WaterResources/MIKE21C.aspx, 01.04.2014), SMS/RMA-2 (http://www.aquaveo.com/software/sms-rma2, 01.04.2014), Telemac (http://www.opentelemac.org/index.php/presentation?id=17, 01.04.2014), SOBEK (http://www.deltaressystems.com/hydro/product/108282/sobek-suite, 01.04.2014) and Aquadyn (http://www.scisoftware.com/products/aquadyn_overview/aquadyn_overview.html, 01.04.2014). These models are generally used for flow in coastal estuaries and lagoons as well as lakes and dam reservoirs.

The data details and computational efforts (time) needed for 2D flow models are much more compared to 1D models. Thus, these models are not usually preferred for river flow modeling. But when the river overflows its bed and a detailed description of the flow over the inundation area is essential, 2D flow models may be preferable. In order to refine the solution of flow, hybrid models have been developed, which are essentially a combination of 1D and 2D models. In these hybrid (or quasi 2D) models the core flow region (river flow network) is defined by cross-sections as in 1D flow case.

When the water level is considerably higher than the flow geometry of the river flow network, then the 2D equations are employed to assess the flow characteristics. A well-structured program frame controls the switch and data transfer between 1D and 2D model domains.

The hybrid models are very advanced models and usually demand as much data as the 2D models. The boundary condition that defines the switch from 1D to 2D flow is very critical and this decision can affect the solution considerably. That is why the setting-up of the model requires expertise and experience. The applied hybrid models in Turkey include so far, MIKE-Flood (http://www.mikebydhi.com/Products/WaterResources/MIKEFLOOD.aspx, 01.04.2014), TUFLOW (http://www.tuflow.com/, 01.04.2014) and Delft-FEWS (http://www.deltares.nl/en/software/479962 /delft-fews, 01.04.2014).

5.4.1.6 Regional Scale Flood Hazard Susceptibility Tools

With the help of flood hazard modeling practices on local scale, it becomes possible to obtain necessary quantitative data for expected flood hazard and to mitigate against such hazards. Yet, the flood hazard practice for a certain location is a difficult, time consuming and expensive task, which needs quite a lot of expertise and experience. Thus, it would be wise to make a pre-screening to assess the susceptibility of flood hazard on a certain "region" and define a certain threshold for need of a more detailed analysis before going for a larger scale local modeling practice. In this way, the most flood-susceptible locations can be determined and local flood hazard assessment effort can be concentrated on these locations.

Furthermore, local scale flood models are usually applied for riverine floods and it is quite difficult to assess flash flood hazard since the latter type of floods are usually dispersed in a wide area, around the ephemeral and perennial branches of the river network. The regional scale assessment models have proved to work well for the first-screening of flash floods [6], [7].

The data necessary for such a regional flood hazard susceptibility assessment is significantly easier to provide with compared to flood modeling practices on local scales. Topographic data (in the format of a digital elevation model) corresponding to a roughly 1/25000 to 1/50000 scale and precipitation data corresponding to a representative characteristic value, such as yearly maximum or monthly maximum rainfall [8].

Although there are example applications of such regional scale flood hazard assessment tools in Turkey [9], they have not been applied as widely as they have been used in the world. Also, there stands a need for determination of a certain set of common physical basis for an indicative parameter (i.e. an index) that can be used generically in any region.

Summing up the aforementioned points, the regional flood (susceptibility) assessment tool that is to be used should bear the following characteristics:

- Must be morphology based
- Must be generic
- Must demand affordable data
- Must be easy to implement
- Must be GIS based.

5.4.2 SOME EXAMPLES OF FLOOD HAZARD ASSESSMENT PRACTICES IN TURKEY

With the help of flood hazard modeling practices on local scale, it becomes possible to obtain necessary quantitative data for expected flood hazard and to mitigate against such hazards. Yet, the flood hazard practice for a certain location is a difficult, time consuming and expensive task which needs quite a lot of expertise and experience. Thus, it would be wise to make a pre-screening to assess the susceptibility of flood hazard on a certain "region" and define a certain threshold for need of a more detailed analysis before going for a larger scale local modeling practice. In this way, the most flood-susceptible locations can be determined and local flood hazard assessment effort can be concentrated on these locations.

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5.4.2.1 Flood Modeling Practices of Turkish State Hydraulic Works (DSI)

DSI has been the major governmental organisation that is responsible from the flood related "hard protection measures" (i.e. structural measures). See Fig. 145 for an inventory of structural flood protection measures in Turkey. Recently, DSI has initiated a flood strategy action plan in 2012 covering 5 years (2013-2017) for the purpose of coping with flood hazard in a more organised, synchronised (with other governmental organisations) and better suited way (http://www.dsi.gov.tr/docs/sempozyumlar/ta%C5%9Fk%C4%B1n-strateji-eylem-plan%C4%B1-kapsam%C4%B1nda-dsi-%C3%A7al%C4%B1%C5%9Fmalar%C4%B1-(y-darama).pdf?sfvrsn=2, 01.04.2014).

DSI governs the operation of hydrological stations in Turkey. In total, 250 of 1478 stations are able to perform real time data connection (using modem). A GIS based inventory of flood events is available for floods since 1955 (Fig. 146).

An important component of the flood strategy action plan of DSI is "obtaining flood maps". This is a pretty difficult, time consuming and expensive task since DSI requires that both hydrological and hydraulic models (1D, 2D or hybrid) should be performed. This can only be done for a limited number of locations within the context of the flood strategy action plan.

For example, approximately a 50 km^2 area in Samsun, Terme, has been modeled by use of MIKE-Flood. Even such a local application took almost 2.5 months to implement and coasted roughly 100 000,00 EUR [12].

Fig. 147 shows the flood inundation map and flood hazard map of Samsun, Terme for 500 year return period flood.

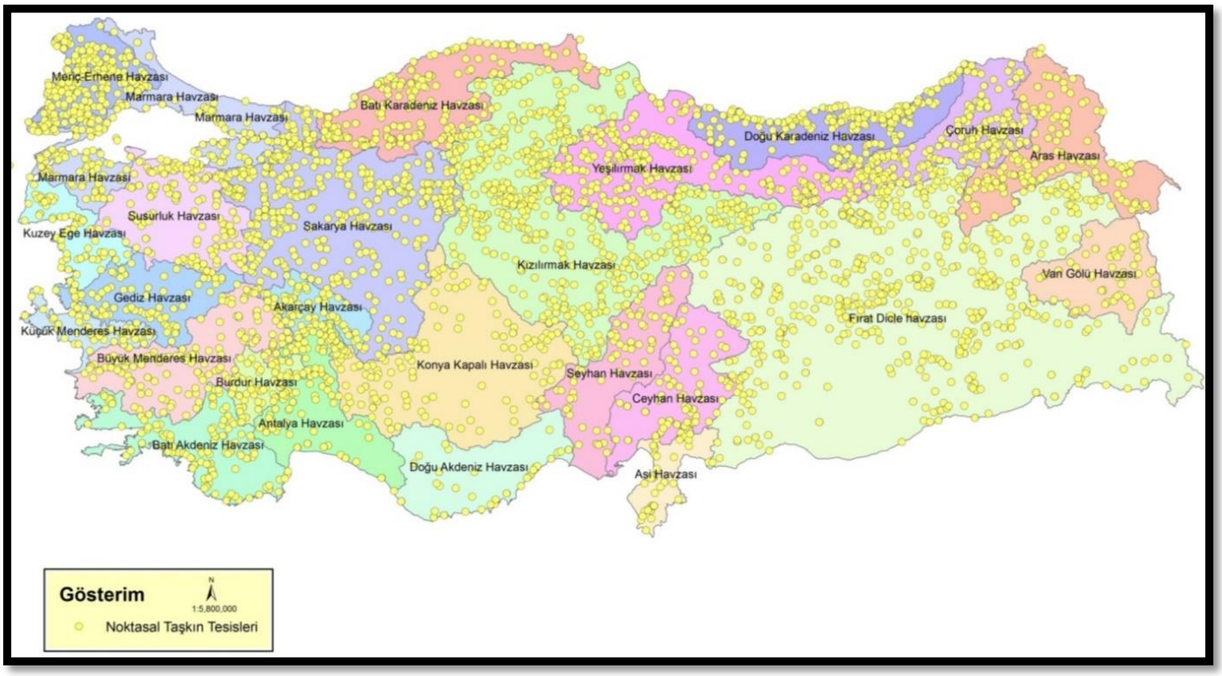
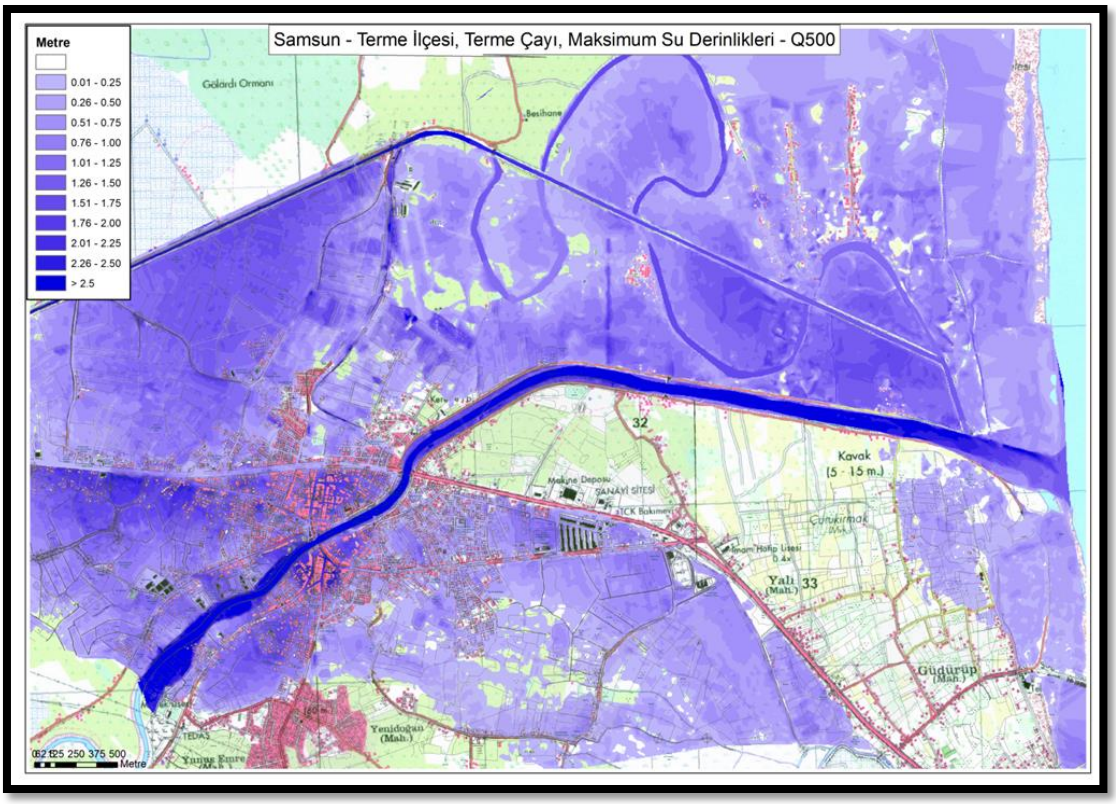
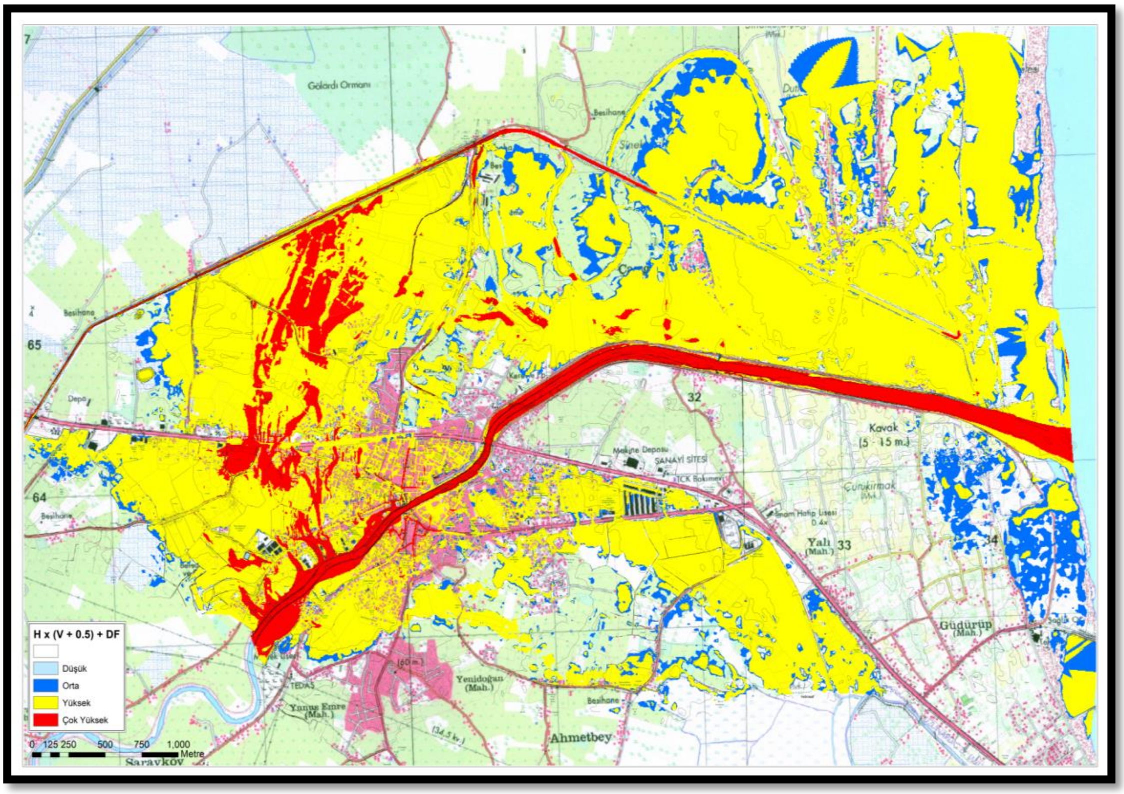


Fig. 145: Structural flood protection measures constructed by DSI in Turkey

Fig. 146: Historical floods in Turkey



a)



b)

Fig. 147: Samsun Terme flood hazard modeling study a) Inundation levels b) Flood hazard map

The planned detailed flood modeling projects in DSI flood strategy action plan until 2017 covers the flood hazard modeling of Kastamonu, Zonguldak, Karabük, Bartın, Sivas, izmir, Manisa and Uşak [13].

The cost of the mentioned modeling activities will be roughly over 1 000 000 EUR. This Fig.ure is a good example of why **the regional scale flood susceptibility tools** are of great importance. If such a GIS based susceptibility analysis is performed over the region of interest prior to detailed modeling, it can be possible to assess where the most flood susceptible locations of the region are, and then the detailed local flood modeling analysis, including the flood maps, can be performed as a priority at those locations.

5.4.2.2 Flood Hydrograph Assessment Guidelines of Turkish State Hydraulic Works (DSI)

These guidelines are essentially a group of work packages, rather than a single method, to be followed for extreme flood assessment [14]. It is advised especially for determination of the design discharge of water resources structures.

Meteorological and hydrological data to be used in the assessment exercise are obtained from MGM (State Meteorological Service) and DSI (State Hydraulic Works) data inventory. By nature, these guidelines are more suitable for riverine floods. Although the method itself is location dependent, it does not present a spatial basis for GIS application. The steps of calculations and computation are given tabulated in Fig. 147. The end-product is a superposed hydrograph (shown in Fig. 147) which combines base flow, snowmelt and direct flow in the most *unsuitable* way.

5.4.2.3 Flood Modeling Practices by Turkish State Meteorological Office (MGM)

Although the primary function of the Turkish State Meteorological Office (MGM) is not flood modeling, the organization has been involved in some of the flood hazard assessment activities, especially regarding flash floods.

During the 15th World meteorological Congress that was held in 2007, MGM and other meteorological offices in Black sea and Middle East regions were requested to conduct studies which would help the respective countries to assess the susceptibility against flash floods. These studies included early warning systems against flash floods, as well. In continuation of these efforts, "the Black Sea and Middle East Flash Flood Early Warning System" project was initiated in 2009 (http://www.mgm.gov.tr/FILES/arastirma/ani-taskin.pdf, 01.04.2014). The project was at international scale, covering the following countries: Turkey, Bulgaria, Azerbaijan, Georgia, Armenia and Syria.

In the project, a series of conceptual models were utilized along with realtime meteorological data: SNOW-17 snow model [15], SAC-SMA Sacramento soil moisture accounting model [16], surface runoff threshold model with which the discharge at bankfull stage is utilized, and the American flash flood guidance system (FFGS) model.

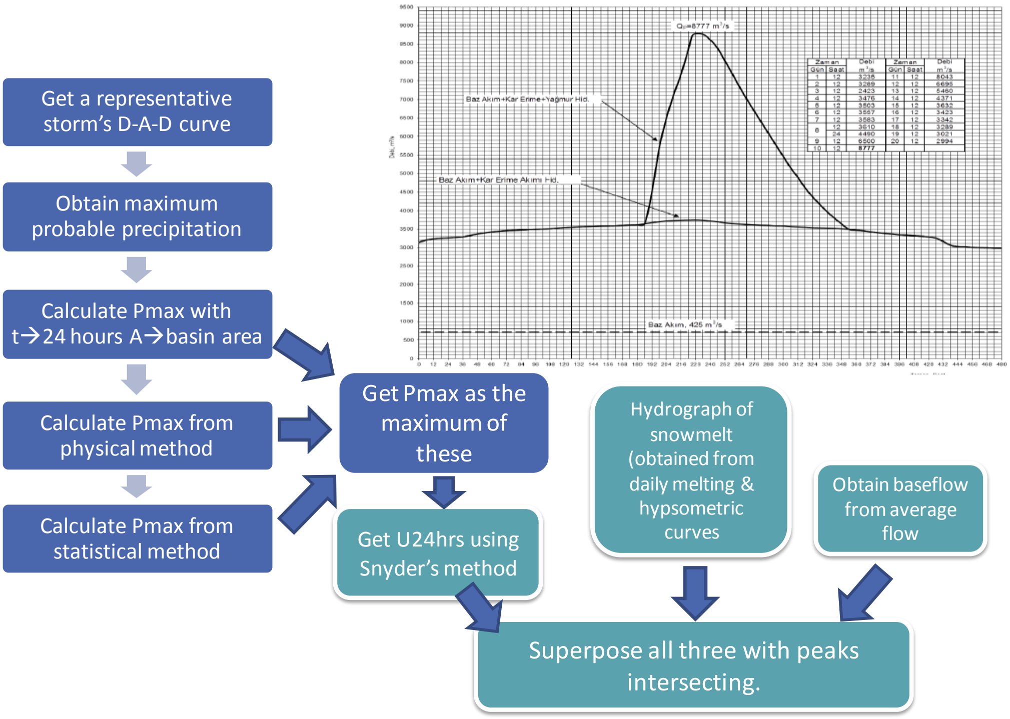


Fig. 148: Computation steps of DSİ flood hydrograph assessment guidelines

The meteorological data along with the topographic data is processed continuously by means of the aforementioned model. The system yields outputs at every 6 hour interval. The output consists of the following: Rainfall forecast map (Fig. 148), snow cover map (Fig. 149), snow-water equivalent map (Fig. 151), river discharge capacity threshold value map (FFG), soil moisture map and **probable flood hazard map** (Fig. 151).

The planned pilot implementation of this project was completed in 2012.

5.4.2.4 Flood Modeling Practices by Directorate General of Water Management (SYGM)

Directorate General of Water Management (SYGM), founded in 2011, is one of the two major governmental bodies (along with DSI) which has authority and responsibility on water related issues. Its main mission is to conduct integrated water management activities in Turkey. The responsibilities of SGYM about flood issues include determination of strategies and policies related to floods and drought, preparation of related legislation and flood management plans, performing studies on effects of climate change on water resources (http://suyonetimi.ormansu.gov.tr/AnaSayfa.aspx?_sflang=tr, 01.04.2014). The Flood and Drought Management Department within SGYM is the division which handles the flood related activities.

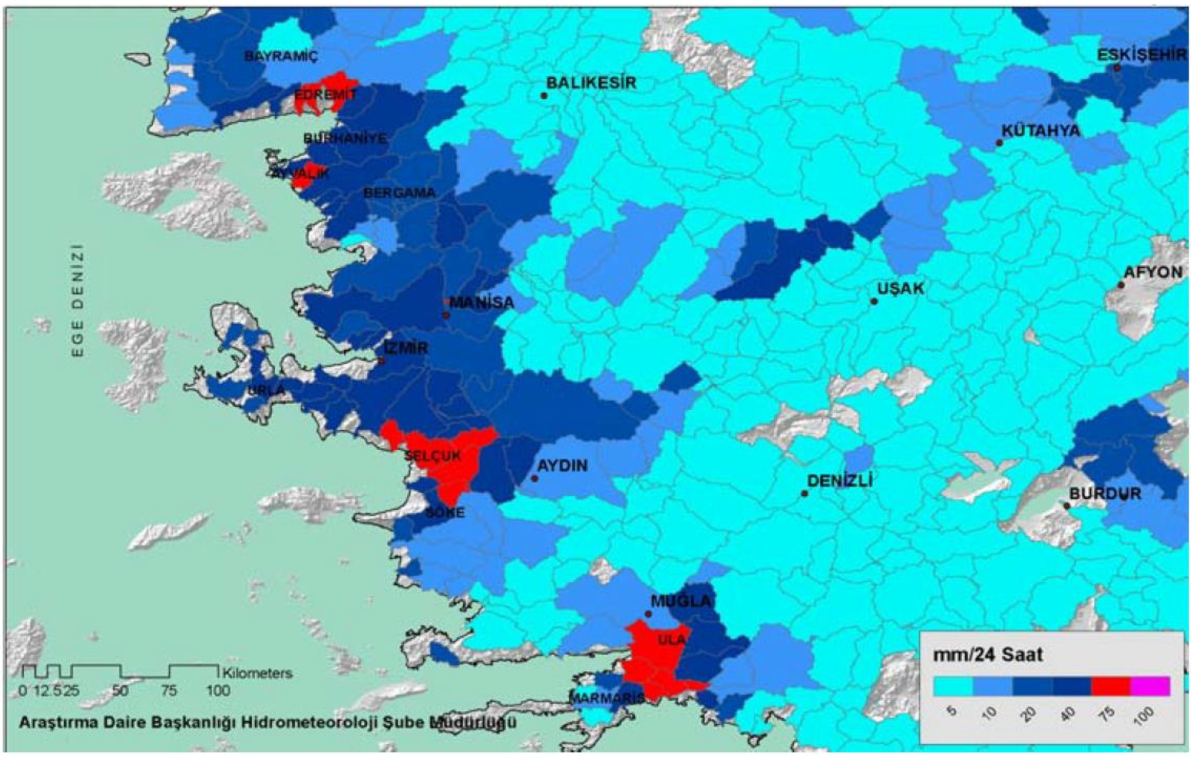


Fig. 149: A sample rainfall forecast map

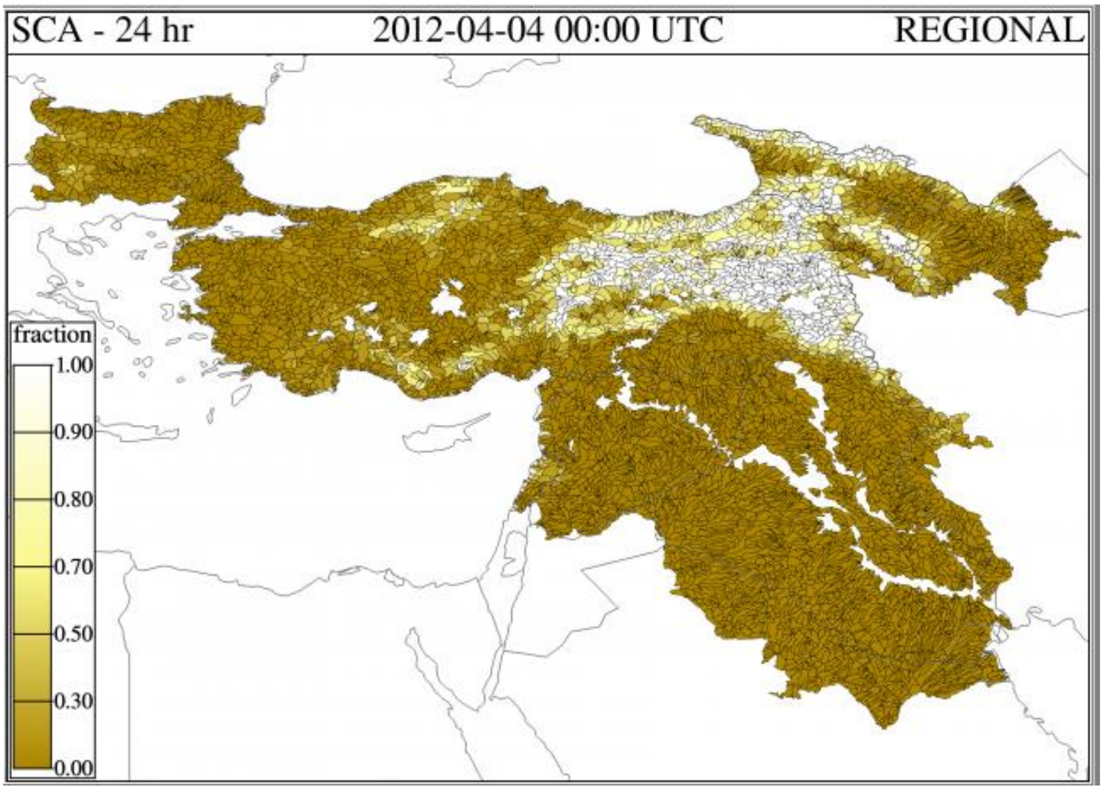


Fig. 150: Snow cover map

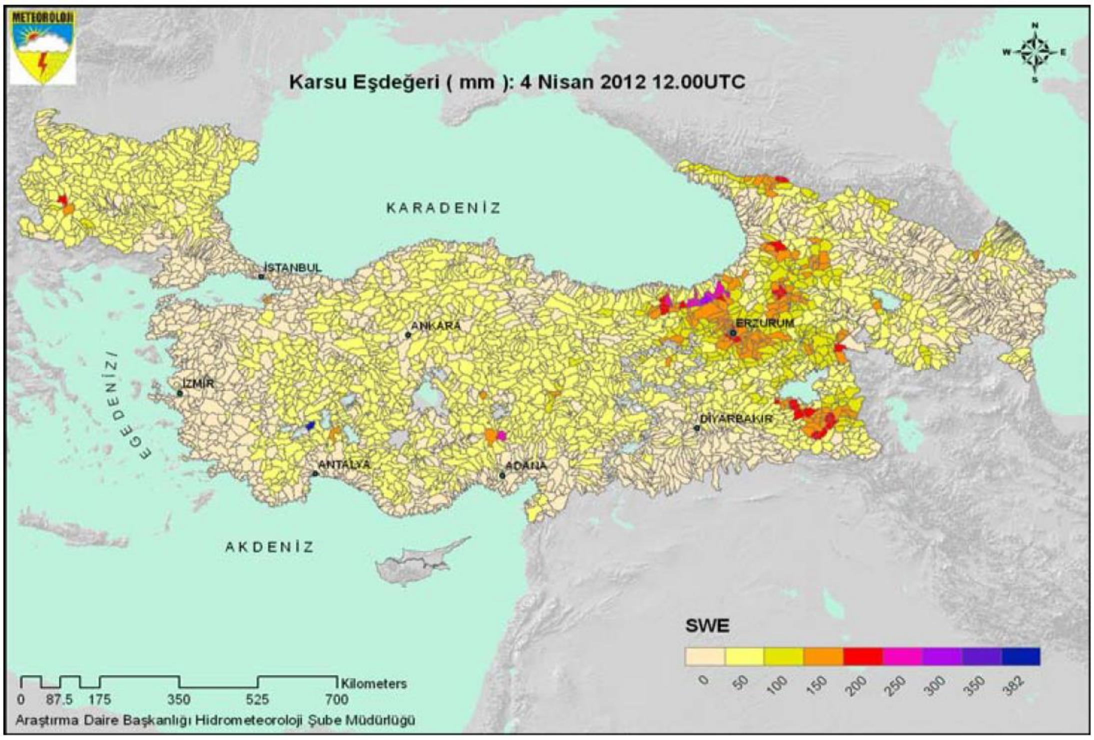


Fig. 151: Snow-water equivalent map

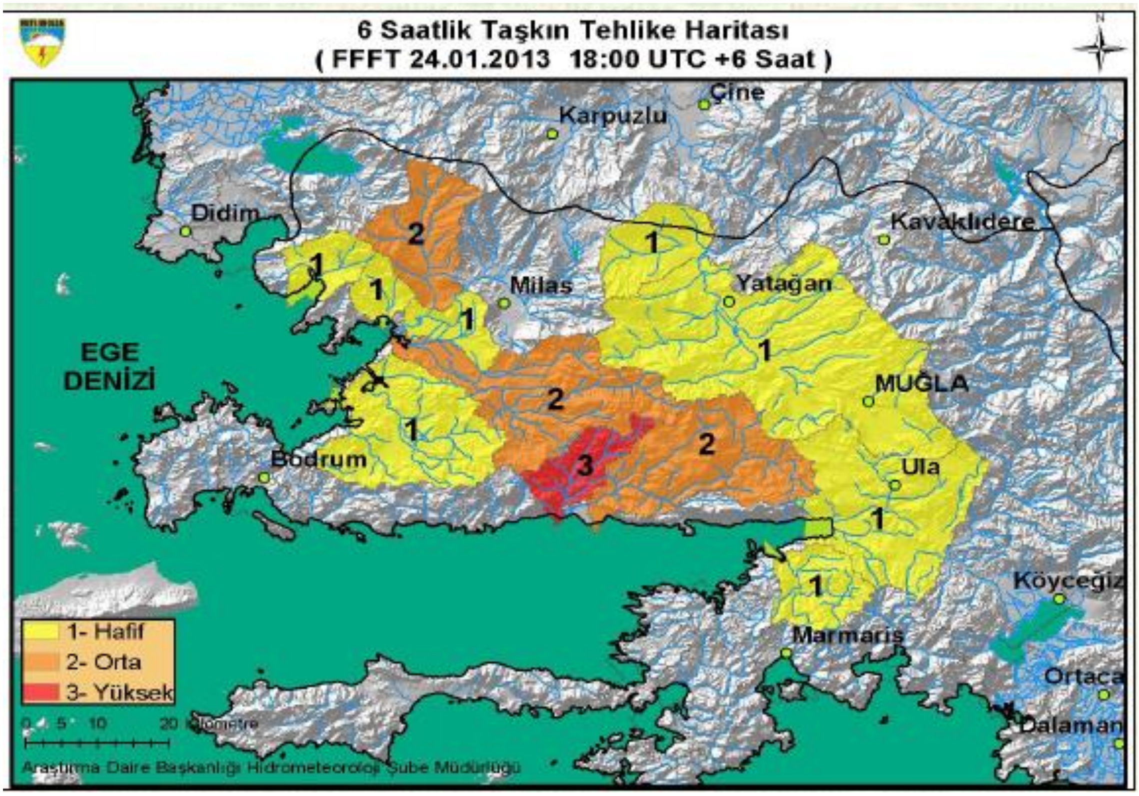


Fig. 152: Flood hazard map

SGYM has been implementing the EU twinning project "Capacity Building to Implement Flood Directive in Turkey". This project is a three-phase plan from 2011 to 2015 which includes the following: Preliminary Flood Risk Assessment by the end of 2011, Flood Hazard and Flood-Risk Mapping by the end of 2013, Flood Risk Management Plans by the end of 2015 [17]. However, the activities of this project started in August 2012 and as of now, the duration of the project is foreseen to be a total of 29 months. For the pilot implementation of this project, 4 basins out of 25 were chosen, three of which will only be used for a quick scan (Akarçay, East Mediterranean and Yeşilırmak basins) and one will be used for a detailed study (West Black sea basin).

As the first phase of flood hazard assessment and flood risk mapping studies, the available data and existing data needs were determined. The data from hydrological stations of DSİ in West Black sea Basin were scanned and past historical floods were determined. For preliminary screening of flood hazard *in regional scale*, three methods were tested:

1. EXZECO Method: This method has been suggested and used by French authorities. It is based on elevation of water level from past floods using Aster GDEM on GIS maps (Fig. 152).

2. <u>Water Level Rise Method:</u> This is similar to EXZECO, but a slightly different method, suggested and used by Romanian authorities. It is based on elevation of water level from past floods using SRTMDEM again on GIS maps (Fig. 153Fig. 154).
3. <u>Alluvion Method:</u> This method is based on the determination of the locations of alluvial depositions in the vicinity of drainage network to find out possible areas of flood (Fig. 154).

At the end of the pilot implementation of these three methods, it was concluded that the alluvion method is the most convenient method among the three for the preliminary screening of floods, since the areas marked by the other two methods were already included within the areas marked by the alluvion method (Fig. 155).

After the preliminary screening of flood hazard in regional scale, the vulnerability characteristics within the pilot implementation region (population density, industrial regions, agricultural areas, etc.) were incorporated with the GIS database to assess the overlapping regions. This presumably leads the direction to the preliminary flood risk maps.

As the second phase of flood hazard assessment, more detailed hydraulic modeling of probable flood scenarios are recently underway to be implemented *in the local scale* within the pilot basin. For this purpose, two critical rivers were chosen: Bartın River and Çaycuma Creek. The local hydraulic modeling studies are being conducted on the 1/1000 scale maps along the river bed and 1/25000 maps in the vicinity of the riverbed. **HEC-GeoRAS** is used as the 1D hydraulic modeling tool. Flood modeling exercise is being repeated for 10, 100 and 1000 year return period expected flood hydrographs, which were obtained from the past studies of DSI in the region. At the end of the hydraulic modeling study, the flood inundation areas will be determined on a GIS based DEM and then, this output will be superposed with the CORINE landuse maps to create a more detailed flood risk map. The mentioned phase of the study is planned to be completed by the end of August 2014.

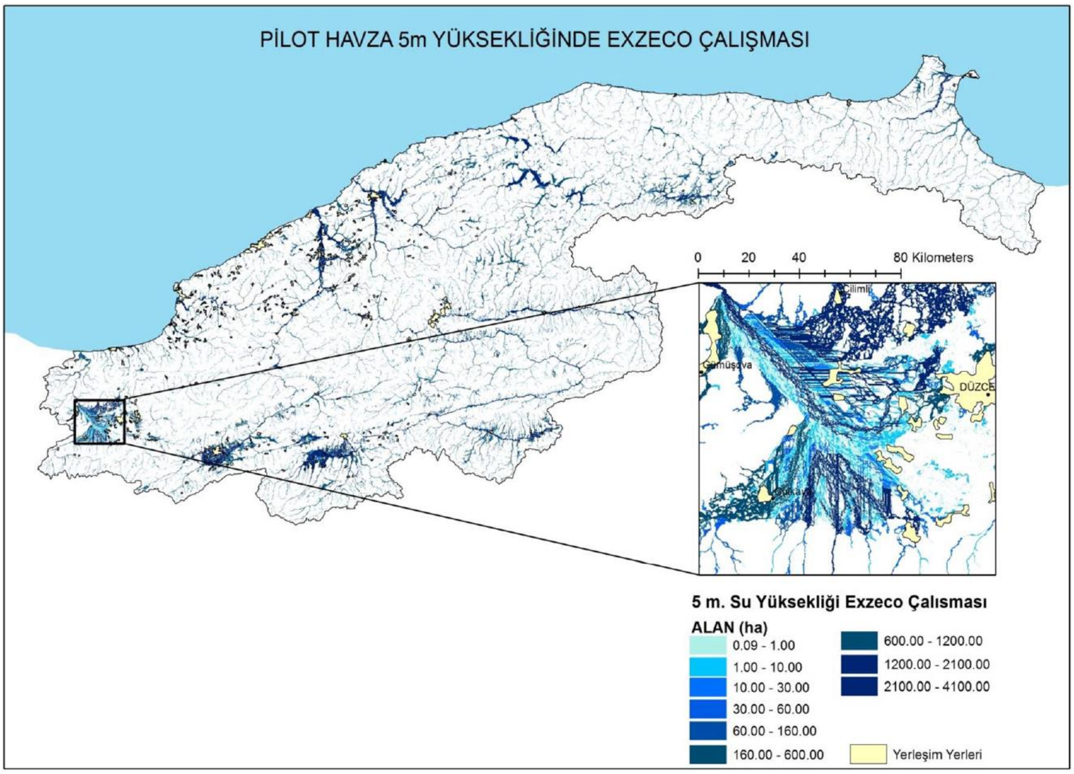


Fig. 153: EXZECO method for preliminary flood hazard screening

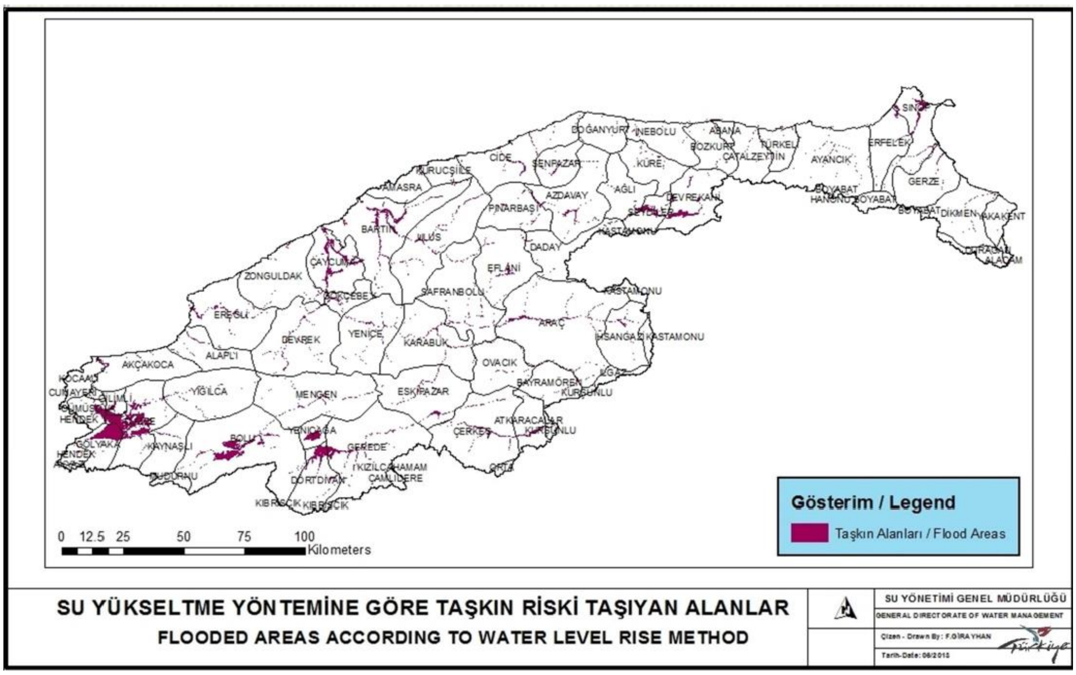


Fig. 154: Water Level Rise method for preliminary flood hazard screening

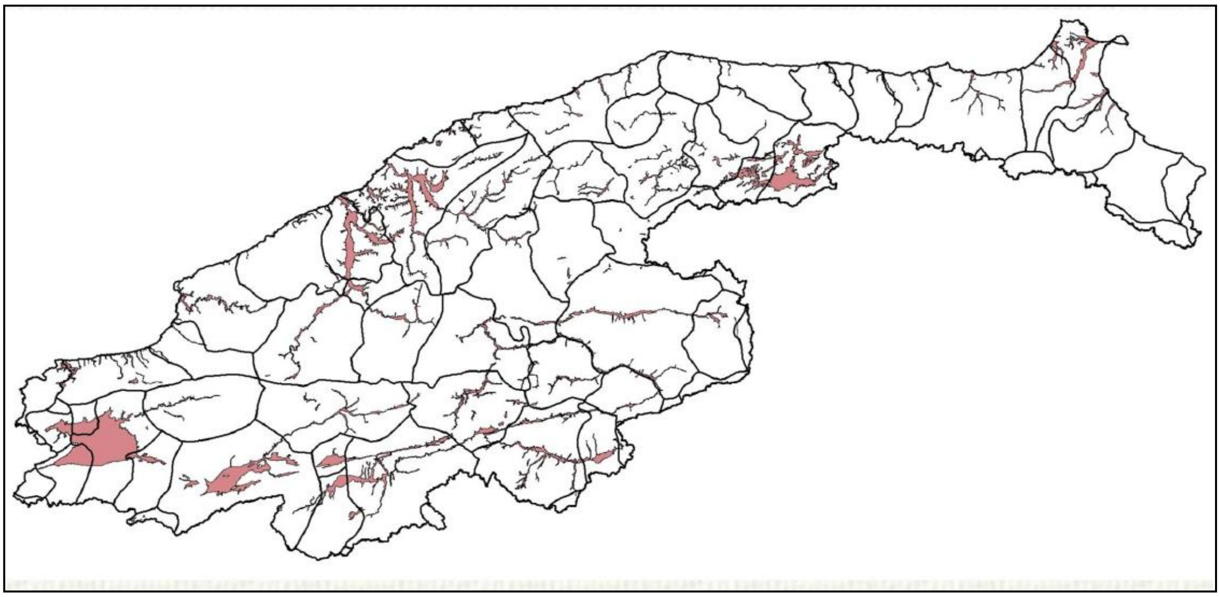


Fig. 155: Alluvium method for preliminary flood hazard screening

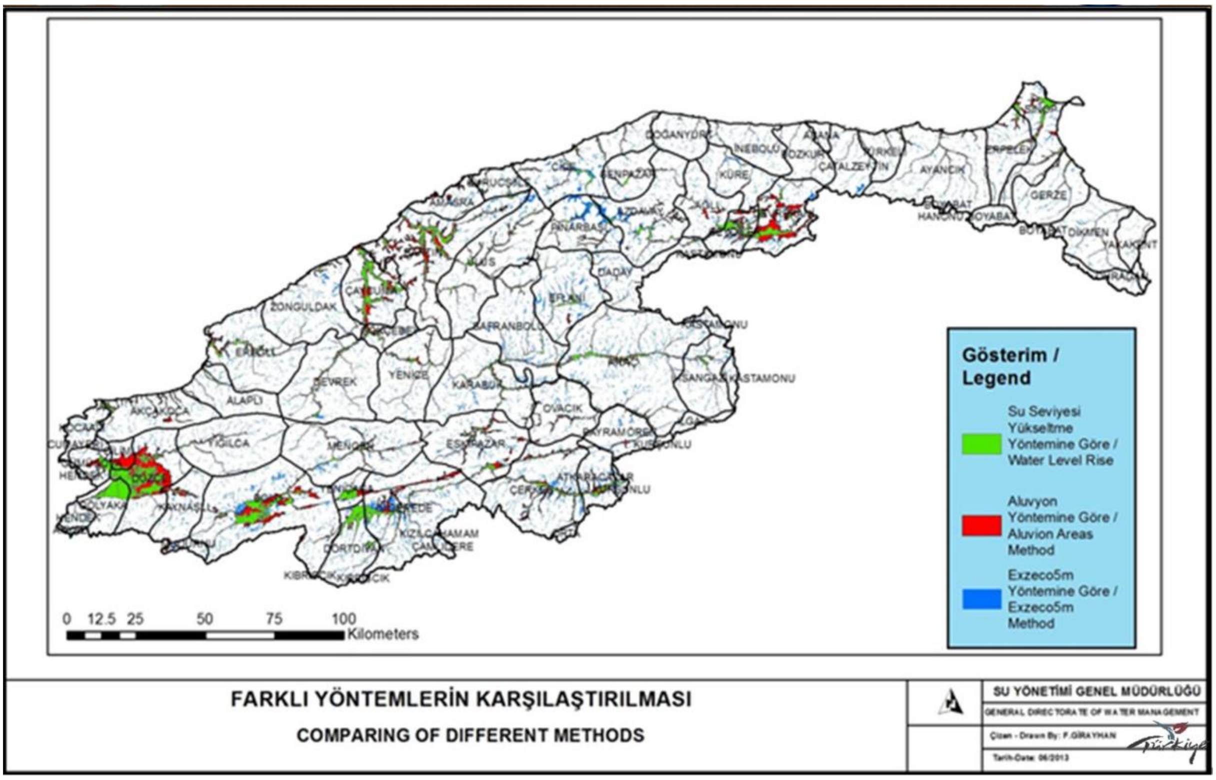


Fig. 156: Comparison of three methods for preliminary flood hazard screening

5.4.2.5 Other Flood Modeling Practices in Turkey

In Turkey, flood modeling has always been a hot-topic both in academic/scientific environment and among engineering practitioners since the experience clearly shows that the geography of Turkey is generally susceptible to floods.

There are two major national technical and scientific meeting series annually organized on flood issues. One of them is the National Flood Symposium (http://www.ulusaltaskinsempozyumu.org/, 01.04.2014) and the other is Flood and Landslide Symposium (http://www.imoths.org/, 01.04.2014). The former has been organized for the third time in 2013 whereas the latter was organized for the first time in 2013. National Flood Symposium was sponsored solely by the Ministry of Forest and Water Affairs and is more generally an academically oriented meeting which focuses on scientific innovation as well as research and innovation. Flood and Landslide Symposium on the other hand, was organized by the Turkish Chamber of Civil Engineers and it is a more application oriented meeting, where practitioners from the governmental and the private sectors as well as academicians, share their experiences and case studies. Indicative of the interest this symposium presents is the fact that more than 40 papers were presented in the 2013's National Flood Symposium alone.

Another important study which has been used in Turkey and that falls in the area of synthesizing different flood frequency prediction methods, comes from the joint COST Action of FLOODFREQ (http://www.cost-floodfreq.eu/, 01.04.2014). Within the context of this study, an attempt has been made to give an image of the different methodologies that have been used in flood frequency analysis (a different but closely related concept when compared with flood hazard assessment). The synthesis report of the aforementioned COST Action, is rather focused on the global warming and changing climate patterns and the existing water scarcity issue [18].

5.4.3 CONCLUSIONS & REMARKS

As can be seen, the flood hazard assessment and flood modeling methods that have been used in Turkey follow more or less the same scientific and technical trends as in the rest of the world. Yet, there are some specific challenges in flood hazard assessment studies in Turkey such as the flash-flood problems, which mostly stem from the spatially diverse topographic and climatic characteristics of Turkey. Speaking of the Black Sea region of Turkey, where many of the high severity flood events have been recorded, the aforementioned specific challenges are shared with other Black Sea basin countries such as Greece, Bulgaria, Romania, Ukraine, Moldova and Azerbaijan. Therefore, it has utmost importance to establish a common scientific cross-border language that can help develop support and common efforts to address these challenges and protect human life, property, infrastructure and sustainable development. This is actually one of the primary targets of the SciNetNatHaz project.

It can be concluded that a two-step approach is the most suitable and efficient way to approach the flash-flood hazard assessment problem. The first step is the regional scale modeling, which primarily aims at a first screening of flood-susceptible areas in a river basin, with the use of most easily obtainable and most affordable data (topographic data and rainfall data). Once this first step is completed, a more detailed local scale flood modeling can be exercised on the areas that are spotted as *susceptible to flash-floods*, with the use of more detailed datasets including land use characteristics and high resolution drainage network geometry. In both steps, there are available freeware (or public license) tools with proven merit, that can be downloaded and used freely and easily by the relevant parties.

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5.5 BULGARIA

5.5.1 METHODOLOGY FOR ASSESSING THE THREAT AND RISK OF FLOODING, AS REQUIRED BY DIRECTIVE 2007/60/EC

The main sections of this Methodology are the following:

Part 1. Common part of terms and abbreviations

Part 2. Methodological guidelines for assessment of flood hazard;

> An example of application of the methodology for assessment and mapping of flood hazard in the absence of gauging stations in the area of modeling (town of Pleven and its surroundings);

> An example of application of the methodology for assessment and mapping of flood hazard in the presence of hydrometric stations in the area of modeling (the area between Plovdiv and Parvomai);

Part 3. Methodological guidelines for threat assessment and risk arising from the Black Sea flooding of coastal areas;

> An example of the mapping of the threat of sea floods at high, medium and low probability of occurrence in the region of Kiten

Part 4. Methodology for assessment and mapping of flood;

> Application of the methodology for mapping flood risk in the region of Pleven (river floods);

> Application of the methodology for mapping flood risk for the area of Pomorie town (sea floods)

5.5.2 CRITERIA AND METHODS FOR THE IDENTIFICATION AND CLASSIFICATION OF RISK AND DETERMINING THE THREAT AND RISK OF FLOODING (16.08.2012)

The first stage of implementation of the "Flood" Directive provides information on areas where significant potential flood risks are believed to exist or are likely to occur (RZPRN) Article 5 Ch. II of DN and chl.146g of WA).

Location of these areas according to Directive is based on the results of the preliminary assessment of flood risks which was carried out according to the requirements given in Chapter II, Article 4 of the Directive.

Areas with significant potential risk of flooding need to be located within each basin. In cases of cross border basins, flood management has to be conducted in a "whole river basin" basis so the process has to be agreed and coordinated with the neighboring riparian countries. Determining areas of potential significant flood risk is an integral part of the preliminary assessment of flood risks and are dealt with in its terminal phase, while it is basic information about the second phase of the application of the Directive defining the areas for which they are produce maps of flood hazard and flood risk.

5.5.3 NATIONAL PROGRAMME FOR DISASTER PROTECTION

The first stage of implementation of the Directive and the development of the National Programme for Disaster Protection defines the objectives priorities and objectives for disaster protection for a period of 5 years (2009-2013).

It is a major policy document in the field of prevention, master and the aftermath of disaster and outlines guidelines for creating an effective, resource and provided technical national system to prevent and respond to disasters

The Programme classifies disasters as follows:

- Flooding from river floods;
- Flash floods;
- Flood of accidents and improper management of hydraulic facilities;
- Floods caused by deliberate action and the measures to prevent such events.
- The initial assessment of the risk of flooding, includes three phases: Preparation of scaled maps of river basins, indicating the boundaries of basins and sub-basins, and the type and amount of land use;
- A description of past flooding in each pool, including scale the flood, its spatial distribution and evaluation of damages;
- Assessment of the possible occurrence of future major flooding based on the topographical conditions, the position of rivers hydrological data for them the status and effectiveness of protective equipment (including retention of existing areas), location of settlements and agricultural land Public Works.

The problems of flood risk are presented in the works of Gerasimov [1], Zyapkov [2]&[4], Zlatunova [3], Modev and Kirilov [5], Nedkov [6], Penkov [7] & [8], Nikolov and Nedkov [11], etc.

Zyapkov represented the map of flood risk in the Monography “Geography of Bulgaria” [10].

The main part of the region corresponded with the map of Zhelezov (Fig. 158) in “Bulgaria Geographical atlas” [9].

The main regions with high level of flood risk in Bulgaria can be observed in three general regions based on the models of Zyapkov (1997) and Zhelezov (2010):

- Danubian – Danube shore, catchments of the rivers Ogosta, Yantra, Osum, Vit na Tsibtitsa;

- Black sea – catchments of rivers Kamchiya, Provadijska nad rivers in Burgas lowlands;

Aegean – catchments of rivers Maritsa and Tundzha and parts of the catchments of rivers Struma and Mesta.

Фиг. 3.10. Рискови райони, застрашени от наводнения и хидромелиоративни защитни средства (по Зяпков, 1997).
1- рискови райони, застрашени от наводнения; *2* - изградени диги; *3* - диги в проект; *4* - изградени корекции на реки в селища; *5* - корекции на реки в селища в проект.

Fig. 157: Regions of flood risk (Zyapkov, 1997)

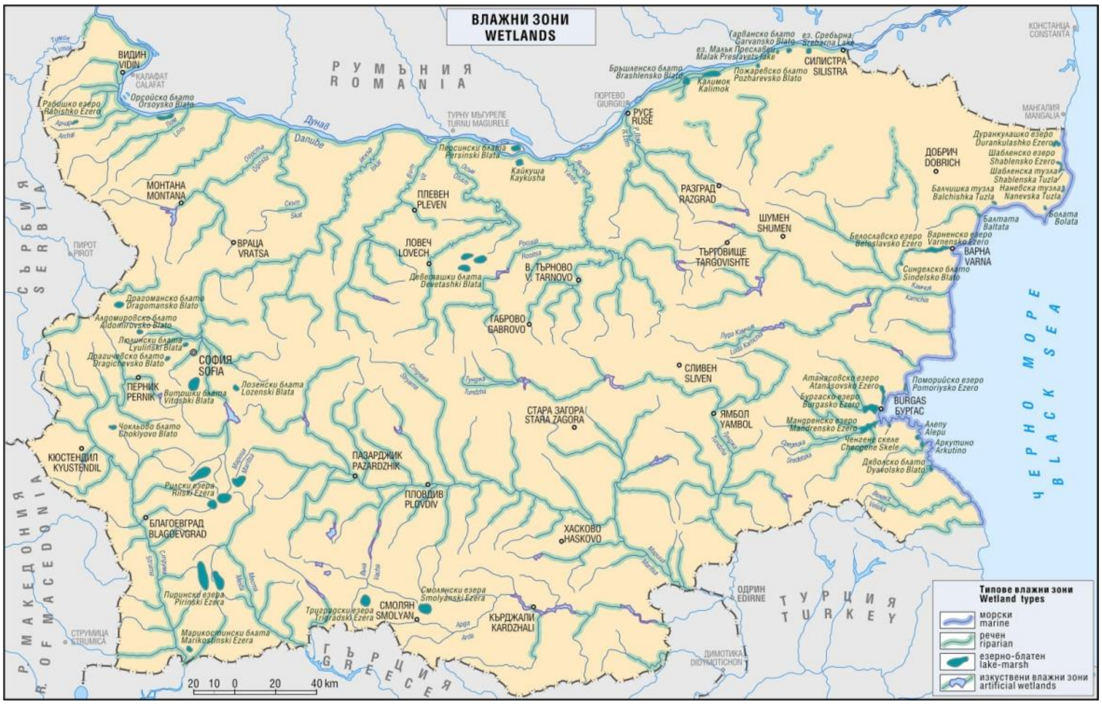

Fig. 158: Wetlands (Zhelezov, 2010)

For both large and small catchments hydraulic modeling (HEC-RAS) and GIS have been used as shown by Dobrinkova & Boyvalenkov [12] by an implementation in Nestos and Evros rivers within the context of the project SEE/A/118/2.2/X: Practical Use of MONITORing in Natural Disaster Management – acronym: MONITOR II.

Geomorphologic methods have also been used [13] to assess flood hazard in small catchments.

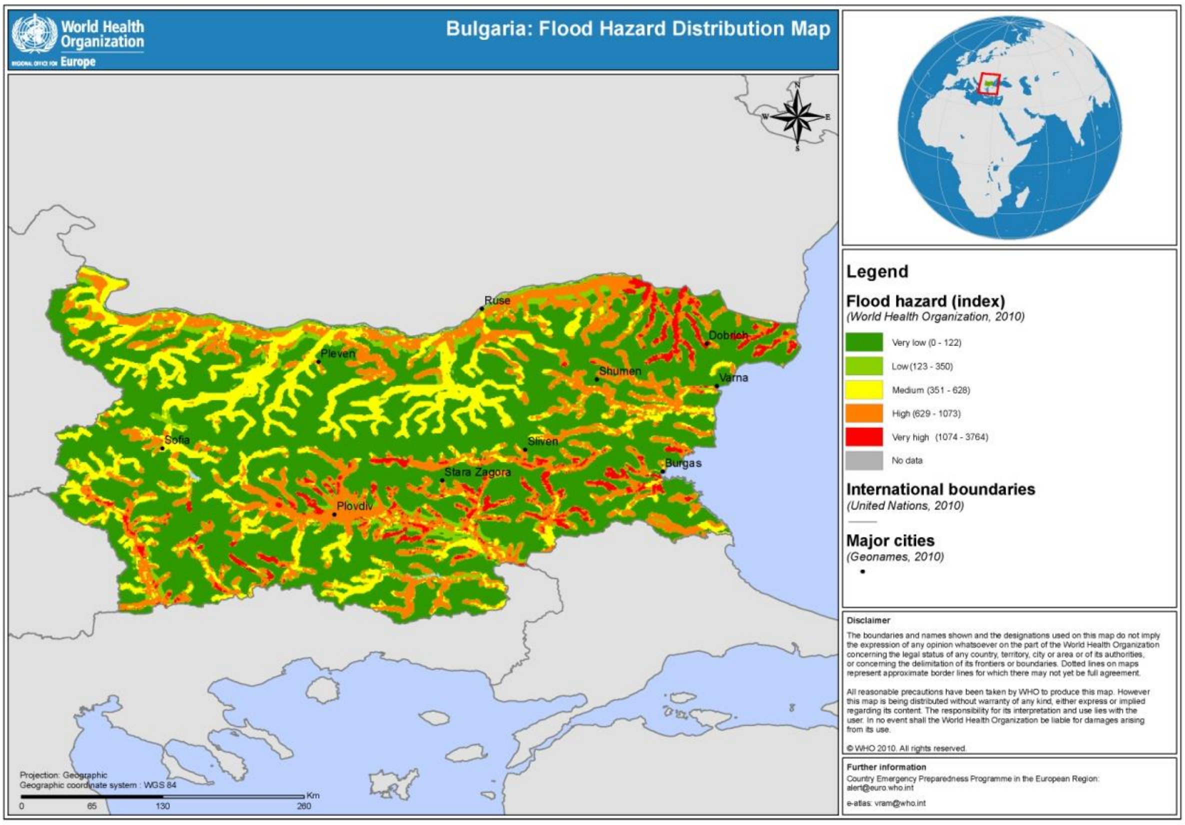

Fig. 159: The WHO e-atlas of disaster risk. Volume 1. Flood hazard [14] and http://www.who-eatlas.org/europe/methodology.html

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5.6 GREECE

5.6.1 INTRODUCTION

Greece is characterized by a fragmented terrain with small river basins (watersheds). The most common type of flooding is flash flooding.

There is a very small correlation between natural phenomena (storms) and floods on an “hour’s” scale. There is also a very small correlation between simultaneous storms and floods [1].

Most of the 13272 Greek settlements are villages where the Flood hazard is minimal. Residents are aware of flood risk and build their houses away from streams.

Urban and coastal residential areas as well as settlements within river flood plains are the ones facing a high flood risk.

Census data regarding the present status, indicate that there are 23 cities with population over 40000, 145 settlements with a population higher than 10000, 300 coastal settlements with an additional number of around 100 coastal settlements in the Hellenic islands and an unknown number of settlements within river flood plains. As an **estimate** based on the above data, there are around 500 settlements which face a flood hazard.

Floods in large rivers are not frequent or violent phenomena with the exception of Evros/Maritsa/Meric river floods. Evros is a cross-border river with a watershed shared between three countries: Greece, Bulgaria and Turkey, so there is an extra need for a specific analysis of the Evros/Maritsa/Meric river flooding issue.

Flash floods on the other hand are the prominent type of flooding in Greece, causing when they occur, serious damage and threatening human life, property and infrastructure. Flooding problems in Greece are classified as low priority problems. Engineering solutions are usually applied on a limited scale and a limited control is applied on illegal (arbitrary) construction. An emphasis is given on solutions-by-construction where the target is to drain (channel) the flood safely to physical or constructed water drainage systems.

5.6.2 THE USE OF FLOOD HAZARD ASSESSMENT METHODOLOGIES IN GREECE

During the past years climatic change in many countries worldwide brought in unpredictable rainfalls; with an increased intensity and quantity in many cases, resulting in an increase of the flash and riverine floods.

European countries, especially central and northern ones are crossed by large rivers; are densely populated and with extended cultivated terrains close to the river catchment areas. In Mediterranean and Balkan areas, flash floods are more common, than riverine floods [1].

As far as Greece is concerned it is evident by relevant literature bibliography, that little has been done in terms of Integrated Flood Hazard Assessment and its modeling Practices. Actually, there was no coordinated and organized methodology in terms of Flood Hazard on a national level up to the 2007/60/ EC Directive.

A comprehensive framework has been established in 2010 by Common Ministerial Decision (CMD) (K.Y.A.31822/1542/E103/20-07-2010 (GG 1108/V/2010), which specifies the methodologies for the assessment and management of flood risks. This framework aims at reducing the negative consequences in Greece (GSCP-General Secretariat of Civil Protection) [2]. By applying the above, in compliance with the provisions of 2007/60 /EC Directive for the assessment and management of flood risk Greece, should immediately complete the preliminary flood risk assessment for each river basin district or as part of an international-transboundary river basin district, lying on the Greek territory. Greece was expected to have completed and adopt to the flood risk hazard maps and flood maps by the end of 2013. The preliminary assessment on Flood Hazard has already been implemented and the results contain homogenized datasets, flood risk maps (GIS based and .kmz files) on a national level and at regional scale, covering each watershed in Greece. The geographical units for implementing the Directive and the Water Framework are the same.

By the 706/16-07-2010 (GG V/02.09.2010 1383) decision of the National Water Commission, forty five (45) river basins have been set at the country level, according to the CMD 31822/1542/E103/2010 geographical application article. These river basins are subjected to fourteen (14) river basin districts (water districts). Still, there is no completed framework and guidelines on regional and/or local scale that provide a well-structured and approved methodology for FHA (Flood Hazard Assessment) and FRM (Flood Risk Mapping). The maps to be produced for FHA and FRM are to identify high, medium and low risk areas, including areas where the occurrence of flooding can be considered as an extreme event. The maps should also include details such as expected water depths, economic activities that could be affected, the number of inhabitants at risk and the potential environmental damage.

During the third stage, Member States are required to produce flood risk management plans by 2015. Such plans will include measures to reduce the probability of flooding and its consequences, with focus on preventing unsustainable practices in land use, thus for instance, preventing building in areas prone to flooding. The plans should also cover the aspect of protecting such areas from the likelihood of flooding and reducing the potential flood impact. Another important aspect of risk management plans is the need to prepare the public for the possibility of flooding. Risk assessments for floods will be reviewed and adjusted according to the effects of climate change and the severity and frequency of flooding in the long term.

In Greece, there are several governmental organizations and services dealing with flood issues according to L.3199/2003 "Protection and Water Management - Compliance with

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 '. (Government Gazette A 280/9.12.2003) [3]:

1. **National Water Commission**, which sets out the policy for the protection and water management, monitor and control the application and approve, after recommendation of the Minister of Environment, Planning and Public Works and opinion, National Water Council and national programs to protect and managewater potential of the country.

   The National Water Commission consists of:

   a) the Minister of Environment, Planning and Public Works, as President ,
   b) the Minister of Economy and Finance,
   c) the Minister of Interior, Public Administration and Decentralization ,
   d) the Minister of Development,
   e) the Minister of Health and Welfare,
   f) The Minister of Agriculture.

   The Commission shall, upon invitation of the President, other Ministers when discussing issues of competence. Participate in the Committee and the Minister of Foreign Affairs, when concerning transnational waters.

2. **Recommended National Water Council**, with the following representatives, the Union of Prefectural Authorities of Greece, the Central Union of Municipalities and Communities of Greece, the Union of Municipal Enterprises for Water Supply and Sewerage, the water and sewerage companies not represented by the Association of Municipal Water Supply and Sewerage, Panhellenic Confederation of Agricultural Cooperatives, the Association of Greek Industries, the Public Power Corporation, the General Confederation of Greek Workers, Technical Chamber of Greece, the Geotechnical Chamber of Greece, Institute of Geology and Mineral Exploration, National Centre for Marine Research, National Biotope Wetland, National Centre for Natural Sciences (NCSR Demokritos), two environmental non-governmental organizations, the National Centre for Environment and Sustainable Development, the Consumer Institute, the National Institute of Rural and Agricultural Research, the President of the National Committee for Combating Desertification.
3. Central Water Agency is the Ministry of Environment and Climate Change
4. Regional Water directorates
5. Regional Water Council

Although governmental integrated actions are detained, an essential effort in FHA and FRM is being developed by research organizations and the private sector. There are several examples of flood hazard modeling in Greece and practices mostly on local scale due to the extended flooding phenomena in specific areas and in small catchments.

As Greece is characterized by ragged topography and the main Flood Hazard comes from flash floods which usually occur in ephemeral streams so there usually are no hydrologic data to use and apply hydrological modeling, efforts have been made towards a "first level" hazard assessment using available data such as topography and rainfall. For that reason, morphometry based models have been used to assess flash flood hazard on a regional scale, for "screening" purposes and then, the use of hydraulic models combined with systematic measurements of all the required parameters, would give the hazard assessment on a site-specific scale and the ability to design preventive measures. The methodologies used include the calculation of the Topographic Wetness Index and of the Stream Power.

The Topographic Wetness Index (TWI) was proposed to delineate flood prone areas predict quick response flow by using morphometric parameters [4], [5], [6] but has been used since then to delineate flood prone areas in Europe [7], [8], [9], [10], [11].

The combination of the TWI and of the SAGA Wetness Index (22) was used to first delineate flash flood prone areas in a stream basin. At the second stage of the same implementation, the hydraulic model HEC_RAS was used to calculate the flooding parameters in an area in Northern Greece [12].

The Stream Power Index model [13], [14], [15], [16] was developed to assess the potential flow erosion at the given point of the ground surface. The model combines slope gradient and catchment area. As Stream Power (SP) is a measure of the rate of stream water energy dissipation against the stream bed and banks, it can provide estimation on the impetuosity of water during a potential flood event. Stream Power calculations have been used to assess the flash flood hazard in several cases in Greece [17], [18], [19], [20], [21].

Stream Power and Morphological parameters have been used by researchers (Fountoulis, Diakakis, Sambaziotis, in many cases [16], [18], [19], [20], [23], [24], [27] with very promising results.

For example, one of the cases was an implementation in Alfeios Ricer region dealt with the evaluation of flood hazard in the drainage basin of Kladeos, which is a tributary of Alfeios River at the eastern part of the Elis prefecture [23]. Hydrological simulation, Unit Hydrograph, Morphological characteristics, Slope gradient and Stream Power were utilized in order to develop a flood hazard map on regional scale.

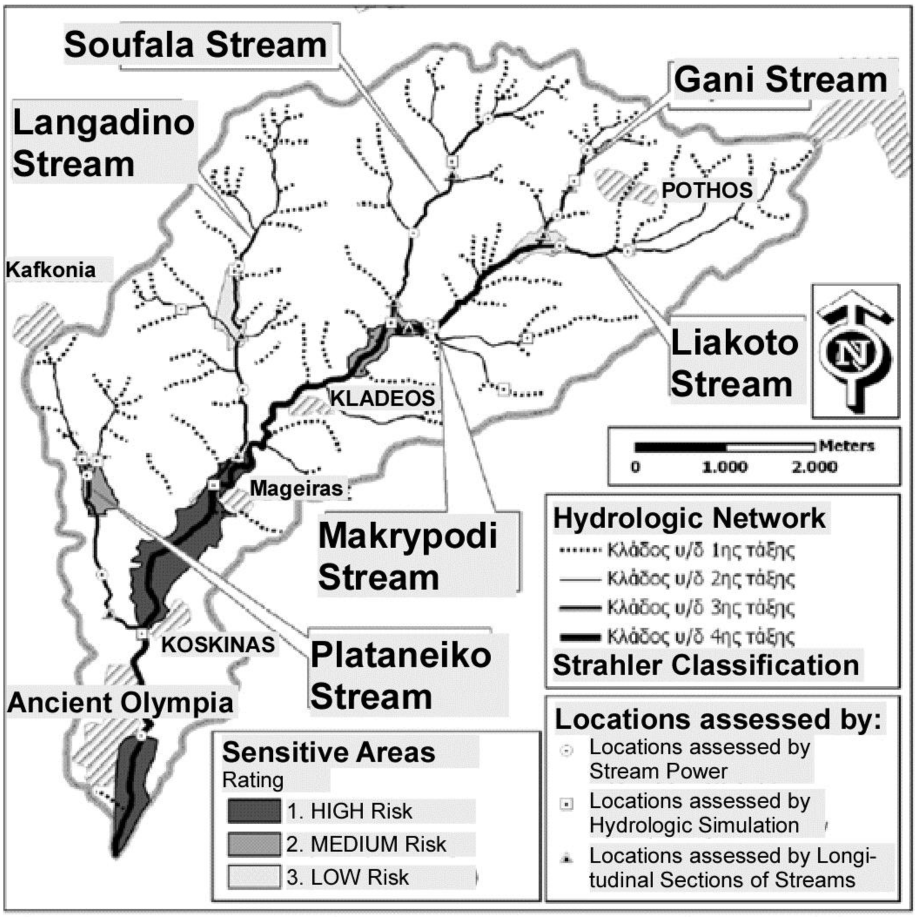

Fig. 160**:** Flood hazard map and hierarchy of the sites based on the applied methodologies in kladeos River [24]

A similar methodology was developed for Estimation of flash flood hazard in the Pidima - Arfara area (Messinia, SW Greece), based on the study of instantaneous unitary hydrographs, longitudinal profiles and stream power [24].

Numerous studies have been conducted in previous years in problematic areas (Xerias River in Peloponnese, Kosynthos River in Eastern Madeconia and Trace region) [25] already flooded, with the use of SCS and Rainfall Curve Number methods in Greece, without a further effort to map flood risk [26].

Combined methods have also been used for flood hazard assessment. For example In a study conducted in Platanorema which is part of the drainage network of Acheloos River in Aetoloakarnania, Western Greece, the peak discharge during the event, damage characteristics and distribution and geomorphic effects were examined and evaluated. Manning formula, Cowan methodology, SCS and CN methods were applied in addition to spatial distribution of damages from former flood events projected [27].

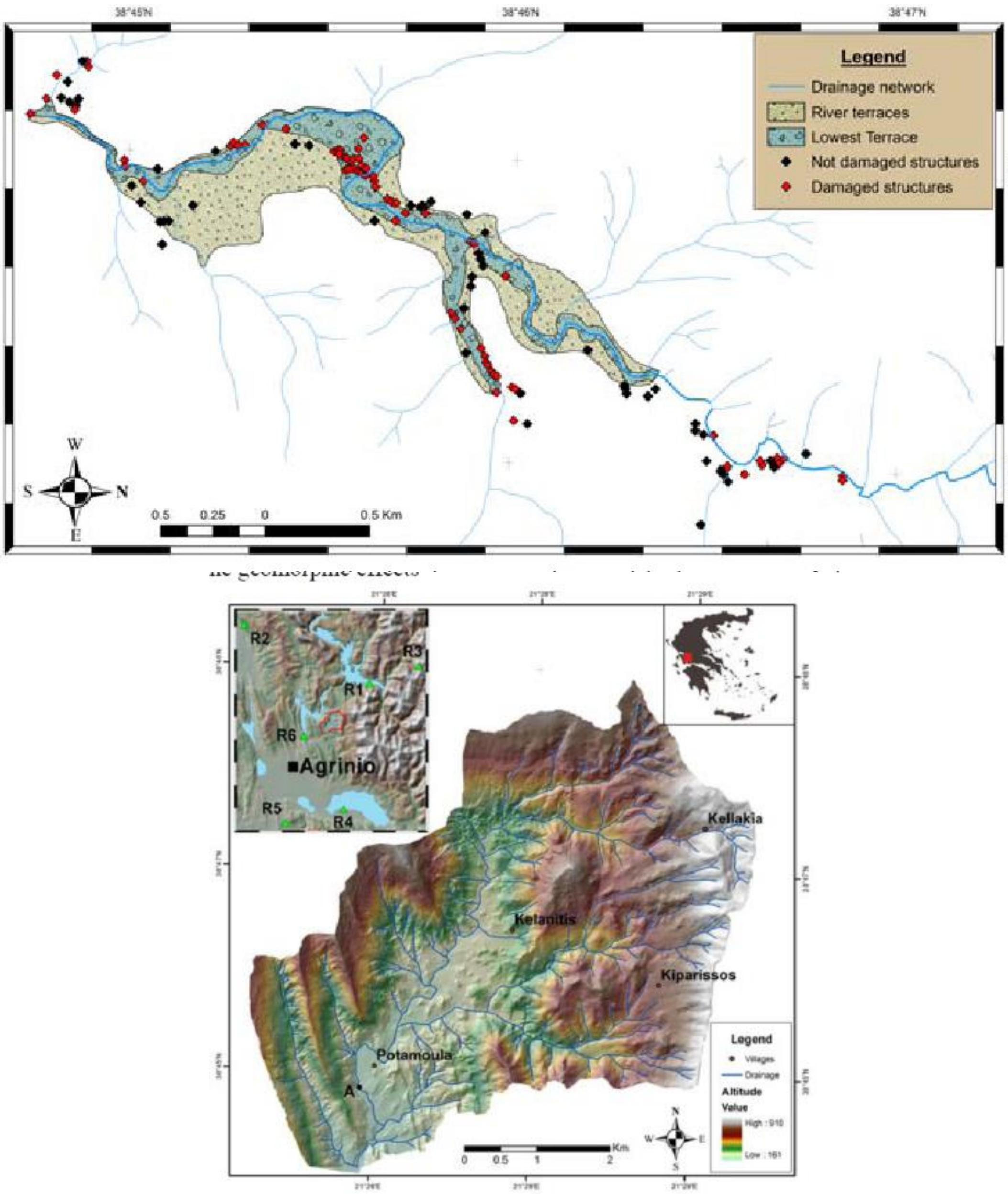

Fig. 161: Damages spatial distribution in comparison with the extent of river terraces and specifically the lower terrace (active floodplain) [27]

Koutroulis et al [28], presented a case study in Giofiros, Grete for flash flood peak discharge estimation. An empirical index is used to generate rainfall data and hydrologic and hydraulic models perform the basin delineation, flood simulation, and flood inundation.

One effort for FHA was made by the HYDRATE project. The objective of the HYDRATE has been to improve the scientific basis of flash flood forecasting by advancing and harmonizing a European-wide innovative flash flood observation strategy and developing a coherent set of technologies and tools for effective early warning systems. To this end, the project included actions on the organization of the existing flash flood data patrimony across Europe. The final aim of HYDRATE was to enhance the capability of flash flood forecasting in ungauged basins by exploiting the extended availability of flash flood data and the improved process understanding. In this project the Institute of Inland Waters, Hellenic Centre for Marine Research, was involved.

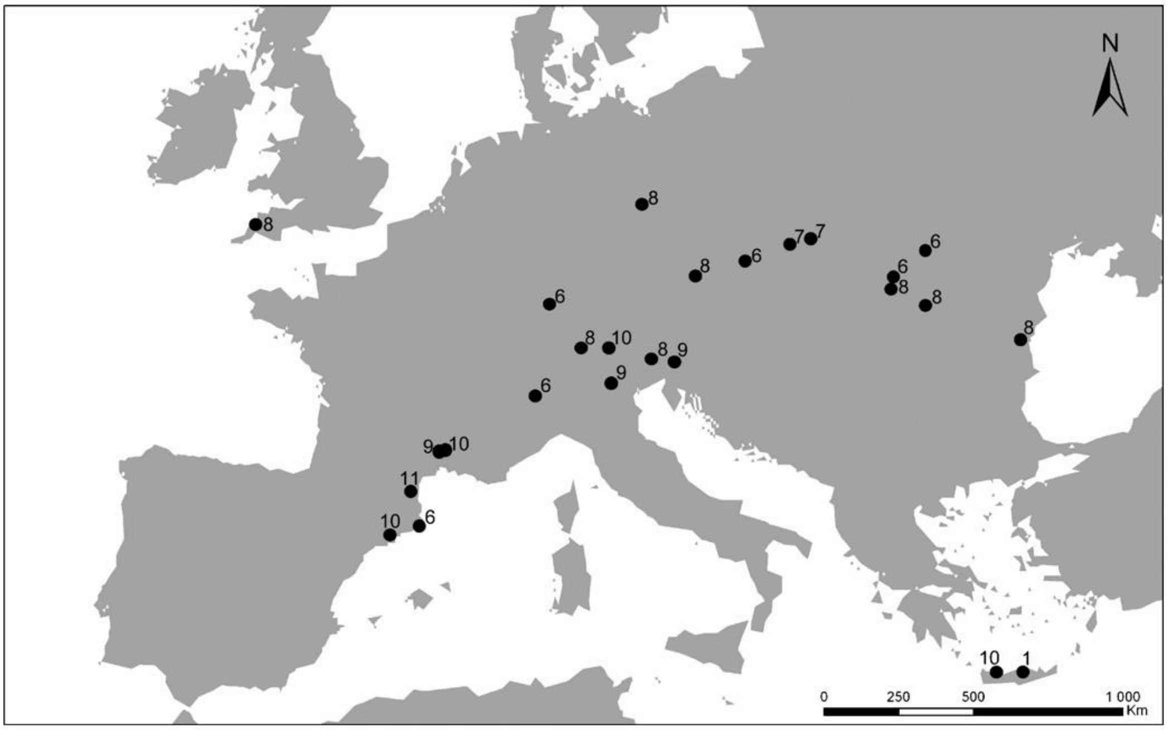

Fig. 162**:** Location of studied flash floods; the numbers indicate the months of flash-flood occurrence [29]

On local scale and in many studies and projects for flood inundation assessment, the HEC-RAS MIKE 11 and HEC-HMS are commonly used [30], [31]. In many cases, the contribution and use of GIS software is essential in conducting these studies.

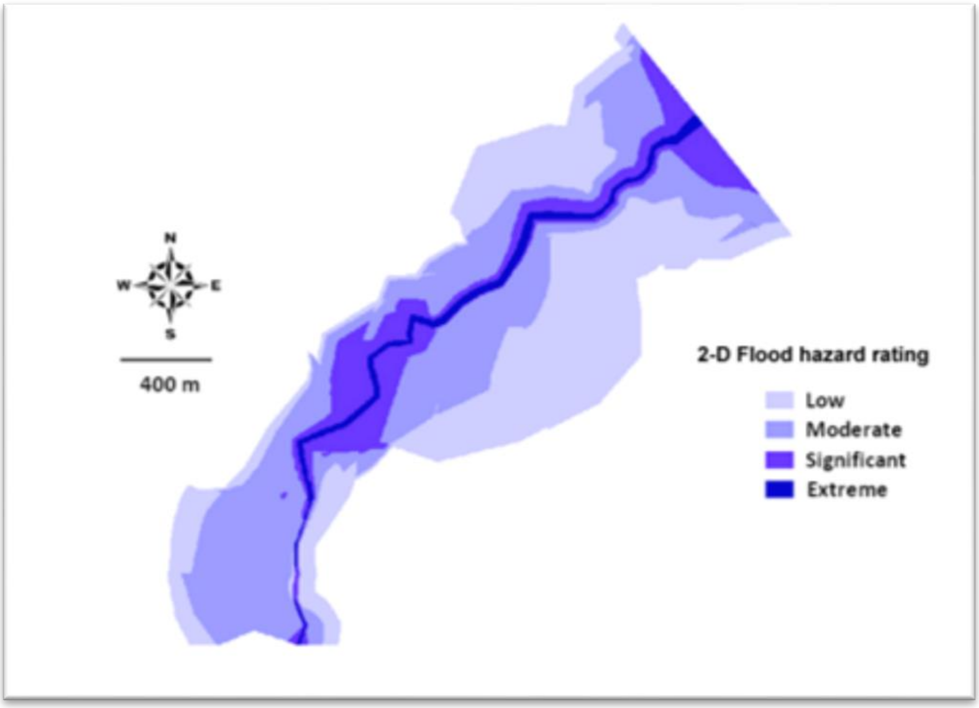

Fig. 163: Flow velocity, flood inundation and flood hazard rating maps in Koiliaris River basin Chania, Crete, Greece [30]

In many cases parts of streams or rivers have been investigated against flood hazard using the combination of HEC-RAS and GIS as in the case of Pinios river (Thessaly, Greece) presented in Fig. 163 [31].

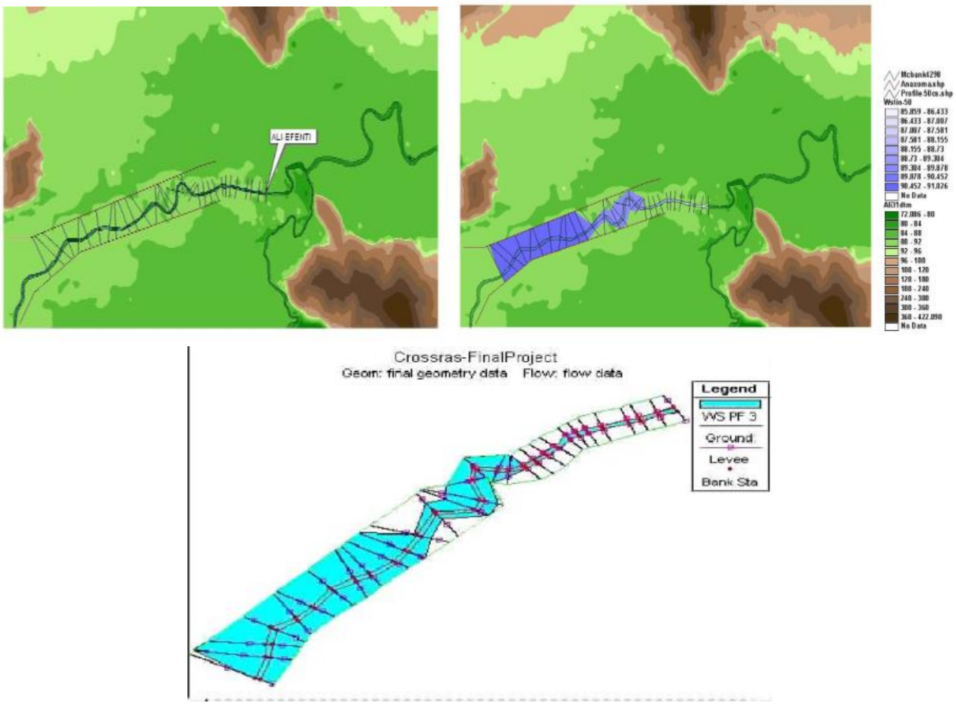

Fig. 164**:** HEC-RAS and GIS used for flood assessment and mapping in Thessaly Greece [31]

HEC_RAS, LISFLOOD F and FLO-2D software has also been used in floodplain mapping via 1D and quasi-2D numerical models in the valley of Thessaly, Greece [34].

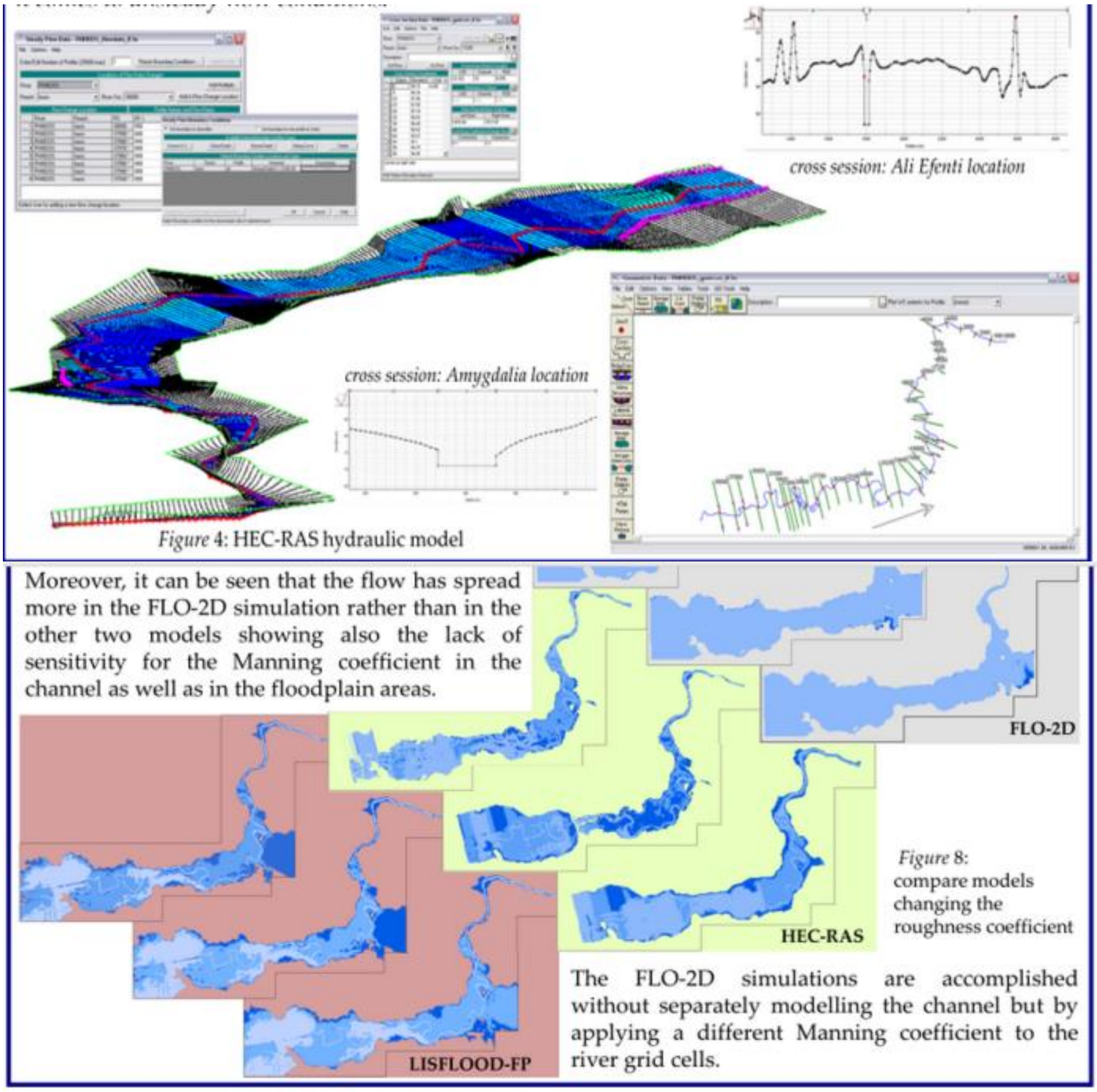

Fig. 165**:** Floodplain mapping via 1D and quasi-2D numerical models in the valley of Thessaly, Greece [32].

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5.7 FLOOD PROBLEM IN THE EVROS/MARITSA/MERIC TRANS-BOUNDARY RIVER BASIN (SHARED BY BULGARIA-TURKEY- GREECE)

5.7.1 CONCEPTS REGARDING INTEGRATED WATER AND FLOOD MANAGEMENT

It is a fact that we are living in an increasingly complicated world with great differences and inequalities among neighbouring / co-riparian countries (e.g. S-E Europe countries) due to political, socio-economic, cultural & environmental constrains-barriers and complexities. For those reasons there are not any easy solutions to existing serious and long-lasting problems in the wider area.

The political dimension of water becomes highly important not only because of its scarcity, but also as a result of its sharing across national boundaries. Approximately, 40% of the global population lives in trans-boundary water basins, shared by more than one country, emphasizing the need for effective management of trans-boundary water bodies and harmonization of related policies by using interdisciplinary & holistic-integrated approaches. Hence, the need for "Hydrodiplomacy" (in terms of both the concept and its tools) rose under the framework of sustainable development and international cooperation. Especially for Greece, effective management (according to existing UN & EU legislations and "state of the art" scientific criteria) of trans-boundary Rivers and their basins, in collaboration with its co-riparian neighbours, is of major importance, since roughly 25% of the country's renewable water resources, are originating from trans-boundary water bodies.

The global scientific community is now convinced that the so called Integrated Water Resources Management (IWRM) represents the framework and the comprehensive approach to the development and management of water, addressing its management both as a resource and for provision of its services. Besides the fact that the trans-boundary IWRM is a political process and involves conflicts of interest that must be mediated, effective water governance is crucial for its sustainable use.

Floods represent a major problem which has to be integrated to the water resources management of the whole trans-boundary river basin. Thus, the needed Integrated Flood Management, IFM, should be obviously considered as a subsystem of the trans-boundary IWRM.

The trans-boundary river Evros/Maritza/Meric basin represents a very complicated case regarding water resources management issues, due to political, cultural and socio-economic differences among the three, basin constituting, co-riparian countries. Up to present, regardless of certain positive cooperation initiatives (please see through the list of EU funded, already implemented Projects in Evros/Maritsa/Meric river, previous paragraphs -EU funded projects related to floods- and in Deliverable D_01.01, pages 92-95 of 325 and), **management of the basin's water resources is taking place in a geographically and operationally fragmented manner**. On the contrary, the repeated and devastating flood events occurring in the three co-riparian countries (Bulgaria, Turkey and Greece) manifest the urgent need for effectively implementing IFM in the framework of IWRM on a whole basin basis. Towards this goal, political initiatives have to be taken and certain prerequisites have to be safeguarded through the use of "Hydrodiplomacy" tools.

5.7.1.1 IWRM

Integrated Water Resources Management (IWRM) has been defined as a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare (efficiency) in an equitable manner without compromising the sustainability of vital ecosystems [2]. The Global Water Partnership interprets "management" as including both "development and management". The term appeared in the 1930s as a new paradigm that reinforces the importance of considering the world's complexities which are due to the interactions between environment, society and technology [3]. In this context, geographic integration is an important dimension in a range of water related activities, such as: planning, controlling, monitoring and resource allocation.

The declaration of the four Dublin principles, the Agenda 21 of the Rio Earth Summit (1992), and the World Summit on Sustainable Development, Johannesburg 2002, are considered milestones towards shaping and implementing IWRM; since they established a new way of thinking, highlighted by its three key strategic objectives: Efficiency, Equity and Environmental Sustainability. The statement of the Dublin Conference equates the term `integrated' (IWRM) to `holistic'. Besides, engaging `sustainability' into the concept of IWRM, the time dimension is activated, because sustainability directly refers to resource use that can be sustained over time for generations to come. Two international bodies were set up to address the issue: the Global Water Partnership (GWP) and the World Water Council (WWC). The principle of IWRM has been now globally established as the accepted rationale.

A river basin is internationally considered as the most suitable geographic unit for IWRM. Dourojeanni et al. [4] justify the use of it as it corresponds to the: 1) principal terrestrial form of the hydrologic cycle; 2) interrelationship and interdependence between water uses and users; and 3) region where water and physical and biotic systems interact, including the socioeconomic system. However, some countries are aggregating other criteria for defining IWRM units, including historic development, cultural and environmental aspects and strategic water uses, representing the "problemshed" concept, as defined by [5] and [6]. Besides political boundaries which in general do not coincide with the hydrological limits, can represent a strong barrier to using river basin areas as territorial units for IWRM. Political boundaries can exist, even between different regions in the same country [7]. Internal issues within national borders and external issues between riparian countries regarding water sharing [7], can be reduced by defining IWRM units and respective comprehensive institutional structure [8] with sufficient power to reduce the boundary effects.

There exist a worldwide acceptance (as it is indicated by the international water advisor, Peter Millington) on the following five main attributes or features as crucial for good integrated river basin management, including management at the trans-boundary level:

1. Clear and strong institutional arrangements, supported by clear regulations, decrees, or agreements and with well-defined implementing procedures;

2. Good water-related data, information, systems, and models readily available to the river basin partners and those agencies and bureaus operating within the basin;

3. A complete and clear suite or package of national policies, procedures, and strategies to guide water and natural resource planning, management, and administration;

4. An appropriate form of communication and participation for all basin stakeholders and partners; and

5. Basin sustainability performance indicators and an agreed approach to monitoring and reporting on how the basin is being managed and the resources consumed and protected.

Sustainable and effective management of water resources demands a holistic approach, linking social and economic development with the protection of natural ecosystems and providing appropriate management links between land and water uses. Therefore, water related disasters, such as floods and droughts, because they play an important part in determining sustainable development, they need to be integrated into water resources management.

5.7.1.2 IFM

Integrated Flood Management, IFM, is a process promoting an integrated – not a fragmented – approach to flood management. It integrates land and water resources development in a river basin, within the context of IWRM, and aims at maximizing the net benefits from the use of floodplains and minimizing loss of life from flooding.

Globally, both land – particularly arable land – and water resources are scarce. Most productive arable land is located on floodplains. When implementing policies to maximize the efficient use of the resources of the river basin as a whole, efforts should be made to maintain or augment the productivity of floodplains. On the other hand, economic losses and the loss of human life due to flooding cannot be ignored. Treating floods as problems in isolation almost necessarily results in a piecemeal, localized approach. IFM calls for a paradigm shift from the traditional fragmented approach of flood management. IFM recognizes the river basin as a dynamic system in which there are many interactions and flux between land and water bodies. In IFM the starting point is a vision of what the river basin should be. Incorporating a sustainable livelihood perspective means looking for ways of working towards identifying opportunities to enhance the performance of the system as a whole. The flows of water, sediment and pollutants from the upper catchments of the river into the coastal zone (ridge to reef) – often taken to extend dozens of kilometres inland and to cover much of the river basin – can have significant consequences. As estuaries embrace both the river basin and the coastal zone, it is important to integrate coastal zone management into IFM.

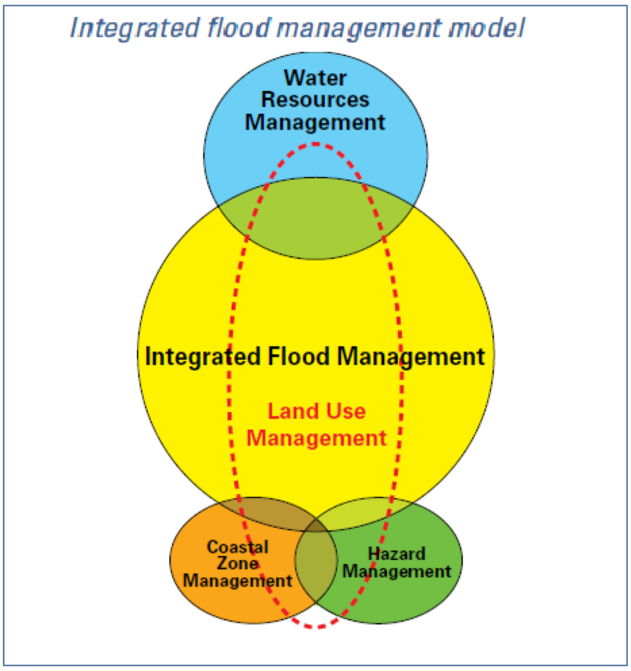

Fig. 166**:** Schematic representation of the IFM model.

IFM takes a participatory, cross-sectoral and transparent approach to decision-making. The defining characteristic of IFM is integration, expressed simultaneously in different forms: an appropriate mix of strategies, carefully selected points of interventions, and appropriate types of interventions (structural or non-structural, short- or long-term). An IFM plan should address the following six key elements that follow logically for managing floods in the context of an IWRM approach:

- Manage the water cycle as a whole;
- Integrate land and water management;
- Manage risk and uncertainty;
- Adopt a best mix of strategies (engaging structural and non-structural measures);
- Ensure a participatory approach; and
- Adopt integrated hazard management approaches.

IFM recognizes that floods indeed have beneficial effects and can never be fully controlled. The IFM approach uses a combination of regulatory, financial, physical and policy measures that focus on coping with floods within a framework of Integrated Water Resources Management (IWRM).

5.7.2 TRANS-BOUNDARY RIVER BASINS AND CO-OPERATION INITIATIVES/STATUS: WORLD, EUROPE, EU, S.E. EUROPE

5.7.2.1 Certain indicative, quantitative data

In a global scale there exist ~275 trans-boundary rivers representing 60% of global river flow. About 40% of world's population lives in trans-boundary basins. 145 nations have a part of their territory within trans-boundary river basins. All major groundwater aquifers of the world are trans-boundary. Up to present, there exist more than 3.600 bilateral and International Agreements regarding trans-boundary water issues (quantitative & qualitative)

In Europe there are 71 trans-boundary river basins, covering about 54% of total European area

In the Mediterranean & S-E Europe countries, trans-boundary river basins cover more than 80% of the total area.

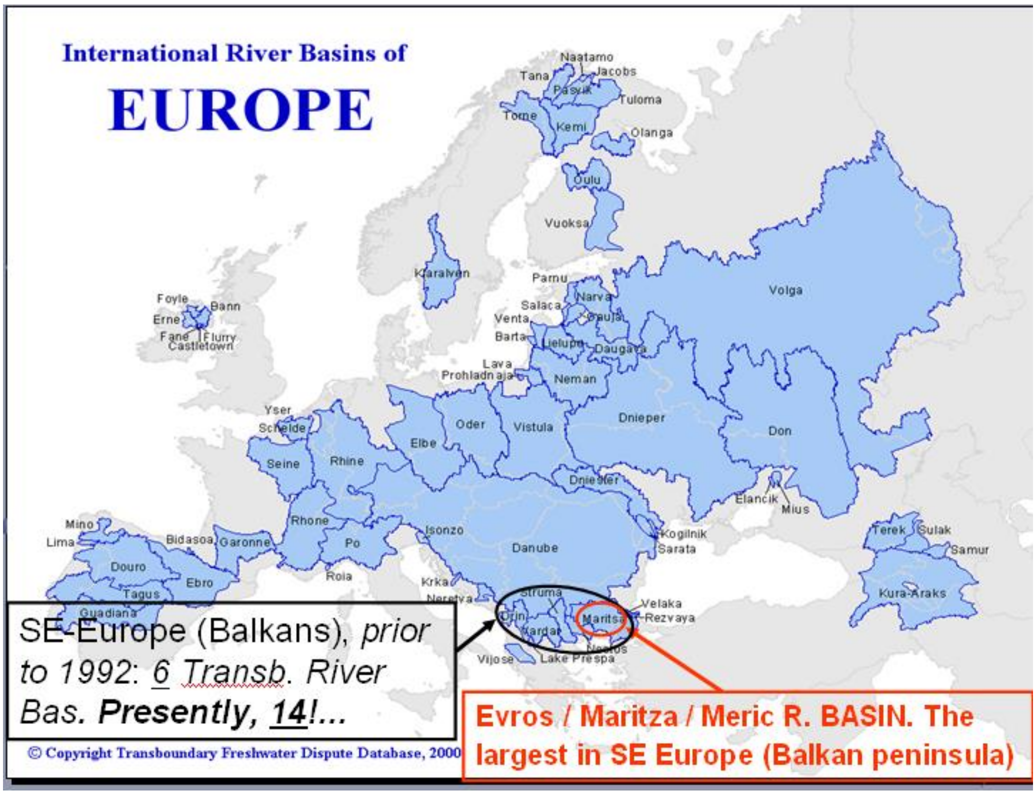

Fig. 167**:** Trans-boundary river basins in the area (by Transboundary Freshwater Dispute Database, 2000)

5.7.2.2 Co-operation status in EU trans-boundary river basins

The total number of the presently existing trans-boundary river basins in EU are categorised in 4 groups according to 3 criteria: a) International Agreement, b) International governing-managing Body and c) International Management Plan.

1st. Existing Criteria: International Agreement, International governing-managing Body and International Management Plan. The case of Rivers: Danube, Rhine, Elbe, Oder.

2nd. Existing Criteria: There exist: International Agreement, International governing-managing Body, but: NO International Management Plan.

3rd. Existing Criteria: There exist: International Agreement, but: NO International governing-managing Body, but: NO International Management Plan

4th. Existing Criteria: NO International Agreement, but: NO International governing-managing Body, but: NO International Management Plan. This is the case of Evros/Maritsa/Meric river.

It must be noted that only a very few trans-boundary river basins within the EU remain at present, in the 4th Category, as it is the case of Evros/Maritsa/Meric!

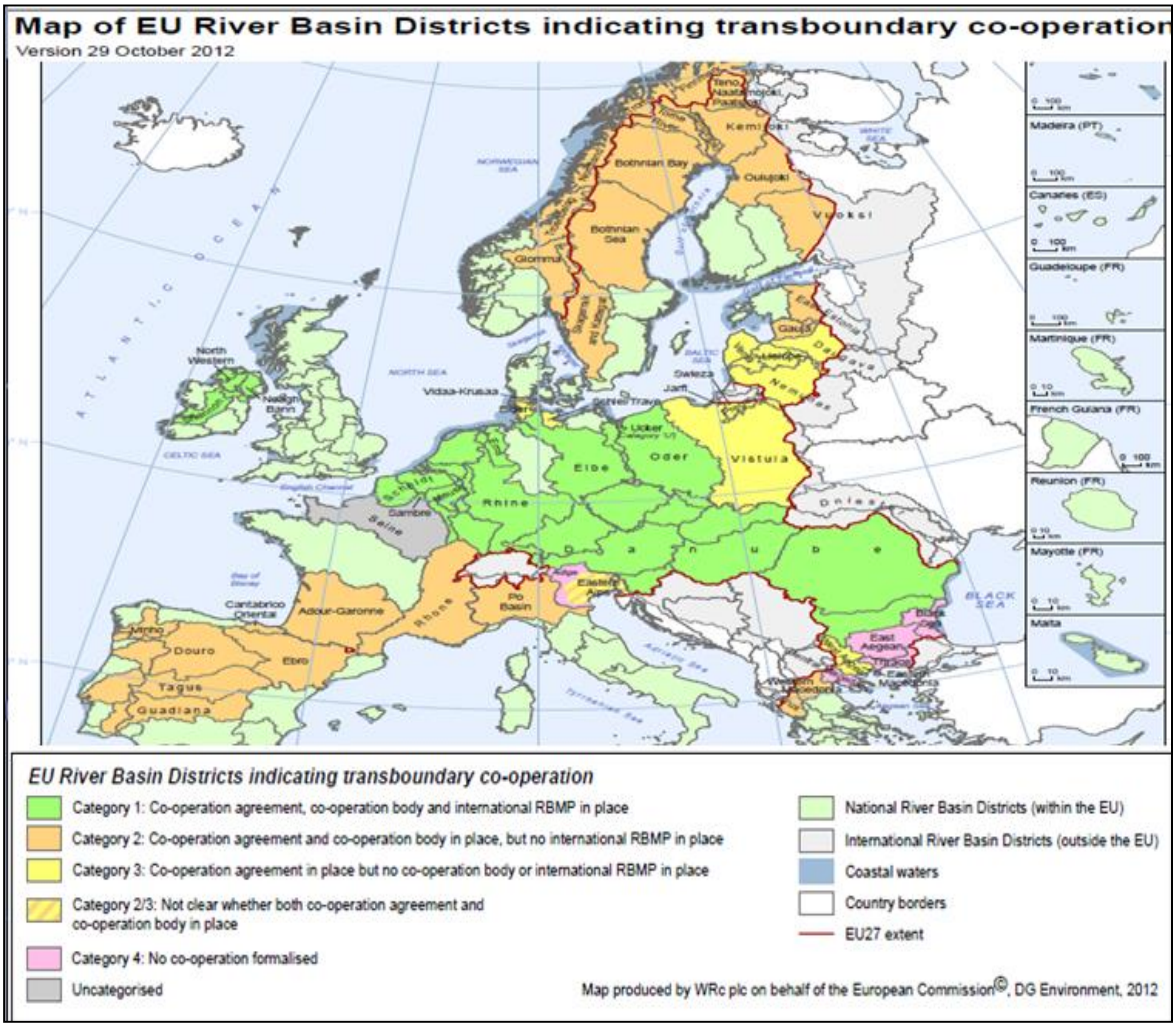

Fig. 168**:** Transboundary cooperation within the EU (by WRc on behalf of the European Commission, 2012)

5.7.2.3 Trans-boundary river basins and cooperation initiatives/status in SE Europe (Balkan countries)

As it is manifested by the existing data, 90% of the area of the SE European (Balkan region) countries falls within trans-boundary river basins including but not limited to the river basins of Danube, Drin, Maritsa/Meric/Evros, Neretva. These and other trans-boundary rivers, flow into the Adriatic, the Aegean, the Ionian and the Black Seas.

More than half of the trans-boundary basins are shared by three or more riparian states. Shared lake basins include Doiran, Ohrid, Prespa and Shkoder.

The SE Europe region is also characterized by a large number of trans-boundary aquifers that are often karstic in their nature. Prior to 1992 there were six major trans-boundary rivers crossing the sub-Danubian geographical area which consists of territories belonging to SE

Europe countries. These rivers are Aoos/Vjosa, Drim, Axios/Vardar, Strymon/Struma, Nestos/Mesta, and Evros/Maritsa/Meric.

With the emergence of new states (Croatia, Slovenia, Bosnia and Herzegovina, FYROM, Serbia, and Montenegro) in the SE Europe, the number of shared rivers in the area has more than doubled. In fact, several other rivers (e.g.: Sava, Kupa/Colpa, Cetina, Una, Drina, Neretva and Trebisnjica) are now listed as trans-boundary ones.

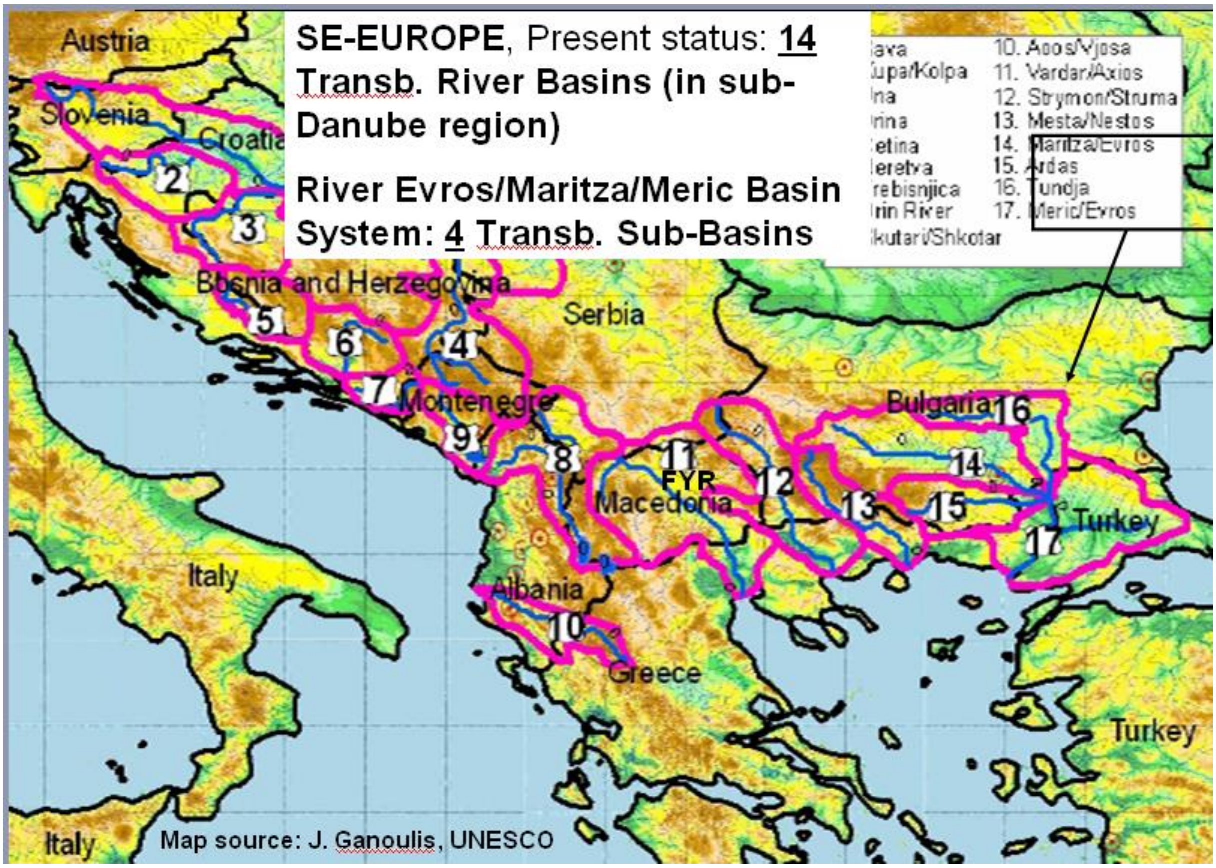

Fig. 169**:** Transboundary river basins in southern Europe (J. Ganoulis, UNESCO)

There have been numerous initiatives regarding cooperation for sharing trans-boundary waters among SE Europe countries, but the existing formal agreements are very limited and they are almost exclusively of a bilateral nature. These bilateral agreements do not cover all existing country-pairs and some of them are rather problematic in their implementation.

For example, cooperation of Greece with the riparian countries is of vital importance, since roughly 25% of the country’s renewable water resources are “imported” as in four out of the five trans-boundary rivers, Greece is the downstream country.

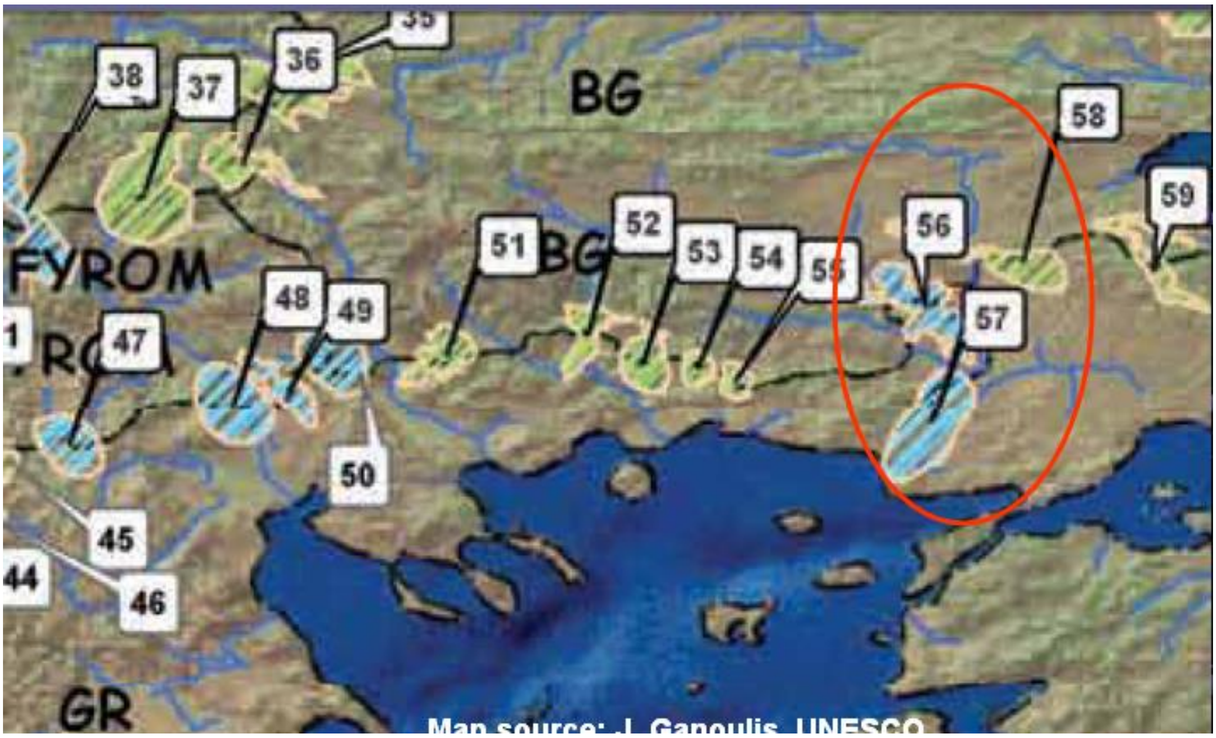

Fig.. 170**:** Transboundary karstic (green color) and alluvial (blue color) aquifers in SE Europe. Three of them (No. 56, 57 & 58) fall within the Evros/Maritsa/Meric river basin (J. Ganoulis, UNESCO).

River name	Source country	Outfall country	Sharing countries	Total length (km)	Length on Greek territory (Km)	Total size of basin (km²)	Size of basin on Greek territory (km²)
Maritza/ Evros*/ Meric	Bulgaria	Greece/Sea of Thrace	Bulgaria Greece Turkey	550	204	53.000	3180
Nestos/ Mesta	Bulgaria	Greece/Sea of Thrace	Bulgaria Greece	234	130	5.800	2.320
Strymon /Struma	Bulgaria	Greece/Northern Aegean Sea	Bulgaria Greece	400	118	18.078	7.281
Axios/ Vardar	FYROM	Greece/ Thermaikos Gulf	FYROM Greece	380	76	24.338	2981
Aoos/ Vjosa	Greece	Albania/ Adriatic Sea	Greece Albania	260	70	6.519	2.154

**The tributary Ardas: length 30 Km on Greek territory (of total 270), river basin 345 km² (of total 5.545)*

Fig. 171**:** Transboundary river basins shared by Greece. In four of them Greece is a "downstream" country and in one, the "upstream" country.

The lack of the needed, functional water agreements between Greece and its neighboring countries (only a few exist with Bulgaria and recently with Albania), is negatively affecting the regional cooperation and the state of the water resources in the engaged trans-boundary basins. Besides, certain existing water related agreements between Greece and Bulgaria are in whole (river Nestos/Mesta) or in part (river Evros/Maritza) rather problematic/disputable and are not effectively covering certain important issues (e.g. protection from flooding in the river Evros basin).

The potential for *international conflicts* as a result of water scarcity, quality degradation or even flooding regarding shared waters, poses a risk to stability and development in SE Europe. The international community (including the EU, Donor countries, International organizations, Inter- and Non-governmental organizations) has undertaken a series of initiatives, many of which are complementary. Particular reference is made to the *St. Petersberg Process* (1998) and the *Athens Declaration Process* (2003). Regrettably, no sound/formal, water related, agreements have occurred up to present as a result of the above mentioned initiatives and processes.

Trans-boundary rivers in SE Europe are at present, crossing few EU member states and mostly, non-member States. The latter ones have obviously, no obligation to implement the European Directives. The EU Water Framework Directive (WFD), 60/2000, is based on a holistic management approach and in the case of international basins; it requires each one of them to be assigned to an international River Basin District (RBD).

The Directive further specifies that member countries shall ensure cooperation for producing one single River Basin Management Plan for an international RBD falling within the territories of the EU; however, somewhat confusingly, the Directive at the same time indicates that if not produced, plans must be set up for the part of the basin falling within each country's own territory. If the basin extends beyond the territories of the EU, the directive encourages Member States to establish cooperation with non-Member States and thus, manage the water resource on a whole basin level (Articles 3 and 13).

The guidance document "*Best Practices in River Basin Management Planning*", produced as a part of the Common Implementation Strategy, reaches upon international RBDs but does not actually, go any further than the Directive in specifying how to designate international RBDs. Thus, the rather vague formulations in the WFD may result in multiple interpretations by Member States (e.g. Bulgaria) in implementing it.

The international dimensions are more explicit in the WFD than in other Directives, *potentially* requiring member States to move towards close cooperation in managing shared river basins. The strict legal requirements to actually achieve joint management are weak. This fact has already created cooperation problems, as in the case of rivers Nestos/Mesta and Evros/Maritza/Meric.

For those reasons presented, a prerequisite for implementing IWRM in trans-boundary rivers, especially within SE Europe, is the formulation of a clear, strict and rational set of legal requirements by the EU (under the Common Implementation Strategy).

5.7.3 THE TRANS-BOUNDARY RIVER EVROS/MARITZA/MERIC BASIN

5.7.3.1 GEOGRAPHICAL SETTING AND QUANTITATIVE DATA OF THE RIVER SYSTEM (MAIN RIVER & BASIC TRIBUTARIES)

River Evros/Maritsa/Meric is the greatest in length river (approximately 528 km,) in the Balkans (SE Europe), with its headwaters at Rila mountain-chain (Bulgaria), draining a basin of about 53,000 km2 (Bulgaria, upstream country, 66%, Turkey, downstream country, 27.5% and Greece, downstream country, 6.5%), affecting almost 2 million people and discharging into the Thracian Sea (NE Aegean Sea), through a delta (approximately 200 km2) of high ecological significance (protected by Ramsar convention & Natura 2000), shared by Greece (~90%) and Turkey.

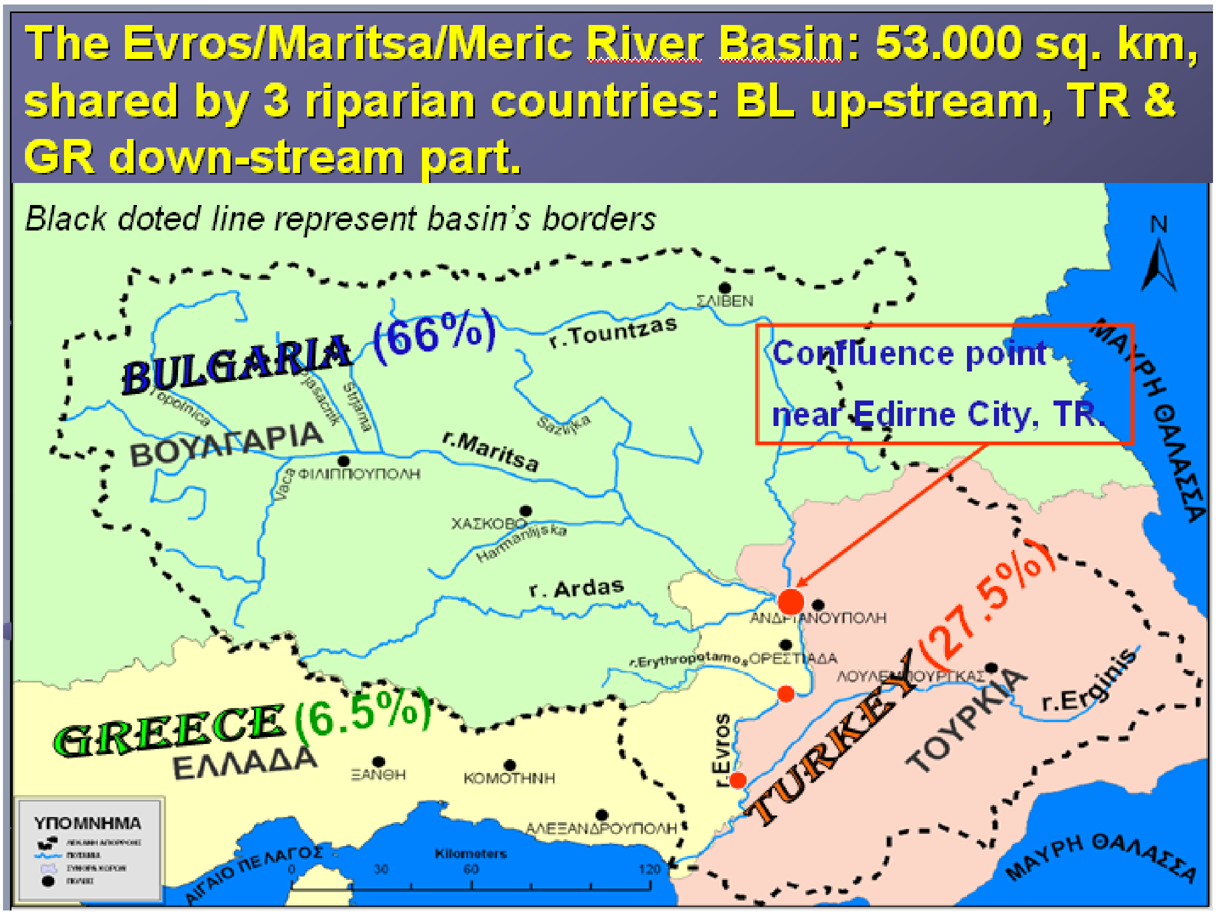

Fig. 172**:** Schematic representation of Evros/Maritsa/Meric river basin.

Two parts of the rivers stretch represent boundaries between Bulgaria and Greece as well as between Turkey and Greece; the latter amounts the last 187 km of the river’s watercourse in its downstream flow to the Aegean Sea (35% of the total length). There exist four main tributaries to the downstream direction of River Evros, which are: Ardas (Bulgaria and Greece), Tundzha (Bulgaria and Turkey), Erythropotamos (mainly in Greece) and Ergenes (entirely in Turkey). The largest tributary -in terms of hydrologic basin coverage- is Ergenes covering about 20.5% of the total river Evros basin, followed by Tundzha (16% of the total Evros basin), Ardas (11% of the total Evros basin) and Erythropotamos (3% of the total Evros basin).

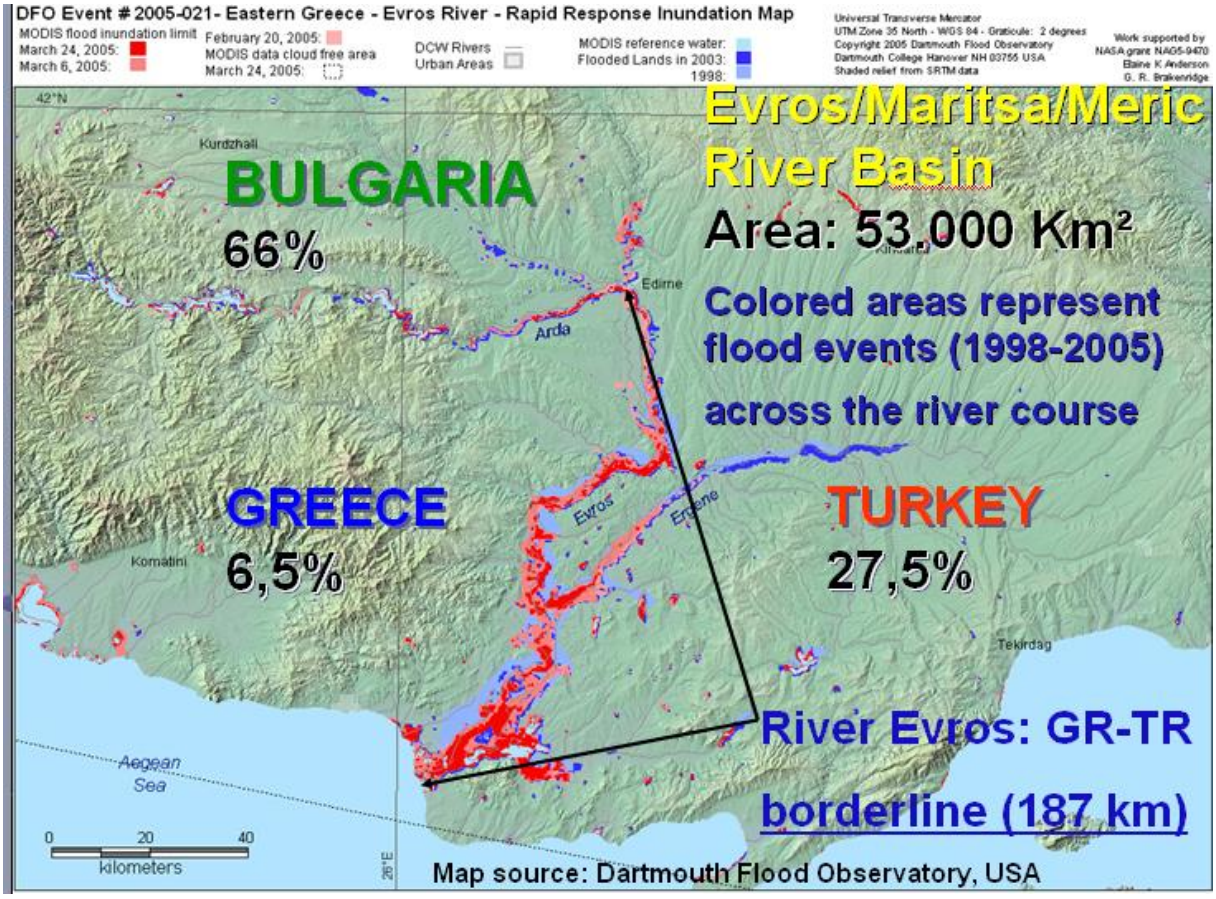

Fig. 173. Floods in Evros/Maritsa/Meric river basin. (Map source:Dartmouth Flood Observatory)

The annual average discharge of the river system fluctuates from 50 to 200m3/s.

Evros river catchment area is one of the most intensively cultivated areas in the Balkans and supports a population of 3.6 million people.

5.7.3.2 Co-operation initiatives / agreements among the three co-riparian countries regarding water management issues in Evros river (including flood protection)

Main summarising points:

- A long record of BILATERAL official/unofficial initiatives: political/scientific meetings, negotiations, declarations. Few ineffective-inefficient agreements, so far.
- NO TRIPARTITE cooperation and agreement has taken place up to present time.

Bilateral co-operation among the three co-riparian countries basin started early in the 20th century, since the end of Balkan wars (1910-15). The initially signed protocols and agreements in general, were referring to settlements on borderline and the related to it water and land reclamation issues in riparian areas of Evros/Meric (Greece & Turkey) and its tributary Ardas (Greece & Bulgaria). Official cooperation regarding the protection and use of trans-boundary waters of Evros basin has a long record of initiatives and related agreements. In fact, it started since 1926 between Greece and Turkey and since 1964 between Greece and Bulgaria. Greece and Bulgaria have ratified the Helsinki and Espoo conventions as well as they have internalised, through particular national legislative acts, all EU Directives related to environmental protection and water resources management (most important being the Water Framework, WFD, and Flood Directives, 2000/60 & 2007/60 respectively).

Greece and Turkey, following the Treaty of Lausanne (1923), signed several protocols regarding the control and technical management of river Evros riparian areas along the borderline. As a result of intensified discussions/negotiations during the period 1932-34, an agreement was signed in 1934, giving the permit to the American company HARZA for compiling an engineering study for the necessary hydraulic and other engineering works in both sides of the trans-boundary part of river Evros. A permanent Greek-Turkish commission has been also agreed for supervising the construction of the adopted by the study projects. Following a long lasting investigation and the engaged to it study compilation, a 4 years scheduled engineering project for banks alignment/protection and land exchange started in 1955 but it was stopped shortly after (in 1956 by a Turkish side initiative), due to disputes over central political issues. Only a part of the project which was engaged to the study of HARZA has been completed ever since.

As far as Bulgaria and Greece, the main bilateral agreements, associated directly or indirectly with river Evros waters, which are signed and ratified by the two countries during the last four decades are the Greek-Bulgarian agreement on co-operation for the use of watercourses flowing through the two countries (Legislative Decree 4393/1964, OG 193/A/4-11-64) as well as the Protocol3 for the Joint Greek-Bulgarian Technical Working Group and Environment Group -approved on 14.3.1990- (JMD Φ 0544/4/ΑΣ 227/Μ.3919, OG 143/A/30-10-1990).

Cooperation between the two countries since 2000 up to present under the umbrella of the EU INTERREG programmes (territorial co-operation), has resulted in constructing networks of hydro-meteorological telemetric monitoring stations in both the Greek and Bulgarian part of the trans-boundary river Evros system. These stations transmit their data in real time and are engaged in the early warning systems for flood protection in the territorial part of Evros basin of the two countries.

Up to now, only a few agreements in the field of water resources management have been signed between Bulgaria and Turkey, as the one concerning the electric energy production and transfer in the Ardas river basin (tributary of Evros) signed in 1992. Besides that, a protocol was signed (3/11/2006) by the responsible Ministers of the two countries regarding the construction and operation of an early warning system for flood prevention consisting mainly, by a network of telemetric monitoring stations (hydro-meteorological parameters) in critical points of the river system. This system is currently operational.

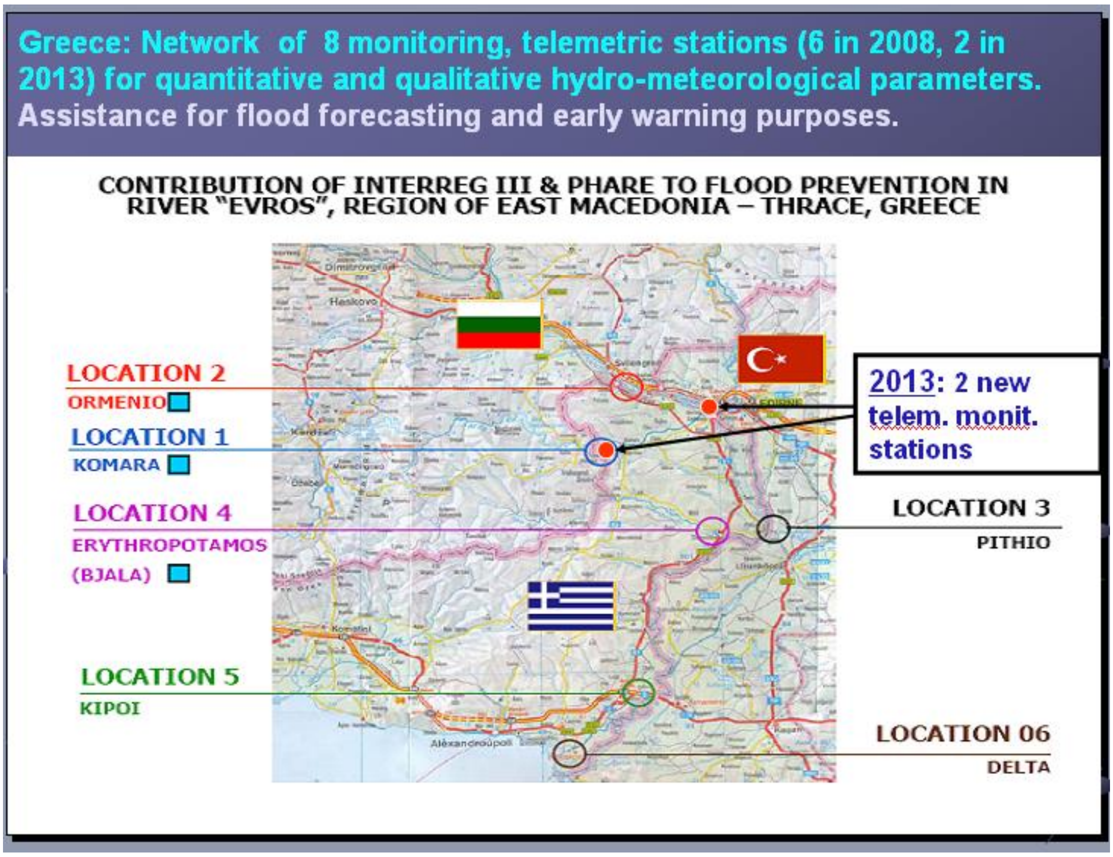

Fig. 174**:** Evros/Maritsa/Meric river Telemetric network.

Two bilateral working groups also exist (GR-BUL and GR-TR), where in periodic meetings, technical experts are discussing technical measures for mitigating the flood hazard in critical parts of the river channel along the boundary stretches of the river system. Very low progress has been made so far.

5.7.3.3 Basic water related, environmental problems

The prevailing problems divided in the two main categories (qualitative, quantitative) are presented in summarized form as follows.

A. Qualitative:

- Water Pollution (surface and underground) from Point + diffuse sources: Agricultural, Urban (untreated waste waters), Industrial (mainly from mining processes). Pollution increases down-stream, along the course of the river, towards its mouth-delta.
- Climatic and human-origin pressures on the aquatic ecosystems (Delta, River channel, Lakes)
- Spatial Elimination, Deforestation, and Degradation of Natural Floodplains.
- Negative role of present position and structure of dikes/levees and other flood protection systems on health of all natural ecosystems of the basin

B. Quantitative:

- Repeated catastrophic Floods. Max. flow quantity (Q) flood in year 1940. More recent flood event in 2012. Huge direct + indirect costs on annual basis!
- Repeated Droughts and water-scarcity due to seasonal fluctuations, climatic changes and aquifer over-pumping, mainly for irrigation (intensive farming).

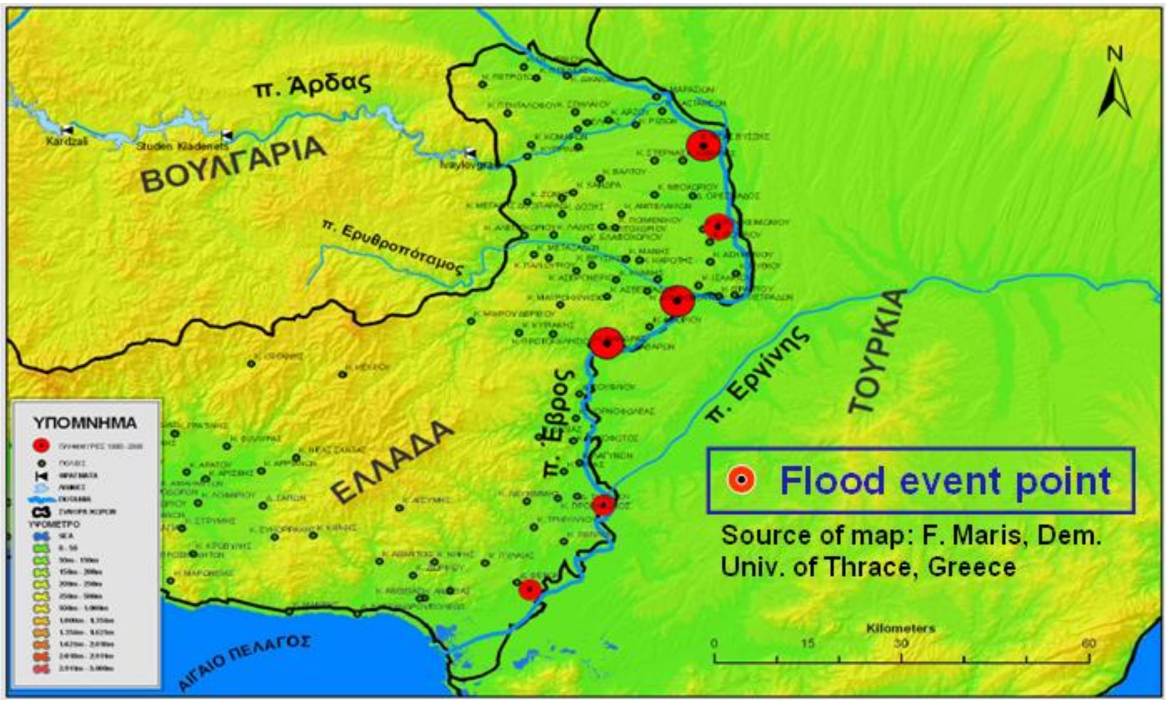

Fig. 175**:** Flood events recorded in the Greek part of the transboundary Evros/Maritsa/Meric river basin, between 2003-2012. Source: F. Maris, Democritus University of Thrace).

5.7.3.4 Main natural & anthropogenic causes of floods on a WHOLE basin scale

The main causes of flooding are classified into natural and anthropogenic and presented in a summarised form as follows.

A. Natural: Intensive and long duration rainfalls AND / OR fast snow melting rainfall in the upstream part of the basin

B. Anthropogenic:

- Operational mismanagement regarding flood control of the large reservoirs of the Hydro-Electric (H/E) dams in the Bulgarian upstream part of the basin. Priority is given to maximum water level for maximum productivity regarding HydroElectricity & irrigation water and there's no "buffer" volume to compensate for extra water due to intense rainfall.
- Improper spatial distribution and poor quality of the technical characteristics of the flood defence line-systems of dikes and other protection designs in the entire basin.
- Intervention in the natural flood plains & natural ecosystems (great reduction, land use change) and in the channel/bed characteristics of the river system. Within the Bulgarian part of trans-boundary basin, there exist more than 40 large and small dams, constructed mainly, during the period 1950-70.

It is calculated that the fifteen larger dams are controlling the runoff water generated within the 34% of the Bulgarian part of the drainage basin.

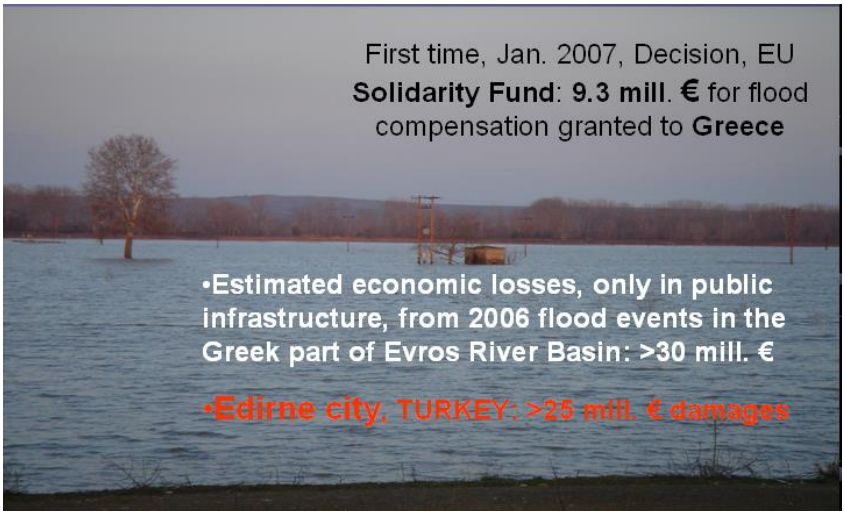

Fig. 176**:** Floods recorded in the Greek part of the transboundary Evros/Maritsa/Meric river basin, between 2005-2006.

Regarding the Bulgarian part of the tributary Ardas basin, there exist 3 large dams, the ones of Kyrdzhali, Studen Kladenets and Ivaylovgrad (very close to Greek-Bulgarian borders).

Particular reference data on the negative role of the spatial allocation and operational regime of the large H/E dams situated in the Bulgarian part of the trans-boundary basin, regarding the rate of occurrence and the intensity of flood events in the downstream part of the river basin (Turkish and Greek parts).

There have been 12 flood events-incidents, in the Greek part of Evros basin, during the time period 1844-1995 (151 years). That means that there has been less than one flood event every 12 years.

It has been observed that flood events are taking place in the Greek part of the basin when the flood flow at the Pythion bridge point of the Evros river channel exceeds 2500-3000 m3/s.

Additional interesting data:

- There was only one flood event during the period 1985-1995 (11 years), flood Q> 2500 m3/s but
- There were seven (7) flood events during the period 1996-2008 (13 years), flood Q> 2500 m3/s

A Gumbel analysis, regarding maximum annual flood flows at the Greek village of Pythion, performed for two different time periods, shows the following results:

A. Time-period 1985–1994: 70 years recurrent period for flood flows of 3000 m3/sec
B. Time-period 1985– 2007: 7 years (only!) recurrent period for flood flows of 3000 m3/sec.

5.7.3.5 Arguments and comments on the role the dams play on the flood problem

This dramatic change in the flood event reoccurrence period is not mainly due to climatic conditions change but mainly due to the induced change in the operational regime of the large Bulgarian H/E dam-reservoirs (as the ones existing in the river Arda’s basin), since their privatization in 1994. The private companies operating these dams, are trying to maximize the electric power production by keeping the water level in the reservoirs at the highest possible water level and volume.

Thus, many times when high runoff is taking place in the rivers basins due to meteorological conditions (intense rain and/or snow melting temperatures) there is no space in the reservoirs for accommodating the suddenly occurring large quantities of water and the dam operators open the gates for safety reasons (risk of dam failure). In this way, large amounts of water are coming out of the gates and cause flooding in the downstream region of the dams.

As it therefore seems, the management of the dams in the Bulgarian territory is greatly controlling the flood flows generated in the Bulgarian part of the basin and thus are directly related to the characteristics of the flooding events encountered in the downstream Greek and Turkish parts of it.

5.7.3.6 CURRENT FLOOD MANAGEMENT STATUS IN THE THREE CO-RIPARIAN COUNTRIES IN EVROS/MARITSA/MERIC RIVER BASIN

The main facts representing the current flood management status in the three countries are summarized as follows.

Each one of the three riparian countries is performing flood management in its own territory (i.e. part of the whole basin). Bilateral cooperation exists only during flood crises periods.

Greece & Bulgaria are implementing the EU Flood management Directive 60/2007, which consists of three main stages: 1. flood hazard mapping, 2. flood risk mapping & 3. Flood risk mitigation plans (a combination of “hard”-structural & “soft”-non structural measures). They have finished stage 1 and have started implementing stage 2.

All three countries are currently: a. improving their network regarding flood forecasting / early warning & preparedness systems and b. restoring/improving the damages/failures in the flood defense infrastructure (mainly the system of dikes).

5.7.3.7 PROPOSED PREREQUISITES FOR AN EFFECTIVE MANAGEMENT OF THE FLOOD PROBLEM

During the last years there has been a great number of EU funded research projects carried out in Evros/Maritsa/Meric river regarding Water management and flood hazard assessment and disaster mitigation. Those research projects have provided important outcomes which from a clearly scientific perspective, can provide the necessary support to tackle the problem. The main problem in this cross-border area seems to be a political one. A proposal towards the flood problem mitigation in Evros river basin is summarized in the following paragraphs.

I. Given the long record of bilateral co-operation initiatives, it is evident that there exist many and mainly political reasons for the lack of a sound tripartite agreement regarding the implementation the needed IWRM and its subsystem IFM on the whole area of the river Evros/Maritsa/Meric trans-boundary basin (as it is the case in many European and most of the EU trans-boundary basins).

Thus, a first priority prerequisite for reaching the above mentioned agreement by the three neighbour and co-riparian countries is the involvement/interference of a third party which should be accepted by all of them. It seems that the European Union can well play this role. The approved third party should use the currently in use Hydrodiplomacy concepts (“all win” and “benefit sharing”) in the process of persuading the three countries to enter willingly in effective negotiations for reaching a sound agreement.

II. Basic prerequisite for the efficiency and sustainability of the negotiated agreement is its conformity to the:

- UN (UNECE) "Water Convention" (for the Protection and Use of Trans-boundary Watercourses and International Lakes) and the
- EU water related Directives (especially the 60/2000 & 60/2007)
- Additionally, the agreement should adapt to the case the good practices implemented in other EU trans-boundary basins by their International river Commissions (managing body) in structuring the management plan on a whole basin scale (E.g. rivers Rhine and Danube).

III. The basic prerequisites towards the optimal effectiveness and sustainability in managing the flood problem in the river Evros basin, are:

- The engineering updating and a proper operation regime regarding the existing large H/E dams in the Bulgarian part of the basin.
- The implementation of the "more room for the river" concept in compiling the flood risk mitigation plans (EU Flood Dir. 60/2007) for the entire basin. This is mainly interpreted, to a spatial rearrangement of the existing networks of flood defence structures (dikes/levees), to increasing the natural floodplains of the river system and using as frequent as possible, non-structural ("soft") measures in the area.

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5.8 ROMANIA

5.8.1 INTRODUCTION

The European Directive on the Assessment and Management of Flood Risks, sets out the requirements for the Member States to develop three kinds of products:

1. a preliminary flood risk assessment: the aim of this step is to evaluate the level of flood risk in all regions and to select those regions on which to undertake flood mapping and flood risk management plans (see section 2 for Romania),
2. flood mapping, with a distinction between flood hazard maps and flood risk maps: the **flood hazard maps** should cover the geographical areas which could be flooded according to different scenarios. These maps are also indicated by flood extension maps;
3. **flood risk maps to display** the potential adverse consequences associated with floods under those scenarios and to support the development of flood risk management plans: based on the previous maps, the flood risk management plans should indicate the objectives of the flood risk management in the concerned areas, and the measures that aim to achieve these objectives.

According to the EU Floods Directive Member states should produce flood mapping according to some minimum recommendations. To be consistent with the proposed European document, Romania by the National Administration "Apele Romana" and the National Institute of Hydrology and Water Management decided to focus its work on the minimum requirements of the Directive concerning flood mapping along the rivers.

5.8.2 PRELIMINARY FLOOD RISK ASSESSMENT IN ROMANIA

In Romania, the river sectors affected by a high potential risk for flooding are shown in Fig. 182. The most flood prone areas are located along the River Danube and in the floodplains of Siret and Prut, where large floods in coincidence with high water levels along the Danube cause backwater effects, thus flooding large areas of the floodplains.

There are also flash floods occurring mainly towards the mountainous central parts of the country and the area around Tulcea, Galati and Vaslui (recent flash floods, September 2013) although less extreme than in Mediterranean regions as suggested by the Hydrate Project outcomes (Gaume et.al, 2009).

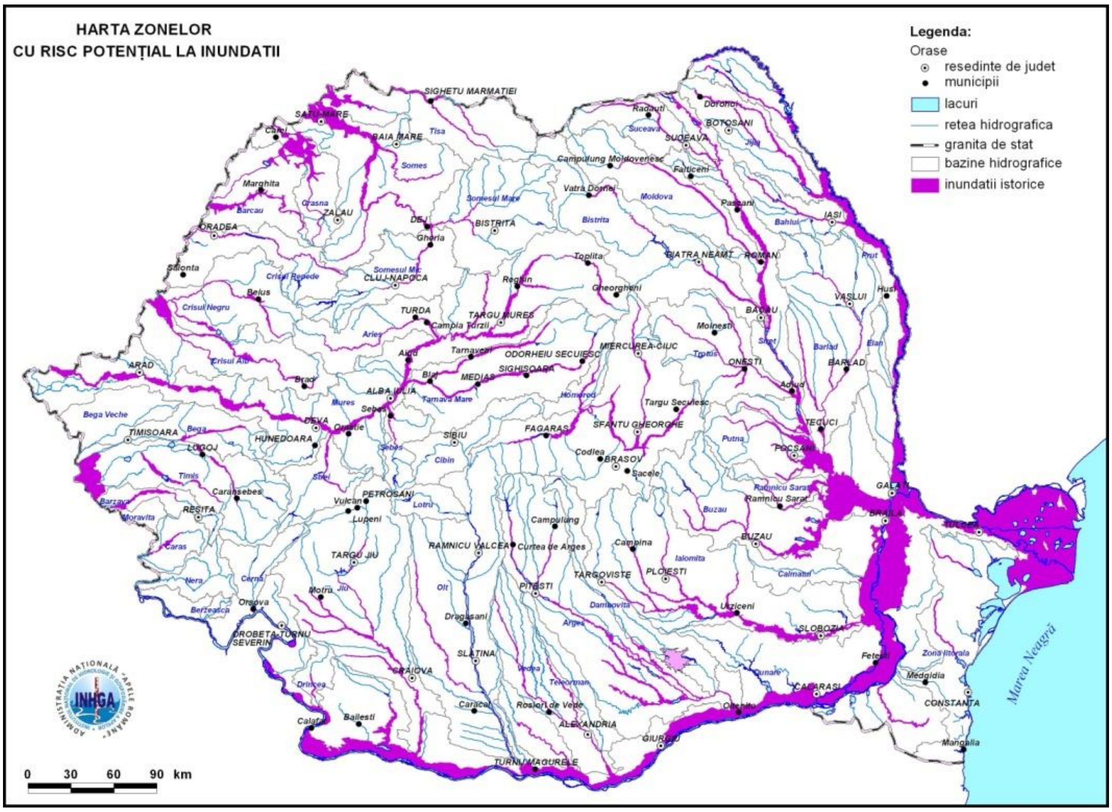

Fig. 177**:** Potential Flood Risk Assessment for Romania (Flood Directive second report) [www.rowater.ro; www.hidro.ro , 28.04.2014]

5.8.3 FLOOD PROBLEM ALONG THE DANUBE RIVER

5.8.3.1 Flood Hazard and Risk Maps along the Danube – The DANUBE Floodrisk project

Considering the large areas of the Danube floodplains affected by potential flood risk, the identification and the hazard and risk map development was very important both to support decisions regarding long term land planning and for the Flood Directive reporting, by implementing the EC policy in this domain. The Danube Floodrisk Project (www.danube-floodrisk.eu), was coordinated by the Ministry of Environment and climate Change of Romania, in cooperation with ICPDR. Flood Hazard maps created for the Danube floodplain over the entire river basin area, were produced based on a unified methodological approach. The finally printed atlas at 1:100 000 scale, comprises of 82 pairs of maps showing flood hazard and damage potential over the entire Danube basin. In addition to the methodology used to cover the low lands of Danube river basin where flood hazard is shown as a function of inundation depth, in the mountainous areas where the river stretches, the hazard is estimated as a function of the specific discharge, which is the product of inundation depth and velocity.

In order to assess the potential damage, different damage assessment functions were used for each of these regions. At a first step, the damage was calculated using different methodological approaches and at the second step, the maximum estimate of them was used as input for the map construction.

For the first time in Romania, in a large-scale mapping project, critical infrastructure facilities like schools, hospitals, air ports, railway stations and power plants are displayed. This action provides additional risk information for planning response and emergency actions, as well as for regional planning.

According to the approach used in developing the Danube Atlas (2012), a distinction was made in flood prone areas in two classes based on whether they are or not, protected:

Protected areas with a high level of protection-with respect to these surfaces, floods are mainly a risk in connection with dyke breaches, which mostly limit the influenced area. This mainly applies to the Upper Danube along the Austria-Hungary Upper Danube, between Vienna and Budapest, where flood protection works constructed to protect against floods up to a recurrence interval of 1 000 years. Since the location of dike breaches cannot be determined in advance, the entire surface area lying below the river water level must be regarded as flood prone area. This amounts to the hypothesis that the dikes do not offer any effective protection. On the whole, this hypothesis is highly unlikely, but the risk of individual dike breaches occurring, must be taken into account. The combination of both the flood risk and the potential damage in the maps, highlights the most unfavorable situation of each location and represents the envelope for different extreme events. It thus represents the protection effects of the dikes.

Unprotected areas or areas with a low level of protection-in cases of extreme floods, low lying areas along a river section are hit. This largely applies to the Danube River sector, downstream of Budapest. Areas affected include Belgrade and the lower sector of the river in Romania. In that part dikes have been designed considering an 1:100 years flood. Along these river sections, the surfaces represented may be flooded during one single event, which as far as diked surfaces are concerned, is only probable on a local scale.

Since the monetary assessment is highly uncertain, indications are limited to orders of magnitude. The rough scale of 1:100.000, which is unsuitable for planning precise local projects, is however suitable for the targeted overview representation.

Particular attention has been paid to the representation of the consequences of potential extreme floods by indicating **the possible flood depth** for these events. As far as comparably frequent events, such as floods with a recurrence interval of 10 or 100 years are concerned, only the outer limits of the affected surfaces are indicated.

5.8.4 THE ATLAS

Life-threatening damages are caused by very rare events, when water levels overtop the dikes or the stability of dikes is threatened by sustained pressure. Until they occur, such damages are usually considered as unlikely to happen.

The Atlas represents the worst case flood depth at any given point and one thing that must be taken into account is that one and the same event cannot hit all surfaces represented along the entire Danube, as the effects of retention and cutting the crest makes floods downstream more unlikely. Thus, the Danube Atlas does not represent the flood situation liable to occur due to a certain event along the entire course of the Danube. The maps rather represent a synthesis of many possible extreme events, the most unfavorable flood situation for any given point and thus the threat posed to any individual and not the overall threat. This overall view is based on a statistic assumption; factors related to time are not taken into account. The focus of the Danube Hazard and Risk Maps was based on a harmonized flood mapping in border areas, integrating limit conditions in modeling, both in hydrologic statistics and hydraulic conditions.

5.8.4.1 Methodological concepts

In the context of damage assessment, a multi-risk approach was followed for the underlying assets map. The Basic European Assets Map (BEAM) provides an assets layer that can be used for all types of natural hazards, giving the information in Euro/m² and the population density. The service is designed to be applicable all over Europe and is mainly based on CORINE land cover and Eurostats data. More detailed information layers can be provided for smaller regions (www.emergencyresponse.eu).

The implementation of the Danube Floodrisk Project, indicated 6 areas which were exposed to a high flood risk. The pilot implementation in those areas, helped to develop long-term practical ideas for managing river sectors in a way that protects the environment, and defends local communities and economy against floods. The methodology used, considered flood risk as a combination of hazard sources, pathways and the consequences of flooding on the “receptors” – people, property and the environment. Flood risk management is a process which comprises pre-flood prevention, risk mitigation measures and preparedness, backed up by flood management actions during and after an event.

Management issues considered and discussed within the pilot activities network, included:

- flood prevention by structural and spatial measures;
- sustainable flood management, especially related to ecologically valuable areas;
- flood forecasting and calamity management;
- cross-border cooperation to stimulate a river basin approach;

- communication with and involvement of the public to increase flood awareness.

This information can be found in a comprehensible abstract in the Brochure of the pilot activities along the Danube (www.danube-floodrisk.eu).

5.8.4.2 Modeling Techniques used

Considering the extent of the Danube River basin and the number of countries involved, data and methodologies harmonization to assess Flood Hazard was a necessary task. The methods used to harmonize data and to select the hydrologic modeling for data inputs in hydraulic models (a packet of models were tested: MIKE, HEC and Sobeq) is an important part of the project; the core activity in the Danube Floodrisk Project implementation, and this experience is very important and needs to be shared with the SciNetNatHaz Project, for the Black Sea Basin application.

The main mapping products are the land use – Fig. 178, land cover –Fig. 179, which will offer the man statistical data for hazard and risk representation – Fig. 180 and Fig. 181.

Fig. 178: Land use map

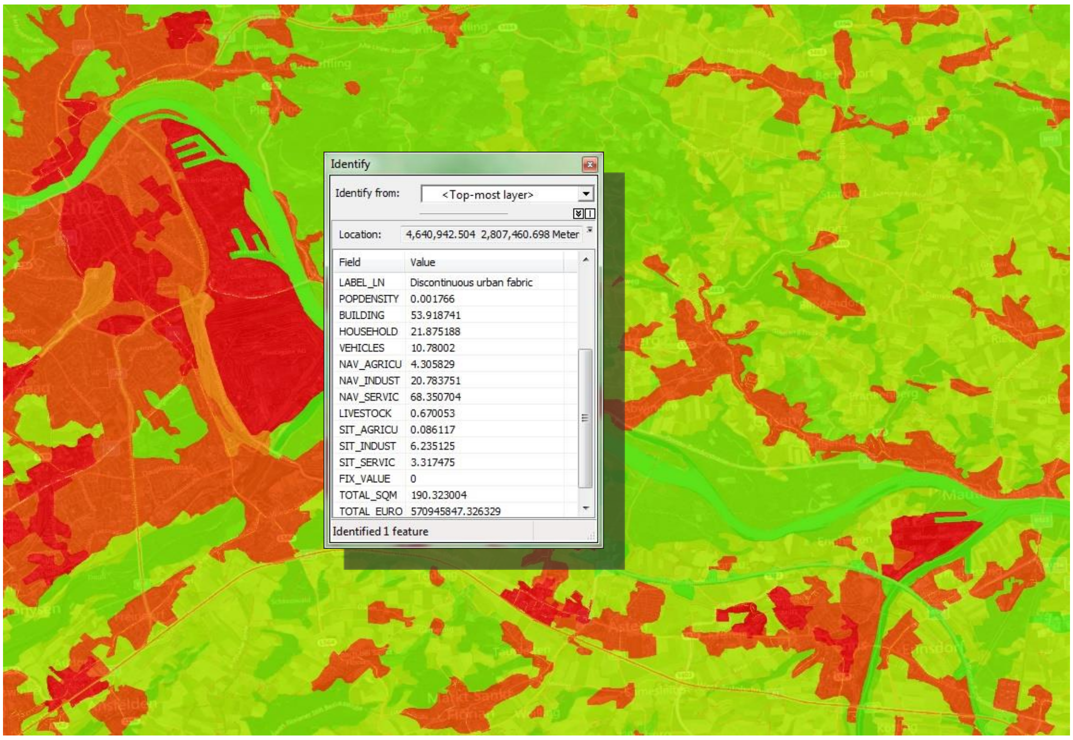

Fig. 179: Land cover map

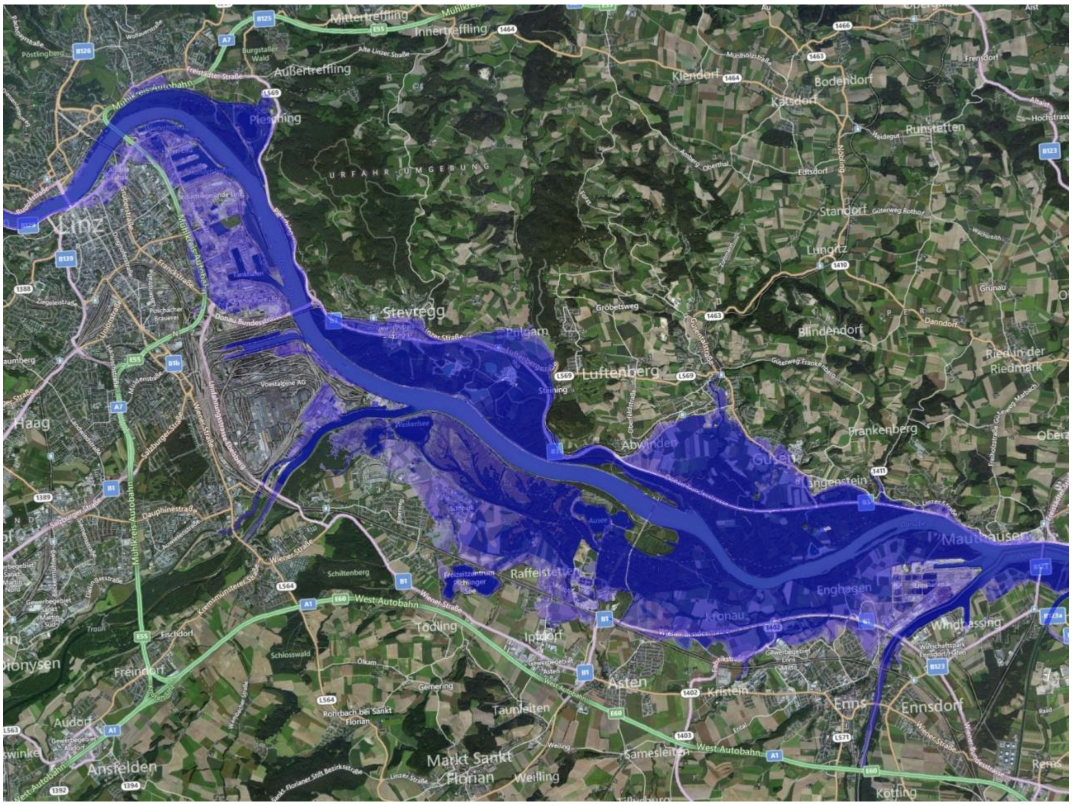

Fig. 180**:** Hazard map

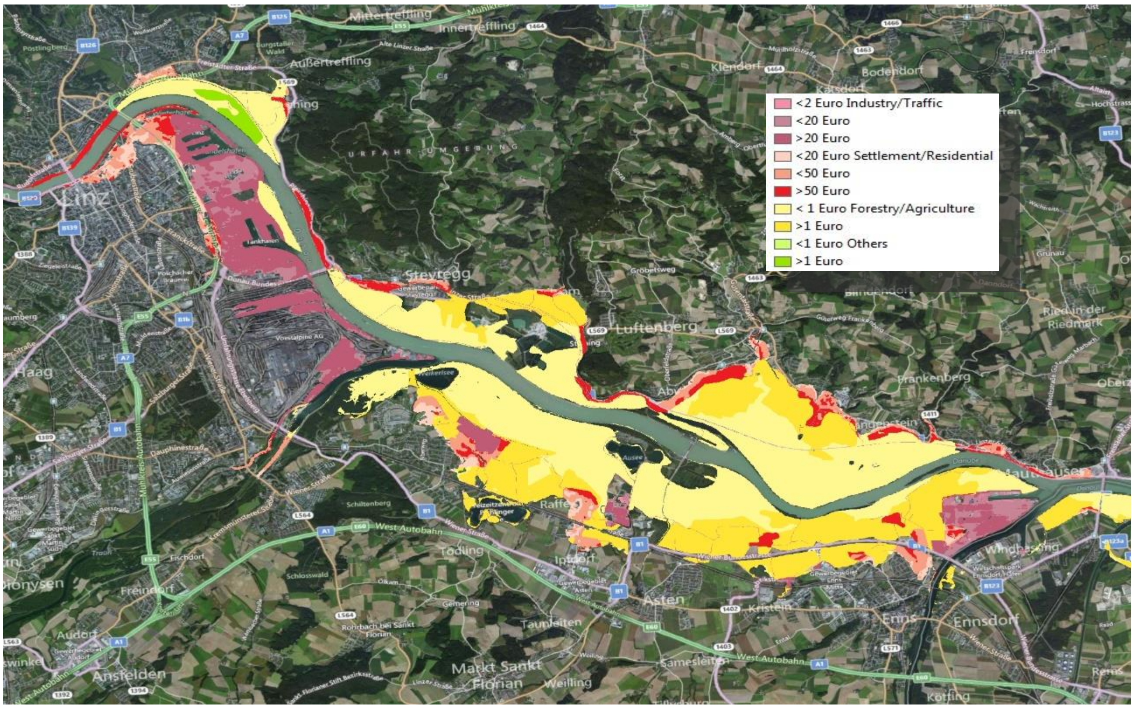

Fig. 181: Risk map

5.8.4.3 Harmonization and joint definition of requirements for hazard mapping along the Danube Floodplain

Harmonization in data and methodologies is needed regarding both different nations for comparability and compatibility reasons, and also regarding different user groups who have both different expectations and potential uses for map content. The bottom line in working in river systems is that the river must be conceived like an entire indivisible system which cannot be limited or restricted by borders. Flood risk management has to be one piece of this puzzle and to take into serious consideration this fact.

The first step towards harmonization was the assessment of the national requirements regarding flood hazard and risk mapping. These have been summarized (“Report on national requirements on the flood mapping procedures for the Danube River”) and the results formed the basis for further actions toward harmonization of data and of methodologies.

5.8.4.4 Harmonization of data

Data are the heart of the risk modelling process. Inconsistencies or quality deficits may lead to insufficient results. The steps taken towards data harmonization were adopted by all partners and included:

- Data Format definition (GIS)
- Overview of data needs in general
- Data needs and minimum quality requirements (resolution, accuracy, up-to-datedness)
- Data screening considering project implementation requirements, national law, copyright issues, cost etc.

A common projection system was selected for the entire data collection; the European Vertical Reference System 2007 (EVRS 2007) whereas for the bathymetric maps the selected Reference System was Lambert Azimuthal Equal Area in the ETRS89 datum (ETRS_1989_LAEA).

In the context of flood hazard and risk modeling, the data needed were collected and stored in a central database. In cases of data unavailability, Meta-data were delivered. This relates especially to input data not acquired with DFRP funds such as DTM, cross-sections, roughness coefficients, hydrological data, but also to input data for risk considerations. Additional data included background data, hydrological, hydraulic, Meteorological, land use data and historical data (past floods, dike breaches, inundation areas etc.).

As not all of this data were relevant with the scale of the Danube river implementation, and considering additionally national concerns and copyright limitations a part of the data initially found was incorporated into the geodatabase.

High accuracy data were used to represent the ground surface. LiDAR scanning data with an accuracy of 10-10cm and point every 5 m were used for most of the implementation area. If no data were available of the requested precision, then the data that comes closest to the requirements were used and a description of the precision available was be added.

Bathymetrical measurements in Danube were also carried out. In all cases, there was a close cooperation between members of the partnership, to solve occurring problems and to further adjust details regarding data specifications.

5.8.4.5 Harmonization of methods for processing of hazard maps along the Danube – Harmonization of methodologies

The methods used for the processing of hazard map data predetermine the quality of the results. The application of different methods might be appropriate if carefully assessed, but more usual is the harmonization of methods which covers: quality management, damage assessment, modeling techniques and model border conditions, scenario definition and simulation methods.

Hydraulic modeling techniques

There was a discussion on using steady or unsteady hydraulic models for the flood hazard mapping. Austria and Slovakia intended to use steady models 1D and 2D in most of the cases. The other riparian countries downstream of Gabcikovo decided to use 1D and 2D unsteady models for simulation.

The conclusions of this discussion were:

1.) For high (1:30 years) and medium (1:100 years) probability floods:

- Use of 1D steady backwater curve calculations are recommended (it is agreed that these floods will be contained between dykes)
- 2D steady models can be used where appropriate (wide floodplain, high damage potential, detailed study etc.)

2.) For low (e.g. 1:300 years; 1:1000 years) probability floods:

- General recommendations for the 2D hydraulic models
- Flooding & drying option needed
- Option to represent linear structures
- Present references on reproduction of velocity distribution
- Prove that a dense enough grid size is used (e.g. presenting series of results of systematic grid refining)
- For the simulation of the inundation of the protected floodplain use of a combined unsteady "1D-Breach-2D model system" is recommended
- For the 2D unsteady hydraulic model the ability of handling flooding and drying processes is a prerequisite.

For Austria and Slovakia:

- The use of 2D steady models on the floodplains are recommended
- 1D steady model can be used on the floodplain depending on the financial and human resources, low damage potential etc.

For Hungary:

- For medium and high probabilities of exceedance, the floods will remain between dykes.
- For 0.1% probability of exceedance combined unsteady "1D-Breach-2D model system" will be used.

For Serbia:

- 1D steady model can be used.
- Quality requirements for the 2D hydrodynamic model (See General recommendations above)

For Romania and Bulgaria:

1D unsteady model will be used all along the Danube. In areas with high vulnerability a quasi-2D unsteady model is recommended.

5.8.5 PRINCIPLES FOR IMPLEMENTING A SUCCESSFUL CROSS-BORDER FLOOD HAZARD & RISK ASSESSMENT PROJECT

One pivotal conclusion of the "Danube Floodrisk" project has been that, in addition to enhancing people's hazard awareness, informing them about the limits of active control measures and the need for an appropriate use of areas at risk. Future handling of this issue will require an intensified risk sharing between the state, insurance companies and private persons.

Apart from the quick and easy retrieval of information about potential flooding risks from a digital risk map provided on the internet (which permits a first risk assessment), the flood control measures required for communities as well as for national and provincial governments, can be optimized and prioritized along the Danube, addressing correctly to high risk sectors, where identified. The project addressed to the EU Floods Framework Directive requirements which refer to better information provided for the population, while also serving the interests of the insurance industry by both increasing people's risk awareness and enhancing identification and assessment of potential risks as a basic prerequisite of insurability.

A point which needs to be underlined is that, a basic constituent of the very successful implementation of the Danube FloodRsisk project was the fact that, it was the implementation of common, harmonized methodologies over the entire Danube River basin considered as a whole.

This is an outcome attributed to consensus among the different countries involved and their determination to address flood hazard and mitigate flood disasters on the Danube River basin. This political consensus is an essential prerequisite in such cases, where only implementation of flood hazard and risk assessment over the entire river basin can provide adequate results for an effective, flood disaster mitigation.

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5.9 UKRAINE

5.9.1 INTRODUCTION

Floods occur at 27% of the territory of Ukraine (165,000 km2). One third of population of Ukraine lives in potentially dangerous areas.

Ukrainian territory covers 18% of Danube Delta. The Ukrainian part of the Danube delta and floodplain occupies about 124,000 ha, including 75,000 ha of land and 50,000 ha of big lakes – Kahul, Kartal, Kugurlui-Yalpug, Katlabuh, Kitay and Stensovsko-Zshebriyansky Plavni. A length of the Ukrainian part of the Danube is 170 km between the border of the Republic of Moldova near the Prut River mouth and the Black Sea and is located in the south-western part of the Odessa Region.

In recent years in the Danube Delta there has been an increase in the quantity of extreme and sudden hydrometeorological phenomena. Considerable increases of water level have been observed in the Ukrainian part of the Danube during the winter because of ice flows (2006, 2012). In 2010, new historical high water records were registered at many hydrological posts of the lower Danube. Significant floods occurred in Reni in 2005, and in Sarata, Tabarbunary and Bolgrad Districts of Odessa Oblast in 2013.

5.9.2 STATE AND PUBLIC ADMINISTRATION

In April 2008 the Danube River Basin Management Department (DRBMD) was founded by the Decree of the State Committee of Ukraine for Water Management, in order to create an institutional background for the implementation of the national policy in introducing a river basin management approach in the Ukrainian part of the Danube Region. The DRBMD is created on the basis of the Danube Flood Protection Department.

The Danube Flood Protection Department was founded in 1966 in Izmail. In 2006 the Centre for Analysis of Flood Situation in the Danube Area, Flood Warning and Information has been created on the Department's basis as an output from the project "Emergency Planning and Flood Protection in the Lower Danube EuroRegion" funded by the European Commission.

The Danube Hydrometeorological Observatory (DHMO) that is a part of the State Hydromet Service of Ukraine is the main authority in charge of the hydrometeorological monitoring in the Danube region of Ukraine.

In order to provide better emergency planning, improvement of early flood warning and public access to information on flood situation in the Ukrainian Danube Region the Centre for Analysis of Flood Situation in the Danube Area, Flood Warning and Information was established in Izmail, 2006. The centre is closely cooperating with Local Authorities and the

Danube Hydrometeorological Observatory responsible for flood forecasting in the Ukrainian Danube Region.

5.9.3 AUTOMATIC HYDROLOGICAL STATIONS

In 2009 three OTT Orpheus Mini automatic hydrological stations were installed along the Ukrainian bank of the Danube at the Danube Hydrometeorological Observatory’s hydrological stations of Izmail, Vilkovo and Bystriy. These automatic stations are equipped by the combined sensor measuring water level and temperature and a data-logger. The results of observations are automatically being transmitted via SMS with a pre-set frequency. OTT Hydras3 Rx software is installed at the DHMO’s server in order to receive the data automatically. Data quality is controlled with OTT Hydras3 Basic software. These 3 stations were successfully integrated into the existing system of hydrological monitoring and is intensively used in DHMO’s regular observations.

Network of monitoring stations of the Danube Hydrometeorological Observatory location is shown in Fig. 182.

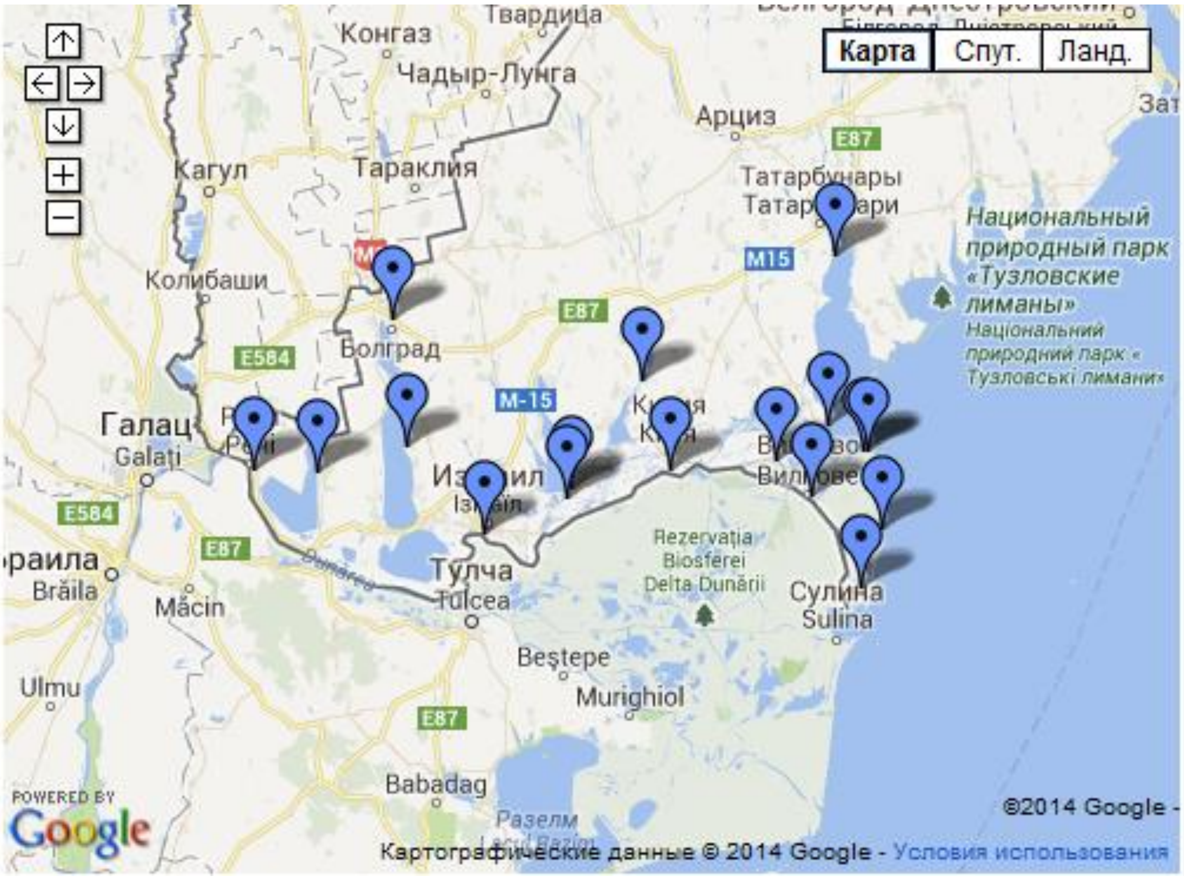

Fig. 182:. Monitoring stations of the Danube Hydrometeorological Observatory [1]

The model of flooded areas shown in Table 5.1, was developed based on the data aquired by the Vylkovo monitoring station.

Table 5.1: Model of flooded area at different water levels (Kiliya), Vylkovo monitoring station, 2006

Region	**Area**	**Month**												**Year**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Kiliyskyi Vilkovo	km2	289	235	296	318	316	307	297	238	225	182	128	126	290
	%	90,2	73,4	93,7	99,1	98,5	95,9	92,8	74,2	70,2	57,0	40,0	39,4	90,5
Water level in Vilkovo		119	93	138	163	162	151	130	94	89	80	75	74	114

At this point there are negotiations ongoing regarding the participation of Ukraine as member in the European Flood Alert System (EFAS). EFAS is being developed at the EC Joint Research Centre (JRC) with support of the national meteorological services and national hydrological services (NHS). Around 25 operational authorities across Europe, all together responsible for more than 85% of the major trans-national river basins, are receiving EFAS information as early flood warning reports for floods in the next 3-10 days.

EFAS-Danube members have 24/7 access to a protected web-server where the twice-daily EFAS forecasts can be examined and viewed. Since its independence in 1991 Ukraine has signed agreements on water management issues related to transboundary watercourses with Hungary, Romania, Slovakia and Moldova.

5.9.4 SATELLITE IMAGERY AND FLOOD RISK MAPPING

In Ukraine satellite imagery to multi-event and event-specific flood hazard mapping is being developed. Flood hazard and flood risk maps are provided to enable flood risk assessment, and flood probability density is to be estimated in order to produce flood hazard maps. Usually, this is done through hydraulic modeling of peak flow. But running such models faces many uncertainties due to the lack of hydrological and other required data, their incompleteness and imperfection. The use of space-borne remote sensing data to flood risk mapping is a complement approach to the existing flood modeling techniques.

In Ukraine, two approaches have developed and tested to flood hazard mapping from satellite imagery [2].The first approach exploits a time-series of Landsat TM/ETM+ images to estimate flood probability density. At a first step, clouds, shadows and SLC-off pixels (for the ETM+ instrument) are identified on Landsat scenes, marked as "No Data" value, and removed from the further analysis. At a second step, water bodies are detected using a density sliding method. Therefore, each pixel in the image can get one of the following values: 0 - «No water», 1 - «Water», 2 - «No Data».

The second approach is targeted for event-specific flood hazard mapping. The proposed approach is based on neural network method for flood mapping from SAR images. This method is extended in such a way that the output of the neural network is probabilistic, showing a posteriori probability of the area being inundated.

Development of flood risk maps is one of the important steps of an efficient flood risk management. Flood risk maps provide information to the population but are also important tools for the decision-makers and insurance companies.

Flood risk maps are used for planning and real time information during floods, flood management measures by competent authorities, communities and water boards; spatial planning; disaster management (planning and information) by communities and authorities; development of regional flood risk policies.

Flood hazard maps contain the following graphic information:

- flood extent;
- water depths or water level;
- flow velocity (m/s) or specific discharge (mC/s).
- Flood risk maps also show the potential vulnerability associated with flood scenarios:
- the indicative number of inhabitants potentially affected;
- type of economic activity of the area potentially affected;
- installations which might cause accidental pollution in case of flooding;
- potentially affected protected areas;
- environmentally important areas.

The methodology of flood mapping presented in Fig. 183.

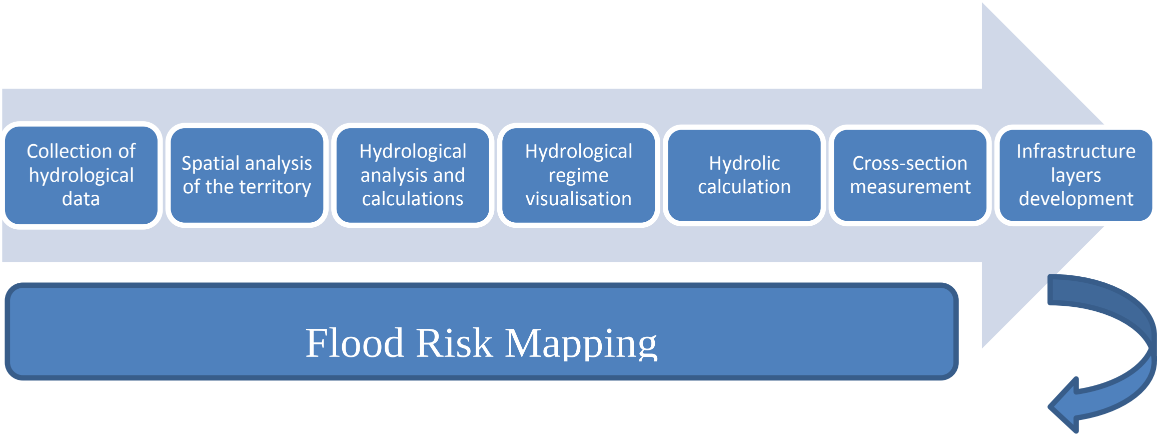

Fig. 183: Flood risk mapping methodology

There is also a Geographic Information System developed for the flood risk management in the Ukrainian part of the Lower Danube area. The following maps have been created: 1) flood zone map; 2) the map of potentially dangerous objects lying within the flood zone; 3) the map of dyke sections in critical condition (including those arising after the 2006 flood).

In 2010, hydrological modeling and flash flood risk mapping of Reni area has been done in accordance with the EU Flood Risk Directive, as a step towards an integrated flood risk management plan for the Danube-Liman Sub-basin. The study was done in the framework of the Ukrainian-Flemish project "Building capacities for effective flood risk management in the Ukrainian part of the Danube Delta" (Fig. 184 - Fig. 186) [3].

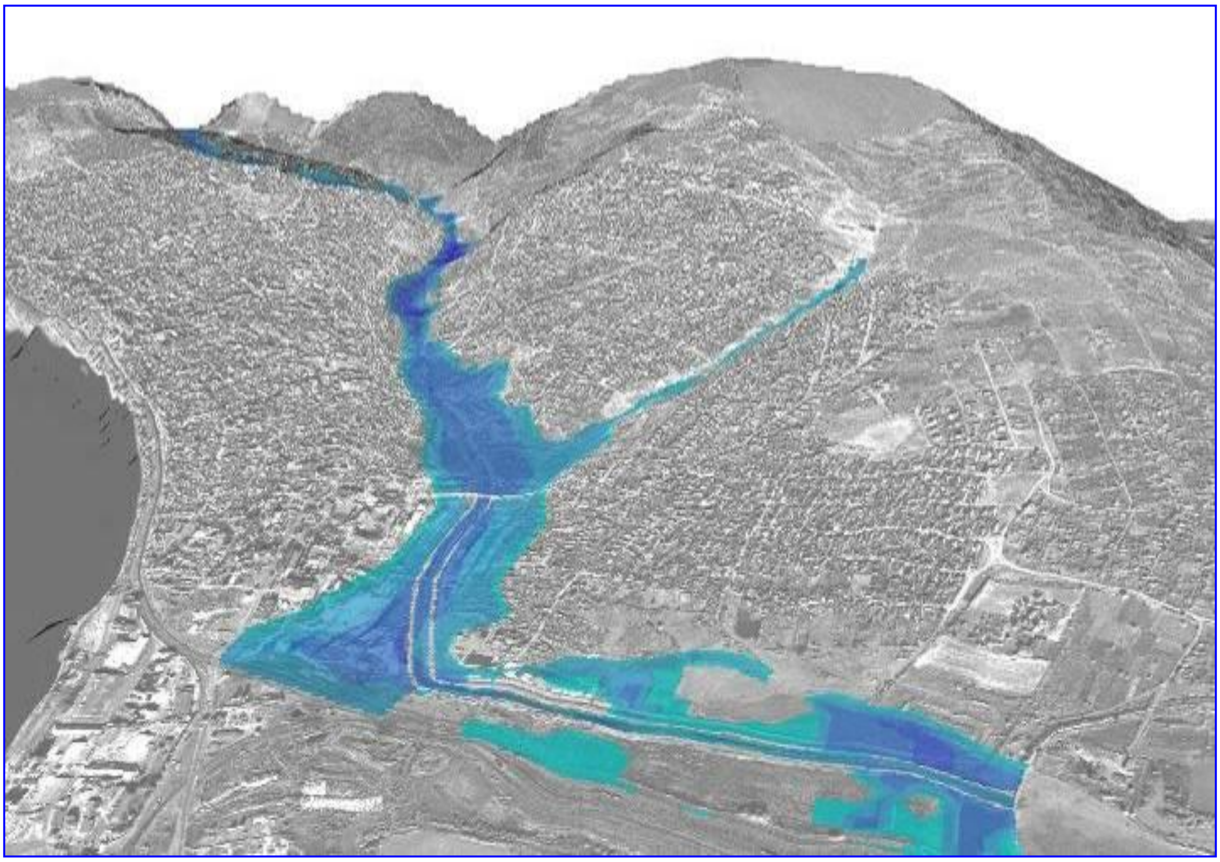

Fig. 184: Model and map of flood in Reni, 2005 [3]

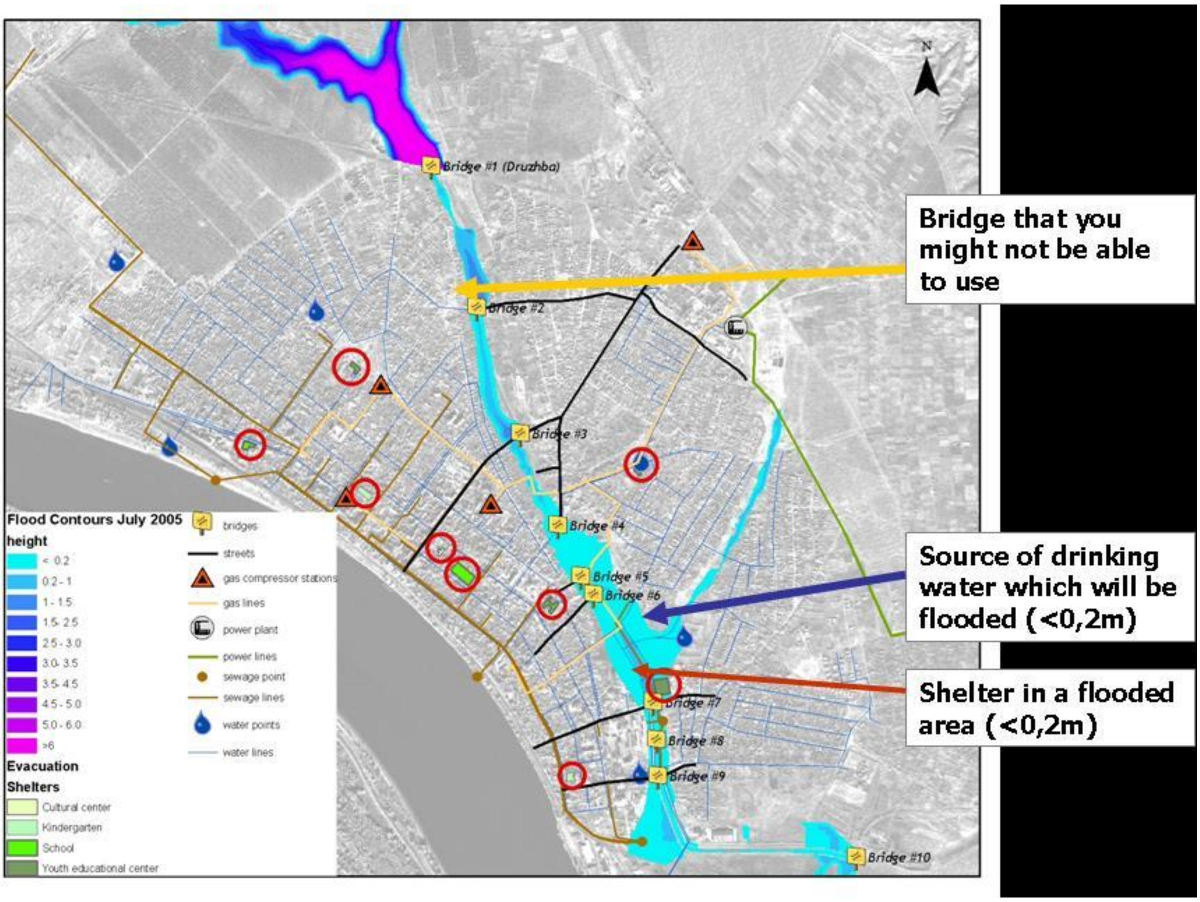

Fig. 185**:** Economic damage mapping [3]

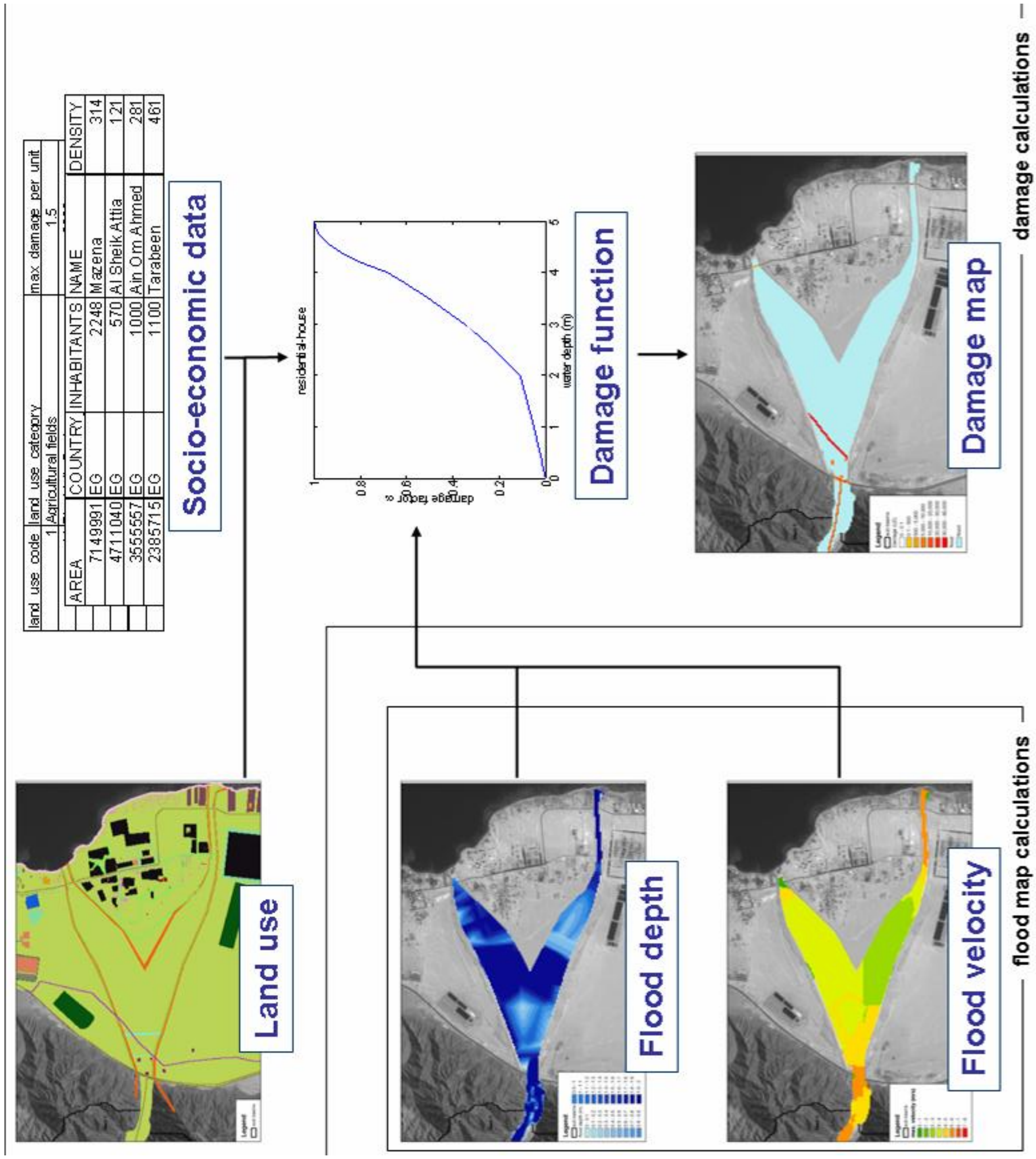

Fig. 186: Methodology of potential flood damage assessment [3]

5.9.5 METHODS AND MODELS OF FLOOD FORECASTING

Currently peak forecasting and continuous forecasting methods are used. Peak forecasts (only the peak water stage and/or discharge values are forecasted, along with the expected time of the peak. Stochastic and graphic methods, based on water stages, are used. There is no information about the flood hydrograph in the peak forecast);

Continuous forecasts (certain parameters of the total flood hydrograph (mainly water stage and/or discharge) are forecasted in discrete time intervals. The time interval is usually determined by the measurement interval of available hydrometeorological data).

Because of the fast accumulation processes rainfall-runoff models are used for middle and lower sections of rivers. The methods used are based on the method of water balance and the actual calculation algorithm varies depending on the nature of the runoff (snow melting, rain, or the two combined). The presently used models were elaborated mainly by the Ukrainian Hydrometeorological Research Institute located in Kyiv.

5.9.5.1 Levels of flood alerts system

The alert system consists of Level I, II and III disaster control.

Level I – water level in rivers and canals reaching bank levels;

Level II – at river overflow of booms, partial inundation of arable lands;

Level III – river level is as close to the crest mark of flood protection dike as 70 cm.

5.9.5.2 National standards and guidelines related to structural flood management

Determination of design flood is standardized in a standard issued in 1982, regulating the loads and influences on hydro technical structures. The calculated maximum discharge of the 1% probability Q1% is used as the design flood discharge. Calculation is made using Q1% = f (A, q) type concentrated parameter function. Recalculation of runoff coefficient and separation of methods to be used in different tributary catchment with different extension was made. A design flood level is determined using rating curves along rivers.

Today passive flood protection with dams constructed in different years and for different water levels in the rivers (different probability level), cannot always guarantee protective functions even after its further reconstruction. It is impossible to solve the problem of flood protection only by using engineering facilities. Costs for eliminating harmful effects of floods increase greatly, if natural factors are not considered, if money is spared on preventive actions providing the ecosystem sustainability. There is a need for introducing comprehensive system of risk management and coordination in emergencies and flood warning on a transboundary level.

5.9.5.3 Flood risk assessment

The flood risk assessment is provided in 4 steps.

1) determining the probability of floods;

2) determining the flood extent and the flood depth;

3) determining the economic and social damage due to floods

Calculation of potential average annual individual risk for life from flooding

$$Ris(f) = P \cdot ((Nsf / Tf) \cdot Vtf \cdot Vsf \cdot Vsd \cdot (1 / Ns) + Ris(af>2))^* \qquad (106)$$

P - average likelihood of flooding due to flood or hydraulic failure;

Nsf - population in the settlements that can get in the zone of flooding;

Tf - the total time during which keeps flooding;

Ns - number of the region where the risk assessment;

Vtf - vulnerability of the population depending on time of wave approach;

Vsf - vulnerability of the population depending on age;

Vsd - vulnerability of the population depending on the depth of flooding;

Ris (af> 2) - a potential individual risk of life from potentially dangerous objects that were flooding into the area> 2 m

5.9.5.4 Methodology of calculation of number of monitoring stations

Floods are the most dangerous natural disasters from the point of view of the territory affected and duration of damaging factors. Well planned, clear and timely implemented activities can provide an opportunity to avoid large population losses and significantly reduce economic damage.

In order to minimize floods negative impacts the following functional can be used [4].

$\min\limits_{L,H,V} F(P,E)$.		(107)

where:

P - number of the affected population ;

E - economic damage of floods.

It should be noted that in most cases the direct damage is considered arising from direct physical contact of floodwater with economic objects. Amount of damage is determined by the cost for restoration of economic objects according to the current market value of destroyed or damaged economic objects – agriculture lands, housing, residential buildings, bridges, roads and railways , communication lines and electricity, gas and oil pipelines.

Indirect damage calculation methodology is completely non-existent in Ukraine. Floods indirect damage may affect the territory for many years after the flood.

In order to minimize the adverse effects of floods this is important to define number and placement of monitoring points and technical possibilities to collect, transmit and process hydrologic data. Thus, to define number and placement of monitoring point the next methodology is used:

$\min\limits_{W_1} N$,		(108)
where: W_1		
$S_i'(L,H,V) \in \bigcup\limits_{l=1}^{r} T_l,\ i=1,\ldots,N'$;		(109)
$S_j''(L,H,V) \in \bigcup\limits_{k=1}^{q} D_k,\ j=1,\ldots,N''$;		(110)
$S_0 = \left(\bigcup\limits_{k=1}^{q} D_k\right) \cap \left(\bigcup\limits_{l=1}^{r} T_l\right)$;		(111)
$N = N' + N''$;		(112)

$Q\left(\bigcup_{i=1}^{N'} S_i', \bigcup_{j=1}^{N''} S_j''\right) \le Q^*.$		(113)

It should be noted that this is necessary to determine the minimum number stationary points N 'and mobile points N" (4) taking into account the next restrictions:

Stationary monitoring points are placed at the possible areas	$\bigcup_{l=1}^{r} T_l$	Eq.(109)
Mobile monitoring points are placed at the areas	$\bigcup_{k=1}^{q} D_k$	Eq. (110)
S_0	Area of monitoring points which can provide hydrologic data adequate, accurate and timely	Eq. (111)

Cost for operation of monitoring points Q shall not exceed the max rate Q * (Eq. (113)).

5.9.6 REFERENCES

Hydrometeorological monitoring network of the Danube Hydrometeorological Observatory, www.dhmo.org.ua/

The use of satellite imagery to multi-event and event-specific flood hazard mapping, www.un-spider.org/page/5381/use-satellite-imagery-multi-event-and-event-specific-flood-hazard-mapping

Joint environmental monitoring, assessment and exchange of information in order to integrated management of the Danube delta region, www.crs.org.ua/ru/5/current/150.html

Task of detecting and liquidation of emergency consequences of hydrodynamical emergencies of landscape type, www. nuczu.edu.ua/sciencearchive/

5.10 CONCLUSIONS: METHODOLOGIES USED TO ASSESS FLOOD HAZARD

A review of Flood Hazard (FH) assessment methodologies used in Greece, Bulgaria, Romania, Moldova, Ukraine and Turkey, provided the ability to overview their input requirements and their outputs. As it appears, the flood hazard assessment and flood modeling methods that have been used follow more or less the same scientific and technical trends as in the rest of the world.

The review of the activities taken in each of the participating countries regarding the Flood Hazard (FH) and Risk assessment reveals that there are differences in the methodologies which have been used to assess those parameters, even between research projects carried out in the same country. On the other hand, there is a large number of projects already carried out, with very important results which have been used to tackle the Flood Hazard problem in large rivers.

In respect to floods occurring in large rivers like the Danube and Evros/Matitza/Meric rivers, located within the eligible Programme area, there have already been several projects concluded, which led to a systematic hazard assessment and even to the installation of early warning systems in both rivers.

In particular, the project Danube FloodRisk appears to be an excellent implementation based on a complete consensus between involved countries which led to transparent cross border cooperation. This seems to be the essential parameter which is a prerequisite to successful cross border flood hazard and Risk assessment for the selection of the appropriate flood disaster mitigation measures. Based on that principle, scientifically sound, worldwide used and accepted methodologies were used to assess Flood Hazard and Risk and to create the respective maps for the Danube river wider area.

In respect to river Evros/Maritza/Meric, there have also been various methodologies applied to assess Flood Hazard and Risk. Geomorphology and hydraulic models have been used to assess FH in Ardas river (a tributary of Evros). Hydraulic models have also been used with data input from measuring stations across the entire river, during the implementation of a number of research projects. All of these have provided detailed information regarding the flood hazard and risk in Evros/Maritza/Meric river. The problem which still remains and prevents an effective flood disaster management is due to the lack of a complete consensus which will lead to a close cooperation between the riparian countries. As already mentioned, this is an essential prerequisite to manage the FH and Risk over the entire river basin and to plan effective prevention measures. This seems to be a political problem due to: the lack of a legal framework for cooperation; the lack of capacity and resources; the lack of trust; differing institutional structures; the lack of political "will" and to the lack of public awareness and participation.

Thus, a top level political agreement of the three neighbour and co-riparian countries is a first priority necessity. As the problem has not been solved for a number of years, it seems that the only way to reach such an agreement is the involvement/interference of a third party, which should be accepted by all of the riparian countries (as it is, preferably, the European Union). Hydro-diplomacy concepts (as the "all win" and "benefit sharing") should be followed so that all countries will enter willingly in an effective negotiations process for reaching a sound agreement over the management of the whole Evros/Maritza/Meric river's basin flood problem. A first step of fundamental importance (which should be the result of the aforementioned political agreement) must be the establishment of an Evros/Maritza/Meric river's Commission as the institutional governing/managing body where the three riparian countries will be both politically and scientifically represented. The existing Commission models regarding the Rhine and Danube rivers may well act as guiding paradigms towards this goal.

Besides, the UNECE "Water Convention" principles, the EU water related Directives and the "Good Practices" implemented in other EU trans-boundary basins should be taken into a serious consideration.

There are also some specific challenges in flood hazard assessment studies in the Black Sea countries such as the flash-flood problems, which mostly stem from the spatially diverse topographic and climatic characteristics of Turkey, Greece, Bulgaria and at a lesser extent, Romania, Moldova and southern Ukraine. Especially for Bulgaria, Greece and for the Black Sea region of Turkey, flash floods pose a very serious and permanent threat so far), causing every year serious and very costly damages.

As it appears therefore, the establishment of a political and/or scientific consensus regarding common harmonized approaches which will lead to common efforts to address the above mentioned problems is extremely important. This achievement will certainly help to protect, in an optimal way, human life, property and infrastructure and foster sustainable development in the area of reference as far as the various types of the flood hazard is concerned.

6 HYDROLOGIC AND FLOOD MODELING FOR IMPLEMENTATION (Activity 1.12)

6.1 PREFACE

Hydrologic Models have been developed for many reasons related to understanding the processes which take place into a watershed and the ability to forecasting such changes, as well as the hydrologic system’s outputs. Specific demands and applications, led to the development of respective models thus their great variety.

Floods as natural phenomena are closely related to hydrological processes. Flood occurrence, spatial distribution and flooding parameters are related to both climatic changes and surface water/soil interactions. The necessity to understand those complex, interrelated phenomena, led to the development of the respective flood hazard assessment models which in any case, strongly depend on hydrologic models.

The overview of the main methodologies and/or models used worldwide to assess flood hazard, provides a scientific basis necessary to better understand the flood processes and the uncertainties in flood hazard mapping.

At a later stage, the selection of the methodology to be used over an extended area, as in the present case, must be based on the evaluation of those methodologies in terms of their adaptability to local conditions and the reliability and accuracy of their outputs by taking at the same time into consideration, their data/input requirements as compared to data actually available.

6.2 EVOLUTION OF HYDROLOGIC MODELING-CURRENT TRENDS

A brief historic overview of Hydrologic Modeling evolution reveals the way those models have evolved during the past century as well as the current and future trends in modeling hydrologic processes including floods.

The first appearance of a hydrologic model was in 1850, when Mulvaney [1] suggested an equation (the rational formula) to estimate the peak flow as a function of runoff coefficient, intensity of rainfall in time and the catchment area.

During the 1920’s, the rational formula which was limited to use in small catchments, was modified to cover larger areas. At that time, the first rainfall-runoff model and the use of Manning’s (or Gauckler–Manning–Strickler formula) to estimate various travel times, was developed.

During the next decade (1930’s) the concept of the unit hydrograph was introduced [2].

The conceptual models originated during the 1950's. The use of mathematical techniques to analyze input and output data as well as the unit hydrograph, lead to the derivation of additional response functions.

During the next two decades (1960's & 1970's) an effort to better understand hydrologic processes led to the development of a large number of conceptual, lumped, rainfall-runoff models including: Stanford Model IV (1966) [3], Sacramento (1973) [4], Tank model (1975) [5] and the HBV (1977) [6]. An effort has also been made to use a statistical approach to assess hydrologic processes and especially floods, like the ARMA or ARIMA model (1970) [7], which applies autoregressive moving average ARMA or ARIMA to calculate the best fit over a time series to past values of this time series, in order to make forecasts. Real time forecasting models developed especially to be use for early warning/protection from floods were developed [8]; [9]; [10]. During the same period, the idea that topography regulates surface flow led to the development of the TOPography based hydrological MODEL (TOPMODEL) [11], which can calculate the unit hydrograph and has been used to assess flood prone areas.

During the 1980's, the expansion of societies brought land use changes caused the spatial variability of various parameters which needed to be assessed, and created the necessity to assess hydrologic processes and the flood hazard in ungauged basins. This led to the development of the physically-based distributed-parameter models. This approach can utilize a combination of variables interlinking them according to the model provisions. This was a great step forward in hydrologic modeling as it provided the ability to combine hydrologic data, Digital Elevation Models (DEM), vegetation cover derived from satellite images, with soil moisture patterns and hydro-geologic information (Systeme Hydrologique Europeen-SHE, 1980) [12].

During the next decades up to present, the interest is directed mostly to water resources management and to environmental problems related to pollution. Models developed during this period are in general macro-scale models, focusing on assessing the spatial variability of hydrologic resources and parameters, over large areas and over time [13].

6.2.1 HYDROLOGIC/FLOOD MODEL CLASSIFICATION

The great complexity of Hydrologic processes related to floods, the variability of potential applications, the availability of required input and the evolution in mathematics and in computer systems has led to the development of a multitude of Hydrologic Models. Each one of them is trying through assumptions, abstraction and simplifications, to simulate hydrologic processes taking place in a watershed and to assess the respective outputs concerning flood hazard [14].

Flood Hazard assessment model classification can depend on various parameters thus the variety of existing classification schemes [15], [16], [17], [18], [19].

The USGS proposed classification scheme, which is based on the accuracy level is presented in the following pages.

6.2.1.1 USGS proposed flood hazard assessment classification scheme

According to the Flood Hazard assessment model scheme proposed by the US Geological Survey (1988), the methodologies used to assess the flood hazard (FH) and to delineate the flood extent are grouped in 3 categories [20]; [21] according to their accuracy level: comprehensive, intermediate and approximate).

The “statistical” methods which are based on historical data, fall into the first category of “comprehensive” methods. The “analytical” and “physiographic” methods are classified as intermediate methods, whereas the “reconnaissance” is considered as an approximate method (Fig. 187).

The analytical and physiographic methods require the determination of the maximum discharge within a given return period (T-years discharge). Once the peak discharge is obtained, the basic steps to follow include the determination of a water-surface profile or/and water depth and the development of a flood-boundary map (for the T-year discharge calculated).

T-year discharge evaluation is the subject of a flood frequency analysis. Flood frequency analyses use different approaches which depend on the available data. For gauged watersheds, an empirical or a theoretical distribution can be computed. In the USA the log-Pearson III distribution, as proposed by the US Water Resource Council (Bulletins 17 A and 17B), is being used [22], [23].

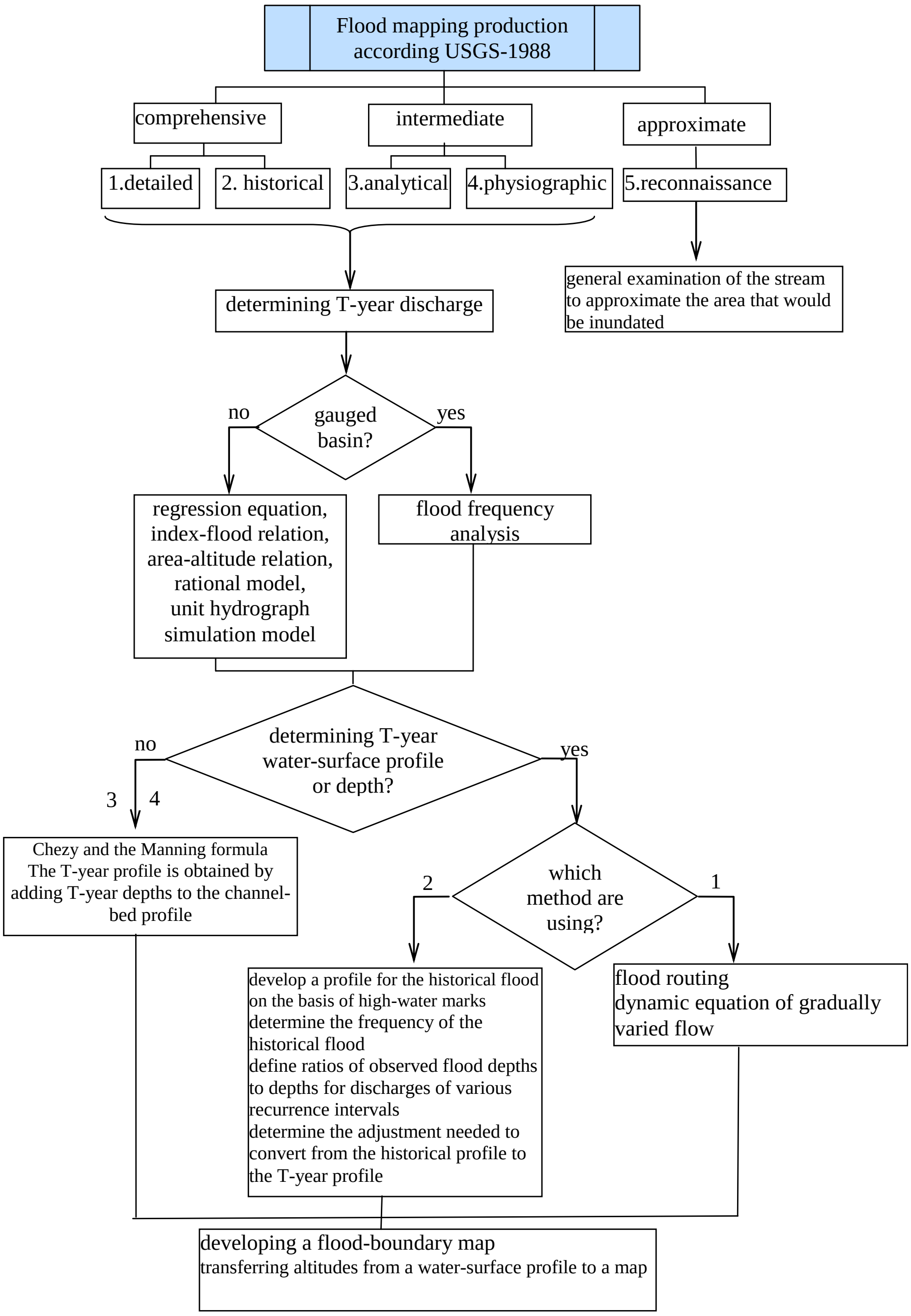

Fig. 187: Classification of Flood Hazard assessment methodologies according to their accuracy (USGS, 1988)

According to the "detailed" methods, there are two ways of calculating the water surface profile: flood routing [29] and the dynamic equation of gradually varied flow [30]; [31].

The Chezy and the Manning formula have also been proposed to assess the same parameter according to the "analytical" methods [30].

Finally, according to the "historical" methods, the profile of the water surface can be estimated using high-water marks from previous flood incidents. Adjustments are required in this case to adjust the historical profile to the T-year profile (Fig. 187).

6.2.2 FLOOD HAZARD ASSESSMENT METHODOLOGIES ADOPTED BY AGENCIES AND ORGANIZATIONS

6.2.2.1 Federal Emergency Management Agency –FEMA (USA)

The National Flood Insurance Program (NFIP) of the Federal Emergency Management Agency -FEMA) [27]; [33] has adopted as the basic procedure to use for flood hazard assessment the following: (1) to calculate flood discharge for different flood frequencies, magnitudes or recurrence intervals and (2) to determine water surface profiles/elevation (Fig. 188).

Adopted by the FEMA's models are posted on the address http://www.fema.gov/national-flood-insurance-program-flood-hazard-mapping/hydrologic-models-meeting-minimum-requirement

In general, the most commonly applied techniques by various Organizations, used to define flood probabilities are:

1. Statistical analyses of stream-flow records -used for gauged basin/station and based on Bulletin 17 B (USGS). Computer programs for performing Bulletin 17B analyses are available from the U.S. Army Corps of Engineers (USACE) *HEC-FFA Frequency Analysis* (USACE, 1992) and the USGS *PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines* [22]. Guidance on frequency analysis can be found in USACE Engineering Manual No.1110-2-1415 [34].
2. Regional method (Kite, 1999, [35], Riggs, 1973; Tasker, 1982; Tasker and Stedinger, 1989; Tasker and Slade, 1994; Tasker et al., 1996; Law and Tasker, 2003; Law et al., 2009). This method can be used if the watershed characteristics of the ungauged sites are similar to those at the gauging stations used to develop the necessary equations (FEMA, 2002). The United States Geological Survey (USGS) has performed regression analyses and developed equations for floods of different frequencies for each hydrologic zone of the USA.

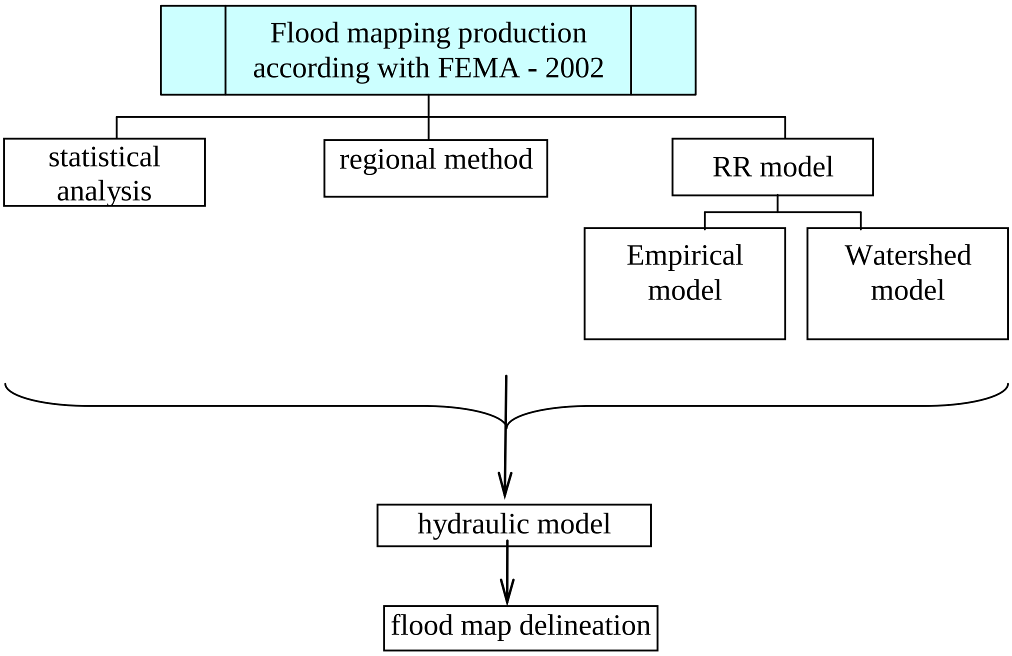

Fig. 188**:** Basic procedures adopted by the National Flood Insurance Program (NFIP) of the Federal Emergency Management Agency -FEMA), to be used for flood hazard assessment

In the Rainfall-runoff (RR) category of hydrological models, fall empirical models like the rational model [1] and the unit hydrograph [2]. In this category, the watershed model may also be included.

The hydrological models can also be classified according to the type of simulation they apply, into two categories: single or continuous event. Software as the WinTR-55 which has been used to apply empirical models, are available from the U.S. Department of Agriculture, Natural Resources Conservation Service.

Additional models include the HEC-HMS of the Hydrologic Centre at the US Army Corps of Engineers (http://www.hec.usace.army.mil/software/hec-hms/), the Storm Water Management Model-SWMM of the Environmental Protection Agency, USA (http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/) and MIKE 11 (http://www.mikebydhi.com/).

Concerning the water surface profile, FEMA has proposed one of the following methods [32]:

- Normal-depth calculations using Manning's Equation integrated in HEC-RAS (UASCE, 2010) model

- Highway culvert nomographs from *Hydraulic Design of Highway Culverts* (Federal HighWay Administration, 1985); or the
- Hydraulic analysis program "Quick-2" (NASA), which may be used to compute both critical and normal depth.

FEMA has also recommended the implementation of a GIS tool to create cross-section and structure data for the HEC-RAS program in order to perform water surface elevation.

The HEC-GeoRAS (http://www.hec.usace.army.mil/software/hec-georas/) tool exists as an extension to ArcGIS and allows the design of the components of the topographical model and their automated export to HEC-RAS. These data are imported into HEC-RAS for the implementation of the model.

6.2.2.2 Associated Programme on Flood Management (APFM)

An interesting approach to assess flood hazard is suggested by the Associated Programme on Flood Management (APFM), which is a joint initiative of the World Meteorological Organization (WMO) and the Global Water Partnership. The main purpose of this effort was to promote the concept of integrated flood management.

In the report "Integrated Flood Management Tools Series: Flood Mapping" [5] published by the aforementioned Organizations, the various tasks necessary to perform a flood hazard map are proposed. According to the report, there are two basic steps: the first is the determination of discharge and hydrographs, and the second is the delineation of the flood prone area.

In order to conclude the first step of obtaining discharge and hydrographs, there are two basic methods available: (1) the flood frequency analysis - observed and simulated; and (2) the physically based hydrological model method. The hydrograph for given return periods is the outcome in both cases independently of the selected method.

According to the same report, the following classifications and return periods are proposed: frequent event (Q10); rare event (Q20 to Q30); very rare event (Q50 to Q100); extreme event (Q300, Q500 or Q1000).

Concerning the location and delineation of the flood prone area, the same report purposes three different ways to develop flood hazard maps:

- The "Historic" approach, which is based on past flood events.
- The "Geomorphologic" approach: floods and flows leave distinct marks in the landscape. All the information provided from various sources (remote sensing images, orthophotos, field observations) may be superimposed in order to develop a comprehensive description of the evolution of the river.
- The "Modeling" approach: hydraulic models are applied to simulate floods.

The historic and geomorphologic approaches are mostly used in the preliminary stage, whereas the modeling approach is mainly used in the detailed mapping stage.

This modeling approach is schematically described in a very suggestive Fig.ure, which is reproduced in Fig. 189.

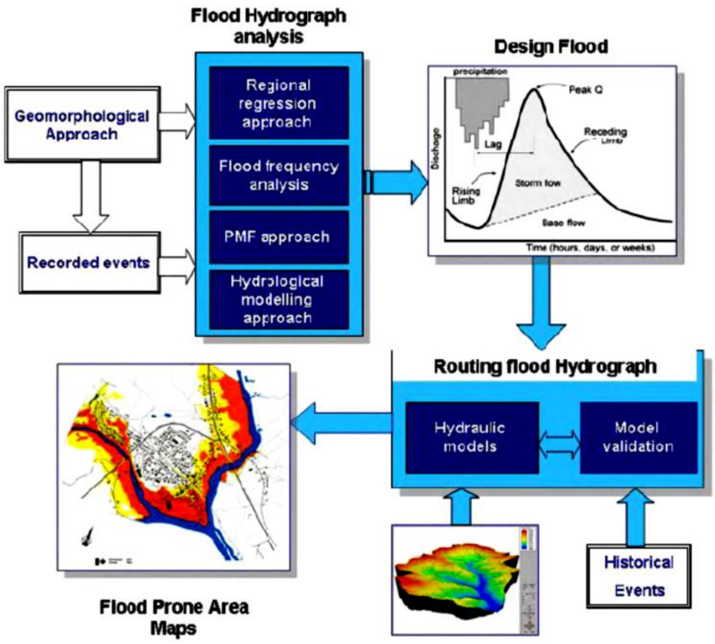

Fig. 189:. Flood Hazard Modeling approach as suggested in the Associated Programme on Flood Management (WMO-World Meteorological Organization and the Global Water Partnership, 2013)

6.2.2.3 European exchange group on flood mapping (EXIMAP)

As is obvious, all methodologies provide information of variable reliability and accuracy regarding the assessment of FH making the selection of the most "appropriate" methodology very difficult.

A very helpful tool to assess the main parameters required to effectively mitigate flood hazard is the "Handbook on good practices for flood mapping in Europe", Excimap [36]. EXCIMAP is a European exchange group on flood mapping. The work of EXCIMAP started before the flood directive issue. This document is not a guide, but it contains the experience gained of mapping floods in 19 European countries, Japan and USA. A lot of valuable information can be found in the report, including key words used to define the main types of floods, type of flood maps currently produced in Europe, and comments on the production of flood maps.

Concerning the production of flood hazard maps the report proposes the use of the hydrological model and the hydraulic model method.

In respect to the hydrological model, various rainfall-runoff (RR) models or statistical models are used to determine the hydrological parameters of the flood. The most widespread RR models in Europe are HBV- Hydrologiska Byråns Vattenbalansavdelningi- (Lindström e. al., 1997) proposed by Swedish Meteorological and Hydrologic Institute (SHMI) and used in 40 countries, LISFLOOD (De Roo, et.al., 2000, van der Knijf et al., 2008) and TOPKAPI (Todini and Ciarapica, 2001; Ciarapica and Todini, 2002).

The related parameters to flood hazard in open floodplains, as they are provided by the hydrodynamic models are: (i) the level of inundation, (ii) the intersection of flood level with terrain (creates flood extent), (iii) the flood depth as the difference between the flood level and the terrain surface, and in case of applying a 2D model, (iv) the distribution of the flood velocity.

These parameters may be described either by one dimensional (1D) or by 2D mathematical models. There is a wide range of tools for applying these methodologies including: Mike11, Telemac (http://www.opentelemac.org/index.php/presentation?id=17) and HEC-RAS.

6.2.3 MORPHOLOGY BASED MODELS

Flash floods occur in a very broad area around the Black Sea, in ephemeral streams and in various locations. Their occurrence is mostly related to sudden and intense rainfall and the respective watershed's morphology.

As flash floods mostly develop on ephemeral streams, little or no runoff data are available so, statistical, probabilistic or hydrologic models used elsewhere to locate flood prone sites over broad areas in order to assess the flood hazard cannot be efficiently applied in this case.

Moreover, as systematically acquired data usually do not exist, it is very difficult to implement hydraulic model analysis in all those watersheds on an "entire watershed" basis. Limiting the number of possible flood occurring sites, can provide the ability to focus on the flood prone areas, then classify them in terms of hazard and risk potential and finally focus on the most interesting ones.

In such cases, morphology based can be used to pinpoint the probable location of flooding so that, at a second stage, hydraulic models can be applied in those specific areas. In this way the time and economic costs for a systematic data acquirement can be significantly reduced without compromising the results.

An important parameter in the occurrence of a flooding event is the presence of sediments transported by the river/stream water. For this reason, soil erosion maps created using the widely accepted methodologies (ie. RUSLE equation) can help delineate areas within the watershed, where outcrop geologic formations of high erodibility and thus support decision making regarding the optimal location of sediment retention structures.

As far as the morphometric based methologies are concerned, the Topographic Wetness Index (TWI) has been proposed to predict quick response flow by using morphometric parameters [11]; [28]; [46] but has been used since then to delineate flood prone areas [47]; [48]; [49]; [50].

The SAGA Index [57] is very similar to TWI, but it is considered to predict for areas (cells in a GIS), a more realistic and higher potential soil moisture than the TWI.

6.2.4 DATA AVAILABILITY AND FH ASSESSMENT MODELS

From the respective conceptual framework (Fig. 190) it appears that flood hazard mapping strongly depends on data availability which defines at large, the methods and models which can be used. Data availability plays a decisive role when evaluating methodologies in order to select the one to use which is always, the most "appropriate" one from a "feasibility" perspective.

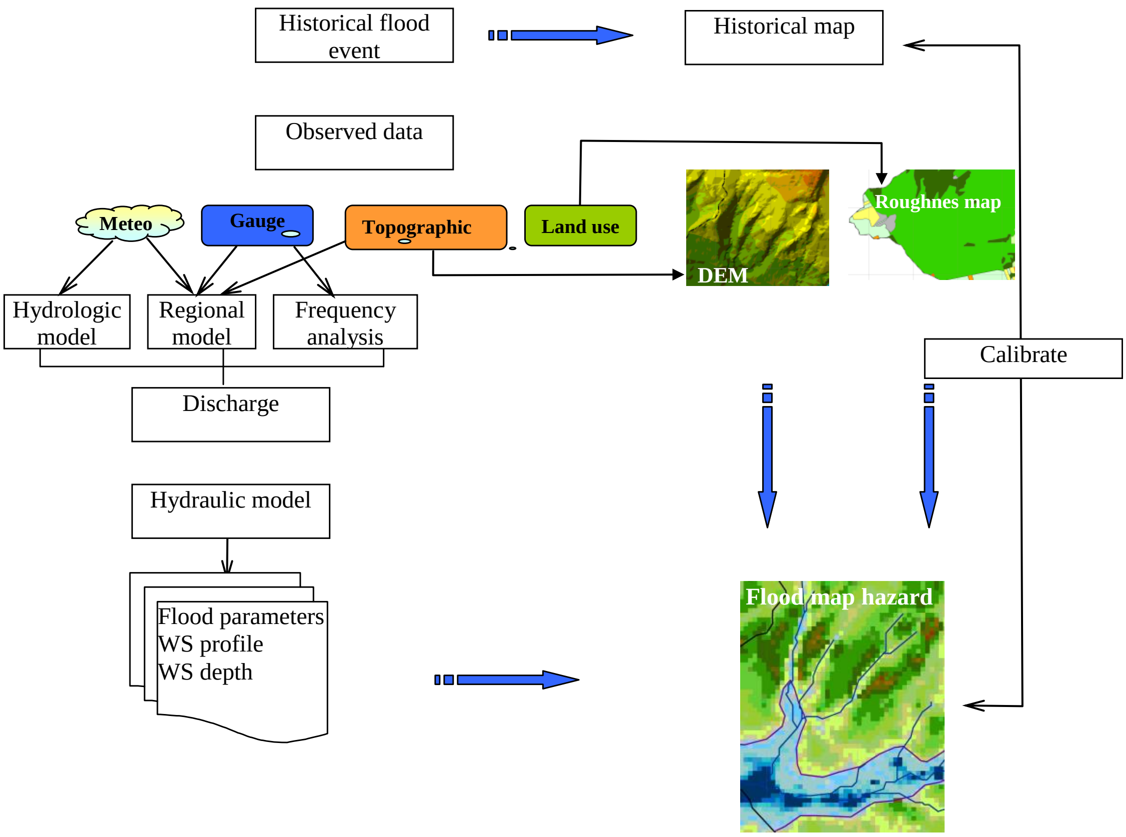

Fig. 190: Conceptual framework for flood hazard mapping

Basic data requirements to implement FH methodologies include systematically collected, reliable and accurate rainfall, hydrologic and Topographic data.

Topographic data are necessary in all cases, regardless of the area of implementation (urban, rural). Topographic maps in various scales related to the scale of implementation, ortophoto maps or remote sensing data (like ASTER DEMs, SRTMs) are the main source of information. Topographic maps in medium scales (smaller that 1:1000) usually provide inadequate information when trying to apply hydraulic models in order to assess flood parameters at local scales.

As suggested by the WMO (2013), Digital Elevation Models (DEM), derived from photogrammetric methods provide an accuracy of +/- 1.0 m or worse. On the other hand, DEMs derived from LIDAR scans are very accurate but the cost of data is very high.

Hydrological data are also very important in order to estimate the peak discharge. From a statistical point of view, duration of the stream flow measurement time series should be as long as possible. In general, 30 years of continuous measurements are recommended [51].

To estimate the peak discharge for given return period, several methods can be used: flood frequency analysis if the discharge data are available; regional methods and hydrological models may be used when the discharge data are not available but other data (meteorological, topographic, land cover, soil, etc.) exist.

Land use and cover are also necessary in applying hydrological and hydraulic models. These data offer essential information regarding the roughness coefficient which one of the requirements in certain cases.

In any case, the type and the specifications of the required data, strongly depends on the complexity of the model selected to be used.

6.2.5 CONCLUSIONS

The overview of the methodologies used worldwide to assess flood hazard provides the necessary information to better understand hydrologic processes which lead to flooding and estimate the uncertainties related to flood hazard mapping.

Flood hazard (FH) maps must provide information about the area affected by floods in terms of the probability and the magnitude of a flood event. According to the Flood Directive (2007/60/EC), the following scenarios must be considered: frequent event (high probability) medium event (medium probability - 100 years) and extreme event (low probability - 1000 years). For each scenario, the hazard maps created must provide information regarding the flood parameters including: the flood extent (inundation area), the flood water surface depth/level, and the flood water velocity if it can be assessed.

In order to map flash flood hazard on a systematic way, considering the extent of the area and the vast number of watersheds where a potential risk exists, a two step procedure is proposed: location of the flash flood prone areas at the first step using widely accepted, tested and used methodologies based on readily available topographic data in order to limit the number of the areas where data must be systematically acquired; and implementation on local/site-specific scales using hydraulic models in order to assess the flood parameters and provide support to make decisions regarding prevention measures.

To conclude, mapping the FH is a four-step procedure regardless of the methods used to assess it:

1. **Historical events mapping**. This step is very important in the calibration stage. Due to GIS and remote sensing techniques, the flood extension maps can be fairly easily obtained. Despite the importance of this stage, flood inventories are not available in all countries and even if available they are rarely easily accessible.
2. **Locate and delineate the flood prone areas**. Easy to implement, data are readily available for implementation in regional scales (1:50 000 or less).
3. **Estimate the peak discharge for different return periods.** Data from gauging stations are necessary for this step. The flood frequency analysis can be used to fit the best probability distribution. If the watershed is ungauged, a regional model (equation regression) which will make use of different data if available (rainfall, topographic, etc.), can be used despite the fact that discharge data are obtained by hydrological models.
4. Once the peak discharge has been estimated, 1D or 2D hydrodynamic models are used in order to **estimate** the **flood parameters**. The **inundation area** is delineated by combining the flood parameters (water level) with accurate enough Digital Elevation Models (DEM). For that reason, most of the contemporary hydraulic models possess DEM use/processing abilities.

6.3 HYDROLOGIC AND FLOOD MODELING IN LARGE RIVERS

6.3.1 THE DANUBE FLOODRISK PROJECT

The Danube FloodRisk project is an example of a successful implementation of Flood Hazard (FH) and Risk Mapping in cross border areas. The project which has already been implemented was included in the selection of the most appropriate methodologies to be used for FH assessment. The following paragraphs are related to that project and have been provided by M.J. Addler through internal communication [52]; [55].

6.3.1.1 Harmonization of methods for processing of hazard maps along the Danube

In general, the methods used for the processing of hazard map data predetermine the quality of the results. The application of different methods might be appropriate if carefully assessed, but more usual is the harmonization of methods which covers: quality management, damage assessment, modeling techniques and model border conditions, scenario definition and simulation methods.

6.3.1.2 Hydraulic modeling techniques

There was a discussion on using steady or unsteady hydraulic models for the flood hazard mapping. Austria and Slovakia intend to use steady models 1D and 2D models in most of the cases. The other riparian countries downstream of Gabcikovo will use 1D and 2D unsteady models for simulation.

The conclusions of this discussion were:

1. For high (1:30 years) and medium (1:100 years) probability floods:
    a. Use of 1D steady backwater curve calculations are recommended (it is agreed that these floods will be contained between dykes)
    b. 2D steady models can be used where appropriate (wide floodplain, high damage potential, detailed study etc.)
2. For low (e.g. 1:300 years; 1:1000 years) probability floods:
    a. General recommendations for the 2D hydraulic models
        i. Flooding & drying option needed
        ii. Option to represent linear structures
        iii. Present references on reproduction of velocity distribution
        iv. Prove that a dense enough grid size is used (e.g. presenting series of results of systematic grid refining)
    b. For the simulation of the inundation of the protected floodplain use of a combined unsteady "1D-Breach-2D model system" is recommended
    c. For the 2D unsteady hydraulic model the ability of handling flooding and drying processes is a prerequisite.
    d. For Austria and Slovakia:
        i. The use of 2D steady models on the floodplains are recommended
        ii. 1D steady model can be used on the floodplain depending on the financial and human resources, low damage potential etc.

e. For Hungary:

   i. For medium and high probabilities of exceedance, the floods will remain between dykes.

   ii. For 0.1% probability of exceedancea combined unsteady "1D-Breach-2D model system" will be used.

f. For Serbia:

   i. 1D steady model can be used.

   ii. Quality requirements for the 2D hydrodynamic model (See General recommendations above)

g. For Romania and Bulgaria:

   i. 1D unsteady model will be used all along the Danube. In areas with high vulnerability a quasi-2D unsteady model is recommended.

6.3.1.3 Boundary conditions for the hydraulic modelling

For hydraulic simulations, the hydrologic data represent boundary conditions. According to the type of the hydraulic simulations (steady or unsteady state) only the maximum discharge $Q_{P\%}^{max}$ corresponding to a given probability of exceedance (P% = 33%; 1% and 0.33/0.1%) or the whole hydrograph $(Q(t))_{P\%}$ of the flood wave for the same probabilities are necessary.

The statistical values $Q_{P\%}^{max}$ can be obtained by selecting each year the maximum annual discharge, or keeping only the maximum discharges over a threshold.In the latter case, in some years more than one flood will be selected, while in other years without significant floods no value will be kept for statistical processing.

In the case of unsteady simulations, the whole hydrograph $(Q(t))_{P\%}$ is necessary. A family of floods $(Q(t))_{P\%}$ for the same probability of exceedance P% can be obtained using either a Markov chain based generation algorithm or a classic statistical processing. Even if the mathematical approach is different, the philosophy behind the family of floods is the same: more than one synthetic flood $(Q(t))_{P\%}$ can be defined for the same return period. According to their characteristics, some of the synthetic floods will be run for flood propagation, while others will be used for the seepage computation.

In Hydrology two types of uncertainty can be identified:

Stochastic uncertainty (natural variability of maximum discharges and volumes)

Epistemic uncertainty (incomplete knowledge of the system: measurement errors, Plotting Position formulae, selection of data and partial series, selection of distribution functions, parameter estimation for distribution functions).In the frame of the latter, there are different sources of uncertainty:

a. Hypothesis concerning the extreme values (stationarity, homogeneity, independence);
b. Data sampling (period selection, selection of the maximum discharges)
c. Theoretical Distribution function (Pearson III, log-normal, Weibull, GEV, GPD etc)
d. Empirical Distribution Function (Weibull, Cunnane, Blom, Gringorten, Hazen, Cegodaev)
e. Parameters estimation (method of moments, maximum likelihood, principle of maximum entropy)
f. Stage-discharge relation: hysteresis during a flood wave; changes in river channel over time, measurements errors, parameters estimation, error in model selection, arbitrary prolongation of the stage-discharge relation for maximum stages.

Severe problems may occur when the uncertainty is ignored (especially for low probabilities).

6.3.1.4 Hydrological MODELS / METHODOLOGIES proposed

Generation of daily discharges

Hungary presented a model based on the generation of the daily discharges. (See Annex 1 and references: [53], [54]. Using daily data for a period of minimum 30-50 years, daily discharges for 10 000 years will be generated. The given approach also requires data sets (water level and discharge data for flood routing stations 2-10 years). From the simulated set of data, the floods with different return periods will then be selected.

Statistical processing

If only one distribution function is used in the statistical processing (for instance GEV distribution like in Austria) unique values are provided for the maximum discharges corresponding to different return periods. This approach is used extensively, mainly due to the fact that in current practice the design prescriptions have to be very clear. The design values (for instance the maximum discharge for 100 years return period) are considered as certain and unique values (like being deterministic values).

For the Austrian Danube the currently most suitable and used method is the AMS method - Annual Maximum Series. For this analysis there is only the highest annual maximum in use.

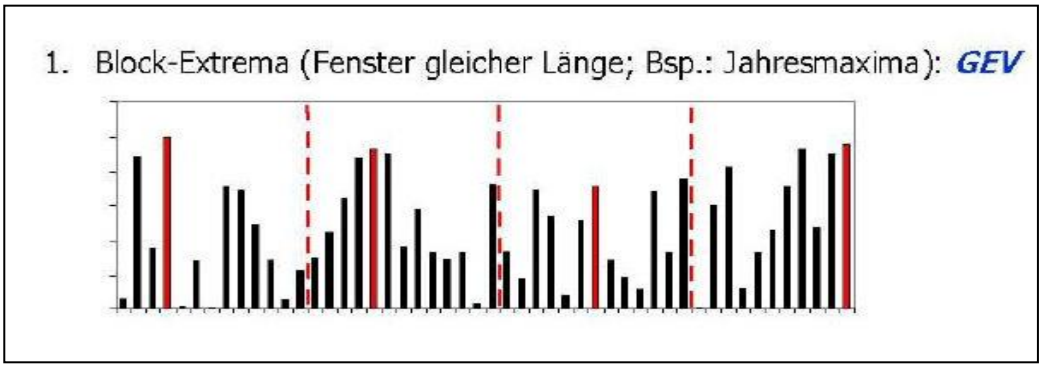

Fig. 191: Annual maximum series (AMS) – for each year one maximum value

For the analysis the generalized extreme value distribution – GEV method, with three different types (I-III), is in use (Fig. 191, Fig. 192). Type I (k=0) is the equivalent of the Gumbel distribution and provides good and rational results.

$$F(x) = \begin{cases} \exp(-(1-k\frac{|x-\xi|}{\alpha})^{\frac{1}{k}}) & \xi+\frac{\alpha}{k}\le x \quad k<0 \quad \text{(EV2 oder Typ II)} \\ \exp(-\exp(-\frac{x-\xi}{\alpha})) & x\in\Re \quad k=0 \quad \text{(EV1 oder Typ I)} \\ \exp(-(1-k\frac{x-\xi}{\alpha})^{\frac{1}{k}}) & x\le\xi+\frac{\alpha}{k} \quad k>0 \quad \text{(EV3 oderTyp III)} \end{cases}$$

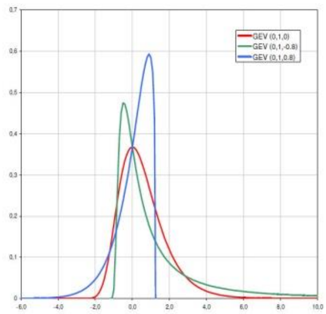

Fig. 192: Generalized extreme value distribution – GEV (I-III)

The data series of some selected gauge stations are going to be adapted to this distribution function (Fig. 193) and thereby the probability can be related to the discharge.

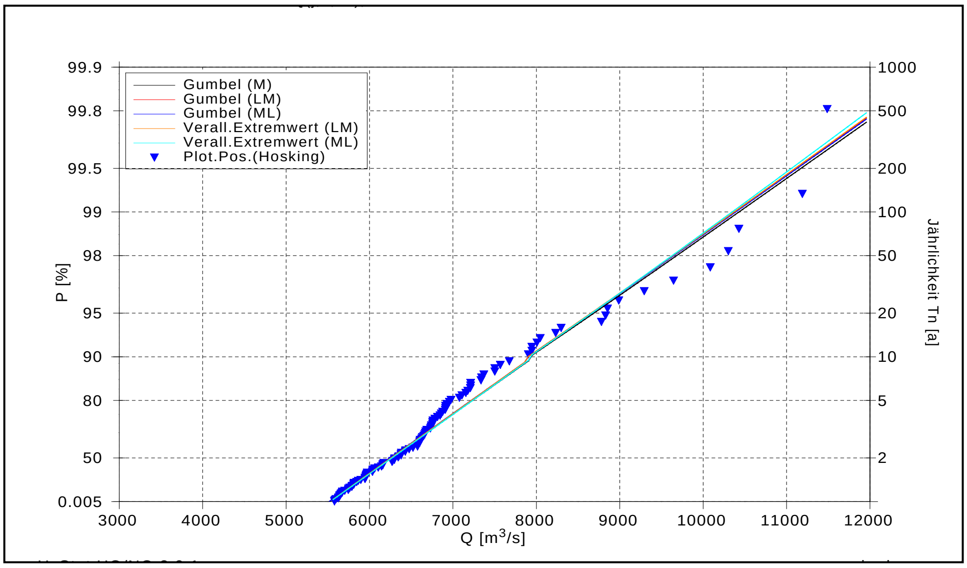

Fig. 193: Adaptation of data series

Another, more complex, approach is using different cumulative distribution functions that fit well the empirical distribution of the maximum discharges. Different values of the maximum discharges corresponding to the same probability of exceedance are obtained. The lowest and the highest values of these discharges define an interval of hydrologic uncertainty, denoted by $(Q_L^{max};\ Q_U^{max})_{P\%}$ where *L* and *U* mean the lower and the upper limits of the interval.

This approach represents in fact a generalization of the current practice based on a single distribution. Even if only one statistical distribution is used (GPD for instance) by increasing the threshold value for the selection of the maximum discharges an uncertainty interval will also be obtained. Of course, further statistical considerations should lead to a reasonable interval of uncertainty.

Similar considerations as for the uncertainty intervals of the maximum discharges may be made for the volumes of the flood waves. As a result, uncertainty intervals will be defined both for the discharges and the volumes of the flood waves: $(Q_L^{max};\ Q_U^{max})_{P\%,}$ and $(V_L^{max};\ V_U^{max})_{P\%}$ respectively.

At the same time, different shapes of the synthetic floods may be obtained based on a clusterization procedure applied to registered floods. Thus, the floods corresponding to a given return period are characterized not only by the maximum discharges, but by the whole hydrograph which has a shape and a volume. The hydrograph $(Q(t))_{P\%}$ is necessary in the case of unsteady simulations.

By using the uncertainty intervals of the maximum discharges and volumes a family of hydrographs corresponding to the same probability of exceedance P% can be obtained. The dykes' failure mechanisms produced by the flood waves are mainly: the crest overtopping and the dyke or foundation internal erosion. The crest overtopping occurs during high levels, corresponding to the maximum discharges $Q_{P\%}^{\max}$, irrespective of the flood volume. The internal erosion develops during long duration floods, which means high volumes of the flood waves, even if the maximum discharge is lower than the $Q_{P\%}^{\max}$.

In order to take into account the mentioned failure mechanisms, at least two flood scenarios should be provided for the probability of exceedance P%: the flood characterized by the upper limit of the maximum discharge and the lower value of the volume $(Q_U^{max}; V_L)_{P\%}$ and the flood corresponding to the upper limit of the volume and the lower value of the discharge $(Q_L^{max}; V_U)_{P\%}$ respectively. In both cases, the upper and the lower limits of the intervals for discharges and volumes are computed for the same probability of exceedance P%. This approach will be called the Synthetic Flood Procedure in the following section.

In conclusion, the hydrological processing can be performed at different degrees of complexity, depending on the future utilization of the results.

Synthesis of the hydrologic methodology adopted

The main steps of the statistical processing are the following:

1. Selection of the time series of the maximum discharges:
   a. Either the maximum annual discharges, or
   b. The maximum discharges exceeding a certain threshold value.
2. Statistical processing of the selected discharges.
   a. If maximum annual discharges were selected, then:
      i. only one distribution function is used for statistical extrapolation, obtaining a unique value $Q_{P\%}^{\max}$, or
      ii. a set of distribution functions can be used for fitting the empirical data, resulting an interval of uncertainty. In this case, some of the distribution functions can be discarded based on statistical tests (Kolmogorov-Smirnov, Anderson-Darling etc.). The extreme values (lowest and highest limits) for a probability of exceedance P% represent in fact the uncertainty interval of the maximum discharge: $(Q_L^{max}; Q_U^{max})_{P\%}$. It should be mentioned that the uncertainty interval is not similar with the confidence interval.
   b. If the maximum discharges exceeding the threshold value were selected, then by modifying the threshold value a different uncertainty interval for maximum discharges will be obtained.
3. After defining the interval of uncertainty for the maximum discharges

a. Either the Markov chain generation procedure is used to obtain the flood hydrographs

b. Or the Synthetic Flood Procedure is used for the same purpose, based on the following steps:

   i. Obtaining the uncertainty interval $(V_L^{max}; V_U^{max})_{P\%}$ of the flood volume for the same probability of exceedance P%.

   ii. Clusterization of the flood shapes

   iii. Preparing data for hydraulic simulations. If the hydraulic simulations will be in steady state, the hydrological data are already obtained. If the hydraulic simulations are in unsteady state, the whole hydrograph $(Q(t))_{P\%}$ is necessary. In the latter case, the hydrograph corresponding to the upper limit of the maximum discharges and the hydrograph having the maximum volume will be selected for further simulations.

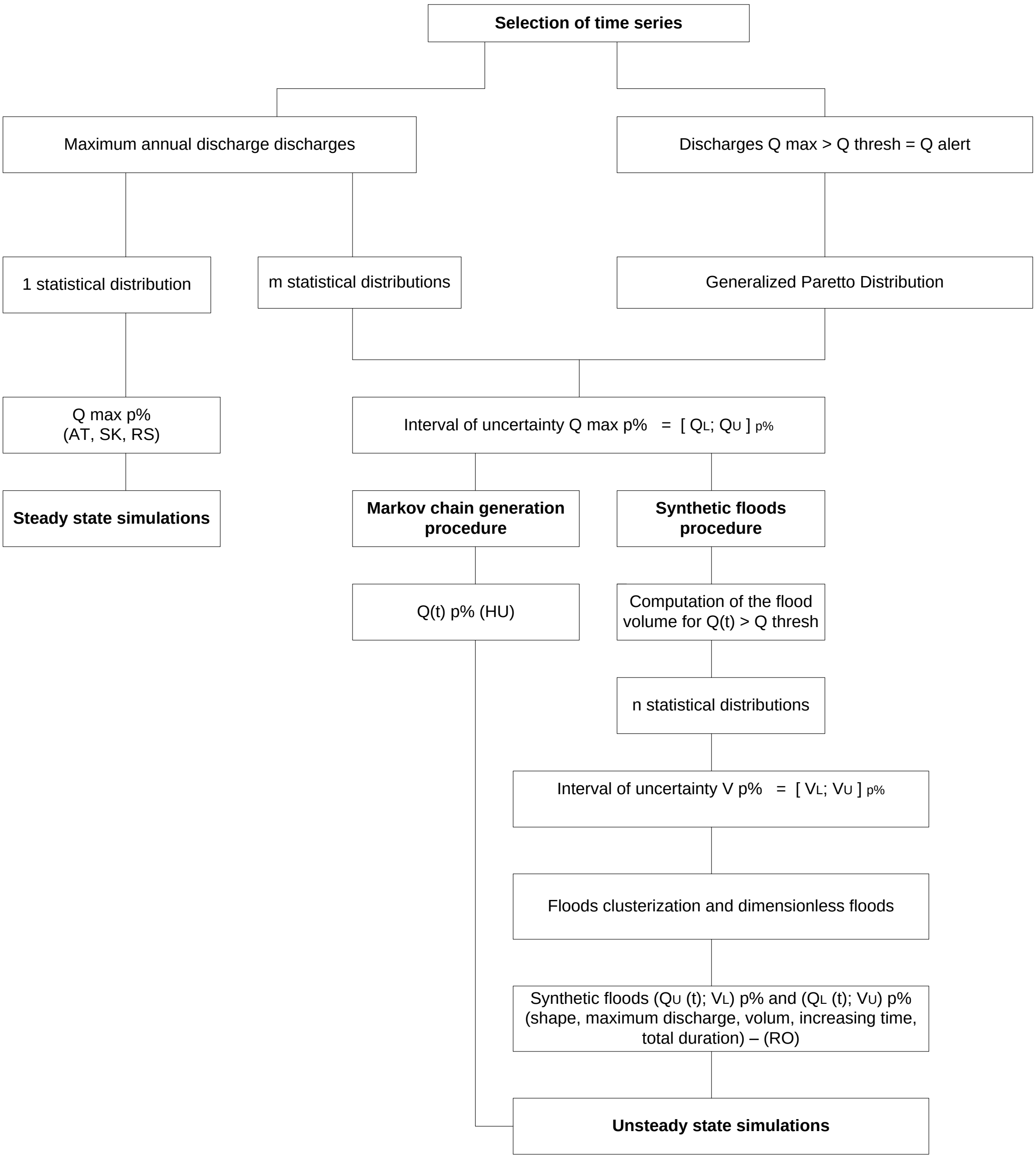

Fig. 194: Flowchart of the hydrological methodology

Scenario definition for the hydraulic modeling

Mountainous regions: Simulation using a 1D-steady state approach.

For regions in plains, either coupled 1D/2D or complete 2D approaches are used for dyke protected areas and there is a need to include dyke failure scenarios (Fig. 195).

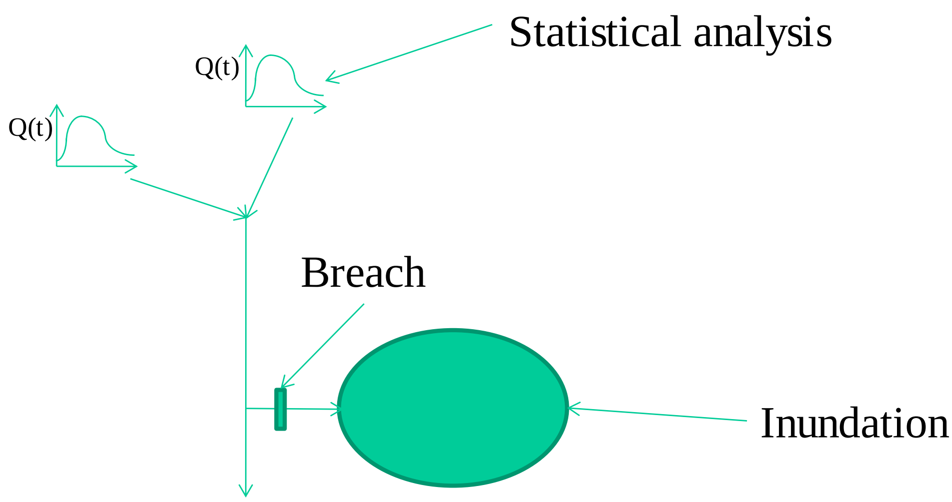

Fig. 195: A schematic representation of the model.

6.3.1.5 Simulation methods and model types used

In mountainous regions 1D model was selected. In Croatia and Serbia, coupled 1D-2D or pure 2D simulations for plain areas were selected.

6.3.1.6 Quality management

Detailed descriptions of all assumptions, are all result data complete, are all meta data available?

The following tests on the result data should be performed:

- Do the different data sets fit at the national borders?
- Are the different recurrence intervals consistent with each other?
- Are the former inundated areas (event data) covered by the extent of the extreme event?
- Visibility tests concerning artifacts of the DTM generation process?
- Are there implausible islands in the inundation area which correlate to land use patterns?
- General plausibility of the inundated area, check by external experts and local water authorities.

Some statistics for setting vulnerability of countries in SEE space, is presented as follows.

6.3.1.7 Vulnerability mapping

Affected population

The affected population was calculated by intersecting the inundated area with the population density. In a second step the data were summed up per NUTS region.

Country	NUTS2	Name	population(thousands)
AT	12	Niederösterreich	20.1
AT	13	Wien	5.9
AT	31	Oberösterreich	30
HR	02	Sredisnja i Istocna (Panonska) Hrvatska	3.2
SK	01	Bratislavský� kraj	78.4
SK	02	Západné Slovensko	180.2
RS	11	Belgrade	166.7
RS	12	Vojvodina	262.4
RS	22	Southern and Eastern Serbia	9.9
HU	10	Közép-Magyarország	301
HU	21	Közép-Dunántúl	25.9
HU	22	Nyugat-Dunántú	21.5
HU	23	Dél-Dunántúl	31.1
HU	33	Dél-Alföld	125.1
BG	31	Severozapaden	32.2
BG	32	Severen tsentralen	7.9
RO	22	Sud-Est	90.6

RO	31	Sud - Muntenia	81.7
RO	41	Sud-Vest Oltenia	21.3

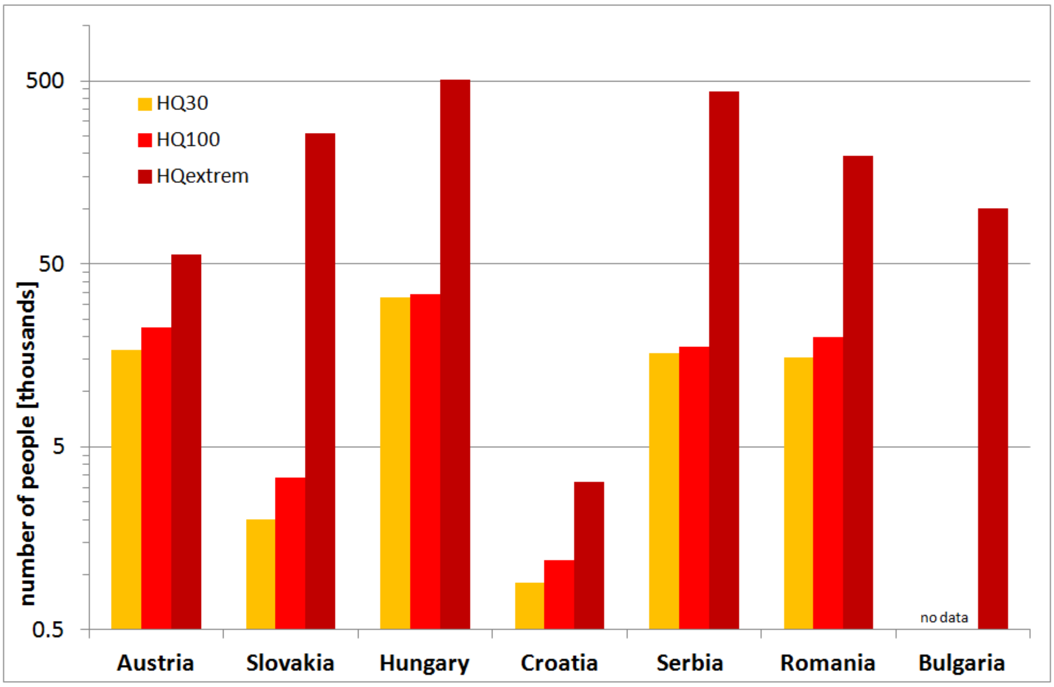

Fig. 196: People at risk [thousands]

Damage assessment

The damage assessment has been performed by applying the damage functions displayed below to the BEAM data layer. The calculation was performed used a Geodatabase. The calculation was performed for all project areas where hazard maps with inundation depth were provided. The damage functions (Fig. 197) results are shown in Fig. 198 and numerical results at the geodatabase level in Fig. 199- Fig. 201**.**

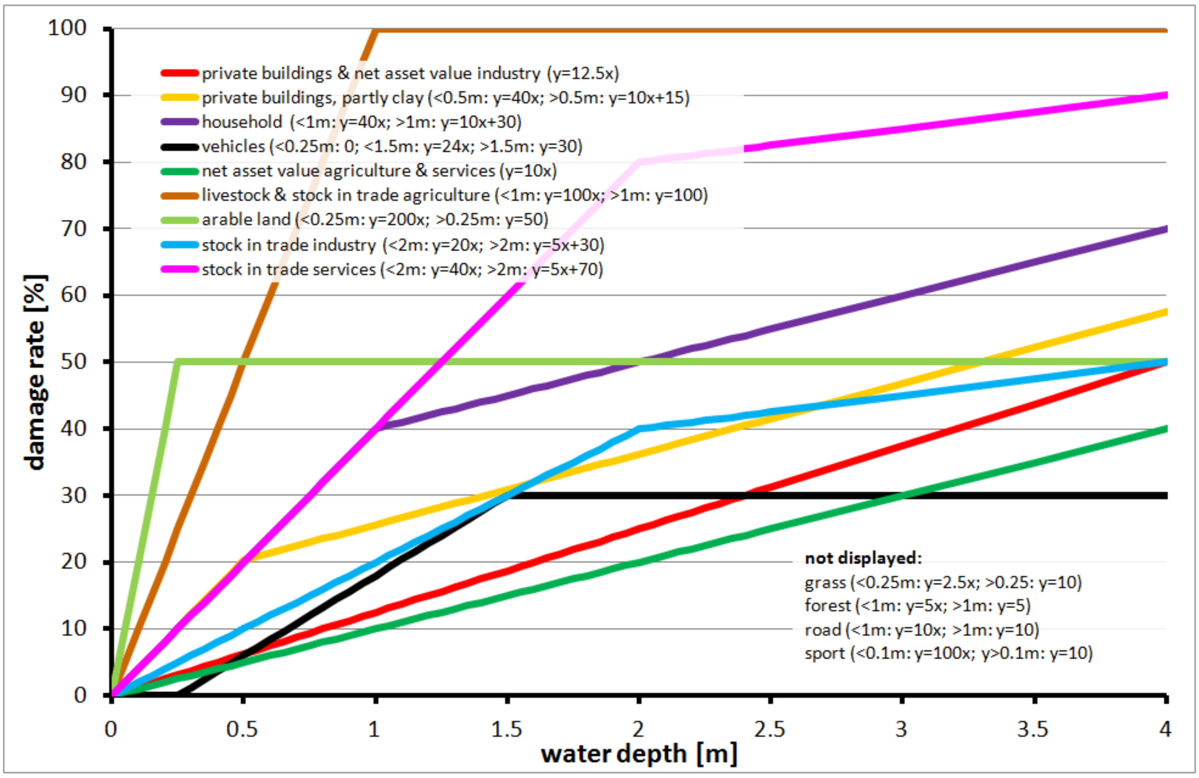

Fig. 197: Damage functions used for damage assessment calculation

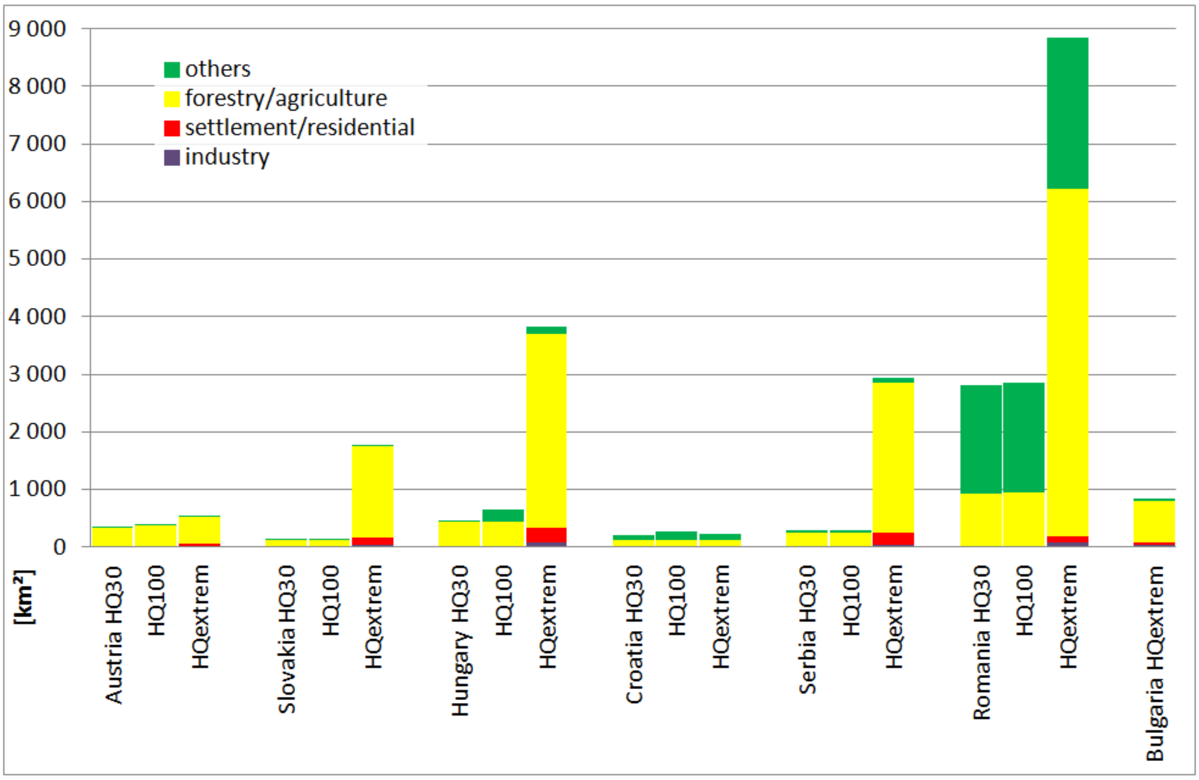

Fig. 198: Potentially inundated area [km²]

damage [mio Euro]	Austria HQ_{30}	HQ_{100}	HQ_{extrem}	Slovakia HQ_{30}	HQ_{100}	HQ_{extrem}	Hungary HQ_{30}	HQ_{100}	HQ_{extrem}	Croatia HQ_{30}	HQ_{100}	HQ_{extrem}	Serbia HQ_{30}	HQ_{100}	HQ_{extrem}	Romania HQ_{30}	HQ_{100}	HQ_{extrem}	Bulgaria HQ_{extrem}
industry	67.05	112.824	324.1	79.16	98.06	839.1	167.4	234.36	1263	2.421	3.191	6.491	177.5	201.7	1382	37.85	45.01	473.7	133.9
settlement/residential	473.3	726.33	1816	35.74	67.99	2959	570.3	784.55	6720	12.03	17.35	52.22	266.3	316	6810	70.03	93.81	976.9	362.2
forestry/agriculture	115.4	136.046	243.3	27.12	30.93	1419	130.8	135.91	2582	15.34	16.63	17.59	22.68	24.45	1916	115.2	125.2	4621	548.7
others	0.663	0.766	0.873	0.227	0.225	0.881	1.448	1.502	4.748	0.001	0	0	0.332	0.337	2.181	0.36	0.371	1.387	0.104
total	656.3	975.966	2384	142.2	197.2	5218	869.9	1156.3	10569	29.8	37.17	76.3	466.9	542.5	10111	223.4	264.4	6073	1045

area [km²]	Austria HQ_{30}	HQ_{100}	HQ_{extrem}	Slovakia HQ_{30}	HQ_{100}	HQ_{extrem}	Hungary HQ_{30}	HQ_{100}	HQ_{extrem}	Croatia HQ_{30}	HQ_{100}	HQ_{extrem}	Serbia HQ_{30}	HQ_{100}	HQ_{extrem}	Romania HQ_{30}	HQ_{100}	HQ_{extrem}	Bulgaria HQ_{extrem}
industry	5.776	7.564	15.17	1.618	1.981	31.66	7.616	7.833	82.71	0.334	0.447	1.186	3.84	4.057	46.69	6.129	6.852	78.56	29.23
settlement/residential	9.446	12.776	34.59	0.945	1.642	125.6	16.35	17.007	260.2	1.153	1.56	4.116	6.117	6.819	206.6	9.336	11.8	117.3	43.92
forestry/agriculture	323.5	351.494	480.7	113.3	118.6	1606	419.9	422.67	3368	118.1	120.8	122.2	240.1	247.8	2592	902.6	926.2	6029	723.7
others	3.332	3.841	4.49	2.1	2.103	10.3	12.33	203.3	113.4	91.07	147.6	91.2	37.32	39.31	84.86	1885	1911	2619	43.79
total	342.1	375.675	535	117.9	124.3	1773	456.2	650.81	3824	210.6	270.4	218.7	287.3	298	2930	2803	2856	8844	840.7

Fig. 199: Table with statistic being calculated from vulnerability study

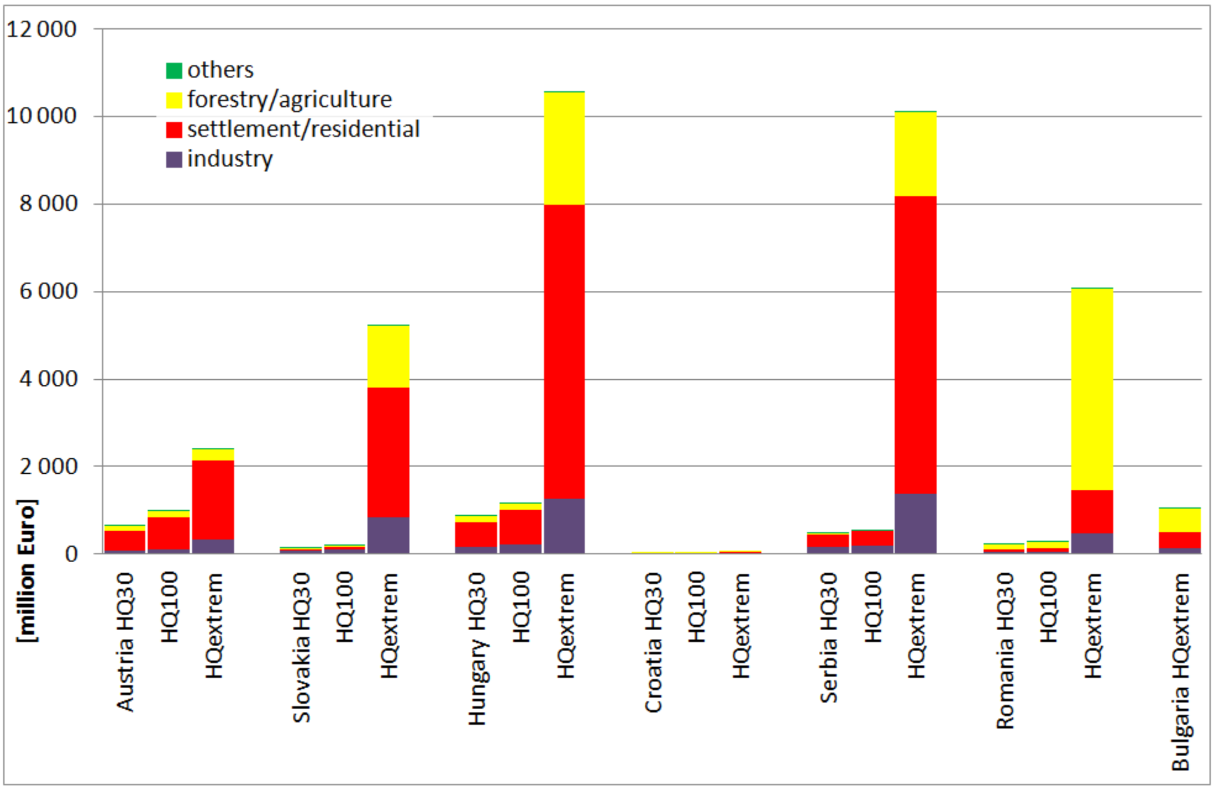

Fig. 200: Potential damage [million Euro]

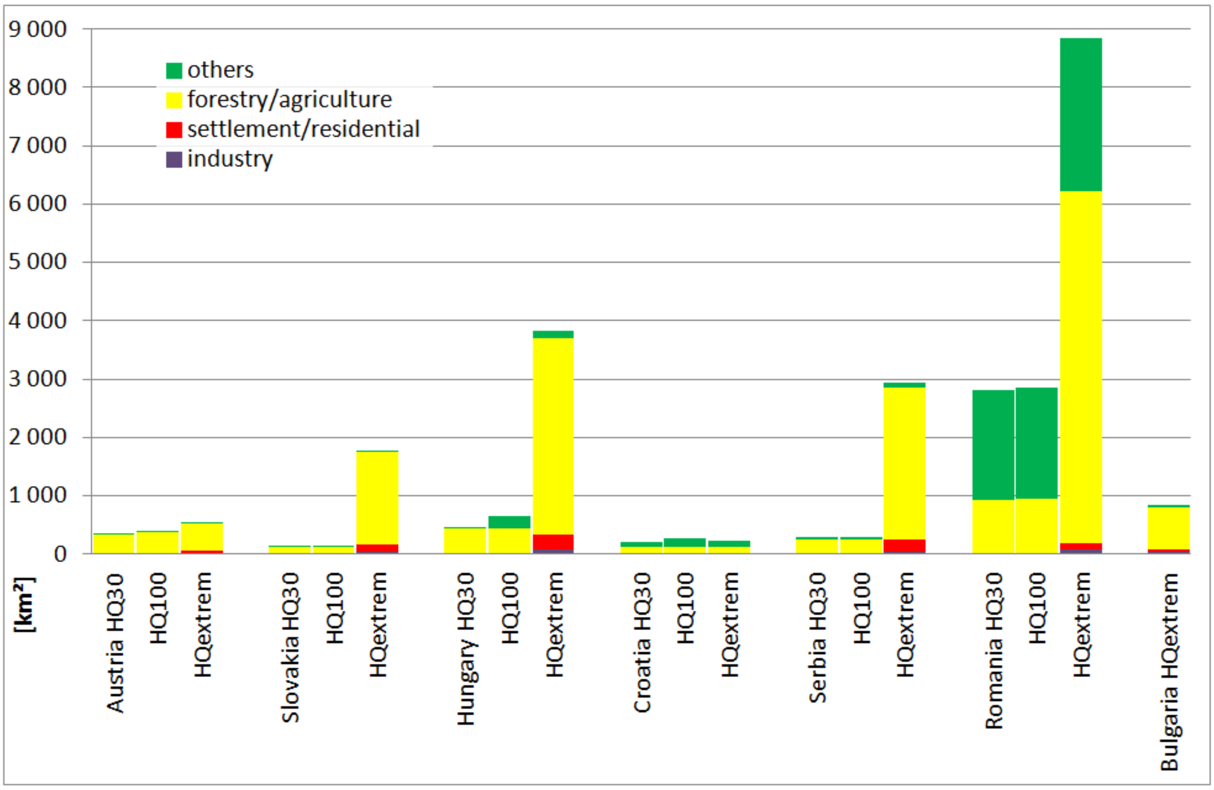

Fig. 201: Potential damage [million Euro]

6.3.1.8 Cartographic pre-processing of vulnerability

To allow for an easy processing, the damage assessment was provided as a geodatabase including the layout (layer file – Fig. 202).

Fig. 202: Area covered with the vulnerability assessment

6.3.1.9 Harmonization of mapping results on the Danube Atlas

GIS formats

The recommendation is to use the ESRI shape and/or Grid including projection, transformation info preferable personal geodatabase (easy to transfer).

Meta data file with additional information, standard template to be setup.

Map layout for printed atlas

The map layout should follow the further down listed guidelines, they relate to a scale of 1: 100 000:

- Size of page: DIN A 3
- Units used: metric system
- Languages: English/Latin writing and national language for countries with other letters
- Coordinate systems: common European coordinate system and additionally one national for each sector of the river.

Legend classes for inundation depth

- <0.5m
- 0.5 - 2m
- 2 - 4m
- 4m
- Colors (different shades of blue) like in Elbe-Atlas

Potential damage standardized by average income of each country

Legend classes for extreme events

- Industry and transport: high, medium, low (shades of magenta).
- Settlement: high, medium, low (shades of red).
- Agriculture and Forestry: high, low (shades of yellow).
- Others: high, low (shades of green).
- Colors resembling to the color scheme of the Atlas of Saxony with adjustments.
- For other types of risk symbols can be plotted on the map. Some of these symbols can be taken from the Atlas of Saxony, others have to be added. The population should be displayed as stickmen per NUTS2-region, showing the total and proportion affected.

Map layout for web-based publication

The web products realized has the following features:

- All languages of the Danube catchment.
- Search function.
- Provision of WMS.
- Normal web mapping features - zoom, measure, print.
- Detailed documentation of data integrated (meta-data provision).

6.3.2 REFERENCES NOT LISTED IN THE CHAPTER

A number of references not listed in this chapter but important for the implementation of the Danube FloodRisk project, which have been used to support various stages of the research, are listed at the end of the "References" chapter, without number indication.

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6.4 FLASH FLOOD HAZARD (FFH) ASSESSMENT MODEL SELECTION

6.4.1 INTRODUCTION

Flash floods are the most prominent type of flooding in many countries of the wider Black Sea area. Flash floods usually occur in ephemeral streams with little or not at all flow during most of the time so systematic hydrologic data are usually not available making the implementation of various types of hydraulic models, difficult or not feasible. The economic cost and the time needed to collect the required data, poses in most cases an obstacle difficult to overcome and this is the reason that a very limited number of flood hazard assessment studies have been conducted in the wider Black Sea area.

It must be pointed out at this point, that the scope of the present study, within the SciNetNatHaz project's scopes, is to select a FH assessment methodology which not only could be adapted to local conditions and applied across the entire Black Sea area, but one which at the same time will provide reliable and accurate enough results to support decision making regarding planning prevention measures. Moreover, the whole proposed procedure must be applicable by the stakeholders, including Public State and Local administration employees, young researchers and in general, all people involved in FH assessment who could work together to tackle the problem in their respective areas of interest.

Within the context of the aforementioned principles, scope of the process is to select a model for flood hazard assessment mainly in river and stream basins in order to assess flash flood hazard. FFH assessment using this model must be readily feasible, in terms of time and economic costs needed to develop the conditions to apply it in various pilot implementation sites across the BSB JOP eligible area.

Certain aspects of the process have been considered; model data requirements as compared to data availability; anticipated results; flexibility to adapt to local conditions and be applied in basins throughout the eligible Black Sea; and user friendliness in order to be distributed for implementation to stakeholders (governmental agencies, local administration, education etc).

The approach as described by Dooge and modified by Singh [56] was followed in order to select the most appropriate methodology to adopt.

According to this approach, sequential steps have to be taken and various factors to be identified: 1. Problem definition; 2. Specification of the objectives; 3. Study of the available data; 4. Determination of the available computer/hardware facilities; 5. Specification of economic & social constrains; 6. Adoption of a particular class of hydrologic models; 7. Selection of the particular type of model within the selected class; 8. Calibration/Adaptation to local conditions of the model; 9. Performance evaluation of the model; 10. Potential use of the model for prediction purposes; 11. The possibility of embedding the model into a more general one.

Step 5 is related to the ability of the stakeholders to implement the model in terms of the required expertise, software tools and hardware requirements, step 6 is related to the flexibility of the model in order to be adapted to local conditions and implemented throughout the area of interest (at least the Black Sea JOP eligible area), steps 8, 9, 10 and 11 are going to be taken in the following pilot implementations in regional and local scales.

6.4.2 BASIC CONSIDERATIONS FOR SELECTING THE APPROPRIATE MODEL

Several approaches in terms of assessing Flood Hazard have been presented and applied. The methodologies applied are accepted techniques for flow estimation and inundation. They range from simple and straightforward engineering approaches to complex scientific models [37], [15]. However, the final choice depends on several parameters and on the goals to be met each time. A lot of discussion has been done between empirical, screening methods and advanced methods. The approach applied in each case comes as a result of the combination of:

- The available input data.
- The cost of data.
- The cost of the software used.
- The complexity of the methodology.
- The flexibility of the method to be calibrated in different situations.
- The amount of expertise and special knowledge needed.
- The required accuracy and reliability of the output.

6.4.2.1 (A) Input data

Data availability, reliability, cost and format are the first parameters to be taken into consideration in order to decide upon a methodology for Flood Hazard Assessment. The term "input data", refers to all possible data requirements including both hydrologic, topographic and additional thematic maps and data.

In many cases, hydrologic historic data are difficult to obtain due to the lack of systematic observations of rainfall data and the systematic recording of past floods. Obtaining such data sets (if available) in the face of limited budgets and limited access to field sites is another problem [38].

In the majority of the EU countries, the hydrologic information and datasets have been collected by various different organizations, each with its own methodology for publishing and retrieving information. The variety of protocols and methods required to access, retrieve and harmonize the data is in most cases, complex, time consuming and rather expensive because there is no central repository where researchers can easily access this kind of information.

On the other hand, topographic data are easier to obtain but their accuracy and reliability is always an issue when it comes to implementing flood hazard assessment methods especially in applied research on local/site-specific scales. The desirable accuracy of the topographic datasets is connected to the area and the scale of the application. When dealing with large catchment areas, regional scale data may be obtained from satellite images, aerial photography with photogrammetric interpretation and/or from digitizing of maps of proper scale. When it comes to local scale, where accuracy and leveling are mostly needed, topographic data must be obtained from field surveying and/or from digitizing of topographic maps of a large scale (greater than 1:1.000) and they serve as ideal data source. The topographic data are usually vector-based data, representing catchment and river entities [39].

In most cases, geological data are needed and can be obtained from geological maps by digitizing. The same applies for land cover and land use where information may be extracted from relevant maps, field observations and EU Organizations as the Joint Research Centre (http://ec.europa.eu/dgs/jrc/).

6.4.2.2 (B) Data Availability

Data requirements are an essential parameter when trying to adopt a methodology to use because they raise data availability to a critical point, giving it a sometimes, restrictive role. A methodology, no matter how sophisticated and complete it is, cannot be applied if its data requirements necessitate for time and money consuming conditions.

Data availability has already been recognized by the EU Commission as an important part of the "information gap" and plays a restrictive role in the adoption of methodologies to assess natural hazards throughout Europe. Selection of data has proved to be by far the most challenging part of the whole process, [40]; [41].

The data cost itself relates to the area of interest, the data availability and of course to the desirable accuracy of the results. Although datasets are more available now in comparison to previous years, it still remains a serious budget issue for numerous reasons; existing datasets are not always available or are expensive to be purchased, their production is expensive, experts are needed, data production is time consuming and…time costs!

Improved and new data collection methods are promising in terms of accuracy and cost reduction in the future, as is the LIDAR, which promises to increase the accuracy and reduce the cost of high-accuracy elevation data in the near future [42].

Open Data Initiatives can boost research, because they will reduces time consuming procedures and costs, simplifying in this way implementation of methodologies regarding various environmental and Natural Disaster mitigation issues. Flood hazard assessment is no exception in this respect; FFH assessment and disaster mitigation can be greatly supported by Open Data initiatives.

6.4.2.3 (C) Complexity

Natural physical phenomena may be described and modeled by using different methods. These methods often require making broad assumptions to develop governing equations. Simple hydraulic modeling methods are fairly sufficient for approximating propagation of floods through river channels. More complex hydrologic and hydraulic analyses are though necessary to incorporate and investigate the effects of infrastructure or complex overland flow. Advanced models are capable of modeling more detailed physical phenomena [43].

Hydrologic and Hydraulic modeling is an important element of establishing a robust flood forecasting framework. Simulation results from hydraulic models can be used to produce inundation maps that Decision Makers can use to make decisions regarding flood risk mitigation measures.

From a purchasing cost reduction perspective, there is a number of available for free software (freeware) including: MIKE FLOOD; HEC-RAS; HEC-HMS that offer the ability of collaborating with GIS and CADD software during input and output of results. The user must first choose between a number of methodologies and then choose the respective software the one that best meets his needs.

6.4.2.4 (D) Expertise and Special Knowledge required

Expert users are in most cases needed in FHA methods. A combination of hydrologic, hydraulic, CADD and GIS field of knowledge would be ideal. The user should choose a method for FHA that best meets the needs in relation to his knowledge and ability to comprehend fundamental concepts. A complex method is of no use if the user can not apply it correctly; in fact its use increases the risk of leading to false results. In any case, a minimum level of expertise is at least required to implement flood hazard assessment models. On the other hand, the use of a fairly simple model in terms of implementation, combined with the presence of readily available information, references, guides and tutorials can support any user interested in using that model.

6.4.2.5 (E) Flexibility

The term “flexibility” applies to the ability of a method to be adjusted or calibrated in individual and particular cases so it could also be described as “adaptability”. A method that is generally more easily adjusted to a specific project is preferable to one that’s not easily or not at all adaptable. In fact, as one of the prime targets of the project is the, as complete as possible, harmonization of methodologies, the implementation of the same methodology over the entire area, if possible, is very much desired. With that concept in mind, methodologies that cannot easily be adapted to local conditions or applied in locations across the wider Black Sea area must be excluded. An additional aspect when considering the term “flexibility” as described here is the ability to provide synergies with other methodologies;

i.e. to exchange data and outputs or even to complement or be complemented by other methodologies.

In this phase, the user is to evaluate the flexibility of the methodology and its importance to the project. Methods and models of "low flexibility" are generally not preferred especially to local scale Flood Assessment Methods.

6.4.2.6 (F) Cost of Implementation

The cost of the implementation of a methodology is in most cases, a combination of data collection and Software purchase which impose a direct cost, but there are additional parameters which should be considered as they contribute to the overall cost of each approach/methodology indirectly (i.e. if experts are needed the cost rises, if the method chosen is more complex then it is more time consuming and the cost rises as well, etc).

As already mentioned, the general Cost of use in most cases, is a combination of data and software purchases cost and it's also related to personnel training in cases where training is required. The essential target when trying to select which software to use, is to select the one that meets the requirements in terms of accuracy and reliability and costs less.

The large number of existing software packages which may be used for implementing various methodologies/models in flood hazard assessment can be classified into hydrological, hydraulic and mapping software packages, though usually, additional software is needed in order to create the input data (CADD, topographic, photogrammetric, remote sensing, GIS etc).

The user has to decide upon the software to use according to it's input data requirements, the cost of purchase, always in relation to the ease of use and the anticipated outputs. In terms of hydrological and hydraulics applications, there are several reliable software solutions which are scientifically accepted and evaluated and are being generally used.

6.4.2.7 (G) Completeness

The term refers to the completeness of results with respect to their usability for decision making regarding Flood Disaster mitigation issues. Methodologies were classified according their results completeness into: Low (cover only a few aspects. The use of additional methodologies is required); Medium (cover most aspects of the problem. Minor issues still remain unsolved); High (cover every aspect of the problem).

6.4.2.8 (H) Accuracy and Reliability

Accuracy and reliability are related to the amount and impact of uncertainties and errors on the outputs of each method. Uncertainties and errors are introduced throughout the development and the processes in every case of any methodology applied. Currently, uncertainties are typically left unspecified when flood inundation maps are released [43]. The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing, and theoretical assumptions, can render results inaccurate and ultimately misleading. In this case, additional data (statistical, historical, morphological, and geological) must be used to evaluate the results.

6.4.3 EVALUATION OF EXISTING METHODOLOGIES

An evaluation of the existing approaches/methodologies for FHA is presented in the next paragraphs and tables. All of the methodologies examined are based on scientifically proven models, have been and are still being used and tested in many cases and projects. These different scientific approaches have many differences; each one of them has advantages and disadvantages as compared to the others, regarding several parameters (scale of the area of implementation, ease of use, input data needed etc.). In any case, the effort to compare them does not aim at rating them as the best or the worst; the scope is to evaluate them and select the one which meets the projects needs better.

The process followed to categorize and evaluate the FH Assessment Methodologies used worldwide is shown in the following tables. Different categorizations are presented according to different characteristics of each methodological approach.

For evaluating the reviewed methodologies a score-scale was decided and several parameters were introduced as criteria (Table 6.1).

Table 6.1: Criteria used to evaluate the available methodologies in terms of their potential use to assess flash flood hazard over the Black Basin area.

(A&B) Data Requirements	1. Heavy (a lot of detailed data (systematic measurements) are needed, 2. Medium (Detailed data are needed), 3. Light (Most of the data are readily available-some additional data needed), 4. Data are readily available
(C&D) Complexity (User Friendlyness)	1. Low (Needs a DEDICATED expert on it), 2. Medium (only Experts can use it), 3. High (Less experienced scientists can use it)
(E) Flexibility (adaptation to local conditions)	1. Low (Very difficult to adapt), 2. Medium (Needs some effort to adapt), 3. High (Easily adaptable to local conditions)

(F) Cost of Implementation	1. High (Very expensive), 2. Medium (Limited cost), 3. Low (Free)
(G) Completeness	1. Low (Covers only a few aspects. Additional Software needed), 2. Medium (Covers most aspects of the problem), 3. High (Covers every aspect of the problem)
(H) Reliability	1. Low (A new proposal, has not been tested extensively), 2. Medium (Has been tested), 3. High (has been tested thoroughly)
(H) Accuracy	1. General (regional scale), 2. Medium (Regional to local scales), 3. High (site-specific scales)
*8 Watershed representation	1. lumped, 2. semidistributed 3. distributed

The parameters introduced for an evaluation of FHA may vary in general but the aforementioned ones were chosen for the needs of the project as they cover all aspects in our case. The final score is produced by summarizing individual criteria scores.

Higher scores are better!

Table 6.2. Evaluation of methodologies according to the selection criteria set.

					Ease of Use					Evaluation of the Output			Score
Method	**Type**	**Area**	**Data needed**	**Evaluation**	**Data Requirements (A&B)**	**Complexity (User Friendly ness) (C&D)**	**Flexibility (adaptation to local conditions) (E)**	**Cost of Implementation (F)**	**watershed representation *8**	**Completeness (G)**	**Reliability (H)**	**Accuracy (H)**	
Geomorphological [8],[9], [44], [45], [46], [47], [48], [49], [50]	Morphometric Analysis	Regional. Basin Characterization, Drainage Features	Topography, Terrain, Hydrological Pattern, Weather records, Aerial photographs, Field work, Geological features, discharge calculations	Highly variable channel morphology High erosive potential	4	3	3	3	1	1	2	1	18
Hydrological [10],[11],[28]	Rainfall-runoff model	Regional hydrological basin	Large data sets, rainfall data, topographic data, vegetation and soil distribution, meteorological data. hydrological soil properties, flood/flow routing	Operational methodology, flood evolution, applicable even if historic data is sparse	2	2	2	2	1	1	2	2	14

Hydraulics [12], [26]	Rational method	Regional and Local scale. Loss characteristics into runoff co-efficient, storage catchment reflected in the time of concentration	Topographic information, hydraulic analysis techniques, dynamic wave hydraulic model, rainfall and losses data	Rapid implementation; low data requirements; widely used	2	1	2	3	2	3	3	3	19
	Rounoff routing method	Regional scale. Runoff production by loss model, large cathments	Rainfall, land use, catchment and stream characteristics, DEM	Moderate data requirements.	2	1	2	3	2	2	3	3	18
Empirical [25],[31]	Quantitative analysis	Local and regional scale	Hydrological model	Forecast credibility, statistical errors	3	2	2	3	2	1	1	2	16

The scores rate the methodologies in terms of their suitability to be used for flash flood hazard assessment given the specific conditions existing in the participating in the project countries, especially in terms of data availability. This is the reason of giving extra weight in data requirements and in the reliability and accuracy of the outputs.

The methodologies taken into consideration in the previous table, can also be classified according to whether one is dealing with flood flow or flood inundation. This classification and a respective rating according to the criteria already set, is given to Table 6.3 and Table 6.4 respectively.

Table 6.3: Methods providing assessment of flood flow and hazard potential

					Ease of Use					**Evaluation of the Output**			**Score**
Method (example)	**Description**	**Advantages**	**Disadvantages**	**Data requirements**	**Data Requirements score *1**	**Complexity (User Friendlyness) *2**	**Flexibility (adaptation to local conditions) *3**	**Cost of Use *4**	**watershed representation *8**	**Completeness *5**	**Reliability *6**	**Accuracy *7**	
Rules of thumb [27]	General approach based on past, more complex studies.	Easy to use; based on comprehensive analysis.	Uncertain applicability outside the rivers where studies were conducted.	Case-by-case considerations	2	3	2	3	1	2	2	3	18
Rational method [27]	Empirical method to estimate peak flow.	Rapid implementation, low data requirements, widely used in the engineering community, guidelines for estimating run-off coefficient.	Not suitable where rainfall varies significantly across the catchment, limited accuracy in validation tests.	Design rainfall intensity; run-off coefficient, which depends on catchment characteristics (ie, slope, land cover, soil); time of concentration and catchment area.	3	2	3	2	3	2	2	2	19

SCS method [27]	Empirical and graphical method to estimate peak flow.	(As for the Rational Method.)	Usually limited database; limited to small to medium-size catchments; limited accuracy in validation tests.	Rainfall; land-use description; hydrological soil group.	3	2	3	2	2	2	2	2	18
Unit hydrograph (HEC_HMS)	Empirical approach that converts a hyetograph into a hydrograph.	Relatively simple approach.	Limited to gauged catchments.	Storm hyetograph.	2	2	2	3	2	1	3	2	17
Storage-routing models [30]	Route rainfall or run-off through a simple catchment.	Moderate data requirements.	Lacks catchment complexities and detailed routing procedure.	Rainfall or run-off time-series; defined storage-routing network.	2	2	3	2	1	2	2	3	17
Kinematic wave models (HEC_HMS)	Flow is routed through a catchment's river network based on kinematic wave	Can be used for operational flood forecasting; more accurate than screening methods when in large complex	Longer computation time; larger data requirements; larger cost of model	Time-series of distributed catchment run-off; digital river network calibrated	1	1	1	1	2	3	2	3	14

	theory.	catchments; ongoing scientific development.	calibration.	parameters.									
Catchment water balance models **(**MIKE)	Models river flow and other hydrological variables across a catchment based on biophysical principles	Suitable for assessing both climate and land-use change impacts on water resources; ongoing scientific development.	Longer computation time; larger data requirements; larger cost of model calibration.	Rainfall and temperature time-series; digital river network; GIS data for soil, land cover and topography	1	1	2	1	2	3	2	3	15

Table 6.4: Methodologies for assessing flood inundation and hazard potential

					Ease of Use					Evaluation of the Output			Score
Method (example)	**Description**	**Advantages**	**Disadvantages**	**Data requirements**	**Data Requirements score *1**	**Complexity (User Friendlyness) *2**	**Flexibility (adaptation to local conditions) *3**	**Cost of Use *4**	**watershed representation *8**	**Completeness *5**	**Reliability *6**	**Accuracy *7**	
Screening methods [27]	A general approach based on past, more complex studies.	Easy to use; based on comprehensive analysis.	Limited to inferences from past studies.	Case-by-case considerations.	2	3	2	3	1	2	2	3	18
1-D flow models [HEC_RAS, MIKE 11, MIKE-Urban), [33]	Produce flow depths and velocities down a 1-D channel.	Low data requirements and relatively rapid computation.	Linear flow paths determined by the modeller; lacks 2- and 3-D flow patterns.	Inflow hydrograph; downstream hydraulic conditions; river and flood-plain cross-sections; roughness coefficients; calibration	2	3	3	3	2	2	2	1	18

				observations.									
2-D flow models [28][33]	Produce flow depths and velocities across a complex 2-D terrain.	Simulate variable flow depth and flow velocity laterally.	More computationally intensive than 1-D; lack 3-D flow patterns.	As with 1-D models; digital elevation model of the river and flood plain.	2	2	3	2	2	2	2	2	17
3-D flow models (FLOW-3D, MIKE 3) [32]	Produce flow depths and velocities around 3-D structures.	Simulate vertical flow patterns.	More computationally intensive than both 1-D and 2-D.	As with 2-D models; 3-D representation of structures.	2	1	3	1	2	2	3	3	17

The study of processes such as flash floods in gauged or ungauged basins often requires the combination of different techniques enabling numerical models to be developed in order to understand the processes.

This flood analysis as already mentioned, typically consists of two components: hydrologic analysis (determination of peak flows and flood hydrographs) and a hydraulic analysis (determination of flood depths, extents and conceptual design of hydraulic structures) so a combination is more proper to be used.

Table 6.5: An evaluation of the most commonly applied techniques concerning Hydrological/Hydraulic Analysis

				Ease of Use					**Evaluation of the Output**			**Score**
METHOD	**PRODUCT**	**ADVANTAGES**	**DISADVANTAGES**	**Data Requirements score *1**	**Complexity (User Friendlyness) *2**	**Flexibility (adaptation to local conditions) *3**	**Cost of Use *4**	**watershed representation *8**	**Completeness *5**	**Reliability *6**	**Accuracy *7**	
Statistical analysis of stream-flow records [34]	Probabilistic Statement for future occurrence	Accurate estimate Widespread application	limited to defining flood potentials in terms of peak discharge and exceedance probability.Stream-flow records do not exist for most of the nation's streams.Not likely to be applicable in urban or urbanizing areas	1	3	2	1	3	2	3	2	17

Regional methods [35]	Watershed and stream system factors for a defined geographic area stream system factors for a defined geographic area	Easy to use. Accurate estimate	Applicable within the region that provided the stream flow and watershed data used to develop the method. An extensive database and a major analytic effort are required to develop a regional method	2	1	2	2	3	3	3	3	19
Transfer methods [35]	Flood flow of specified recurrence interval for a stream of a given size and runoff characteristics is used to estimate a flood flow of the same interval for a larger or smaller portion of the watershed having similar runoff	Easy to use	Assumption that the area to which it is being applied has runoff characteristics similar to the area for which a flow of specified recurrence interval is known	2	3	1	2	3	2	2	2	17

	characteristics											
Empirical methods, Mostly used in Greece according to Greek Legislation [35]	Determining peak flood flows	Universal application"Every one is using it" Easy, cheap. Utilize formulas developed without regression or unit hydrograph techniques	Rainfall intensity-duration-frequency curves are needed. Doubts about accuracy	2	3	3	2	1	2	3	2	18
Watershed modeling methods [35]	Peak flood flows for a stream	Most accurate of the hydrological approaches because of the level of detail of the analyses	Time consuming and expensive	1	2	3	1	3	3	3	3	19

A well established and commonly used methodology for assessing flood hazard is the combination of Empirical methods (such as rational or screening) and the advanced hydraulic method of inundation respectively.

6.4.4 SELECTION OF METHODOLOGIES PROPOSED TO ASSESS FLASH FLOOD HAZARD IN WIDER BLACK SEA BASIN

The review of Flood Hazard (FH) assessment methodologies used worldwide, provided the ability to overview their input requirements and their expected outputs and to rate them according their fitness into the SciNetNatHaz project's requirements in terms of available data and in terms of anticipated outputs.

Hydrologic and hydraulic models provide the most complete and accurate results but in order to provide, they require systematically recorded data of various parameters, available. Reality in most of the Black Sea countries shows that this kind of data either does not exist at all or is not easily available and the term "easy" in this case includes both procedures and costs.

Especially for flash floods which usually occur throughout the Black Sea area in ephemeral streams, there are no available historic or hydrologic data to effectively apply statistical or hydraulic models wherever necessary. This fact poses a serious problem when considering the extent of the area, the numerous river watersheds where a flood may occur and the cost of acquiring even the basic, high resolution topographic data in order to implement flash flood hazard assessment on a local scale, to support decision making regarding preventive measures.

Given the available data already collected and harmonized by the project partners (there are rainfall data, topographic and land use maps readily available), and the extent of the potential implementation area **a two step procedure to assess flash flood hazard is proposed**.

The first step is essentially a screening process which aims to reduce the areas of interest and provide the ability to prioritize them according to the flood hazard and risk. Technically, scope of the first step is to locate the flood prone areas in a reliable and accurate way by using available data and widely accepted methodologies.

Risk assessment in those flash flood prone locations can then define if the application of the second step is required. In such a case, detailed topographic and additional required must be collected.

The **Topographic Wetness Index** (TWI) approach [11]; [45]; [46] and it's variant, the SAGA TW index [57] were selected to assess flash flood hazard on a regional scale. The methodology has already been used for that reason in many cases [47]; [48]; [49]; [50]. Using this methodology, flash flood prone (FFP) locations can be located even for areas where flash floods have not been recorded but may occur in the future.

Additional information regarding factors influencing the occurrence of flooding can be provided by additional widely accepted and adaptable methodologies. For instance, the sediment production areas within a watershed can be delineated using the RUSLE soil erosion assessment method. This information can help make decisions regarding the **location of sediment retention structures** in order to prevent sediments of being transferred downstream to the flood prone areas.

At the second and final step, an analysis made on a site-specific scale will help calculate all the necessary flood related parameters (inundation area and depth, flow velocity etc) in order to provide support to decision making regarding the design of preventive measures. The **HEC-RAS hydraulic model was selected** for that purpose as it has been tested and widely accepted for such implementations.

Another way to help tackle the problem of the large number of potentially flood prone areas around the Black Sea basin, is by broadening the range of potential stakeholders and users of the proposed methodologies.

To that end, efforts have been made to ensure that all selected methodologies can be implemented using **Open Source software**. Given the economic status in most of the countries around Black Sea, this fact is expected to increase the number of the potential project stakeholders including young researchers, Higher Education Institutions and State and Local authorities.

The free and Open Source Geographic Information System **Quantum GIS** (http://www.qgis.org/en/site/) which incorporates the "System for Automated Geoscientific Analysis" (**SAGA)** algorithms (http://www.saga-gis.org/en/index.html) was selected as the GIS platform on which the implementation for the flood hazard assessment on regional scales will be based.

For the second stage implementation on local (site-specific) scale, the HEC-RAS software which HEC-RAS allows to perform one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling, was selected (http://www.hec.usace.army.mil/software/hec-ras/).

The adoption and use of Open Source software will be complemented with detailed information about the selected methodologies and the procedures used. These will be given in the form of step-by-step tutorials freely accessible.

6.4.5 CONCLUSIONS

A review of Flood Hazard (FH) assessment methodologies used worldwide, provided the ability to overview their **input requirements** and their **expected outputs**.

Different methodologies have been used to assess flood hazard, even between research projects which were carried out in the same country. A **harmonization of methodologies** used to assess FH, is therefore required in order to allow the scientific community to work together in order to address common challenges, especially in cross border regions.

Riverine floods cause serious problems, but flood hazard has been successfully assessed in most cases. The concepts and methodologies that the **“Danube FloodRisk”** project has followed to assess FH, are a very good example of this implementation and can **be the basis for Flood Hazard assessment in large rivers**.

Flash flood hazard has not been assessed in most cases despite the fact that it is a serious threat in all countries and the prominent type of hazard in Greece and across the Black Sea area of Turkey. In order to assess flash hazard across the wider Black Sea area effectively, the cooperation of the scientific community is required and this can be only based on harmonized methodologies.

Given the differing situation in each of the involved countries regarding used methodologies and data availability, the harmonization of methodologies is a process influenced by many factors. There are some basic parameters related to the selection of the appropriate harmonized methodologies, in order for everybody to be able to apply them in the respective areas of interest across the wider Black Sea area. Those parameters include **the availability of required data** which is a **decisive** or even a **restrictive parameter** for the potential use of methodologies; the **cost** of implementation and; the **quality** and **completeness of the outputs**.

With this concept in mind, widely accepted and used **methodologies were classified according to their accuracy and to the basic principles** they follow.

A classification/rating scheme was developed which took into consideration:

- the input data requirements as compared to the available data,
- the cost of data,
- the cost of the software used,
- the complexity of the methodology (the amount of expertise and special knowledge needed to implement),
- the flexibility of the method (adaptability in different conditions),
- the expected accuracy and reliability of the outputs.

Based on the results of the rating of methodologies and taking into consideration the data already available (collected and harmonized by the project partners) as well as the extent of the potential implementation area, **a two step procedure to assess flash flood hazard is proposed**.

The first step is essentially a screening process which aims to locate flash flood prone (FFP) areas and thus reduce the number of potential areas of interest. Risk assessment in those FFP locations will help prioritize them according to the flood hazard and risk. Detailed topographic and additional required data can then be collected in order to proceed to the second step and access the flooding parameters in a site-specific scale in order to support decisions regarding preventive measures.

The **Topographic Wetness Index** (TWI) and it's variant, the SAGA TW index were selected for the initial FFP area location.

The **HEC-RAS hydraulic model was selected** for the analysis on a site-specific scale to calculate all the necessary flood related parameters (inundation area and depth, flow velocity etc).

Additional complementary information regarding the sediment production areas can be provided by the RUSLE soil erosion assessment method. This information can help make decisions regarding the **location of sediment retention structures** in order to prevent sediments of being transferred to the flood prone areas.

Open Source software is proposed to be used for the entire process.

Quantum GIS (incorporating the **SAGA** algorithms) was selected as the GIS platform on which the implementation for the flood hazard assessment on regional scales will be based.

The HEC-RAS software (USACE) which allows to perform one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling, was selected for the site-specific hydraulic analyses.

The project partners will provide additional support to potential users by producing and distributing detailed step-by-step tutorials of the process.

The use of Open Source Software combined with the procedures adopted will give free access to everyone interested, including State and Local authorities, to implement those methodologies and assess flood hazard. Given the economic status in most of the countries around Black Sea, this fact is expected to increase the number of the potential project stakeholders.

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6.4.8 APPENDIX I: TOPOGRAPHIC WETNESS INDEX CALCULATION USING QGIS

The topographic wetness index (TWI) was developed by Beven and Kirkby (1979) within the runoff model TOPMODEL. The TWI was proposed to predict quick response flow by using morphometric parameters [1]; [2]; [3] but has been used since then to delineate flood prone areas [4]; [5]; [6]; [7]; [8]; [9].

It is defined as ln(a/tanβ) where a is the local upslope area draining through a certain point per unit contour length and tanβ is the local slope.

Calculation of the TWI involves the following steps/procedures:

1. Create/Import a Digital Elevation Model (DEM)
2. Fill Sinks
3. Calculate Flow Directions
4. Delineate Watershed Basins
5. Calculate Flow Accumulation (Catchment Area)
6. Calculate Catchment Slope
7. Calculate the "Modified Catchment Area"
8. Calculate the SAGA WI
9. Calculate the Specific Catchment Area which corresponds to the local upslope area draining through a certain point per unit contour length
10. Calculate the TWI

From this point, additional actions can be added to complement the created maps with additional data:

- Calculate the Stream Power Index
- LS factor to use in RUSLE calculations and more…

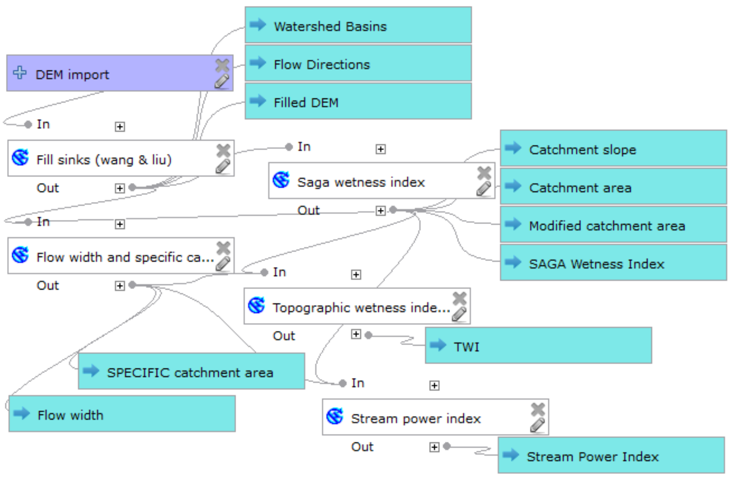

Fig. 203**:** Topographic Wetness Index calculation Model, built in Quantum GIS.

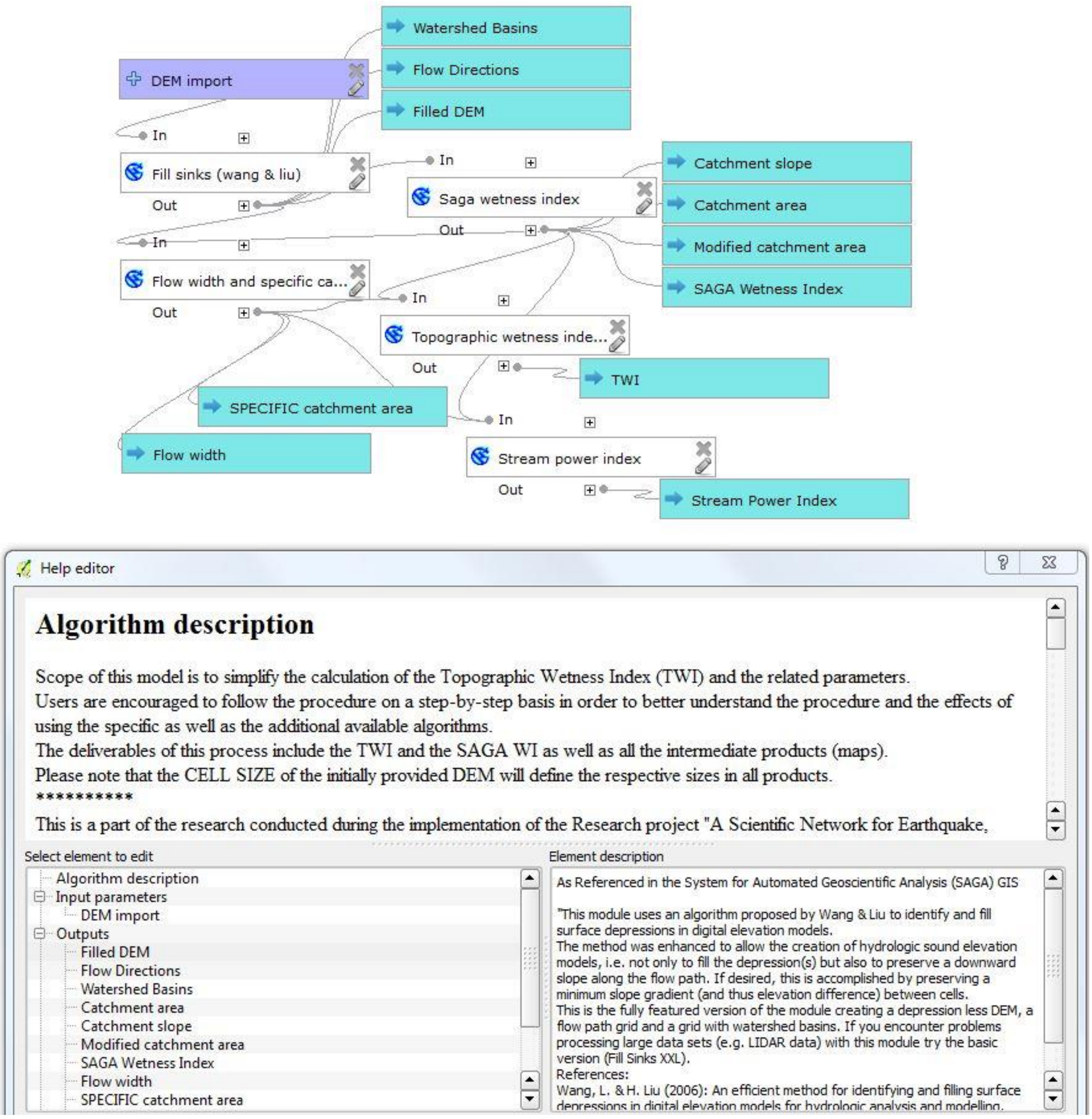

Fig. 204: Comments and help to document and support the Model implementation (SAGA GIS).

For consistency reasons, the colors and labels used to map TWI and SAGA WI were assigned respective attributes and a color table was created (Fig. 205). The color table will be distributed along with the rest of the supporting material (tutorials, built Model, etc.) to potential users.

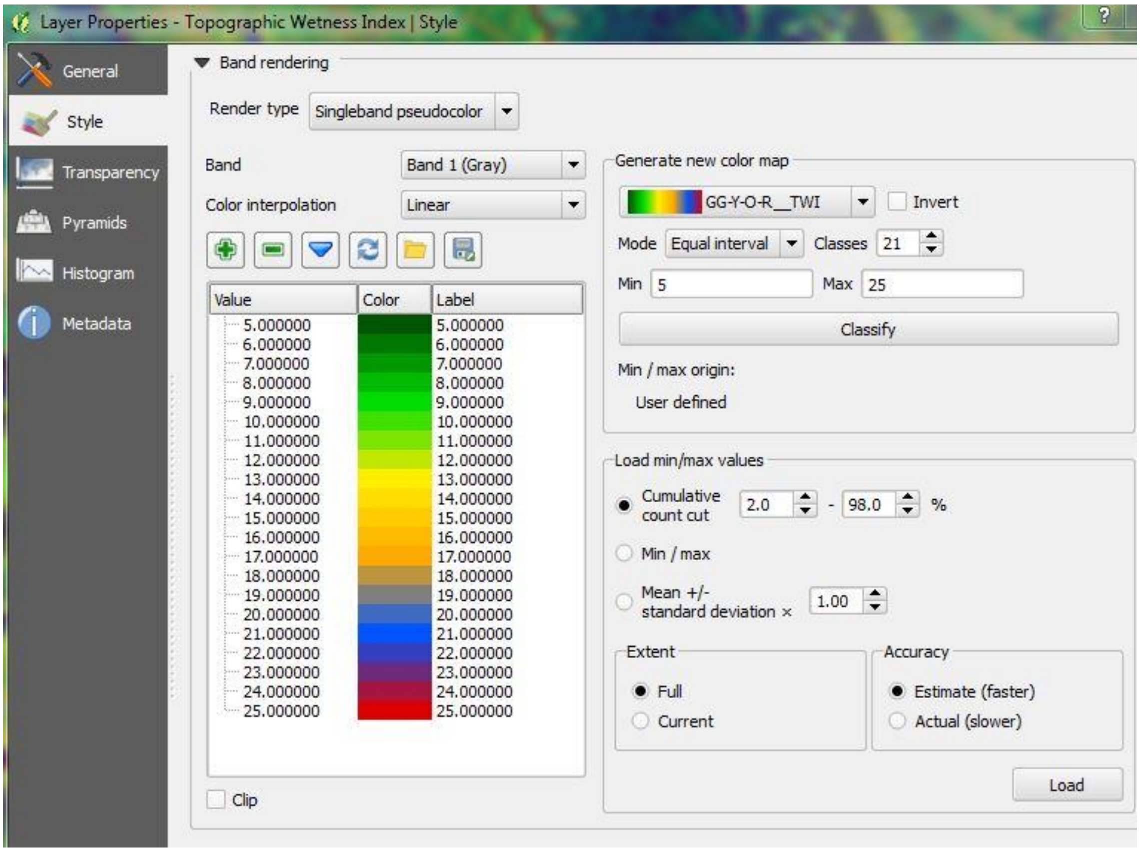

Fig. 205**:** Proposed color scheme for both the Topographic Wetness Index and the SAGA WI (QGIS screen shot).

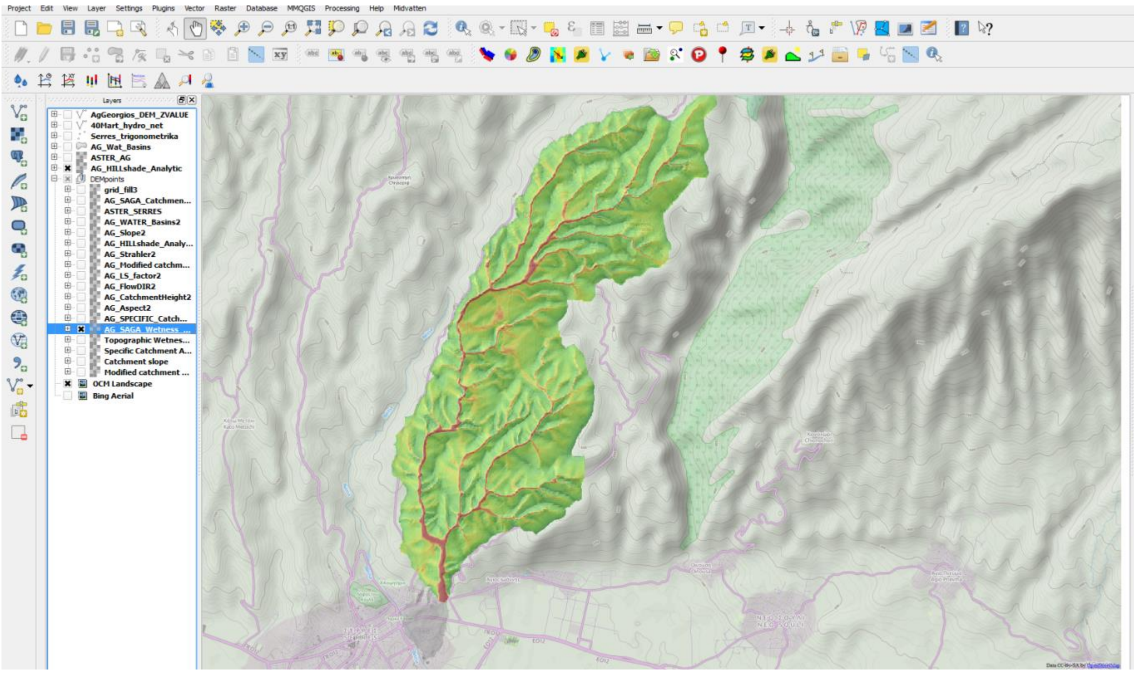

Fig. 206: Quantum GIS working space (QGIS screen shot).

6.4.8.1 References

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6.4.8.2 Important Web Sites

1. Quantum GIS Home and Download: http://www.qgis.org/en/site/
2. QGIS Documents (Manuals, Tutorials, Help): http://www.qgis.org/en/docs/index.html
3. System for Automated Geoscientific Analysis (SAGA) Home: http://www.saga-gis.org/en/index.html
4. SAGA software description: http://www.saga-gis.org/en/about/software.html
5. SAGA documentation: http://sourceforge.net/projects/saga-gis/files/
6. SAGA Research: http://www.saga-gis.org/en/about/research.html
7. SAGA References: http://www.saga-gis.org/en/index.html

6.4.9 APPENDIX II: HEC-RAS HYDRAULIC ANALYSIS-BASIC STEPS

Hydraulic Analysis for assessing hydraulic behaviour for streams is being implemented with HEC-RAS software.

The following approach is a quick-start simplified guide for HEC-RAS projects, containing the basic steps for running a hydraulic analysis. The software may be downloaded from the official Hydrologic Engineering Centers River Analysis System (HEC-RAS) web site (extended manual and examples available):

(http://www.hec.usace.army.mil/software/hec-ras/)

Basic steps in hydraulic analysis using HEC-RAS:

1. Getting Started

Open HEC-RAS software. Click on the **File**, and then select **New Project** to create and save the path for the project (Fig. 207). In the New Project window, insert the Title of the project and File name of your choice and then click **OK** to save. Then the main window of HEC-RAS River Analysis System appears on screen.

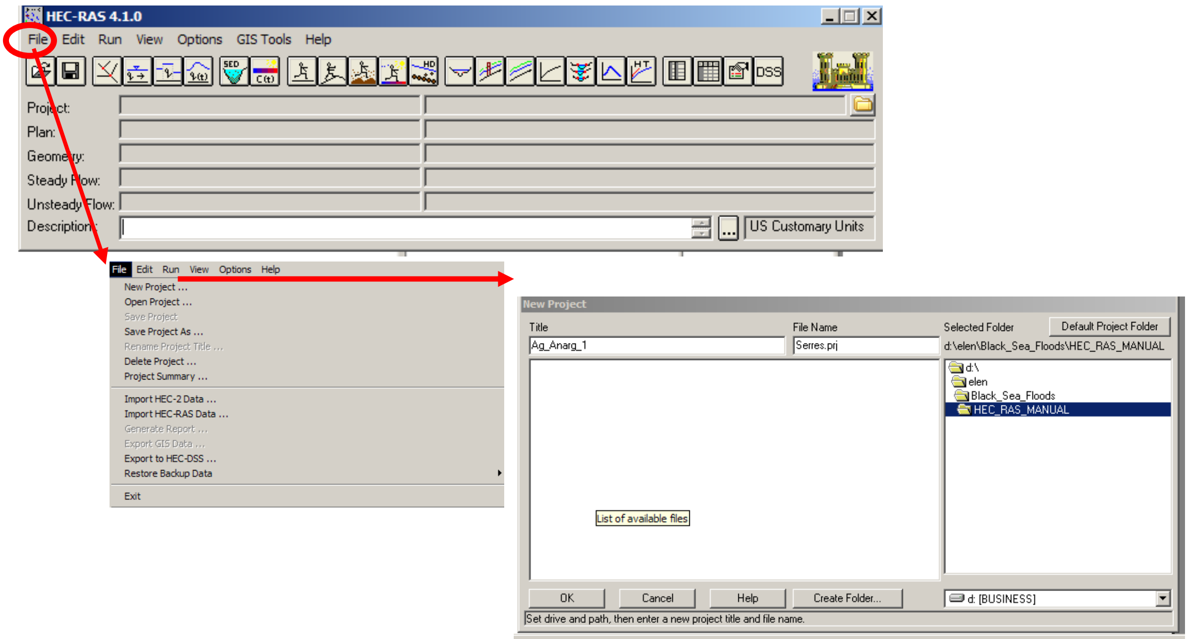

Fig. 207: HEC-RAS main window and starting options

By the same procedure an existing project may be opened by choosing **Open Project.**

The following data should be obtained before starting a HEC-RAS project.

- Stream/channel shape, geometry and slope
- structure details if any (bridges, levees, culverts etc)
- flow data

You may select units system by choosing the **Unit System** in the **Options** tab in the main HEC-RAS menu (Fig. 208).

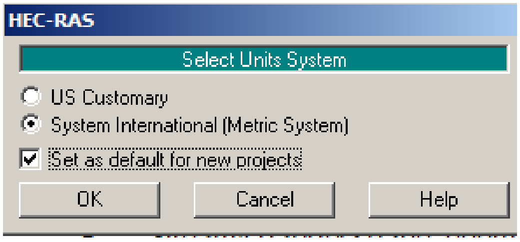

Fig. 208: HEC-RAS unit system options

The **Options** tab also includes general set up parameters for the project. (These can by also set during project editing)

2. Entering Geometry Data

Choose **Edit** from the main HEC-RAS menu and then choose **Geometric Data**

(Fig. 209**)**

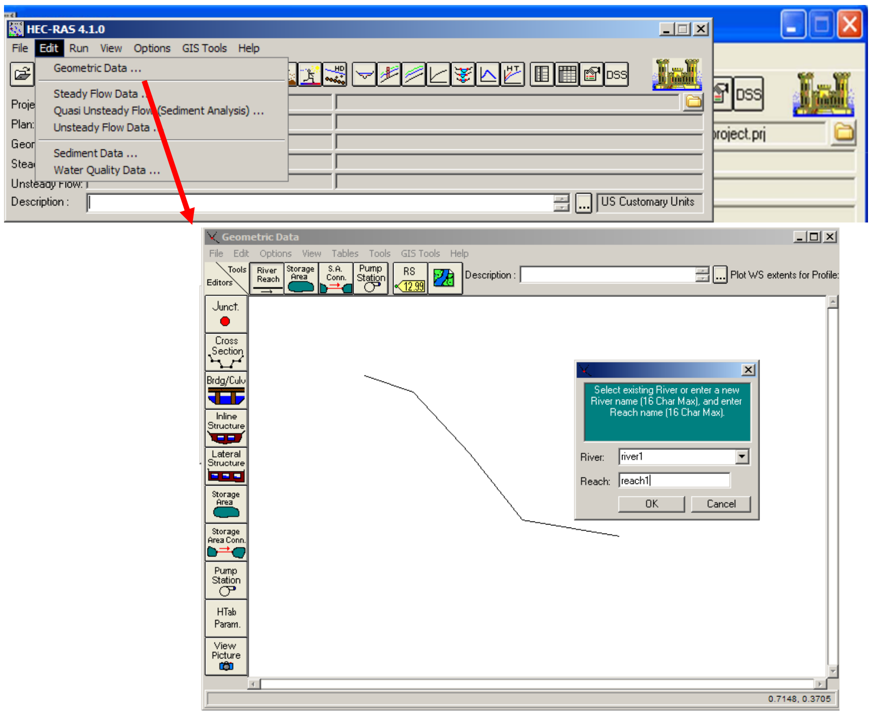

Fig. 209: HEC-RAS Geometric Data window

In the **Geometric Data** window, click on the **River Reach** and draw the stream/ river line from upstream to downstream. Set the **River** name and **Reach** name when finishing sketching the stream line (Fig. 210). You may add reaches by adding junctions and other river lines.

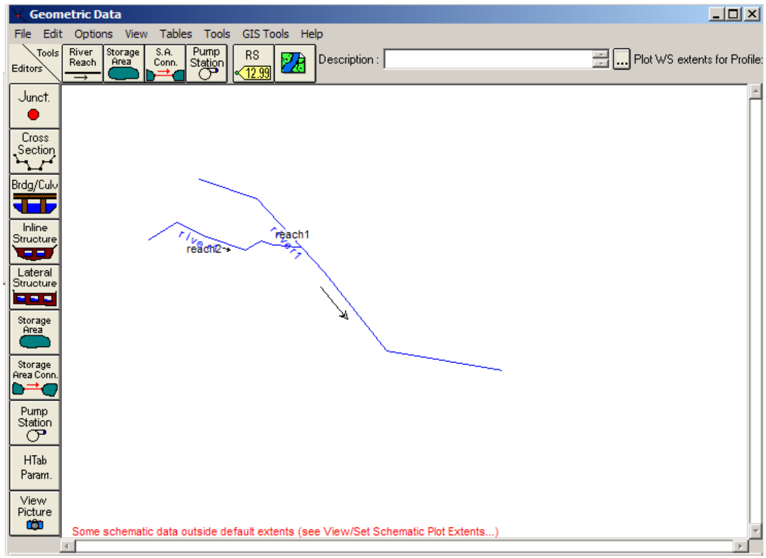

Fig. 210: HEC-RAS Geometric Data Input

*Notice messages on bottom of Geometry Data window for errors and Information

3. Entering Cross-Section Data

In the Geometry Data window select the **cross-section** button. Click the Options button. Choose "**Add a new cross-section**" Enter the number of the cross-section you want to add. Then type in the Cross-Section Coordinates the **Station** and the **Station Elevation** fro each point of the cross-section to create the geometry. (Station is the position along the stream) You must also insert **Downstream Reach Lengths** to adjust geometry by typing distance values in **LeftOverBank** (LOB) and **RightOverBank** (ROB) tabs, **Manning** values and **Bank Stations** positions etc. (Fig. 211) The cross-station may extend further off of bank stations. On the right side of the window the inputs are plotted. You may alter the view of cross-sections from the plot options button.

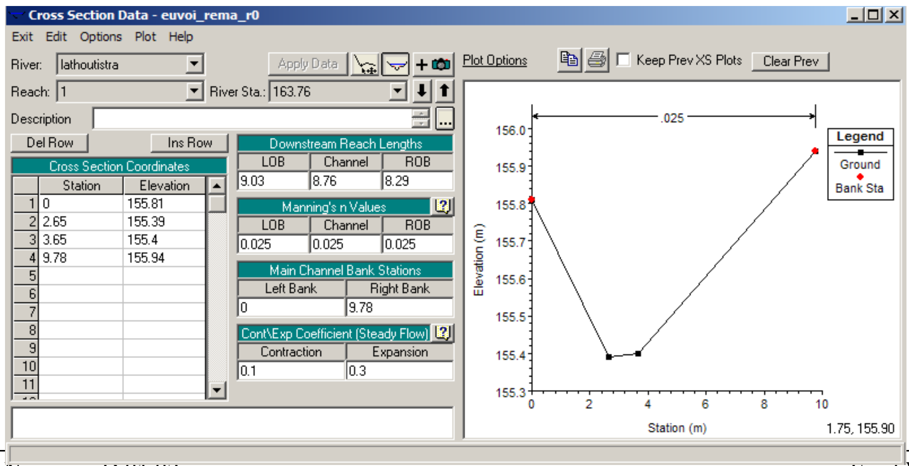

Fig. 211**:** HEC-RAS Cross-section Input

Repeat step 3 for adding additional cross-sections. You may either copy the current cross-section to another location and modify the geometry or add a new cross-section to another location.

4. Entering other data

Once the basic geometry is set other structure data may be introduced. On the cross-section data window choose the **Options** tab. You may modify and add additional data such as **levees, culvers, obstructions** etc. (Fig. 212)

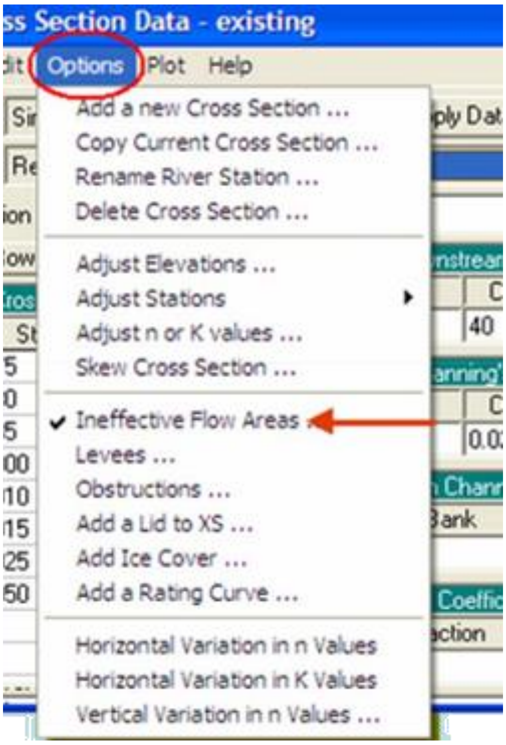

Fig. 212: HEC-RAS Cross-section editing options

5. Entering Flow Data

Flow data is necessary at this point for hydraulic computations. There are three choices of data flow: **Steady Flow Data, quasi-unsteady flow data and, unsteady flow data (**Fig. 213**)**. The choice depends on the desired type of hydraulic analysis. Different computations and flow data may be inserted and saved in the same project.

From the main HEC-RAS Window choose **Edit** and scroll down to the flow data types. Choose the one you wish and add flow data.

You must set **Boundary Conditions** and **Flow Data**. Flow data is inserted ad a Profile (PR). Many Profiles may be added and saved separately.

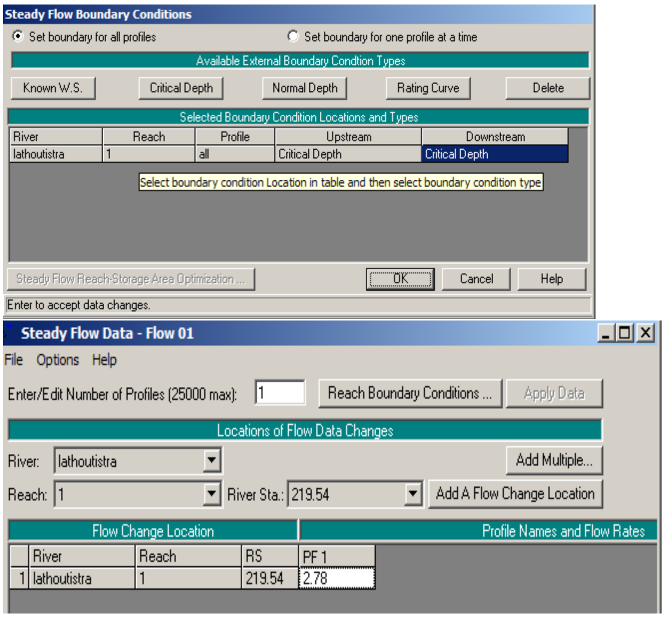

Fig. 213: HEC-RAS entering flow data

6. Computations/Running of Model

In main HEC-RAS window, click on **Run**, then choose **Flow Analysis** (any type). In the Flow Analysis menu, choose **File, New Plan**. Enter the title and click on **Compute** to run the model (Fig. 214). Save the plan. Address any errors/information until plan runs successfully.

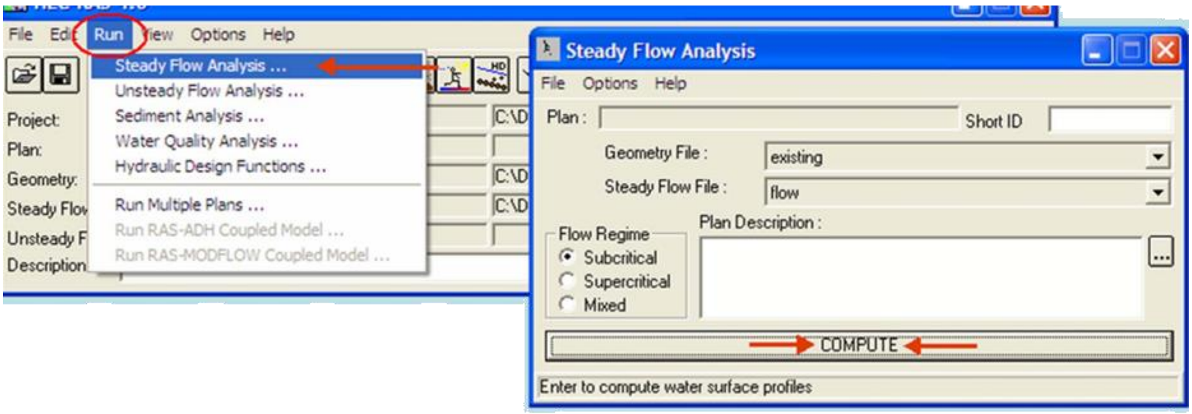

Fig. 214: Model Run

7. Outputs/Results

Once the computations are completed, output tables are instantly and automatically created. From the main HEC-RAS window choose the **output tables (**Fig. 215**)** to view the results. The output tables may be formatted according to the desired viewed data and may be saved and printed. In the tables all the hydraulic related data are presented for every single cross-section.

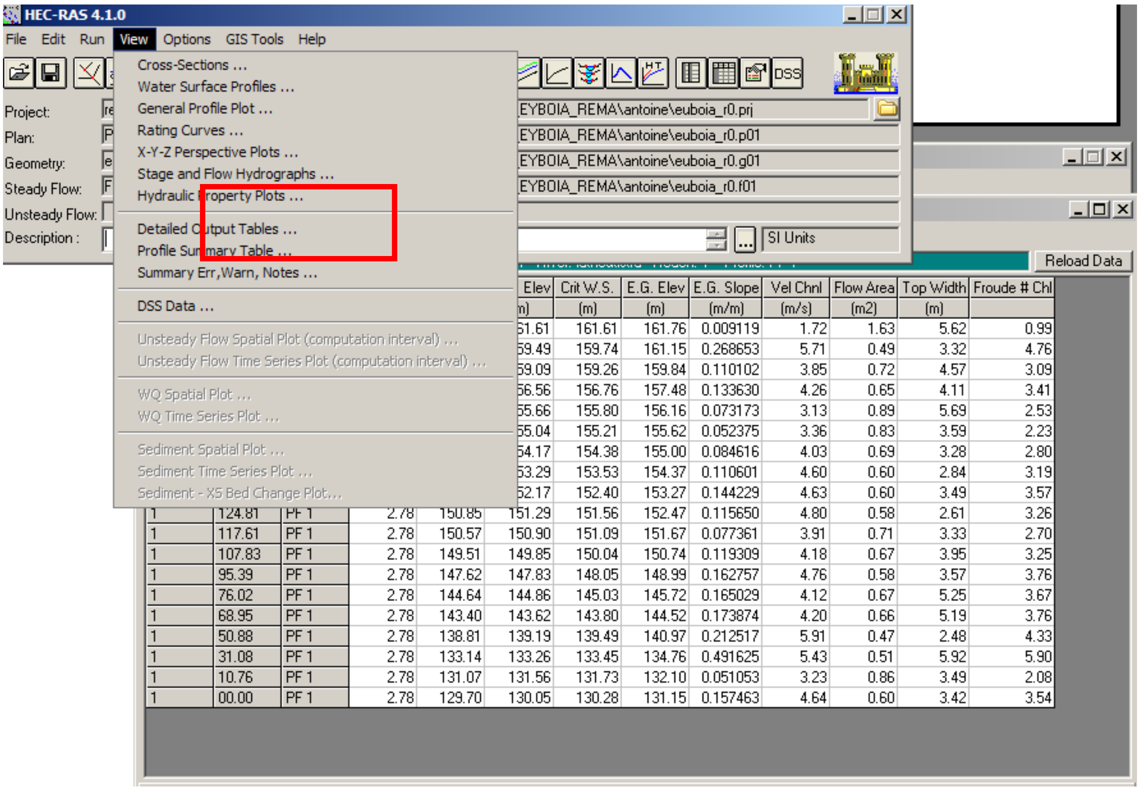

Fig. 215: Output tables

Profile plots, perspective plots and cross-section plots may be viewed (Fig. 216), saved, written in .dxf file format. Project may also be exported in GIS format. This way hydraulic data (water surface/profiles and geometry data may be inserted in other software for further mapping.

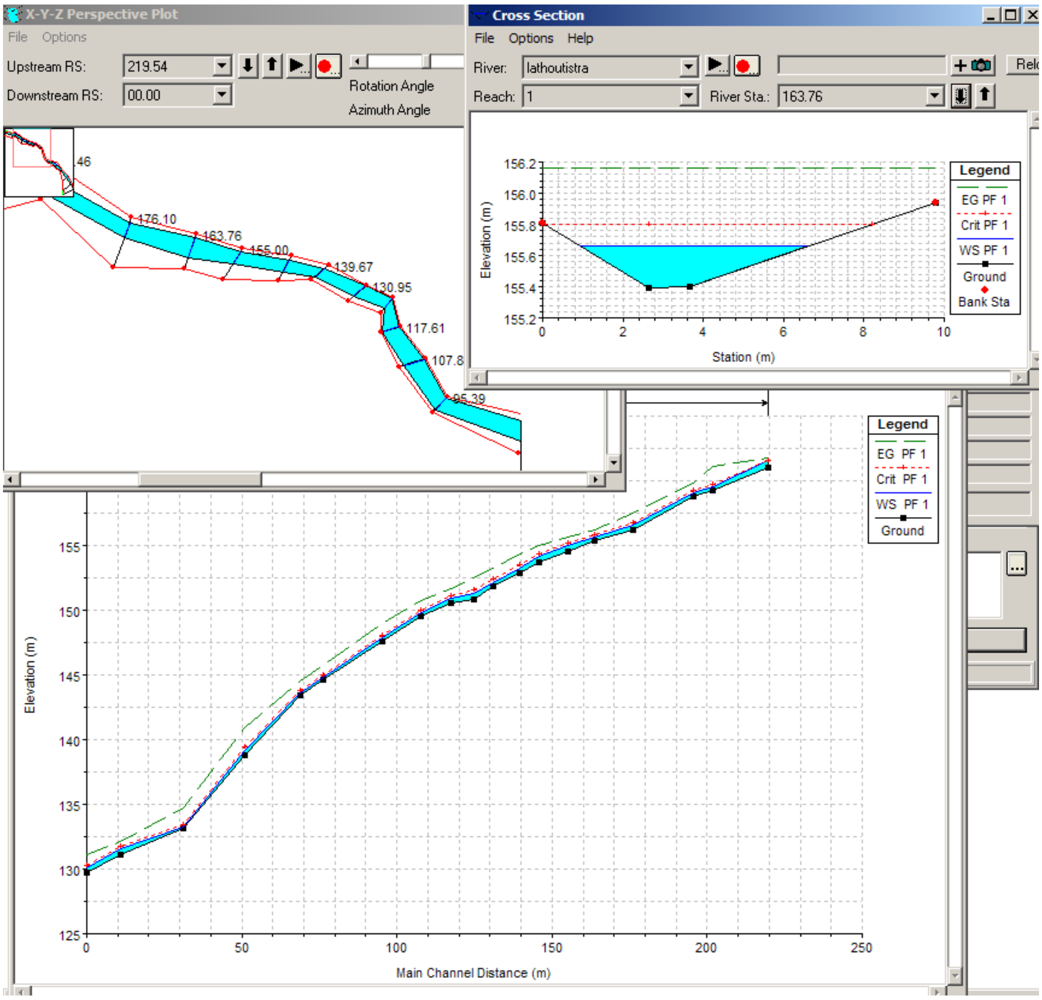

Fig. 216: Output tables

6.4.9.1 Important Web Sites

1. Quantum GIS Home and Download: http://www.qgis.org/en/site/
2. QGIS Documents (Manuals, Tutorials, Help): http://www.qgis.org/en/docs/index.html
3. System for Automated Geoscientific Analysis (SAGA) Home: http://www.saga-gis.org/en/index.html
4. SAGA software description: http://www.saga-gis.org/en/about/software.html
5. SAGA documentation: http://sourceforge.net/projects/saga-gis/files/
6. SAGA Research: http://www.saga-gis.org/en/about/research.html
7. SAGA References: http://www.saga-gis.org/en/index.html
8. HEC-RAS official software site http://www.hec.usace.army.mil/software/hec-ras/

6.4.10 APPENDIX III: HYDROLOGICAL TERMS

Consistency in using terms is a prerequisite for cooperative work. For that reason, a list of commonly used terms follows. Terminology listed, was adopted from various sources and harmonized in order to cover as fully as possible, the regularly used terms. Sources of information were the National Weather Service, National Oceanic and Atmospheric Administration –NOAA (http://www.nws.noaa.gov/om/hod/SHManual/SHMan014_ glossary.htm), the USGS (http://or.water.usgs.gov/projs_dir/willgw/glossary.html) and (https://water.usgs.gov/edu/dictionary.html) and the European Environmental Agency (http://www.eea.europa.eu/themes/water/wise-help-centre/guided-tours/introduction-to-general-terms).

Alluvium (Alluvial formations): Sediments deposited by erosional processes, usually by streams

Annual Flood : The maximum discharge peak, during a given hydrologic (water) year (October 1 - September 30).

Aquiclude : A formation which does not permit groundwater movement through it.

Aquifer : Permeable geologic formations which can hold or transmit groundwater with a water yield in sufficient quantities for beneficial use.

Aquifuge : A geologic formation which has no interconnected openings and cannot hold or transmit water.

Bank Storage : Water stored in the permeable formations of the bed and banks of a stream, lake, or reservoir, and returned in whole or in part when the water level drops.

Base Flood (100 year flood): The flood which has at least one chance in 100 of occurring in any given year

Baseflow : Groundwater flow, which results from precipitation that infiltrates into the soil and eventually moves through the soil to the stream channel and contributes to the streamflow.

Base Width : The time duration of a unit hydrograph.

Basin (stream or river basin) : An area having a common outlet for its surface runoff.

Basin Boundary : The topographic dividing line around the perimeter of a basin, beyond which overland flow (i.e.; runoff) drains away into another basin.

Basin Lag : The time it takes from the centroid of rainfall for the hydrograph to peak.

Recharge : Amount of rainfall that infiltrates into the ground and adds to the residual moisture of the basin in order to help recharge the ground water deficit. (Can also be found as Groundwater recharge or basin recharge).

Bed Load : Sediments (sand, silt, gravel, or soil and rock detritus) carried by a stream on or immediately above its bed. The particles of this material have a density or grain size such as to preclude movement far above or for a long distance out of contact with the stream bed under natural conditions of flow.

Braided Stream : Characterized by successive division and rejoining of streamflow with accompanying islands. A braided stream is composed of anabranches (diverging branches of a river which re-enter the main stream)

Capillary Zone : The soil area just above the water table where water can rise up slightly through the cohesive force of capillary action. This layer ranges in depth from a couple of inches, to a few feet, and it depends on the pore sizes of the materials. The capillary zone is also called the capillary fringe.

Catchment Area : An area having a common outlet for its surface runoff (also as Drainage Area, Basin, Watershed).

Channel (watercourse) :

An open conduit either naturally or artificially created which periodically, or continuously contains moving water, or forms a connecting link between two bodies of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels. Natural channels may be single or braided. Canal and floodway are some of the terms used to describe artificial channels.

Channel Inflow : Water, which at any instant, is flowing into the channel system form surface flow, subsurface flow, base flow, and rainfall that has directly fallen onto the channel.

Channel Lead : An elongated opening in the ice cover caused by a water current.

Channel Routing : The process of determining progressively timing and shape of the flood wave at successive points along a river.

Channelization : The modification of a natural river channel.

Closed Basin : A basin without a surface outlet; draining to some depression or pond within its area, from which water is lost only by evaporation or percolation.

Closed Basin Lake Flooding : Flooding that occurs on lakes with either no outlet or a relatively small one.

Composite Hydrograph : A stream discharge hydrograph which includes base flow, or one which corresponds to a net rain storm of duration longer than one unit period.

Crest : The highest level to which water must rise before passing over a structure or the river bank or the highest stage or level of a flood wave as it passes a point.

Critical Rainfall Probability (CRP) : The probability that the actual precipitation during a rainfall event will exceed the flash flood guidance value.

Cross-sectional area : Area perpendicular to the direction of flow.

Deep Seepage : Infiltration which reaches the water table.

Design Criteria : The hypothetical flood used in the sizing of construction to prevent failure by overtopping (for Dams and Flood protection structures)

Deterministic (Model): A set of natural processes such as rainfall and runoff described by mathematic equations in order to describe a given flow rate for a given location (spot).

Direct Flood Damage : The damage done to property, structures, goods, etc., by a flood as measured by the cost of replacement and repairs.

Direct Runoff : The runoff entering stream channels promptly after rainfall or snow melt. Superposed on base runoff, it forms the bulk of the hydrograph of a flood.

Discharge : The rate at which water passes a given point expressed in volume per time.

Discharge Curve : A curve that expresses the relation between the discharge of a stream at a given location and the water table at or near that location.

Discharge Table (Rating Table)**:** A table showing the relation between the gage height and the discharge of a stream at a given gaging station.

Distribution (Hydro)Graph : A unit hydrograph of direct runoff modified to show the proportions of the volume of runoff that occur during successive equal units of time.

Diversion : The taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Divide : The high ground that forms the boundary of a watershed. A divide is also called a ridge.

Drainage Area : An area having a common outlet for its surface runoff (also Watershed and Catchment Area).

Drainage Basin : A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage Density : The relative density of natural drainage channels in a given area. It is expressed in terms of length of stream channels per area (km/km^2).

Drainage Divide : The boundary line, along a topographic ridge or along a subsurface formation, separating two adjacent drainage basins.

Empirical (Model): The use of relationships between known watershed parameters and outputs for large datasets, in order to predict flow for a given location (spot).

Flash Flood : A flood which follows within a few hours (usually less than 6 hours) of heavy or excessive rainfall, dam or levee failure, or any sudden release of water.

Flood : “‘flood’ means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems” (Directive 2007/60/EC)

Flood Control Storage : Storage of water in reservoirs to abate flood damage.

Flood Crest : The maximum height of a flood wave as it passes a location.

Flood Plain : The portion of a river valley that has been inundated by the river during historic floods.

Flood Prevention : Measures that are taken in order to preventing floods. Planning, land acquisition, river channel maintenance, wetlands protection, and other regulations all help modify development on flood plains and watersheds to reduce their susceptibility to flood damage. Preventive measures are usually administered by the building, zoning, planning and/ or code enforcement offices of the local government.

Flood Profile : A graph of elevation of the water surface of a river in flood, plotted as ordinate, against distance, measured in the downstream direction, plotted as abscissa. A flood profile may be drawn to show elevation at a given time, crests during a particular flood, or to show stages of concordant flows.

Flood Routing : Process of determining progressively the timing, shape, and amplitude of a flood wave as it moves downstream to successive points along the river.

Flood Stage : A gage height at which a watercourse overtops its banks and begins to cause damage to any portion of the defined reach. Flood stage is usually higher than or equal to bankfull stage.

Flood Wave : A rise in streamflow to a crest and its subsequent recession caused by precipitation, snow melt, dam failure, or reservoir releases.

Hydrograph : A graph showing the water level, discharge, or other property of a river volume with respect to time (ASCE, 1985).

Hydrologic Equation : The water inventory equation (Inflow = Outflow + Change in Storage) which expresses the basic principle that during a given time interval the total inflow to an area must equal the total outflow plus the net change in storage.

Hydrologic Model : A conceptual or physically-based procedure for numerically simulating a process or processes which occur in a watershed.

Hydrologic Unit : A geographical area representing part or all of a surface drainage basin or distinct hydrologic feature such as a reservoir, lake.

Hyetograph : A graphical representation of rainfall intensity with respect to time.

Impermeable : Geologic formation that does not permit water to pass through it.

Impervious : Geologic formation that does not let water infiltrate.

Infiltration : The vertical downward movement of water into the soil or rock (SSSA, 1975).

Infiltration capacity : The maximum rate at which a soil or rock is capable of absorbing water or limiting infiltration (after ASCE, 1985).

Infiltration Capacity Curve : A graph showing the time-variation of infiltration capacity

Infiltration Index : An average rate of infiltration in mm per hour, equal to the average rate of rainfall such as that the volume of rainfall at greater rates equals the total direct runoff.

Infiltration Rate : (1) The rate at which infiltration takes place expressed in depth of water per unit time (in mm per hour).

Initial Water Deficiency : The quantity that the actual water content of a given soil zone in an area is less than the field capacity of that zone at the beginning of the rainy season.

Instantaneous Unit Hydrograph : The theoretical, ideal, unit hydrograph that has a infinitesimal duration.

Intermittent (Ephemeral) Stream : A stream that flows periodically.

Inundation Map : A map delineating the area that would be inundated in the event of a flood.

Isohyet : A line that connects points of equal rainfall.

Lag (Time) : The time it takes a flood wave to move downstream.

Laminar Flow : Streamline flow in which successive flow particles follow similar path lines and head loss varies with velocity to the first power.

Levee (Dike) : A long, narrow embankment usually built to to prevent flooding. If built of concrete or masonry, it is usually referred to as a flood wall.

Local Flooding : Flooding conditions over a relatively limited (localized) area.

Lowland Flooding : Inundation of low areas near the river, often rural, but may also occur in urban areas.

Major Flooding : Extensive inundation and property damage.

Minor Flooding : A general term indicating minimal or no property damage but possibly some public inconvenience.

Moderate Flooding : The inundation of secondary roads; transfer to higher elevation necessary to save property -- some evacuation may be required.

Net Rainfall : The portion of rainfall which reaches a stream channel or the concentration point as direct surface flow.

Outlet : An opening through which water can be freely discharged from a reservoir.

Overland Flow : The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a watercourse it becomes runoff.

Peak Discharge : Highest rate of discharge of a volume of water passing a given location during a given period of time (during the year, a flood event, etc..).

Percolation : The movement of water, under hydrostatic pressure, through the fractures of a rock or small voids between soil particles.

Permeability : The ability of a material to transmit water through its pores/voids/fractures when subjected to a difference in head.

Point Discharge : Instantaneous rate of discharge, in contrast to the mean rate for an interval of time.

Point Precipitation : Precipitation at a particular site, in contrast to the mean precipitation over an area.

Porosity : The ratio (as percentage) of the volume of openings/voids to the total volume of soil or rock.

Precipitation : The amount of rainfall, snow and hail onto a land or water surface.

Profile : A graph showing variation of elevation with distance along a traverse.

Response Time : The amount of time in which it will take a watershed to react to a given rainfall event.

River Basin : Drainage area of a river and its tributaries.

River Flooding : The rise of a river to an elevation such that the river overflows its natural banks causing or threatening damage.

Stochastic (Model): Statistical determination of the probability of occurrence of a given flow rate at a given location (spot).

Storm Hydrograph : A hydrograph representing the total flow or discharge past a point.

Stormwater Discharge : Precipitation that does not infiltrate into the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems.

Stream Gage : A location where the stage (water level) is measured.

Streamflow : Water flowing in the stream channel.

Surface Runoff : The runoff that travels overland to the stream channel.

Threshold Runoff : The runoff from a rain of specified duration, that causes a small stream to slightly exceed bankfull. When available, flood stage is used instead of slightly over bankfull.

Unit Hydrograph Theory : Unit Hydrograph Theory states that surface runoff hydrographs for storm events of the same duration will have the same shape, and the ordinates of the hydrograph will be proportional to the ordinates of the unit hydrograph. For example, the hydrograph for ½" of storm runoff will be half that of that from the unit hydrograph.

Urban Flooding : Flooding of streets, underpasses, low lying areas, or storm drains. This type of flooding is mainly an inconvenience and is generally not life threatening.

Watershed : Land area from which water drains toward a common watercourse in a natural basin (coincides with "basin")..

Water (Hydrologic) Year : The time period form October 1 through September 30.