Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common Borders. Common Solutions.

A Scientific Network for Earthquake, Landslide & Flood Hazard Prevention

Pilot Implementation of Flood Hazard Assessment at Regional and Local Scales

Deliverable No.: D.03.01, Vol. 3

GA 3. Earthquake, Landslide and Flood Hazard Assessment: Implementation at regional and Local scales, Activities A.3.2 & A.3.5

OVERALL RESPONSIBLE for GA.3: Democritus University of Thrace (P.1)

RESPONSIBLE for A.3.2 & A.3.5: TEI of Central Macedonia (Lead Beneficiary)

INVOLVED PARTNERS: ALL

Project Details

Programme	Black Sea JOP
Priority and Measure	Priority 2 (Sharing resources and competencies for environmental protection and conservation), Measure 2.1. (Strengthening the joint knowledge and information base needed to address common challenges in the environmental protection of river and maritime systems)
Objective	Development of a Scientific Network
Project Title	**A Scientific Network for Earthquake, Landslide and Flood Hazard Prevention**
Project Acronym	**SciNetNatHaz**
Contract No	MIS-ETC 2614
Lead Partner	TEI OF KENTRIKI MAKEDONIA, GREECE
Total Budget	700.000,00 Euro (€)
Time Frame	

Start Date - End Date 01/05/2013 – 30/11/2015

Book Captain: **K. PAPATHEODOROU (TEI of KENTRIKI MAKEDONIA)**

Contributing Authors: **K. Papatheodorou, E. Tzanou, K. Ntouros, D. Kotzinos, C. Maftei, H. Aksoy, O. Kirca, Dorukhan Kellecioglu, Halil Ibrahim, R. Sizo, V. Nenov, H. Yermendjev, A. Sidorenko**

Document Release Sheet

Book captain:	K. PAPATHEODOROU (TEI KENTRIKIS MAKEDONIAS)	Sign Konstantinos Papatheodorou	Date 20.01.2016
Approval	K. PAPATHEODOROU (TEI KENTRIKIS MAKEDONIAS)	Sign Konstantinos Papatheodorou	Date 20.01.2016
Approval	ATTILA ANSAL (KOERI/BOGAZICI UNIVERSI) UNIVERSITY)	Sign M.Atilla Ansal	Date 20.01.2016
Approval	N. KLIMIS (DEMOCRITUS UNIVERSITY of THRAKI)	Sign Nikolaos Klimis	Date 20.01.2016
Approval	B. MARGARIS (EPPO/ITSAK)	Sign Basil N. Margaris	Date 20.01.2016
Approval	V. NENOV (“ASSEN ZLATAROV” UNIVERSITY)	Sign	Date 20.01.2016
Approval	L. TOFAN (“OVIDIUS” UNIVERSITY)	Sign	Date 20.01.2016
Approval	A. SIDORENKO (“Dr. GHITU” INSTITUTE ACAD. of SCIENCES	Sign	Date 20.01.2016
Approval	K. STEPANOVA (BSB UEAS)	Sign	Date 20.01.2016

RECORD of REVISIONS

Issue/Rev	Date	Page(s)	Description of Change	Release
-	31.10.2015	139	First draft (K. Papatheodorou)	I.01
	10.11.2015	144	Incorporation of P5 contribution	I.02
	01.12.2015	150	Incorporation of P6 contribution	I.03
	10.12.2015	155	Second Draft (K. Papatheodorou)	I.04
	20.12.2015	192	Third draft with ANNEXES - Distribution	I.05
	08.01.2016	192	Minor changes requested by IPA	1.06
	15.012016	194	Ukraine Flood susceptibility maps (regional scale) added	1.07
	16.01.2016	194	Final Revision	1.08

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 BACKGROUND OF THE DOCUMENT

1.1 GENERAL NOTE

Pilot implementation on regional and on local scale actions, fall into the GA.3 "Pilot Implementation on Regional and on Local Scales"; started for all types of hazards on March 2014 and ended at the end of October 2015 (instead the end of August) in order to have time to evaluate the outputs and complete the respective reports.

This report was written in stages during September and October 2015. Responsible for the Flood Hazard Implementation activities was the Lead Beneficiary (TEI if Kentriki Makedonia) and all partners with the exception of P1 and P2 (as foreseen in the GAF) have contributed.

1.2 SCOPE AND OBJECTIVES

Pilot implementation for FHA were scheduled and implemented by all partners in their respective Pilot Implementation Areas (PIA), in order to evaluate the outputs of the selected methodologies and their adaptability to specific conditions. Evaluation is based on comparison of their outputs to actual facts and on assessing their dissemination potential in order to promote their use by the project's stakeholders (administration staff members, scientific community, engineers, geologists, planners etc.).

An additional target is the development of flood hazard maps which can be used by the State Regional and Local Administration to support strategic planning for flood disaster prevention.

1.3 RELATED DOCUMENTS

1.3.1 Input

List of former deliverables acting as inputs to this document

Document ID	**Descriptor**

1.3.2 Output

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

Document ID	Descriptor

2 INTRODUCTION

Flood Hazard Assessment on a regional scale can provide useful information which when combined with a preliminary risk assessment can support decision regarding strategic planning for disaster prevention. Flood Hazard maps can be used to assess the potential risks, prioritize areas in terms of the necessity to apply preventive measures and plan local investigations which require a more detailed planning for funding and implementation. Such a strategic planning can provide the State Regional and local administration the tool to plan effective flood disaster mitigation measures in both their financial and technical aspects.

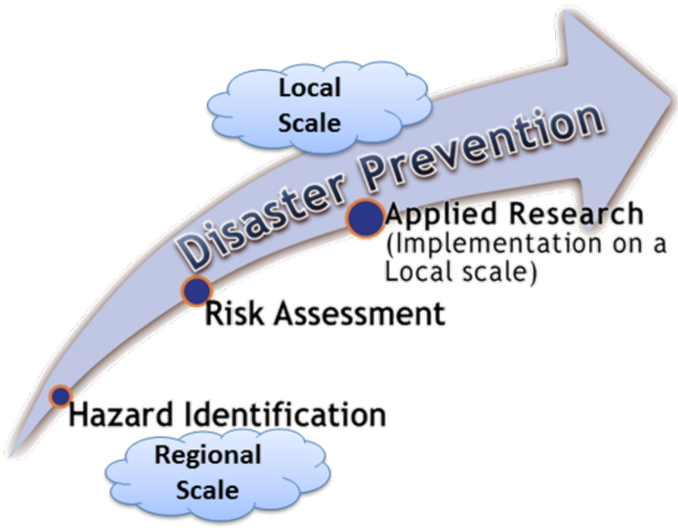


Fig1. A schematic representation of Flood Disaster Prevention actions.

The accuracy in locating areas of a high Flood Hazard and the reliability of detecting them are of high importance since this information will be the basis for risk assessment, prioritization of high risk areas, decision making regarding the management of available funds and effective strategic planning.

Numerous methodologies exist for assessing Flood Hazard on regional scales as has already been presented in previous project work (Deliverable D.01.02). The multitude of methodologies used results into non comparable outputs, a fact which especially in cross-border areas forms a block for cross-border cooperation. One of the basic targets of the SciNetNatHaz-Prevention project is the harmonization of methodologies for Flood Hazard Assessment (FHA) taking into consideration the existing status in countries around the Black Sea: lack of data and meta-data, restricted budgets available for applied research and innovation.

One more issue to consider is the fact that although flash floods are the most prominent type of flooding around the Mediterranean and in most of the Black Sea countries yet, it is the least investigated hazard as compared to reverie floods. As flash floods mostly develop on ephemeral streams, little or no runoff data are available so, statistical, probabilistic or hydrologic models used elsewhere to assess the flood hazard cannot be efficiently applied in this case.

Within this context, project partners after having examined all possible solutions and evaluated numerous methodologies (D.01.02, par. 17.4.3) according to their data requirements, complexity, flexibility/adaptation to different conditions, cost of implementation, completeness, watershed representation, reliability and accuracy of outputs, have decided to suggest a two-step process in assessing flood hazard and calculating flood parameters. The first step, which is implemented on a regional scale, is essentially a screening process aiming at detecting and mapping flood prone areas. This is actually a susceptibility assessment process and is followed by a preliminary risk assessment in order to prioritize those flood prone areas in terms of the importance of the assets at risk.

The Topographic Wetness Index (TWI) approach [1]; [2]; [3]; [4]; [5]; [6] and it's variant, the SAGA TW index [6] were selected to assess flash flood hazard on a regional scale. The methodology has already been used for that reason in many cases [7]; [8]; [9]; [10]; [11]; [12]. 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.

The second stage is to implement applied research on a local scale, using the hydraulic model HEC-RAS (or any equivalent) in order to calculate flood parameters including the inundation area (flood extent) as well as the depth and the velocity of water in order to provide support to decision making regarding the design of preventive measures. The HEC-RAS hydraulic model was selected by the project partners as it has been tested and widely accepted for such kind of applications.

Implementation of these methodologies is feasible under the current circumstances as these were described above so, their adaptability to specific conditions, their reliability and accuracy in mapping flood prone areas and assessing flood hazard, needs to be once more verified by pilot implementations within the BSB JOP 2007-13 programme eligible areas.

Pilot implementations on a regional scale were thus scheduled and implemented by all partners but local implementations were carried out only by the LB, P3, P4, and IPA in order to verify the outputs of the selected methodologies, to assess their adaptability to specific conditions and to evaluate them by comparing their outputs to actual facts.

Pilot implementation on regional and on local scale actions, fall into the GA.3 "Pilot Implementation on Regional and on Local Scales"; started for all types of hazards on March 2014 and ended at the end of October 2015 (instead the end of August) in order to have time to evaluate the outputs and complete the respective reports.

2.1 PROBLEMS IN ASSESSING FLOOD HAZARD-METHODOLOGIES IMPLEMENTED

As already concluded in previous project documents (D.01.02), the main problems in designing preventive measures to reduce risk from floods [13]; [14]; [15]; [16]; [17] include:

- Flash flood hazard issue has not been extensively dealt with. Flood inventories are difficult to access or even in certain cases, completely lacking. In those cases, if such inventories exist they are inaccessible.
- Flash floods usually occur in ephemeral streams so there are no hydrologic/hydraulic data available.
- Usable data are lacking. Even if data are found, they are not usable since there are no metadata, so the evaluation of their accuracy and reliability is impossible compromising their potential use.
- Systematic Flood Hazard (FH) on Regional and on Local scales in order to locate the problems and define prevention measure design parameters, have only been sparsely implemented.
- An additional problem especially in cross-border areas where there's a need for cooperation, is the use of various methodologies by scientists making comparison of outputs impossible and cooperation to find common solutions to common problems, very difficult.

In order to tackle the problems indicated, the SciNetNatHaz proposal and related actions as defined by the project partners include:

- The selection of widely accepted and used, scientifically sound methodologies to assess FH on regional scales. The finally selected methodologies can be applicable in the wider Black Sea area, considering the existing restrictions and problems.

- Adapting the FHA methodologies to regional conditions in respect to the pilot implementation areas (PIA).
- Evaluation of the selected methodologies in terms of their "applicability", adaptability, ease of use and reliability and accuracy of results with pilot implementations in selected areas within the projects eligible area.
- To produce metadata according to the INSPIRE directive and to provide free access to data and outputs produced to the scientific and the technical communities.

After an extensive review of available LHA methodologies used worldwide (D.01.02), the project partners concluded (D.01.02) to adopting the following:

A. The use of the Topographic Wetness Index (TWI) and its variant the SAGA WI in order to map flood prone areas on a regional scale and

B. The HEC-RAS 1D hydraulic analysis model and software which allows performing one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling (http://www.hec.usace.army.mil/software/hec-ras/features.aspx). The fact that the outputs of this model have been applied in numerous cases over the entire world in flood plain management and flood insurance studies indicates the reliability and accuracy of the outputs it can provide.

2.2 DATA AND COORDINATE REFERENCE SYSTEMS USED

Data input is an essential part of the process since they define at large the quality of the respective outputs. The data requirements for applying the selected FHA methods include:

A. FHA on a Regional Scale

- Digitized Topographic Maps and elevation points (scale 1:50.000, contour interval 20m)
- Digitized Geologic Maps (faults and dip and dip direction of geologic planes was also digitized)
- In some cases (P5, P6), ASTER DEMs with cell size of 30x30m were also used.

B. FHA on a Local Scale

- Topographic Map of a 1:500 scale (contour interval 0.25m)
- Rainfall data (30 years' time series), peak intensities. Rainfall data were recovered from previous research in the PIAs.

- Detailed geologic map of the specific location

All the above parameters were harmonized and incorporated into a Geographic Information System (GIS) developed for each Pilot Implementation Area (PIA). The Coordinate Reference System used to produce the outputs for each of the PIAs fits the National GRS of the respective country. Reason for this decision is the fact that these outputs have to be presented in the Open Seminars scheduled for the immediately next period, with the scope of transferring competencies to State authorities and building the capacity of the respective public bodies, to prevent flood disasters so there's a need for compliance with local Coordinate Reference Systems (CRS).

In PIAs within the Hellenic territory, the Hellenic Geodetic Reference System 1987 (HGRS 87 or GGRS 87) was used in order for the produced maps to be readily available to Hellenic authorities and scientific community. It must be noted though that the data and outputs produced are also available in any of the existing Coordinate/Geodetic Reference Systems including the WGS 84 and the ETRS 89. In fact all produced data and outputs will be available through the projects WebGIS platform using the WGS84 GRS. Respective coordinate systems have been used for Bulgaria, Romania, Moldova and Ukraine but all investigated areas can easily (automatically when using QGIS as the GIS platform) be re-projected to UTM WGS84, Zone 35.

All raster files created during the entire process, were created using the optimal cell size for the respective input elevation data. For data produced from 1:50.000 topographic maps, a cell size of 15x15m was selected. For 1:500 scale maps used in local scale FHA, 1m pixel size was used for DEMs created.

2.3 ACTIVITIES

Implementation comprised of research activities and field work.

Research activities included:

i. Review and analysis of published scientific research regarding flood hazard assessment methodologies in order to select the ones that are feasible to implement without compromising reliability and accuracy of their outputs (D.01.02).

ii. Review and analysis of published scientific research regarding flood hazard assessment related issues (including extreme weather events) in the wider area.

iii. Evaluation of outputs by comparing them to actual facts.

Field work comprised of:

i. Engineering geological surveys to record the respective characteristics of the geologic formations in the area and assess the sediment production potential.

ii. Differential GPS surveying in Serres PIA (in two sites) to construct a detailed topographic maps of 1:500 scale in order to apply the hydraulic model.

iii. Map and document flooded areas (historic data).

Office work included:

i. Preparation of required digitized data (topographic and geologic maps, rainfall data, etc.).

ii. The development of a GIS to incorporate, analyze and further process the data, and

iii. Implementation of the selected FHA models, development of the processing model and production of the respective cartographic material (various maps, tables, graphs etc.).

iv. Evaluation of outputs by comparing them to actual past flood events recorded in the PIA.

Hardware and software used:

i. Partners have used their available infrastructure in terms of hardware. He entire data processing and analysis, implementation of models and map production was based on Open Source GIS software and freeware, including Quantum GIS (QGIS), SAGA GIS and Multispec©.

Specific items were purchased to enhance field work efficiency and thus to reduce time at the field and costs. Moreover to ensure implementation of complicated processing and timely deliverance of a large volume of outputs. Purchased instruments included:

ii. A high performance Toshiba laptop, purchased in order to:

    a. cover the very high processing requirements both in the office, given the facts of the very large areas covered and the demand or high resolution outputs and
    b. in situ processing in order to reduce time in the field and the respective costs.

iii. A field data collection device running Android 5.02 OS, water and dust proof, to measure all required parameters (geotagged photos, database for data collection etc), store and deliver data to the GIS in real time to boost field work efficiency.

3 SERRES PILOT IMPLEMENTATION AREA

Serres Pilot Implementation Area (PIA) characteristics have already been presented in the respective chapter for landslide hazard assessment.

Serres PIA covers a total area of approximately 495km^2 in the eastern part of Kentriki Makedonia (Central Macedonia), Hellas (Fig.2).

This specific PIA was selected for many reasons including:

i) its proximity to the Lead Beneficiary basis; a fact that limits the costs of field work and implementation time;
ii) its great importance for the city of Serres and the wider area;
iii) Flooding events which have occurred in the past.
iv) The multitude of geologic formations outcropping in the area with varying engineering geological attributes and geotechnical behavior; a factor which strongly affects the sediment production in upstream and flood hazard in downstream areas.

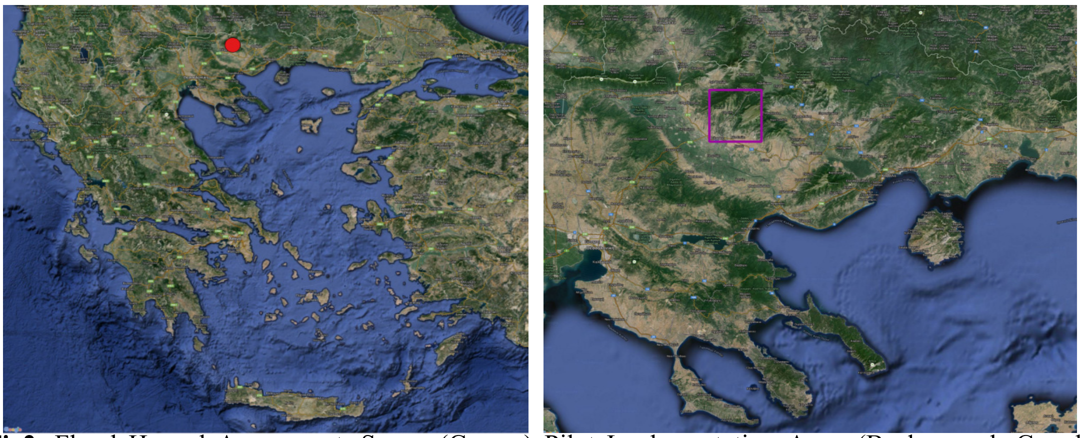


Fig2. Flood Hazard Assessment, Serres (Greece) Pilot Implementation Area. (Background: Google Maps physical)

3.1 GEOMORPHOLOGY AND GEOLOGY

The natural processes that shape the morphology of an area, are closely linked to the geotechnical behavior of its geologic formations and therefore to the event of slope failures and intense erosion phenomena. In that aspect, the examination of the morphological characteristics of an area provides information regarding the processes of weathering and erosion related phenomena and helps estimate the expected geotechnical behavior of the outcropping geologic formations and thus assess important parameters to estimate sediment production in upstream areas.

The lowermost part of the area morphology is characterized by elongated hills having a N-S direction. In all the natural slopes of this area there are indications of strong erosion processes leading to badland topography in certain cases.

Large amounts of sediments are deposited in stream beds, consisting mainly of large size particles (greater than 30cm in diameter). This fact is indicative or intense erosional phenomena taking part in the areas natural slopes.

The upper half of the Serres PIA presents an intense morphology, with high and steep natural slopes ranging from 25 to 50^{o}. The middle part consists of smoothly sloping areas on top of hills and very steep, almost vertical slopes in streams due to intense erosion phenomena despite that fact that this area is densely vegetated. The lower part of Serres PIA is a hilly area with smooth slopes and low elevations (Fig.3).

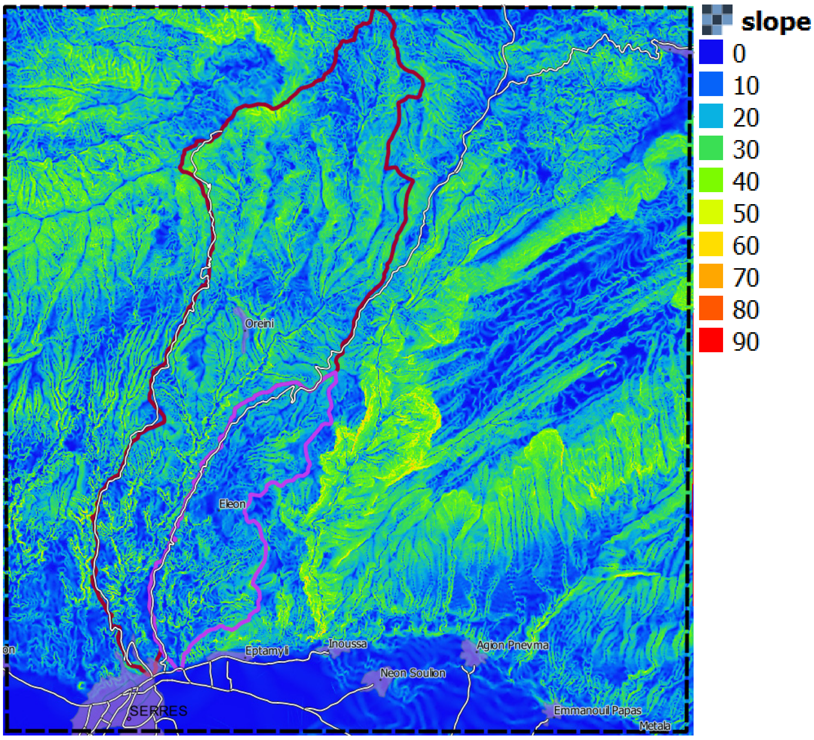


Fig3. Serres Pilot Implementation Area (PIA). A complex morphology is evident by steep slopes and abrupt slope changes in most of the area.

The intensive erosion phenomena abundant in the Miocenic and Quaternary formations of the area are indicative of the mechanical characteristics of these formations and of their geotechnical behavior (Fig.4).

Another important phenomenon occurring on the steep natural slopes of the center of the area and indicative of the sediment production are the numerous landslides (Fig.5).

Fig4. Intense erosional processes on natural slopes of the lowermost part of Serres PIA

Fig5. Landslides on the natural slopes of Serres PIA

Serres PIA geological units consist of Quaternary deposits which cover the metamorphic rocks of Rodopi massif and magmatic intrusions forming mainly granites and monzonites (Fig. 6-Geologic Map of the area).

The presence of soil formations rich in clayey minerals, the presence of conglomerates with clayey cementing material which are extremely erodible, the intense tectonism of metamorphic and igneous rocks evident by plastic deformation and intense fracturing, create an unfavorable geologic environment in respect to natural slope stability.

Intense tectonism of rocks combined with the presence of a thin (up to 1.5m), loose eluvial mantle and the action of surface and ground water cause numerous instability phenomena of limited extend, on the natural slopes of the area. These natural slope failures are mainly slab slides and rock falls (limited extend failures) but there are also large circular slides especially within the conglomerates.

Full description of the geologic formations outcropping in Serres PIA and their respective engineering properties is given in the respective chapter for the Landslide Hazard Assessment.

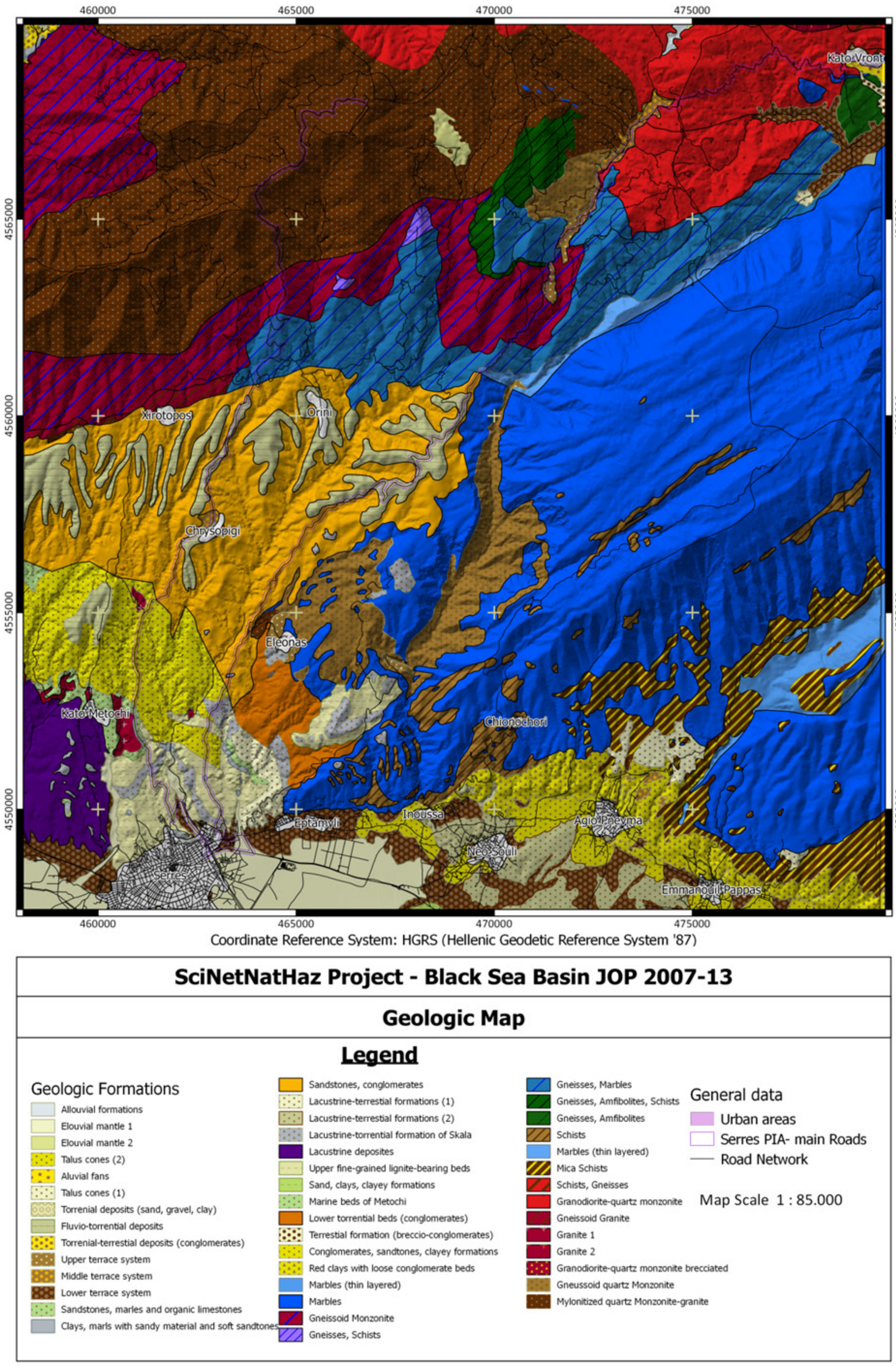


Fig6. Geologic Map of Serres Pilot Implementation Area (PIA).

According to Corine Landcover (Fig. 7) verified by the classification of remotely sensed Landsat ETM+ data, 72% of the Agioi Anargyroi and Eleonas stream basin areas are covered by forests and woodland-scrubs and 10% is occupied by agriculture (Table 3.1.1).

Table 3.1.1 Area coverage of various land covers in Agioi Anargyroi stream basin

Land Cover	Area Coverage (%)
Broad-leaved forest	32.23
Coniferous forest	2.65
Sclerophyllous vegetation	21.59
Mixed forest	8.07
Transitional woodland-shrub	6.64
Natural grasslands	17.51
Discontinuous urban fabric	1.74
Land principally occupied by agriculture, with significant areas of natural vegetation	5.20
Non-irrigated arable land	4.38
Total	100.00

The respective figures for Eleonas stream basin are given in Table 3.1.2.

Table 3.1.2 Area coverage of various land covers in Eleonas stream basin.

Land Cover	Area Coverage (%)
Areas ocuupied by Agriculture (Olive groves, non irrigated arrable land, complex cultivation patterns)	31.44
Natural grasslands	37.12
Forest	31.44
Total	100.00

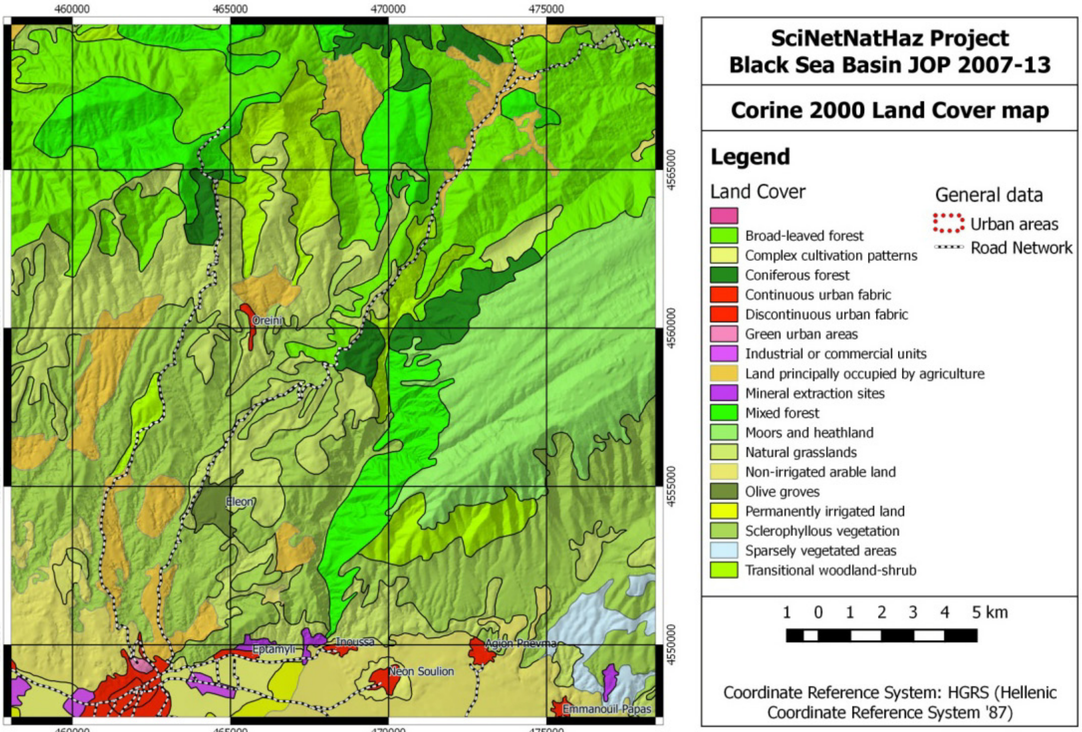


Fig7. Serres PIA land Cover map (Corine 2000).

3.2 RAINFALL

3.2.1 Introduction

Evaluation of rainfall data is crucial in water resources planning and management. Rainfall data is needed in many fields and applications such as design and construction of sewerage and storm systems, determination of channel discharge capacity, flood estimations etc. Rainfall data and the appropriate processing are very important parameter for the as accurate as possible hazard assessment which could lead to effective disaster mitigation [18].

One of the tools mainly used to estimate rainfall intensity, is the development of an empirical formula that combines rainfall intensity, rainfall duration and occurrence frequency. Rainfall data are introduced to analytical and statistical methods to produce Rainfall intensity–Duration–Frequency (IDF) curve, which can be mathematically described by a specific formula. Three different frequency methods are most commonly used; Gumbel, Log Pearson III, and Log normal, with the Gumbel Distribution to be the one mostly used in Greece.

3.2.2 Rainfall Data Analysis

As was already stated, the main effort regarding the Flood Hazard Assessment in this project, focused on producing a tool that would correlate flooding estimation between regional and local scales by using approved and well-established scientific methods. In terms of assessing flood susceptibility on a regional scale (1st “screening” step of the proposed procedure), rainfall data was not used since only elevation data were necessary. When it comes to local scale flooding analysis, the amount of maximum-peak water discharge for performing a hydraulic analysis in a river or stream is necessary. Maximum discharge (Qmax) can either be obtained from data coming from meteorological and rainfall measuring stations or discharge measurement stations which record real time data. These data are then processed in order to give rainfall intensity data for selected return periods. The issue in most cases is that flash floods occur mainly on ephemeral streams in ungauged basins; therefore hydrologic data of this kind are usually not available as is the case in Serres PIA.

Intensity–duration–frequency (IDF) relationship is a tool for relating rainfall frequency to precipitation. It is mainly used to obtain “design storm” for different water system projects of certain reoccurrence interval [19]. The relationships depict the probability of intense bursts of precipitation based upon data from many unrelated storms.

The typical estimation procedure for IDF curves was presented by Chow et al. (1988) [19], and consists of three steps. i) fitting a probability distribution function to each group of the data values for a specific duration; ii) calculating the rainfall intensities for each duration and a set of selected return periods (e.g. 2, 5, 10, 25, 50, 100 years, etc.). iii) The final IDF relationship can be obtained in two different ways: either (a) for each selected return period the rainfall intensities are computed and a graphical relationship of intensity and duration for different return periods is established, or (b) the rainfall intensity is related in functional relationship to the rainfall duration and the return period using mathematical and regression analysis to derive an equation.

Design storm for a catchment can be derived on the basis of the IDF-relationships. For any project and for a given return period and specified rainfall duration, the required design storm intensity can be obtained either from IDF-curves plots, or from derived IDF formula, [20].

Nguyen et al. (1998) [21] proposed a generalized extreme value (GEV) distribution model for regional estimation of short duration design storms based on the scaling theory (4). Application of Geographical Information System (GIS) to automate the evaluation, the design storm prediction and the flood discharge associated with a selected risk level has been done by Castrogiovanni et al. (2005) [22].

3.2.2.1 The Gumbel Method

Gumbel Distribution function (1958) is the most used distribution for IDF analysis. In this method, the frequency precipitation depth $\mathbf{P_T}$ (in mm) for any rainfall duration $\mathbf{t_d}$ (in hours) with specified return period $\mathbf{T_r}$ (in years) is computed using the following relation (1):

$$P_T = P_{av} + K_T S \tag{1}$$

Where:

K_T is Gumbel frequency factor,

S is standard deviation of precipitation data

I_T is rainfall intensity (in mm/h) for return period Tr, and is obtained from

$I_T = P_T / t_d$

t_d is duration in hour

The results (intensity and duration) are plotted in logarithmic and normal scale producing the IDF curves.

A generalized empirical IDF relationship between rainfall intensity, $\mathbf{I_T}$, rainfall duration ($\mathbf{t_d}$), and return period ($\mathbf{T_r}$), can be formed as follows [18]:

I_T=a ($\mathbf{T_r}$)^m/ ($\mathbf{t_d}$)^b

Where, I_T is the rainfall intensity for return period $\mathbf{T_r}$ (in years) and duration $\mathbf{t_d}$ (in min). Constants a, b, and m are empirical parameters depend on location, shape, and scale of the area which are obtained from area characteristics and precipitation data using logarithmic relationships [18].

3.2.2.2 The Rational Method

Rainfall intensity for the design storm, as previously described, is necessary to calculate peak runoff rate from a drainage area, for the design of storm water structures using the rational method. Time of concentration, return period, and an IDF relationship are used to calculate design rainfall intensity.

The rational method is a tool for estimating peak (maximum) discharge from relatively small drainage areas [24]. The rational method relates peak discharge to contributing drainage area, average rainfall intensity for a duration equal to a watershed response time (typically the time of concentration), and a coefficient that represents hydrologic abstractions and hydrograph attenuation. The coefficient is generally termed the runoff coefficient and has a range from 0 (no peak discharge or runoff produced for a given rainfall intensity) to 1 (perfect conversion of rainfall intensity to a peak discharge). The Rational Equation (2) is representative of the rational method.

$$Q = k\,C\,i\,A \tag{2}$$

Where: Q = Peak discharge, m^3/s; c = Runoff coefficient; i = Rainfall intensity, mm/hour; A = Drainage area, ha; k= conversion factor.

There are a few assumptions and limitations regarding the rational method. The method provides the peak discharge value, but does not provide a time series of flow nor flow volume. It can be used for relatively small drainage areas. The method is applicable if Td for the drainage area is less than the duration of peak rainfall intensity. The calculated runoff is directly proportional to the rainfall intensity.

Rainfall intensity is uniform throughout the duration of the storm and the frequency of occurrence for the peak discharge is the same as the frequency of the rainfall producing that event. In the Rational Method, Rainfall is distributed uniformly over the drainage area. The rational method does not account for storage in the drainage area.

In our study area in Serres, both catchments are of medium-size in terms of areas covered so the rational method is applicable in both of these cases.

3.2.3 Rainfall Data of the greater Study Area

To determine the climatic, meteorological, and rainfall conditions in the study area of Serres, data from the meteorological stations "Serres", "Chrisopigi" and rainfall measuring station "Oreini" were obtained.

The available data included, temperature data, rainfall, humidity, evaporation, snowfall and wind direction.

The available data showed some problems concerning uniformity, in terms of collection intervals and dates, while in some cases the data proved of poor quality.

The problem in obtaining such data has been an issue concerning the Greek territory. To overcome this obstacle in collecting reliable rainfall data so as to estimate peak flow discharge which is needed for local-scale hydraulic channel analysis, former studies of the area were retrieved to assess, evaluate and cross-check the results extracted from our study.

The meteorological station of Chrisopigi is located in 41° 10' E and 23° 31' N (WGS 84), and appertains to the Forest Research Institute, Greece. Collecting data from 1978-1995, and 2000 until today.

Unfortunately, poor data concerning precipitation episodes and time series were obtained. To overcome this issue, data from other studies were also used, mainly concerning rainfall intensity equations for different return periods.

Examples in summary of the meteorological data available data are given in the following tables.

Table 3.2.1 Mean Temperature Data of Chrisopigi station.

	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1978	2,0	5,6	7,9	10,6	15,6	20,9	23,6	21,4	16,7	12,9	7,2	6,0	12,5
1979	2,5	4,6	9,4	9,9	17,4	22,3	22,7	21,7	19,5	11,9	9,4	6,3	13,1
1980	-0,1	3,3	6,1	10,6	14,2	20,6	23,6	22,7	18,1	14,7	10,5	5,6	12,5
1981	1,3	3,5	9,4	12,2	15,1	23,0	22,6	22,3	20,2	16,2	6,2	6,2	13,2
1982	3,1	1,6	6,1	9,9	17,6	22,5	22,1	22,3	21,6	13,9	8,0	5,9	12,9
1983	4,4	2,0	8,6	14,7	18,3	18,6	22,8	21,2	18,8	12,9	6,3	5,1	12,8
1984	4,1	3,1	5,1	9,4	17,9	20,9	23,1	20,6	20,6	17,2	8,9	3,5	12,9
1985	3,6	0,2	5,3	13,9	18,8	20,9	24,4	24,4	20,0	12,6	9,1	7,3	13,4
1986	4,6	3,5	6,4	15,1	17,1	20,9	22,8	24,4	20,8	13,2	6,7	3,0	13,2
1987	3,2	5,1	3,2	11,1	15,2	21,8	25,9	22,6	22,2	12,2	9,1	5,3	13,1
1988	4,8	4,7	6,4	10,7	17,0	21,6	27,4	25,2	20,0	13,3	4,3	3,9	13,3
1989	3,0	5,8	9,8	14,2	15,3	18,7	22,3	23,6	18,7	12,6	7,4	4,4	13,0
1990	2,4	6,4	11,1	11,7	16,8	21,1	24,1	23,1	18,5	14,3	10,4	4,9	13,7
1991	2,6	2,7	7,2	9,3	13,5	21,7	22,3	21,8	19,1	13,8	8,8	1,1	12,0
1992	3,3	3,0	6,7	11,5	15,5	20,0	21,9	25,6	18,8	15,7	8,9	2,2	12,8
1993	3,9	1,6	6,5	11,4	16,0	21,8	23,8	23,9	19,8	16,8	5,5	6,8	13,2
1994	5,8	4,3	9,0	12,8	17,8	21,2	23,8	25,6	24,3	15,5	8,4	4,9	14,5
2001								24,7	20,8	15,9	9,2	-1,1	
2002	2,0	7,1	7,7	9,2	15,4	21,0	22,6	20,9	16,1	12,5	8,7	2,0	12,1
2003	4,0	-1,6	4,1	8,0	18,1	21,4	22,6	24,1	16,9	12,3	8,9	3,2	11,8
2004	0,8	3,8	6,3	9,9	13,7	19,1	22,0	22,2	18,7	15,1	8,7	5,9	12,2
2005	4,1	2,5	6,7	11,5	16,8	19,7	23,1	22,7	18,6	12,6	7,1	4,8	12,5
2006	1,1	3,0	7,0	11,8	16,3	19,6	22,3	24,2	18,5	13,8	8,4	4,5	12,5
2007	6,8	5,3	8,0	12,1	17,6	22,9	26,0	24,3	17,5	13,8	7,5	3,4	13,8
2008	3,2	5,2	9,4	12,1	16,5	21,4	23,2	25,3	18,1	14,3	9,6	5,3	13,6
2009	4,0	3,6	6,5	11,8	17,5	20,7							
MEAN	3,2	3,6	7,2	11,4	16,4	21,0	23,4	23,2	19,3	14,0	8,1	4,4	12,9

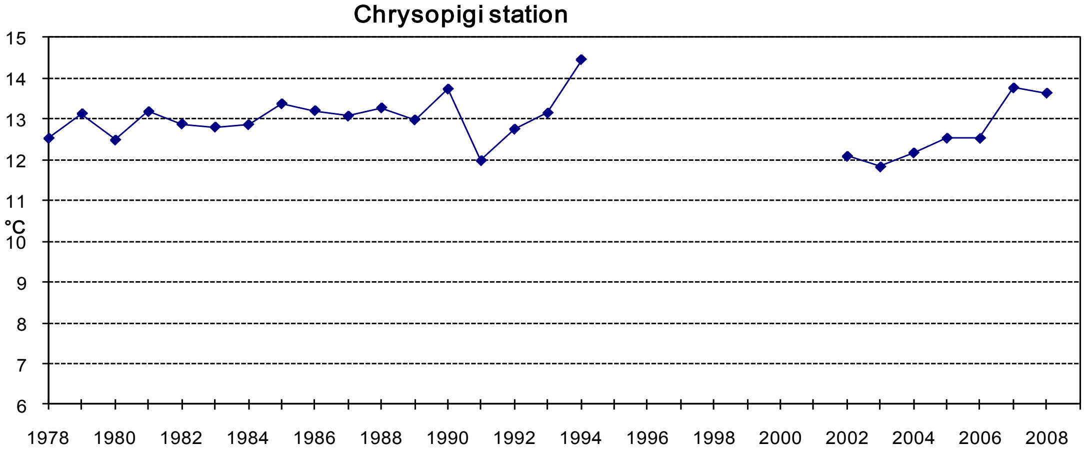


Fig8. Time series of mean air temperature

Table 3.2.2 Rainfall in mm on a monthly basis, Chrysopigi station.

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1978	38	28	22	111	160	62	7	40	105	88	34	56	751
1979	46	62	20	92	55	19	25	66	24	128	80	32	648
1980	59	11	32	44	99	39	22	28	73	81	51	76	614
1981	54	58	29	32	41	20	51	58	2	50	76	112	582
1982	30	62	59	63	81	29	82	51	0	28	80	93	658
1983	15	17	15	21	53	115	167	77	15	9	82	68	654
1984	62	71	98	27	15	33	12	53	13	0	36	16	434
1985	27	47	68	31	70	63	3	26	20	5	165	7	529
1986	45	141	29	6	65	103	19	11	11	25	16	12	480
1987	53	60	55	62	36	41	64	34	18	74	102	56	652
1988	13	49	59	38	15	30	3	0	2	18	104	60	390
1989	0	4	36	26	68	85	67	25	39	32	46	33	458
1990	0	9	18	74	83	24	21	41	21	70	23	101	483
1991	6	41	31	83	60	17	48	89	14	29	75	10	501
1992	0	4	38	76	45	84	22	5	17	61	48	51	450
1993	14	27	22	25	70	51	8	27	7	14	63	68	394
1994	78	47	18	65	31	34	44	13	0	71	46	98	545
2001								27,8	10,2	20,2	102,2	61,0	
2002	18,2	20,6	0,0	0,0	0,0	35,8	104,	68,0	176,2	69,2	70,8	50,8	613,8
2003	75,8	13,4	2,6	38,0	96,7	61,9	28,2	16,4	26,6	83,8	34,8	169,	648,0
2004	45,3	5,4	46,9	34,4	58,7	28,1	32,4	21,4	116,4	27,2	59,6	93,0	568,8
2005	47,4	49,2	56,8	28,8	56,8	35,6	45,6	39,4	74,4	57,8	46,4	77,4	615,6
2006	39,8	47,2	64,2	84,0	28,8	81,6	32,2	6,8	66,6	64,0	58,6	47,6	621,4
2007	32,6	25,6	26,8	24,6	109,	39,2	1,6	98,2	94,8	59,4	100,2	48,2	660,2

2008	16,0	10,2	43,2	80,0	29,8	59,4	55,4	0,0	74,2	10,6	22,2	53,8	454,8
2009	138,6	23,8	48,2	45,0	60,4	121,8							
MEAN	38,1	37,3	37,5	48,3	59,4	52,4	40,0	36,8	40,7	46,9	64,8	61,9	564,2

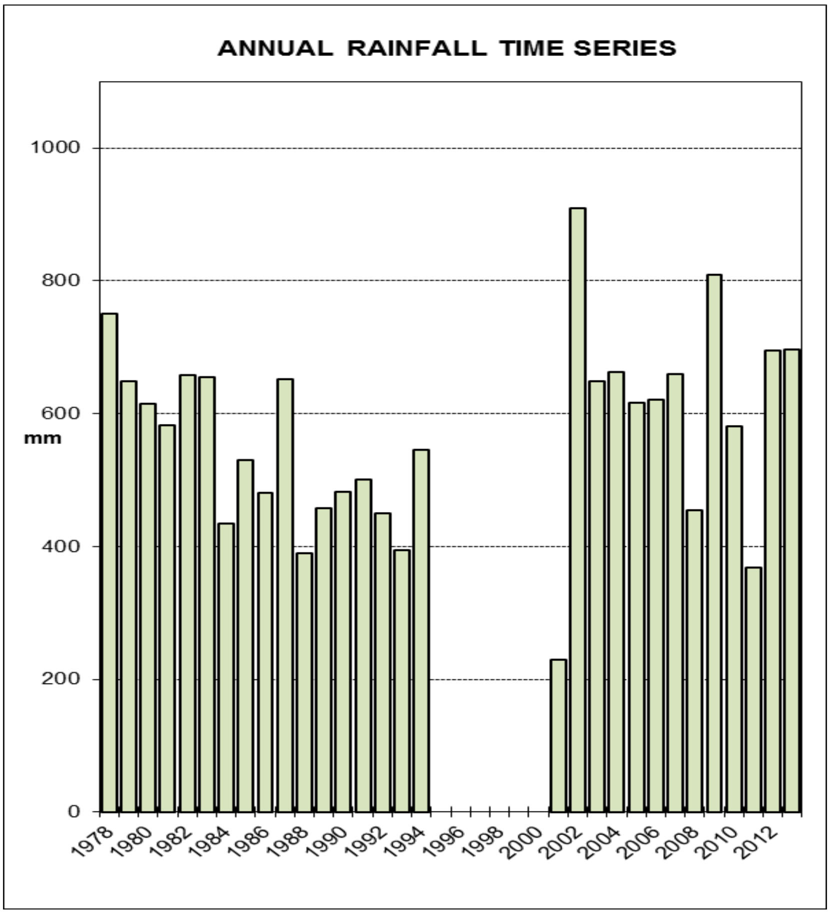


Fig9. Annual rainfall time series

Table 3.2.3 Days of rainfall, Chrysopigi station data.

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1978	6	9	8	14	15	6	2	2	10	4	4	9	89
1979	10	7	8	14	13	8	4	6	3	10	11	7	101
1980	13	4	11	12	15	7	2	5	7	7	12	12	107
1981	13	7	9	6	10	5	4	9	1	7	8	17	96
1982	8	5	6	15	6	6	6	7	0	6	7	7	79
1983	4	4	3	6	9	11	16	5	6	3	8	13	88
1984	13	17	17	14	7	6	2	14	4	1	5	4	104
1985	12	9	14	5	12	7	3	3	1	3	18	2	89

1986	11	16	10	4	14	13	7	5	2	5	4	6	97
1987	9	8	6	11	8	5	5	6	6	6	10	10	90
1988	7	5	11	7	5	9	3	0	1	4	13	6	71
1989	0	1	7	4	9	11	10	2	4	6	10	4	68
1990	0	3	3	10	10	5	3	3	2	9	7	14	69
1991	2	7	7	15	8	5	9	7	4	6	10	1	81
1992	0	2	4	9	9	7	10	3	3	8	6	3	64
1993	3	3	4	6	14	2	2	3	2	4	11	7	61
1994	9	9	3	10	7	4	9	3	0	10	8	9	81
2002	4	4	0	0	0	8	12	8	19	8	5	12	80
2003	16	8	5	11	16	21	8	7	13	19	16	18	158
2004	24	2	8	13	15	11	5	6	9	6	8	14	121
2005	11	14	13	7	14	8	9	4	6	4	7	19	116
2006	9	11	13	13	10	15	10	3	11	8	6	6	115
2007	4	8	7	9	11	4	2	3	8	11	14	11	92
2008	8	4	12	12	5	9	5	0	9	6	6	12	88
2009	19	10	8	11	10	14	4	11	10	11	6	20	134
2010	13	12		13	10	14	9	1	4	20	8	14	118
2011	13	9	10	8	18	10	2	2			2	13	87
2012	6	13	8	14	20	0	1	4	7	5	8	12	98
2013	8	16	15	5	8	17	12	1	8	3	14	6	113
2014	10	9	12	13	13	12	9	5					
AVE.	9	8	8	10	11	9	6	5	6	7	9	10	95

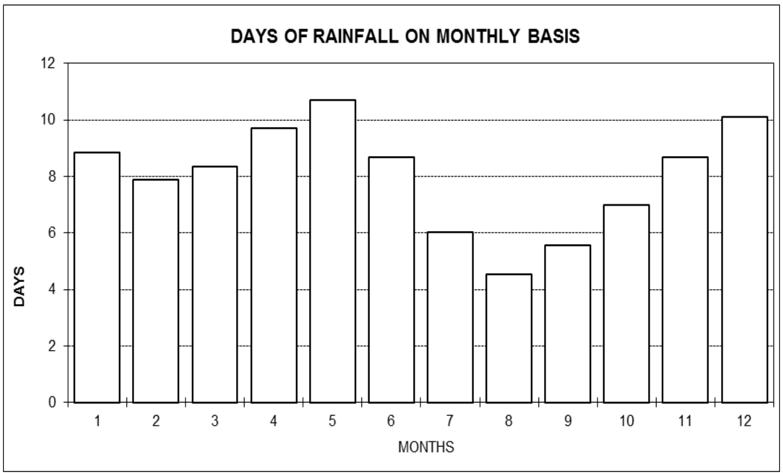


Fig10. Days of Rainfall on a monthly basis. Chrysopigi station

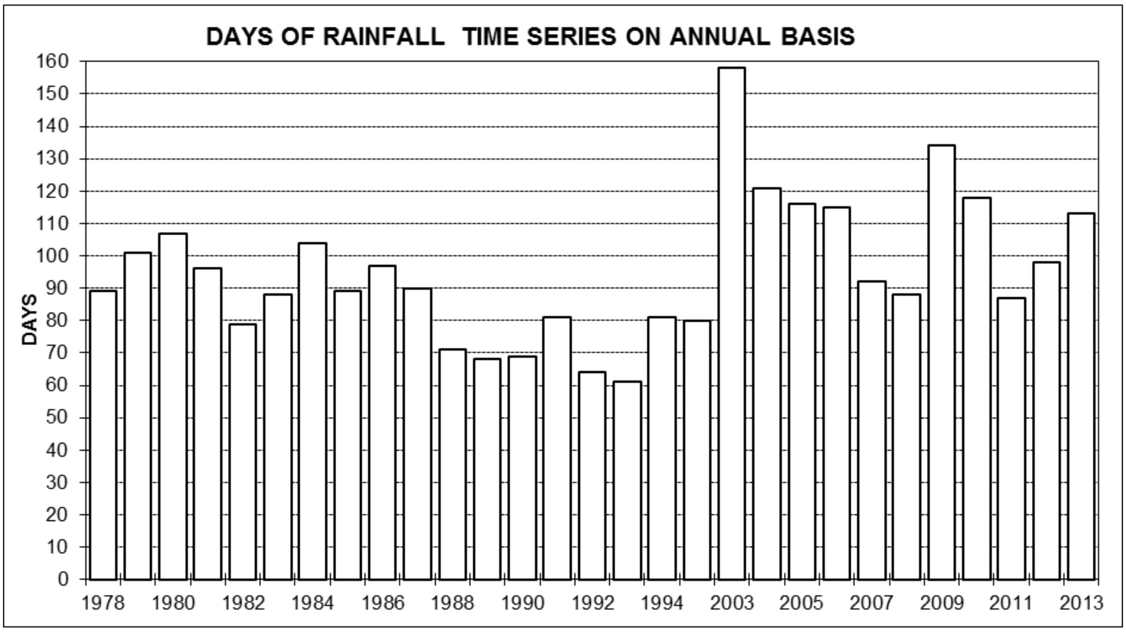


Fig11. Days of rainfall, time series on annual basis.

IDF curves (GUMBEL method) from data obtained from Serres HNMS station

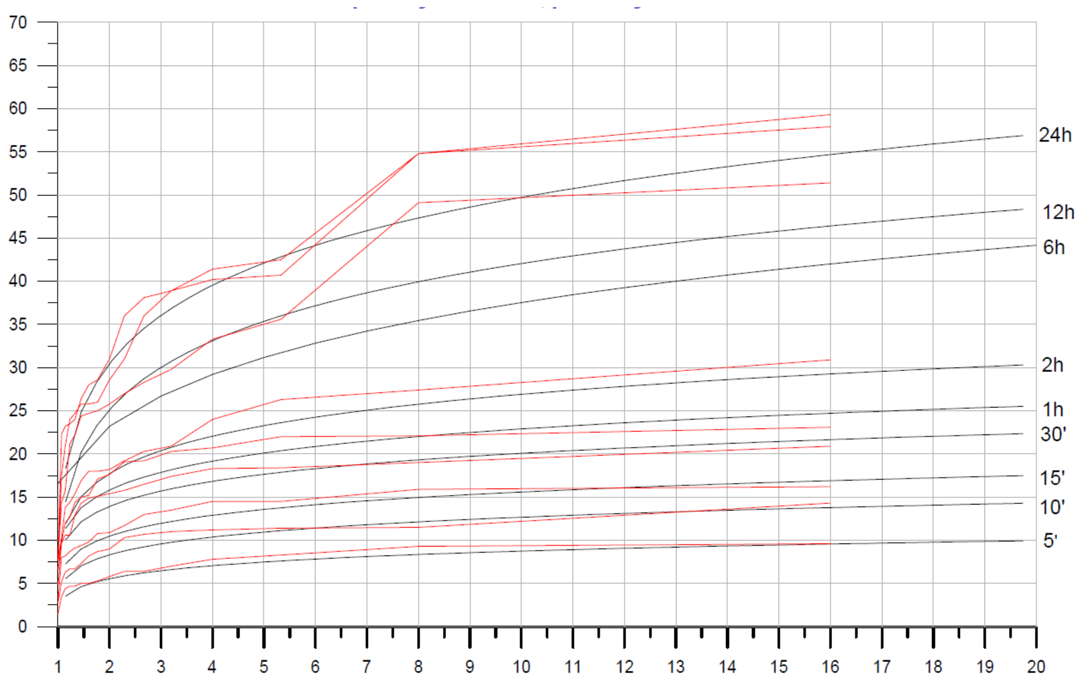


Fig12. IDF curves (GUMBEL method) from data obtained from Serres HNMS station. Return period in years. (After M. Vafiadis).

Table 3.2.4 Maximum rainfall heights for different duration times, Serres NHMS Station (16 years data).

	5*	10'	15·	30'
16	9.6	14.3	16.2	20.9
15	9.3	11.5	15.9	19.0
14	8.3	11.4	14.5	18.4
13	7.8	11.2	14.5	18.3
12	7.0	11.0	13.5	17.4
11	6.4	10.7	13.0	16.5
10	6.4	10.3	11.7	15.8
9	5.8	9.0	10.9	15.4
8	5.3	8.7	10.8	15.1
7	5.0	8.2	9.8	14.9
6	5.0	7.3	9.4	14.3
5	4.7	6.7	9.1	12.9
4	4.7	6.7	8.7	10.6
3	4.4	6.3	8.2	10.6
2	3.5	5.2	8.0	9.7
1	1.5	2.8	3.3	4.9
m	5.91	8.83	11.09	14.66
s	2.13	2.91	3.41	4.11

Table 3.2.5 Estimation of maximum rainfall heights (mm) for different duration and return periods in serres, Gumbel Method.

T	5'	10'	15'	30'	lh	2h	6h	12h	24h
2->	5.56	8.35	10.53	13.99	15.91	17.84	25.38	29.16	30.76
5->	7.46	10.93	13.55	17.63	20.10	23.28	35.41	40.68	42.17
10->	8.71	12.64	15.55	20.04	22.87	26.89	42.05	48.30	49.73
20->	9.91	14.27	17.48	22.35	25.53	30.34	48.42	55.62	56.97
30->	10.60	15.22	18.58	23.68	27.06	32.33	52.09	59.83	61.14
50->	11.46	16.39	19.96	25.35	28.97	34.81	56.67	65.09	66.36
100->	12.63	17.98	21.82	27.59	31.55	38.16	62.85	72.18	73.39
200->	13.79	19.56	23.68	29.83	34.13	41.50	69.00	79.25	80.39
500->	15.32	21.65	26.13	32.77	37.52	45.91	77.12	88.58	89.64
1000->	16.48	23.23	27.98	35.00	40.08	49.24	83.26	95.62	96.62

Analysis of the combined available data for the area of interest led to the rainfall intensity equation:

$$i=a*t_c{}^{b}$$

Where: t_c is the concentration time according to the Giandotti formula, which is extensively used in Greece.

$$t_c = \frac{4 \cdot \sqrt{A} + 1{,}5 \cdot L}{0{,}8 \cdot \sqrt{\Delta z}}$$

where: A is the drainage area (Km^2), L the length of the main watercourse in Km and H the elevation difference of the average basin elevation from the outlet elevation in m.

As already stated, two catchments in the area of Serres were chosen to be studied: the catchment of Agioi Anargyroi stream, and the catchment of Eleonas stream. The outlet of each catchment was decided to be the point that both streams meet the main urban tissue of Serres city. The area of interest as already mentioned in previous chapters, has suffered from flood events in the past.

The rainfall intensity equation for the 50year return period for the area under investigation became as follows:

$$i=83.94*t_c{}^{-0.681}$$

In order to calculate the peak discharge for both catchments, the following computations took place.

Table 3.2.6 Peak Discharge Ag. Anargyroi Stream (Ag Anargyroi Catchment)

Peak Discharge Ag. Anargyroi Stream (Ag Anargyroi Catchment)		
Railfall intensity		
Return period (years)		50
Return period IDF curve (years)		50
IDF curve equation		
coefficients	a	83.94
	b	-0.6810
Runoff coefficient etsimation		
Runoff Coefficient C		0.5
Caculation of Time of Concentration		
Catchment area A (m^2)		79,420,436
Catchment area A (ha)		7,942
Catchment area ς A (km^2)		79.42

L, length of the main watercourse (km)	23.93
Z max Highest basin elevation (m)	1,432.00
Zmin Outlet elevation (m)	68.00
Average basin elevation (m)	750.00
ΔZ, elevation difference of the average basin elevation from the outlet elevation in m	1,364.00
Stream slope (m/m)	0.0570
Centreweighted avg elevation(m)	750.0
Time of Concentration, Giandotti: tc (min)	205.46
Rainfall Intensity	
Rainfall Instensity (mm/h)	15.85
Peak Discharge (Rational Method)	
Q (m^3/s)	64.50

Table 3.2.7 Peak Discharge Eleonas Stream

Peak Discharge Eleonas Stream		
Railfall intensity		
Return period (years)		50
Return period IDF curve (years)		50
IDF curve equation		
coefficients	a	83.94
	b	-0.68100
Runoff coefficient etsimation		
Runoff Coefficient C		0.5
Caculation of Time of Concentration		
Catchment area A (m^2)		23,454,595
Catchment area A (ha)		2,345
Catchment area ς A (km^2)		23.45
L, length of the main watercourse (km)		10.55
Z max Highest basin elevationi (m)		1,033.00
Zmin Outlet elevation (m)		75.00
Average basin elevation (m)		554.00

ΔZ, elevation difference of the average basin elevation from the outlet elevation (m)	958.00
Stream slope (m/m)	0.0908
Centreweighted avg elevation(m)	554.0
Time of Concentration, Giandotti: tc (min)	120.61
Rainfall Intensity	
Rainfall Instensity (mm/h)	5.85
Peak Discharge (Rational Method	
Q (m^3/s)	19.05

It should be noted that **peak discharge is calculated at this point without the amount of sediment transport**. In the hydraulic analysis chapter, sediment transport will be introduced and added to the overall peak discharge as an extra parameter to a flooding event scenario.

3.3 RUNOFF COEFFICIENT

The runoff coefficient (C) is a dimensionless coefficient that represents the correlation between the amounts of runoff to the amount of precipitation received. It takes a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land).

It is important to estimate the runoff coefficient for flood control channel construction and for possible flood zone hazard delineation [21].

Runoff coefficients are needed to calculate storm water runoff rate using the Rational Method. The main factors affecting the rational method runoff coefficient value for a watershed are the land use, the soil type and the slope of the watershed. The physical interpretation of the runoff coefficient for a watershed is the fraction of rainfall on that watershed that becomes storm water runoff. Thus the runoff coefficient must have a value between zero and one.

Land Use: Surfaces that are relatively impervious like streets and parking lots, have runoff coefficients approaching one (1.0). Surfaces with vegetation to intercept surface runoff and those that allow infiltration of rainfall, have lower runoff coefficients.

Slope: All other things being equal, a watershed with a greater slope will have more storm water runoff and thus a higher runoff coefficient than a watershed with a lower slope.

Soil Type: Soils that have a high clay content don't allow very much infiltration and thus have relatively high runoff coefficients, while soils with high sand content have higher infiltration rates and low runoff coefficients.

The U.S. Soil Conservation Service (SCS) has four soil group identifications that provide information helpful in determining watershed runoff coefficients. The four soil groups are identified as A, B, C, and D. Classification of a given soil into one of these SCS groups can be on the basis of a description of the soil characteristics or on the basis of a measured minimum infiltration rate for the soil.

There are many bibliographical references about runoff coefficient values, with similar values in most of them. The user each time must decide up the values and use judgment to select the appropriate "C" value. The table given below shows the range of runoff coefficient values and is presented in the ODOT Hydraulics Manual, Hydrologic Module of the FHWA's Watershed Modeling System.

Table 3.3.1 Runoff Coefficient Values (ODOT Hydraulics Manual)

	FLAT	*ROLLING*	*HILLY*
Pavement & Roofs	*0.90*	*0.90*	*0.90*
Earth Shoulders	*0.50*	*0.50*	*0.50*
Drives & Walks	*0.75*	*0.S0*	*0.85*
Gravel Pavement	*0.85*	*0.85*	*0.85*
City Business Areas	*0.80*	*0.85*	*0.85*
Apartment Dwelling Areas	*0.50*	*0.60*	*0.70*
Light Residential: 1 to 3 units acre	*0.35*	*0.40*	*0.45*
Normal Residential: 3 to 6 units/acre	*0.50*	*0.55*	*0.60*
Dense Residential: 6 to 15 units/acre	*0.70*	*0.75*	*0.60*
Lawns	*0.17*	*0.22*	*0.35*
Grass Shoulders	*0.25*	*0.25*	*0.25*
Side Slopes. Earth	*0.60*	*0.60*	*0.60*
Side Slopes. Turf	*0.30*	*0.30*	*0.30*
Median .Areas. Turf	*0.25*	*0.30*	*0.30*
Cultivated Land. Clay & Loam	*0.50*	*0.55*	*0.60*
Cultivated Land. Sand & Gravel	*0.25*	*0.30*	*0.35*
Industrial Areas. Light	*0.50*	*0.70*	*0.80*
Industrial Areas. Heavy	*0.60*	*0.80*	*0.90*
Parks & Cemeteries	*0.10*	*0.15*	*0.25*

Playgrounds	*0.20*	*0.25*	*0.30*
Woodland & Forests	*0.10*	*0.15*	*0.20*
Meadows & Pasture Land	*0.25*	*0.30*	*0.35*
Unimproved Areas	*0.10*	*0.20*	*0.30*

Note:

Impervious surfaces in bold

Rolling = ground slope between 2 percent to 10 percent

Hilly = ground slope greater than 10 percent

3.4 STREAMS UNDER INVESTIGATION

The most important, in respect to flood hazard streams, are two streams located at the eastern edge of the city of Serres; "Agioi Anargyroi" and "Eleonas" streams covering areas of 78 and 24 km^2 respectively (fig. 13).

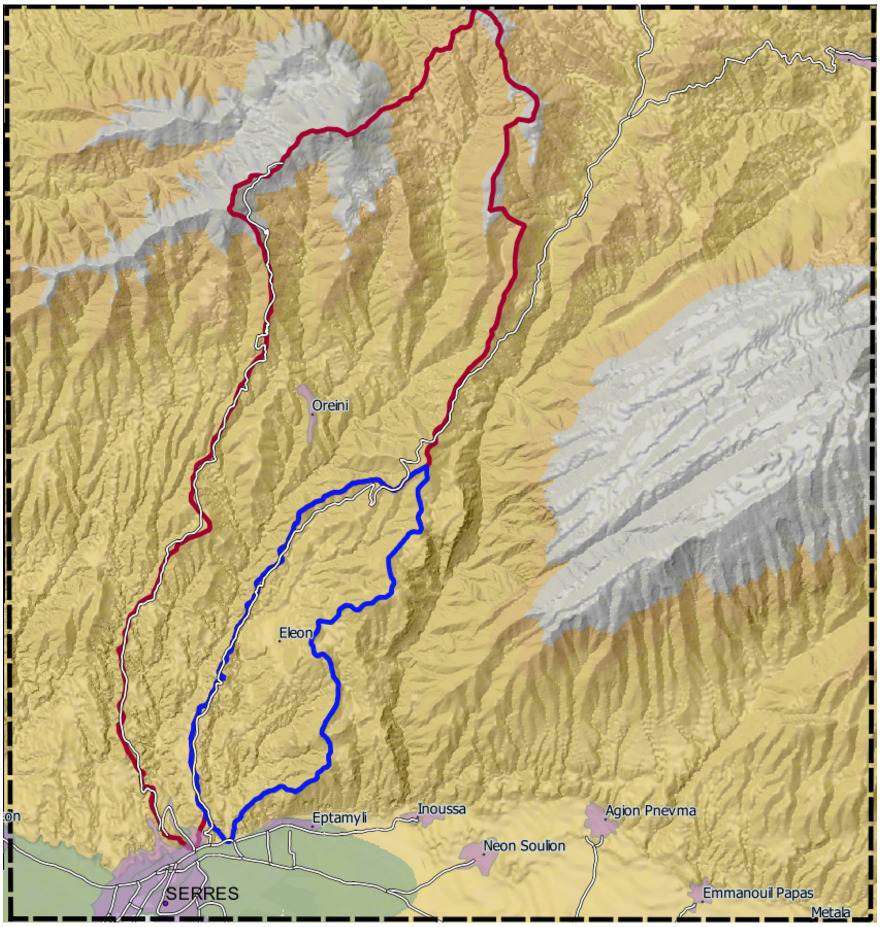


Fig13. Agioi Anargyroi" (red) and "Eleonas" (blue) stream basins.

Since 1936, measures have been planned and gradually taken in order to reduce flood risk by the respective actions including construction and reforestation

The two streams present characteristics of semi-mountainous and mountainous areas. Relief is intense with minimum/maximum elevation values of 61m/1489m for the Agioi Anargyroi stream and 69m/1026m for the Eleonas stream respectively.

3.5 FLOOD HAZARD ASSESSMENT AT REGIONAL AND LOCAL SCALES-DATA AND PROCEDURES

As already stated in previous paragraphs the proposed approach to assess flood hazard is a two-step process, the first step involving the detection and mapping of flood prone areas, and after selecting the ones which are at risk, implement the HEC-RAS hydraulic model at the second step in order to assess flooding parameters.

The first step is actually a flood susceptibility assessment process and is followed by a preliminary risk assessment in order to prioritize those flood prone areas in terms of the importance of the assets at risk. The second step is in fact the Flood Hazard Assessment stage, leading to results which can support decisions regarding the selection of preventive measures.

The Topographic Wetness Index (TWI) approach and it's variant, the SAGA TW index were selected to map flash flood prone areas on a regional scale.

TWI is calculated as TWI = ln(As/tanb) where As is the (upslope) flow accumulation per contour unit length and b is the slope (more details are included in previous project documents (D.01.02).

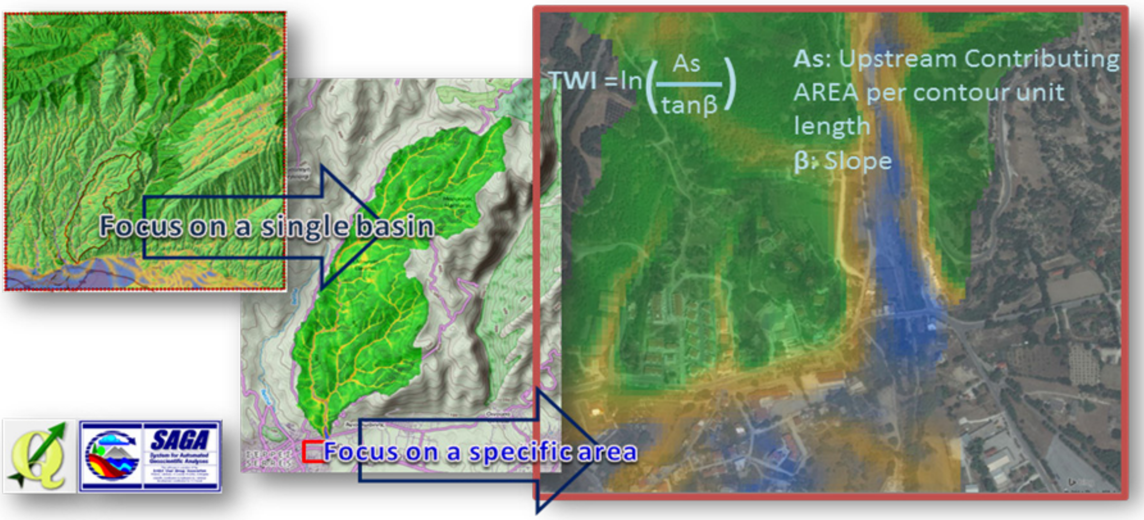


Fig14. Proposed methodological approach to assess Flood Hazard with a two-step procedure: a screening step to locate flood prone areas (left), focus on a single stream and on a specific area (middle) and implement a preliminary assessment of assets at risk (right).

A geodatabase and a respective Geographic Information System were developed for hosting the required data and for the processing and the cartographic production activities that followed.

The scale of implementation for the regional FH scale assessment, in terms of the specifications and analysis of the respective data input was 1:50.000, so elevation data were produced from topographic maps of 1:50.000 scale.

Additional data input and produced during the implementation phase included:

- Digitized geologic Maps
- Mean monthly rainfall (mm), max daily precipitations (mm) and peak rainfall intensity (mm/hour)
- Digital Elevation Model (DEM) with cell size of 15x15m
- Various maps related to the area morphology (slope, aspect, valley depth, hillshade etc.) and numerous intermediate and final "products" during the processing phase and according to the requirements of the specific methodology applied.
- Ancillary data (Corine 2000 Landuse Maps, road network, urban areas etc)
- Differential GPS surveying and produced topographic maps of 1:500 scale
- A DEM of 0.50x0.50m pixel size
- Digitized entities (stream reach, cross sections etc.).

It must be noted that all raster files used for the regional scale assessment were produced with a cell size of 15x15m which is considered as a high resolution analysis considering the regional scale of implementation. The respective cell size for the local scale implementation was 0.50m. Reason for this decision was the commitment to produce outputs with the most effective spatial accuracy taking into consideration the inherent accuracy of the input data.

3.6 MAPPING THE FLOOD PRONE AREAS ON A REGIONAL SCALE – PARAMETERS CALCULATED

The Topographic Wetness Index (TWI) can effectively be used to map the flooding susceptibility by mapping the flood prone areas [8]; [9]; [10]; [11]; [12].

The procedure to calculate the Topographic Wetness Index (TWI) and the SAGA-TWI in order to define the susceptibility to flooding (flood prone areas) is very straight forward since the selected Open Source software Quantum GIS (QGIS) incorporates the respective routines built into the SAGA GIS. A model describing the entire procedure is presented in Fig. 15.

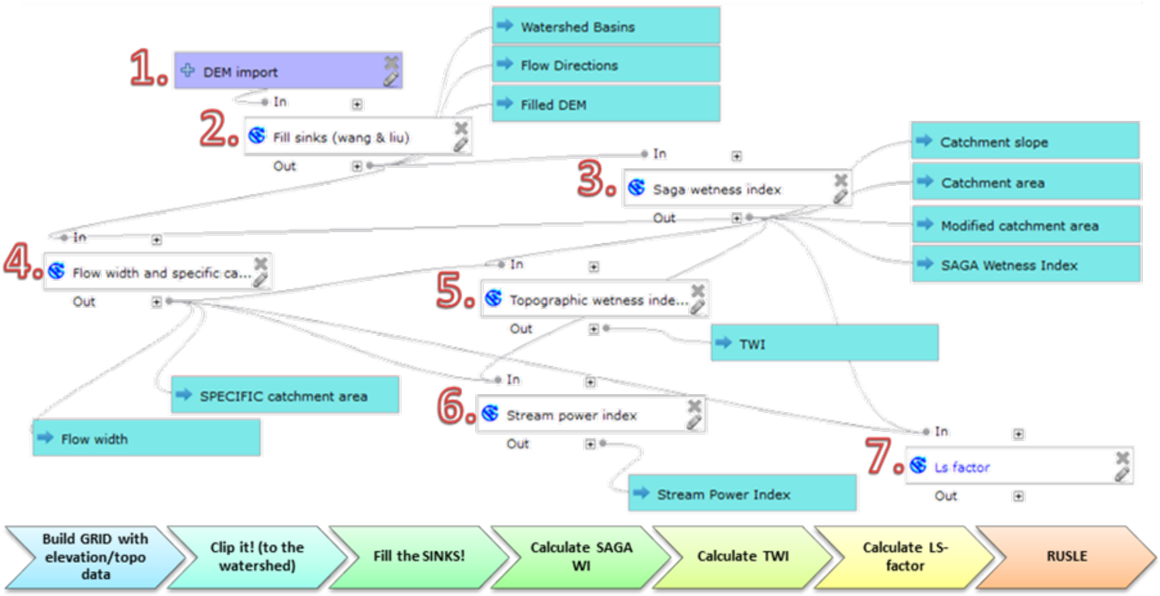


Fig15. Schematic representation of the entire process to develop TWI, SAGA WI and Stream Power spatial distribution maps. At the bottom, left to right, the consecutive steps are shown.

Mapping the Flooding prone areas was first carried out using the Topographic Wetness Index –TWI:

$$w = \ln\left(\frac{A_s}{\tan\beta}\right) \tag{1}$$

Where, As is the upslope contributing area at a certain contour unit location and β is the slope.

Uniform soil properties are assumed so that soil Transmissivity (T) equals to unity.

There are many variants of TWI based mainly on the way the upslope contributing (catchment) area is calculated. One of them is the SAGA TWI which is based on a "Modified Catchment Area"-MCA calculation which does not consider the flow as very thin film. As result, it predicts for cells situated in valley floors with a small vertical distance to a channel, a more realistic and with higher potential soil moisture as compared to the normal TWI value [5]; [6]. This fact is translated to a wider area calculated as potentially covered with water during a flood event.

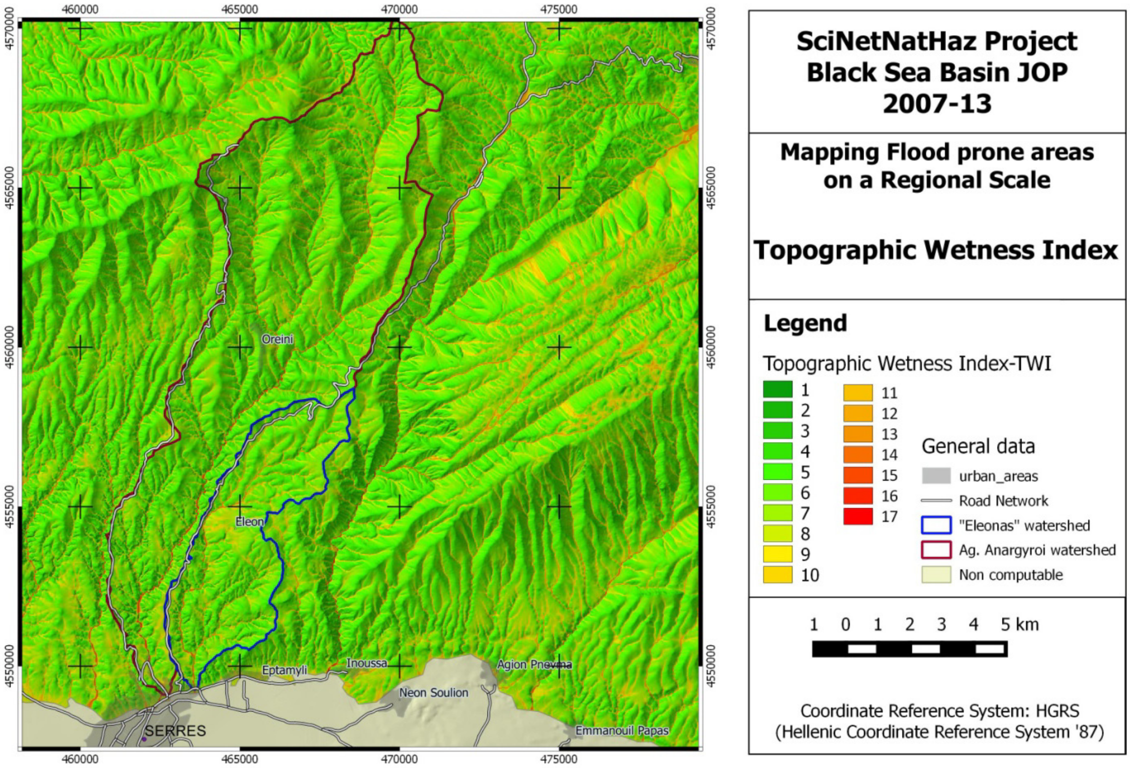


Fig16. Topographic Wetness Index of the entire Serres PIA covering almost 500km^2. The two stream watersheds under investigation are shown in red (Agioi Anargyroi) and blue (Eleonas). Note: the layout is designed for demonstration purposes. The respective scale is 1:130.000 for a full A4 size page printed.

It must be noted that the map layout presented herein has been designed with a scale of 1:130.000 for presentation reasons. Data and maps are based on data of 1:50.000 scales or better and can be accessed at full scale over the projects WebGIS.

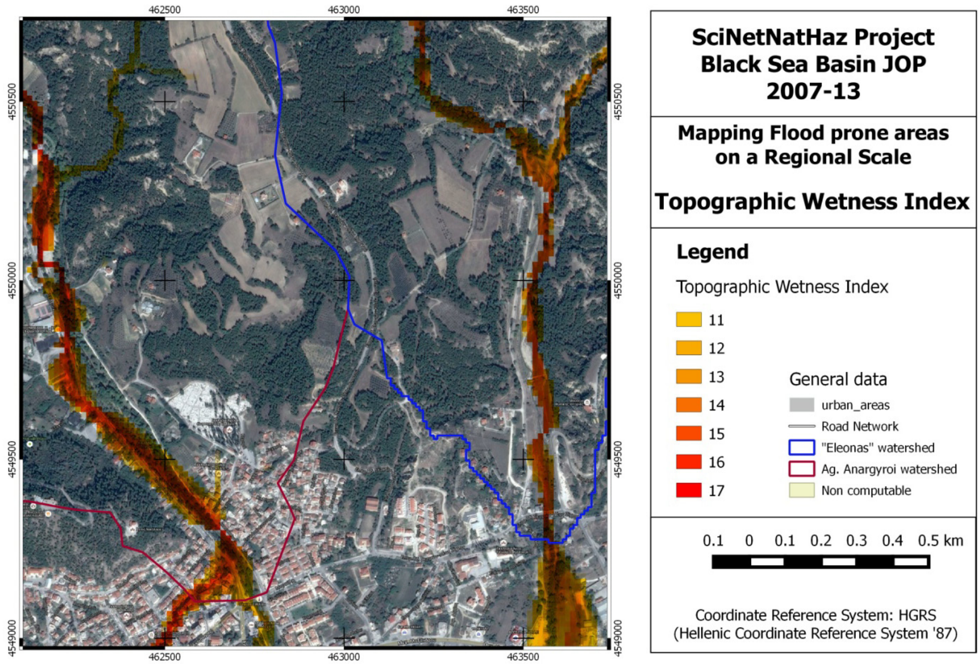


Fig17. TWI spatial distribution map "zoomed in" to larger scale at the northern limits of Serres city. For presentation reasons, the higher only values of TWI are plotted on a Google maps background in order to demonstrate the potential for a preliminary risk assessment.

The spatial distribution of both TWI (fig.17) and SAGA-TWI (fig.18) show high index values in various areas along the stream beds, the most important being those areas which are very near (even covering northern parts of) the city of Serres (fig. 18).

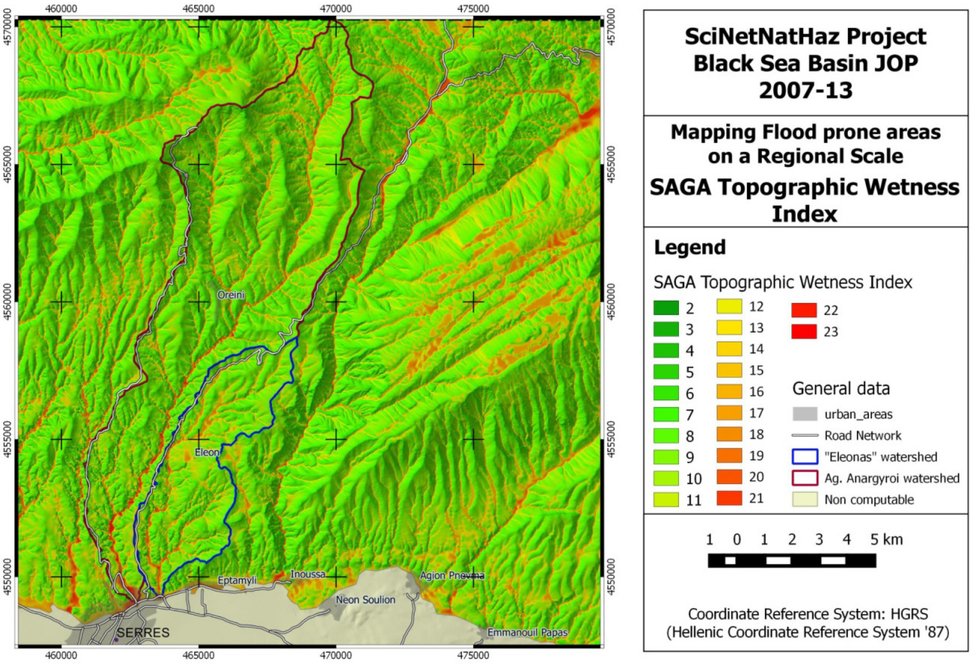


Fig18. SAGA TWI of Serres PIA.

According to the methodology these areas are considered as "flood prone" or areas of high susceptibility to flooding. The superposition of the TWI on Google images as the evaluation of additional information about the location of important assets at risk, can be used to have a preliminary risk assessment and decide upon the exact location to which implement applied research on a local scale. At this point, the first "screening" step, is concluded.

Based on the above, the areas of "Koilada" along the "AgioiAnargyroi" stream and "Agios Georgios" along the "Eleonas" stream were selected.

3.7 HYDRAULIC ANALYSIS

3.7.1 Introduction

The study of water bodies, its properties and behavior has led to the necessity of hydrologic and hydraulic principles and methods. Hydrologic analyses are performed to quantify the volumetric flow rate of water draining from a watershed over time. The amount of water that flows from a watershed depends on the characteristics of the watershed and the presence of water (e.g. the intensity and duration of a precipitation event, rate of snowmelt, or regulation from a dam). These topics were previously discussed in the Hydrologic Analysis part. The step that follows is the hydraulic analysis that is performed to determine hydraulic characteristics of water flow, such as depth of flow, flow velocity, forces from flowing water on a surface or at hydraulic structures, etc.

Hydrologic and hydraulic analyses are also performed for hazard mitigation and forensic investigations, when developing reservoir management plans, and when performing floodplain mapping etc.

The aim of this part of the project is to determine the characteristics of flow and potential flooding in streams and areas that have suffered flooding in the past. The two catchments in the area of Serres that were chosen to be studied are: the catchment of Agioi Anargyroi stream, and the catchment of Ag. Georgios stream. The outlet of each catchment was decided to be the point that both streams meet the main urban tissue of Serres.

3.7.2 Hydraulic Modeling and Analysis in HEC - RAS

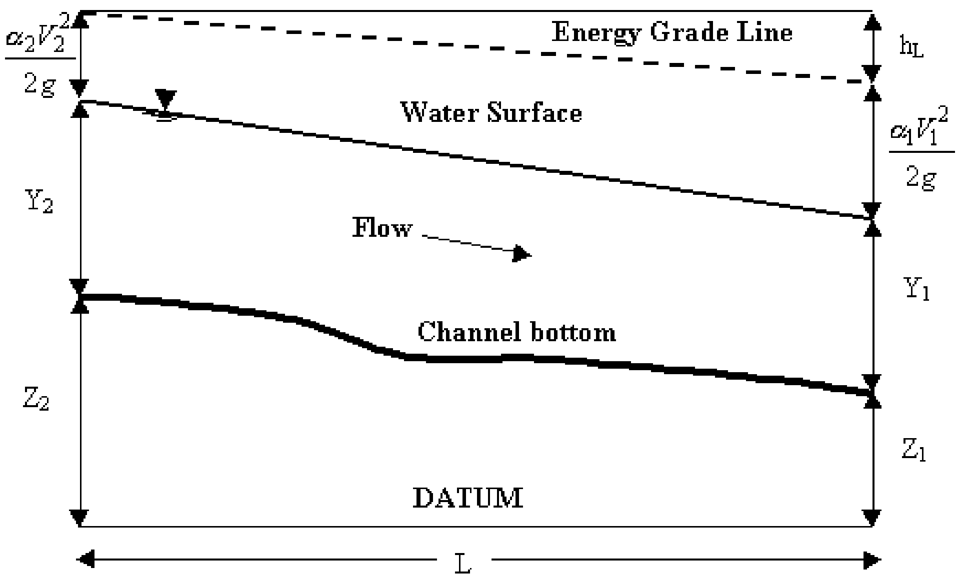
Hydraulic Analysis and Modeling has shown extensive research effort to simulate flood propagation in rivers and this is expressed by numerous 1D and 2D simulation models including: HEC-RAS, Mike11, FLO-2D etc. The outcomes of these models, in riverine flood hazard assessment, include: the level of inundation (flood water level), the intersection of the flood level with the terrain (ground surface) to create the flood plain extent, the difference between the flood level and the terrain, which is used to calculate the depth and the distribution of velocity.

Hydraulic Analysis for assessing hydraulic behaviour for the needs of this project was 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/).

HEC-RAS is a flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination. The results of the model can be applied in floodplain management and flood insurance studies. Steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario, and is called the direct step method. The basic computational procedure is based on an iterative solution of the energy equation:

$$H = Z + Y + \frac{\alpha V^2}{2g}$$

which states that the total energy (H) at any given location along the stream is the sum of potential energy (Z + Y) and kinetic energy (aV2/2g). The change in energy between two cross-sections is called head loss (hL). The energy equation parameters are illustrated in the following graphic:



Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section. Whether the computations proceed from upstream to downstream or vice versa, depend on the flow regime. The dimensionless Froude number (Fr) is used to characterize flow regime, where:

- Fr < 1 denotes subcritical flow
- Fr > 1 denotes supercritical flow
- Fr = 1 denotes critical flow

For a subcritical flow scenario, which is very common in natural and man-made channels, direct step computations would begin at the downstream end of the reach, and progress upstream between adjacent cross-sections. For supercritical flow, the computations would begin at the upstream end of the reach and proceed downstream.

3.7.3 Implementation in HEC-RAS 4.1.0

The procedure for the implementation of the analysis of hydraulic characteristics and floodplain mapping for the two streams selected in Greece is presented in the following paragraphs.

A "technical" approach describing the procedures taken was followed in these paragraphs, in order to familiarize potential users with the software and to assist them in its implementation.

The software is quite flexible, quick and easy to use, but the user has to be familiar with the hydraulic principals. For example, experience is needed when choosing input data, coefficients, conditions, while most important is the comprehension and evaluation of the results.

A brief description of the steps to calculate important flood parameters follows in the next paragraphs.

3.7.3.1 Creating a project in HEC-RAS

The first step is to create a project in HEC-RAS. In each project all the geometric data, flow data, and plan are set. The software provides the ability to create multiple data sets that can be called each time for a new project execution.

To start a new project, the user selects New Project from the file menu to create and save the path for the project (fig. 19). In the New Project window, the Title of the project and File name is inserted and saved. Then the main window of HEC-RAS River Analysis System appears on screen.

An existing project may be opened using the same procedure. The following data are required for starting the HEC-RAS project:

- Unit system
- Stream/channel shape, geometry and slope
- Structure details if any (bridges, levees, culverts etc)
- Flow data

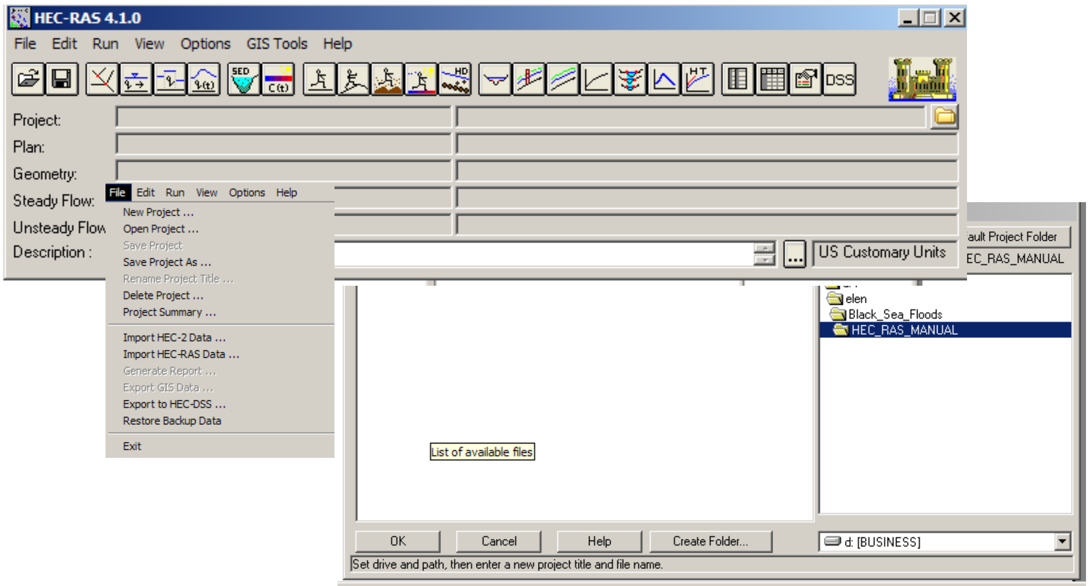


Fig19. HEC-RAS main window and starting options

3.7.3.2 Entering Geometry Data

Once entered, all the geometric data are collected and saved in a "geometry" file (*.sdf).

A very convenient option since the entire previous work is done in QGIS, is to directly import QGIS cross sections to HEC-RAS as in this project. Cross sections can be created in QGIS either automatically by defining the stream line, the distance (spacing) between cross sections and the length of each cross section or by hand drawing each cross section. In this specific application, the geometric data were entered as a "geometry file (*.sdf) that was formerly created in QIS and exported to HEC-RAS geometry using the Q-RAS plug-in.

When dealing with geometric data, the following aspects must be made clear:

- Cross sections define the channel geometry.
- Cross sections are defined by the respective Station(x) and Elevation (y).

- Cross sections (among other parameters) define the channel slope.
- Overbank stations differentiate channel and floodplain characteristics.
- Manning **n** coefficients define resistance to flow.
- Expansion and contraction coefficients define energy losses associated with velocity head changes between cross sections.
- Ineffective flow areas can store but not convey water downstream.
- Obstruction areas block flow completely.
- Levee elevations confine flow to channel until the levees are overtopped

Please note! Caution must be given to the way cross sections are drawn in order for HEC-RAS to create the correct geometry. Cross sections must be drawn in a queue, downstream to upstream and left to their right edge (fig.20). Failing to follow this procedure will cause a false geometry in HEC-RAS and false outputs.

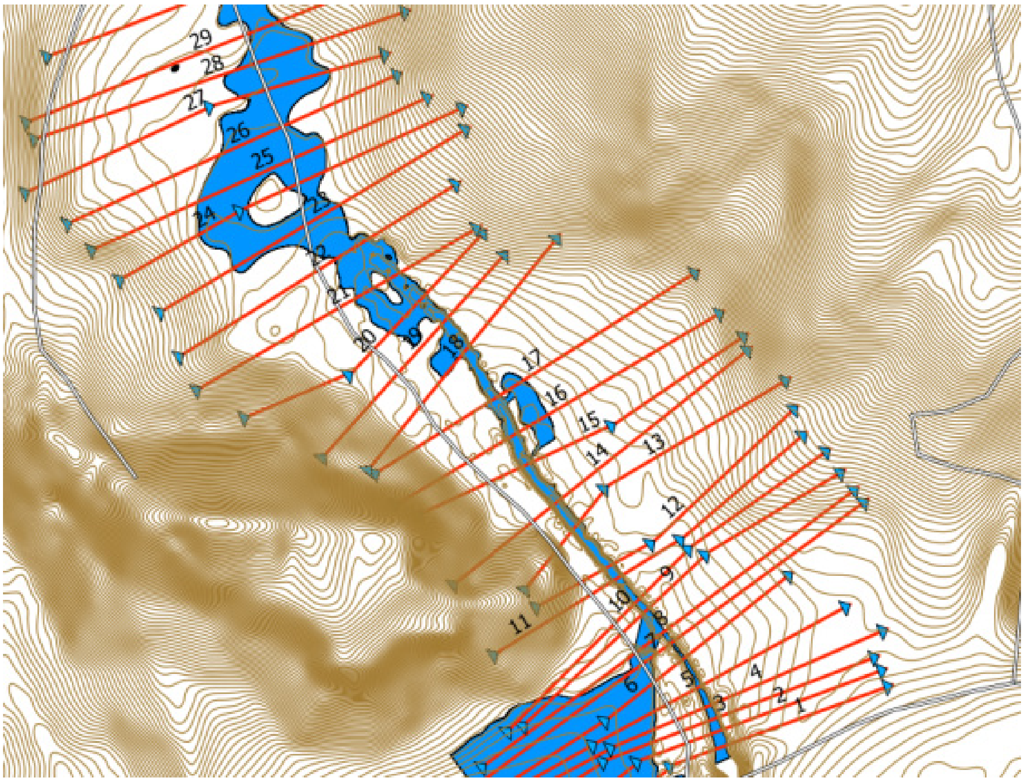


Fig20. Cross section drawn in Agioi Anargyroi stream. The drawing direction is shown by the blue arrows and the order is defined by the respective number.

HEC-RAS also provides the ability to create geometry from scratch, by adding streams and cross sections inside the "geometry editor".

The geometry data is handled by the geometry editing menu and window (Fig. 21).

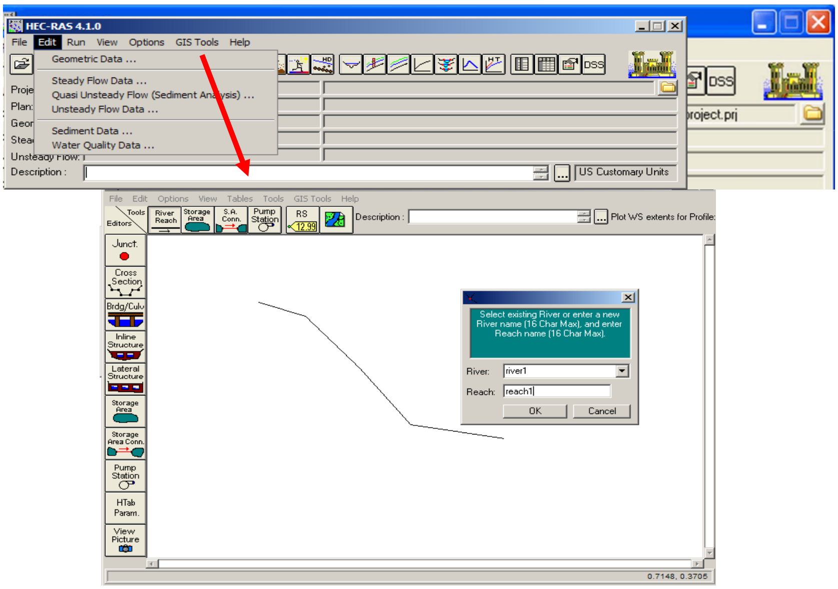


Fig21. HEC-RAS Geometric Data window

In the Geometric Data window, the River Reach is set by drawing the stream/ river line from upstream to downstream. The River name and Reach name when finishing sketching the stream line is set (fig. 22). It is possible to add reaches by adding junctions and other river lines.

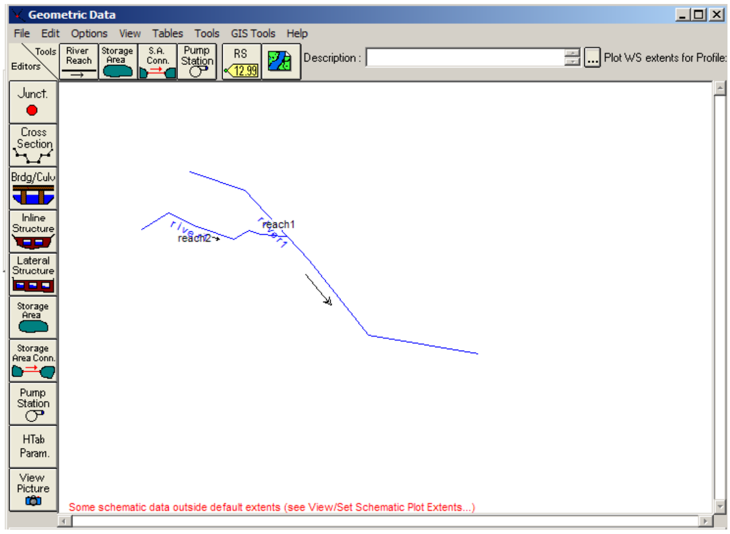


Fig22. HEC-RAS Geometric Data Input

**Notice messages (in red) at the bottom of Geometry Data window for errors and additional Information.*

Georeferenced image files can be inserted as background only in HEC-RAS in order to overcome the problem of coordinates (fig. 23) because the software does not recognize coordinates as geographic or spatial features.

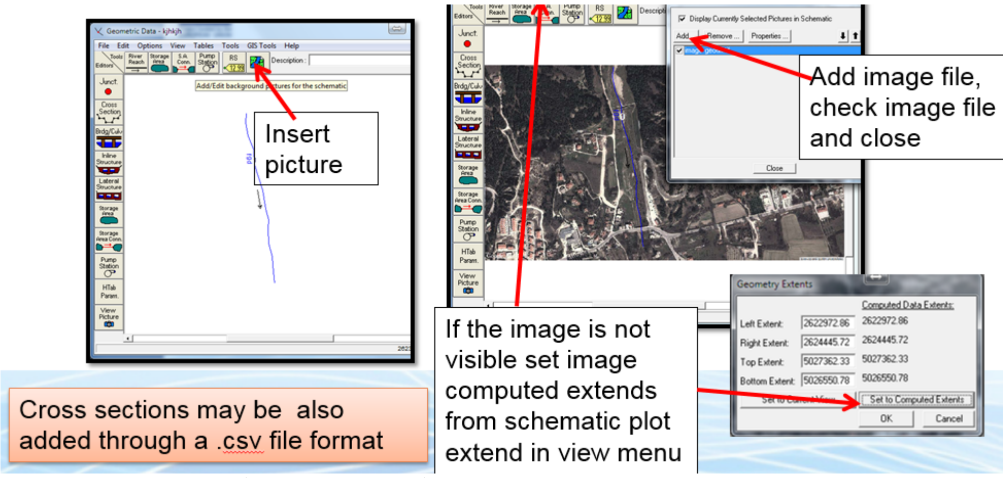


Fig23. HEC-RAS Geometric Data Input and Raster Input

In the case of introducing Geometry Data in HEC-RAS, cross sections shall be added one-by-one, by the "Add a new cross-section" tool. The user sets the number of the specific cross-section and then types in the Cross-Section Coordinates, the Station and the Station Elevation for each point of the cross-section to create the geometry. "Station" is the position along the stream.

Downstream Reach Lengths must also be inserted in order to adjust geometry by typing distance values in LeftOverBank (LOB) and RightOverBank (ROB) tabs, Manning values and Bank Stations positions etc. (fig. 24).

A cross-station may extend further off of bank stations. On the right side of the window, the inputs are plotted. The view of cross-sections may be altered using the plot options button.

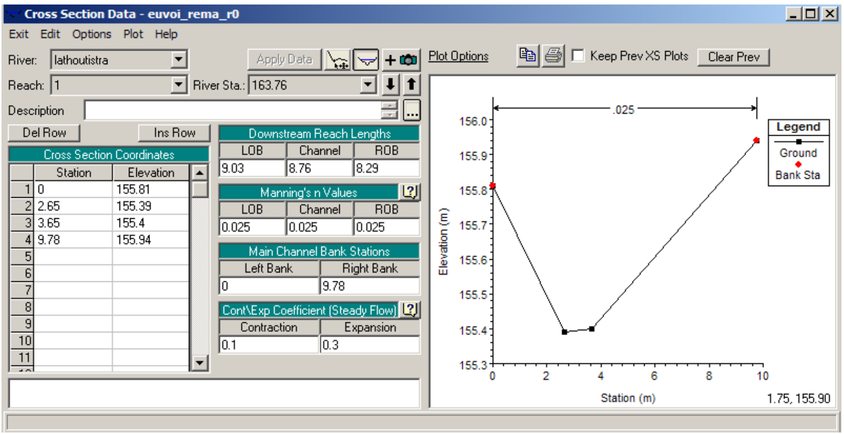


Fig24. HEC-RAS Cross-section Input

Finally, all cross sections are set in the same way. This is a rather time-consuming procedure, especially for long and wide streams, where cross-sections are numerous (the more cross-sections the better for the analysis). Care must be taken when selecting/drawing cross sections since these define the stream geometry thus strogly influencing flood related outputs (flood extension and depth, water velocity etc)

Figure 25 shows the geometry data input menu.

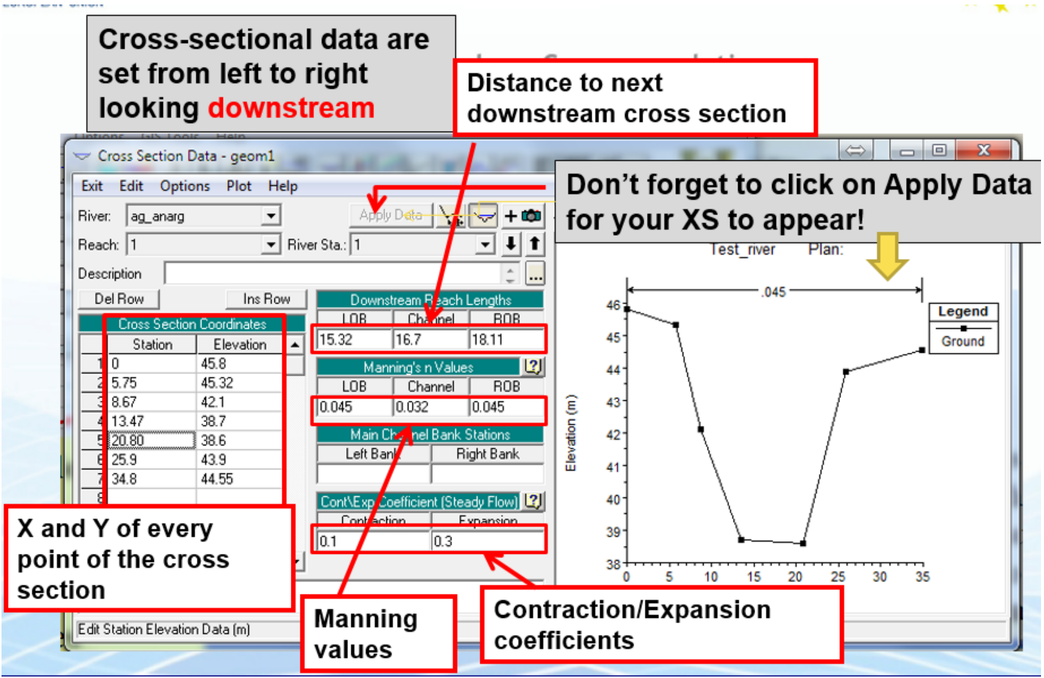


Fig25. HEC-RAS Cross-section Input

3.7.3.3 Entering additional information

Once the basic geometry is set, additional structure data may be introduced.

This task is implemented through the cross-section data window. The user can modify and add additional data such as levees, culvers, obstructions etc. (fig. 26).

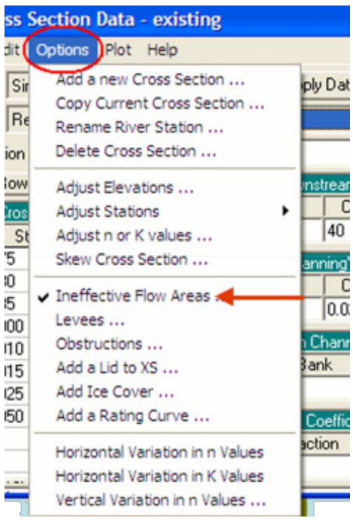


Fig26. HEC-RAS Cross-section editing options

In our case geometry data was imported, by the Import GIS Data tool were *.sdf files are imported, that contain all the necessary geometric characteristics. The sdf file was created in QRAS, a tool in QGIS that produces stream and cross-section sdf file, readable in HEC-RAS.

The stream and cross-section geometry in of Agioi Anarguroi stream is presented in (fig. 27).

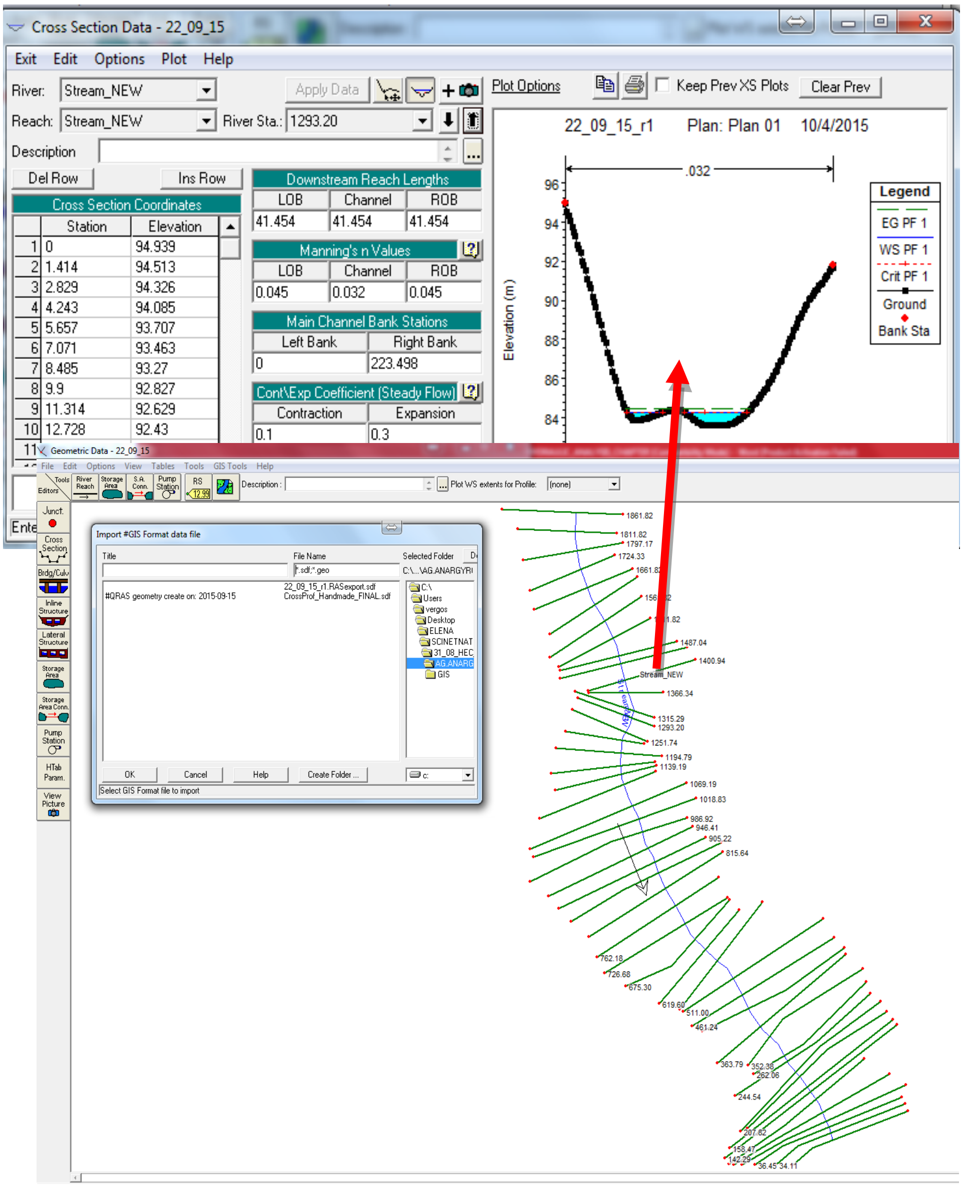


Fig27. HEC-RAS geometry through ".sdf" file import

3.7.3.4 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. 28). The choice depends on the desired type of hydraulic analysis. Different computations and flow data may be inserted and saved in the same project.

Boundary Conditions and Flow Data were then set. As far as Boundary conditions is concerned caution and experience is needed because wrong assumptions would lead to false results. Flow data (from hydrologic analysis and Rational Method) was inserted as a Profile (PR). Many Profiles may be added and saved separately.

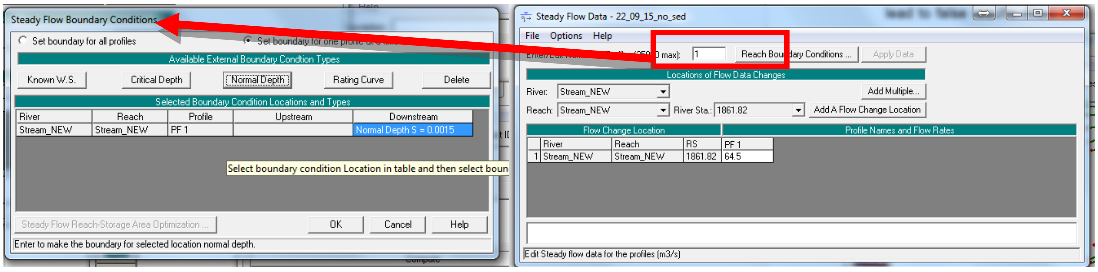


Fig28. HEC-RAS entering flow data

3.7.3.5 Computations - Running the Model

Once everything necessary was introduced to HEC-RAS then hydraulic analysis was performed.

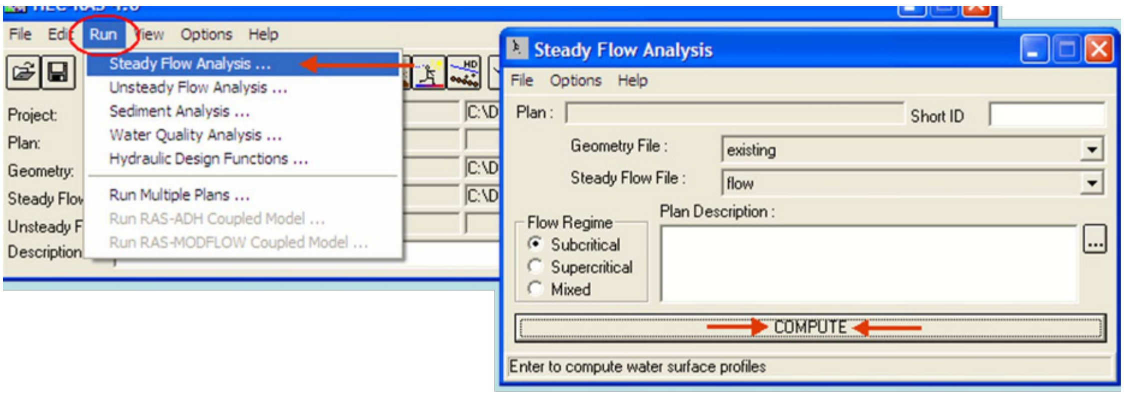


Fig29. Run the model

3.7.3.6 Outputs/Results

Once the computations are completed, output tables are instantly and automatically generated. From the main HEC-RAS window the output tables (Fig. 30) can be chosen to view the results. These tables contain useful data for the user to evaluate the results and the hydraulic conditions of the stream. The output tables may be formatted according to the desired viewed data and may be saved and printed. In the output tables all the hydraulic related data are presented for every single cross-section.

Profile plots, perspective plots and cross-section plots may be viewed (as in fig. 27), saved and exported as "*.dxf" files. Project may also be exported in GIS format. In this way, hydraulic data (water surface/profiles and geometry data may be inserted in other software for further mapping.

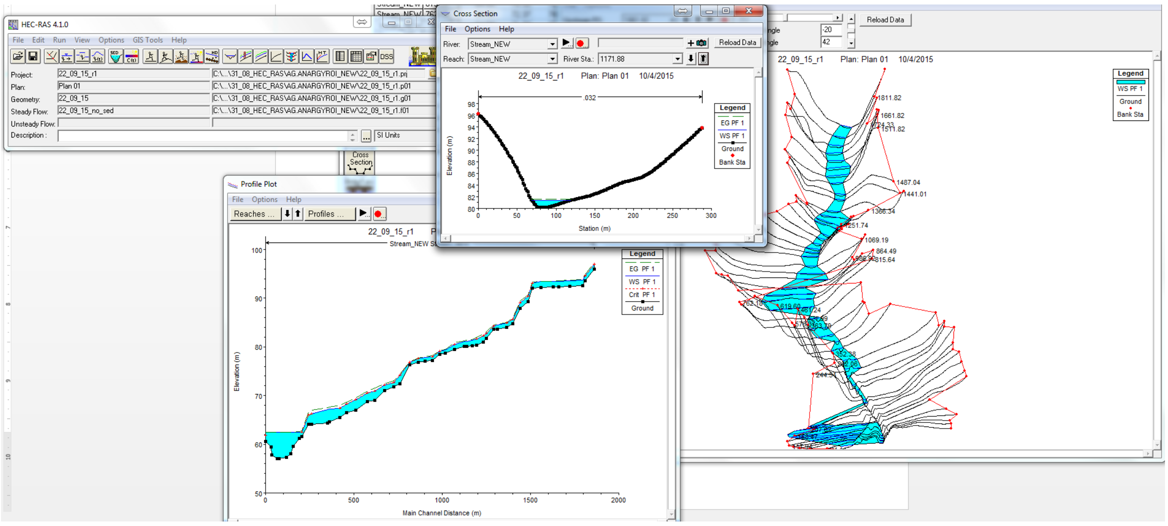


Fig30. Output plots and profiles in HEC-RAS (Agioi Anargyroi stream)

Table 3.7.1 Output table for Agioi Anargyroi Stream

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Stream_NEW	1861.82	64.50	95.94	96.98	96.98	97.31	0.01180	2.55	25.26	38.62	1.01
Stream_NEW	1811.82	64.50	93.63	94.59	94.59	94.89	0.01213	2.41	26.82	45.84	1.00
Stream_NEW	1797.17	64.50	92.55	93.71		93.81	0.00221	1.40	46.12	49.47	0.46
Stream_NEW	1724.33	64.50	92.46	93.57		93.65	0.00192	1.29	50.00	54.54	0.43
Stream_NEW	1661.82	64.50	92.36	93.45		93.53	0.00190	1.30	49.63	53.05	0.43
Stream_NEW	1628.48	64.50	92.26	93.46		93.49	0.00052	0.74	86.74	80.87	0.23
Stream_NEW	1561.82	64.50	92.17	93.42		93.45	0.00055	0.77	83.66	77.37	0.24
Stream_NEW	1511.82	64.50	92.08	93.03	93.03	93.35	0.01174	2.51	25.72	40.30	1.00
Stream_NEW	1487.04	64.50	89.30	90.39	90.39	90.74	0.01153	2.60	24.76	36.11	1.00
Stream_NEW	1441.01	64.50	87.95	89.09	89.09	89.45	0.01131	2.64	24.39	34.25	1.00
Stream_NEW	1400.94	64.50	84.75	85.65	85.65	85.95	0.01234	2.42	26.69	45.88	1.01
Stream_NEW	1366.34	64.50	83.97	84.86	84.86	85.06	0.01444	1.98	32.66	85.55	1.02
Stream_NEW	1315.29	64.50	83.66	84.55		84.63	0.00373	1.24	52.14	99.94	0.55
Stream_NEW	1293.20	64.50	83.63	84.27	84.27	84.48	0.01395	1.99	32.44	81.96	1.01
Stream_NEW	1251.74	64.50	81.69	82.75	82.75	83.09	0.01173	2.58	24.99	37.42	1.01
Stream_NEW	1233.75	64.50	81.01	82.19	82.19	82.56	0.01129	2.71	23.80	32.17	1.01
Stream_NEW	1194.79	64.50	80.38	81.61	81.61	82.00	0.01118	2.79	23.16	29.78	1.01
Stream_NEW	1171.88	64.50	80.20	81.39		81.54	0.00424	1.68	38.29	50.75	0.62
Stream_NEW	1139.19	64.50	80.16	81.17		81.36	0.00665	1.94	33.17	49.67	0.76
Stream_NEW	1127.56	64.50	80.11	81.14		81.28	0.00470	1.66	38.74	56.46	0.64
Stream_NEW	1069.19	64.50	79.47	80.51	80.51	80.85	0.01153	2.57	25.12	37.44	1.00
Stream_NEW	1018.83	64.50	78.75	79.38		79.47	0.00466	1.36	47.36	92.72	0.61
Stream_NEW	986.92	64.50	78.51	79.05	79.05	79.22	0.01451	1.84	35.08	102.69	1.00
Stream_NEW	946.41	64.50	77.21	78.00	77.98	78.19	0.01181	1.89	34.08	81.86	0.94
Stream_NEW	905.22	64.50	77.09	77.90		77.94	0.00272	0.94	68.87	158.00	0.45
Stream_NEW	864.49	64.50	76.88	77.54	77.54	77.71	0.01497	1.82	35.37	107.33	1.01
Stream_NEW	815.64	64.50	76.38	76.80	76.80	76.93	0.01592	1.64	39.37	146.99	1.01
Stream_NEW	762.18	64.50	72.37	74.16	74.16	74.47	0.01228	2.48	26.04	42.61	1.01
Stream_NEW	726.68	64.50	71.79	72.70	72.69	73.01	0.01165	2.49	25.93	40.54	0.99
Stream_NEW	675.30	64.50	70.97	72.12	72.12	72.36	0.01294	2.18	29.56	61.21	1.00
Stream_NEW	619.60	64.50	69.04	70.88	70.88	71.50	0.01007	3.49	18.46	14.90	1.00
Stream_NEW	576.37	64.50	68.70	70.59	70.59	70.92	0.01181	2.58	25.04	37.24	1.00
Stream_NEW	511.00	64.50	67.05	69.18	69.18	69.51	0.01206	2.56	25.17	38.24	1.01
Stream_NEW	461.24	64.50	66.50	68.29	68.29	68.62	0.01211	2.53	25.52	39.75	1.01
Stream_NEW	421.99	64.50	65.46	67.39	67.39	68.07	0.00992	3.64	17.71	13.11	1.00
Stream_NEW	363.79	64.50	64.55	67.20		67.58	0.00417	2.72	23.74	13.93	0.66
Stream_NEW	352.38	64.50	64.39	67.19		67.52	0.00359	2.56	25.24	14.53	0.62
Stream_NEW	262.06	64.50	64.14	66.23	66.23	66.97	0.01025	3.82	16.89	11.43	1.00
Stream_NEW	244.54	64.50	64.10	65.95	65.95	66.59	0.00999	3.54	18.23	14.30	1.00
Stream_NEW	207.82	64.50	61.57	62.44	62.43	62.72	0.01163	2.34	27.52	46.59	0.97
Stream_NEW	191.87	64.50	61.22	62.41		62.58	0.00463	1.80	35.85	44.81	0.64
Stream_NEW	158.47	64.50	59.57	62.52		62.52	0.00004	0.27	235.32	133.76	0.07
Stream_NEW	142.29	64.50	58.08	62.52		62.52	0.00001	0.13	488.93	269.98	0.03
Stream_NEW	117.94	64.50	57.26	62.52		62.52	0.00000	0.09	716.40	253.15	0.02
Stream_NEW	78.84	64.50	57.07	62.52		62.52	0.00000	0.10	667.93	224.98	0.02
Stream_NEW	68.38	64.50	57.01	62.52		62.52	0.00000	0.11	568.21	198.43	0.02
Stream_NEW	36.45	64.50	57.80	62.52		62.52	0.00001	0.17	389.66	161.99	0.03
Stream_NEW	34.11	64.50	59.44	62.51		62.52	0.00007	0.37	175.50	105.11	0.09
Stream_NEW	1.28	64.50	60.63	62.44	61.79	62.51	0.00150	1.17	55.11	56.07	0.38

In the following step of the procedure, HEC-RAS outputs must be imported into the QGIS in order to prepare the flood hazard maps depicting the flood parameters (extend, water depth and velocity).

Introducing the HEC-RAS outputs into QGIS is a straightforward process presented in brief, in the next paragraphs.

3.7.3.7 Mapping the inundation area - Export HEC-RAS outputs to QGIS

HEC-RAS provides the option of exporting data in GIS format usind two different options: a) by exporting the results directly as an "*.sdf" file (fig. 31), and b) by using the RAS Mapper to export outputs as images.

Using the first option, HEC-RAS outputs in the form of an ".sdf" file can be directly imported into QGIS and further processed in order to map the flood parameters.

An ".SDF" files contains all necessary information for floodplain mapping. The ".sdf" is in fact a text file describing the flood geometry. As such, it can be opened in a text editor and read for checking and of course it can be imported into QGIS as text as described in the following paragraphs.

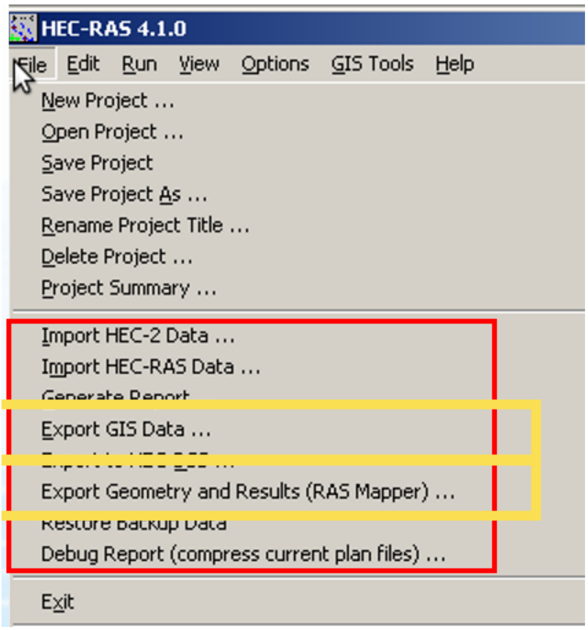


Fig31. Export geometry and results from HEC-RAS

All the parameters chosen and checked in this window, will be available in the .sdf file in text format. As marked in blue, the "*.sdf" file opened by a text editor (Fig. 32) and processed; water surface extends, elevation, velocity and other data and hydraulic analysis results are available in the defined cartographic projection system.

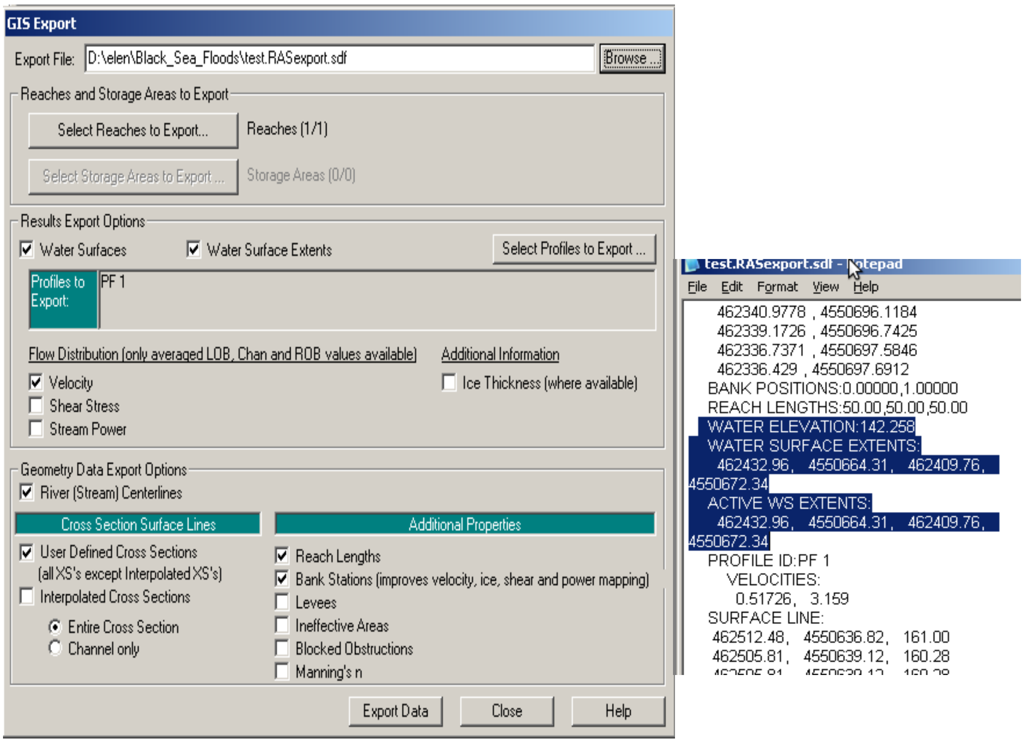


Fig32. HEC-RAS GIS Export Window and geometry file

From the sdf file, a *.cvs or a *.txt file can be created and then imported in QGIS by creating a new Layer (fig 33). In this way, the extents of the water surface will be available as points (edge points of floodline for each cross section) or when linked to cross sections, as attributes.

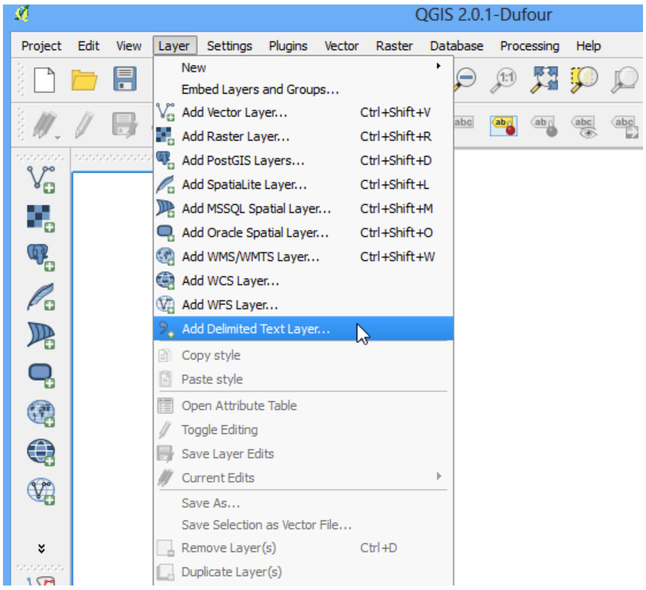


Fig33. Importing Delimited Text file in QGIS

3.8 FLOODPLAIN MAPPING IN QGIS

The first, important step in this procedure is to open the HEC-RAS outputs file with a text editor or a spreadsheet, in order to create an attribute used as the ID field used for the "joining" process (the common attribute between the QGIS cross sections and the HEC-RAS outputs).

Importing HEC-RAS outputs into the GIS developed with QGIS is a very straightforward two-step procedure. It is based on Joining the HEC-RAS outputs to the cross sections originally created into QGIS and used for the hydraulic analysis.

Reach	River Sta	Q Total	MinEl	W.S. El	Cr. W.S.	E.G. El.	E.G. Slope	Vel	Fl.Area	Top W.	Froude # Chl
AG.ANARGYROI		(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Stream_NEW	1.28	64.5	60.63	62.44	61.79	62.51	0.0015	1.17	55.11	56.07	0.38
Stream_NEW	34.11	64.5	59.44	62.51		62.52	0.00007	0.37	175.5	105.11	0.09
Stream_NEW	36.45	64.5	57.8	62.52		62.52	0.00001	0.17	389.66	161.99	0.03
Stream_NEW	68.38	64.5	57.01	62.52		62.52	0	0.11	568.21	198.43	0.02
Stream_NEW	78.84	64.5	57.07	62.52		62.52	0	0.1	667.93	224.98	0.02
Stream_NEW	117.94	64.5	57.26	62.52		62.52	0	0.09	716.4	253.15	0.02
Stream_NEW	142.29	64.5	58.08	62.52		62.52	0.00001	0.13	488.93	269.98	0.03
Stream_NEW	158.47	64.5	59.57	62.52		62.52	0.00004	0.27	235.32	133.76	0.07
Stream_NEW	191.87	64.5	61.22	62.41		62.58	0.00463	1.8	35.85	44.81	0.64
Stream_NEW	207.82	64.5	61.57	62.44	62.43	62.72	0.01163	2.34	27.52	46.59	0.97
Stream_NEW	244.54	64.5	64.1	65.95	65.95	66.59	0.00999	3.54	18.23	14.3	1
Stream_NEW	262.06	64.5	64.14	66.23	66.23	66.97	0.01025	3.82	16.89	11.43	1
Stream_NEW	352.38	64.5	64.39	67.19		67.52	0.00359	2.56	25.24	14.53	0.62
Stream_NEW	363.79	64.5	64.55	67.2		67.58	0.00417	2.72	23.74	13.93	0.66
Stream_NEW	421.99	64.5	65.46	67.39	67.39	68.07	0.00992	3.64	17.71	13.11	1
Stream_NEW	461.24	64.5	66.5	68.29	68.29	68.62	0.01211	2.53	25.52	39.75	1.01
Stream_NEW	511	64.5	67.05	69.18	69.18	69.51	0.01206	2.56	25.17	38.24	1.01

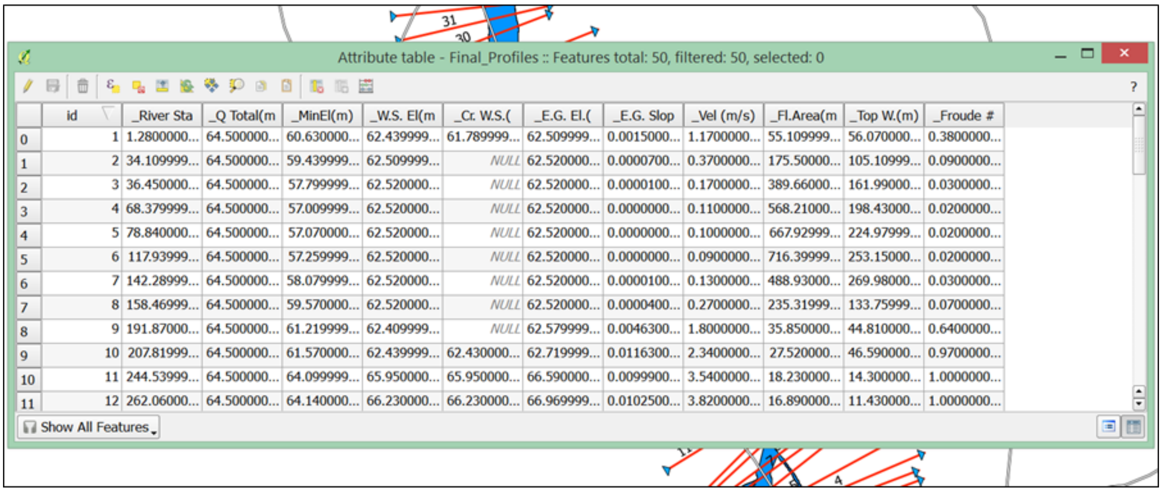
Fig34. HEC-RAS outputs imported into EXCEL. A NEW column will be created in order to define a parameter called ID, identical to the ID the cross sections have which is going to be used as the linking/joining attribute. The River Station column actually defines the order of cross sections since it provide their distance from the river mouth.

	A	B	C	D	E	F	G	H	I	J	K	L
1	ID	River Sta	Q Total(m:	MinEl(m)	W.S. El(m)	Cr. W.S.(m	E.G. El.(m)	E.G. Slope(r	Vel (m/s)	Fl.Area(m2	Top W.(m)	Froude # Chl
2	1	1.28	64.5	60.63	62.44	61.79	62.51	0.0015	1.17	55.11	56.07	0.38
3	2	34.11	64.5	59.44	62.51		62.52	0.00007	0.37	175.5	105.11	0.09
4	3	36.45	64.5	57.8	62.52		62.52	0.00001	0.17	389.66	161.99	0.03
5	4	68.38	64.5	57.01	62.52		62.52	0	0.11	568.21	198.43	0.02
6	5	78.84	64.5	57.07	62.52		62.52	0	0.1	667.93	224.98	0.02
7	6	117.94	64.5	57.26	62.52		62.52	0	0.09	716.4	253.15	0.02
8	7	142.29	64.5	58.08	62.52		62.52	0.00001	0.13	488.93	269.98	0.03
9	8	158.47	64.5	59.57	62.52		62.52	0.00004	0.27	235.32	133.76	0.07
10	9	191.87	64.5	61.22	62.41		62.58	0.00463	1.8	35.85	44.81	0.64
11	10	207.82	64.5	61.57	62.44	62.43	62.72	0.01163	2.34	27.52	46.59	0.97
12	11	244.54	64.5	64.1	65.95	65.95	66.59	0.00999	3.54	18.23	14.3	1
13	12	262.06	64.5	64.14	66.23	66.23	66.97	0.01025	3.82	16.89	11.43	1
14	13	352.38	64.5	64.39	67.19		67.52	0.00359	2.56	25.24	14.53	0.62
15	14	363.79	64.5	64.55	67.2		67.58	0.00417	2.72	23.74	13.93	0.66
16	15	421.99	64.5	65.46	67.39	67.39	68.07	0.00992	3.64	17.71	13.11	1
17	16	461.24	64.5	66.5	68.29	68.29	68.62	0.01211	2.53	25.52	39.75	1.01
18	17	511	64.5	67.05	69.18	69.18	69.51	0.01206	2.56	25.17	38.24	1.01
19	18	576.37	64.5	68.7	70.59	70.59	70.92	0.01181	2.58	25.04	37.24	1

Fig35. Column "Reach" was replaced by column "ID". The ID value corresponds to the Cross Section ID (Fig. 22, the label number shown on the Cross Sections)

Once the joining is done, the HEC-RAS outputs can be seen in QGIS, as attributes of the Cross Sections shapefile (Fig. 36).

The file is saved as "*.txt" or "*.csv" file and imported into QGIS for further processing. Joining tables in QGIS is a simple procedure accessed through the properties dialogue. The user has only to define the joining field.



Attribute table - Final_Profiles :: Features total: 50, filtered: 50, selected: 0

	id	_River Sta	_Q Total(m	_MinEl(m)	_W.S. El(m	_Cr. W.S.(	_E.G. El.(	_E.G. Slop	_Vel (m/s)	_Fl.Area(m	_Top W.(m)	_Froude #
0	1	1.2800000...	64.500000...	60.630000...	62.439999...	61.789999...	62.509999...	0.0015000...	1.1700000...	55.109999...	56.070000...	0.3800000...
1	2	34.109999...	64.500000...	59.439999...	62.509999...	NULL	62.520000...	0.0000700...	0.3700000...	175.50000...	105.10999...	0.0900000...
2	3	36.450000...	64.500000...	57.799999...	62.520000...	NULL	62.520000...	0.0000100...	0.1700000...	389.66000...	161.99000...	0.0300000...
3	4	68.379999...	64.500000...	57.009999...	62.520000...	NULL	62.520000...	0.0000000...	0.1100000...	568.21000...	198.43000...	0.0200000...
4	5	78.840000...	64.500000...	57.070000...	62.520000...	NULL	62.520000...	0.0000000...	0.1000000...	667.92999...	224.97999...	0.0200000...
5	6	117.93999...	64.500000...	57.259999...	62.520000...	NULL	62.520000...	0.0000000...	0.0900000...	716.39999...	253.15000...	0.0200000...
6	7	142.28999...	64.500000...	58.079999...	62.520000...	NULL	62.520000...	0.0000100...	0.1300000...	488.93000...	269.98000...	0.0300000...
7	8	158.46999...	64.500000...	59.570000...	62.520000...	NULL	62.520000...	0.0000400...	0.2700000...	235.31999...	133.75999...	0.0700000...
8	9	191.87000...	64.500000...	61.219999...	62.409999...	NULL	62.579999...	0.0046300...	1.8000000...	35.850000...	44.810000...	0.6400000...
9	10	207.81999...	64.500000...	61.570000...	62.439999...	62.430000...	62.719999...	0.0116300...	2.3400000...	27.520000...	46.590000...	0.9700000...
10	11	244.53999...	64.500000...	64.099999...	65.950000...	65.950000...	66.590000...	0.0099900...	3.5400000...	18.230000...	14.300000...	1.0000000...
11	12	262.06000...	64.500000...	64.140000...	66.230000...	66.230000...	66.969999...	0.0102500...	3.8200000...	16.890000...	11.430000...	1.0000000...

Show All Features

Fig36. HEC-RAS outputs imported into QGIS shown in the cross sections attribute table.

Creating spatial distribution maps of the flood parameters in QGIS, is a matter of creating the respective "surfaces" using the available tools. Flood extend, water depth and water velocity for a 50 year flood return period are shown in the following figures.

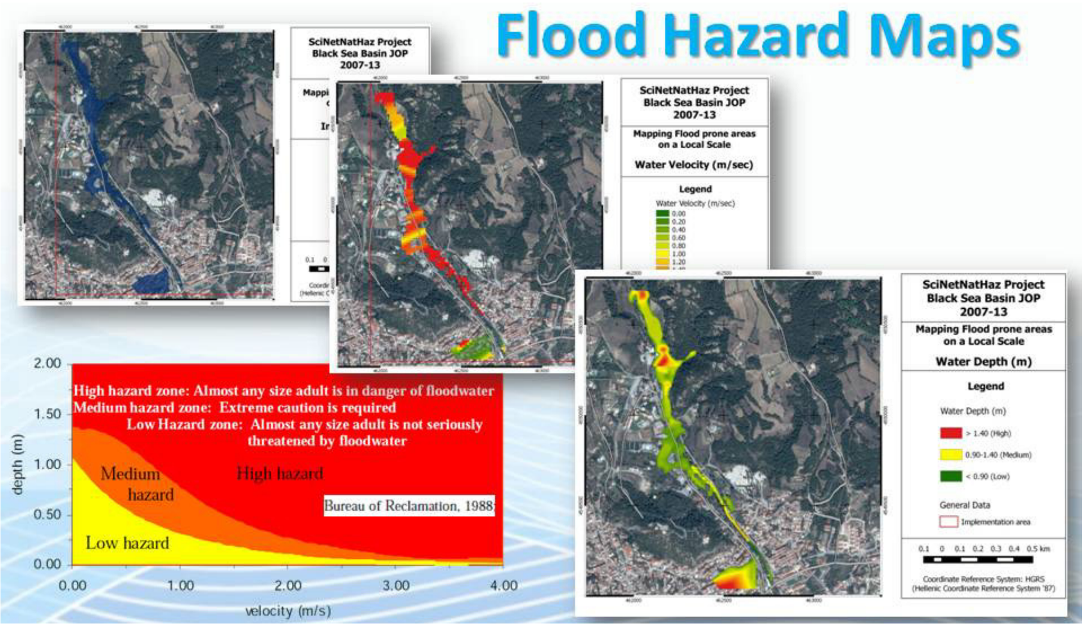


Fig37. Flood Hazard Maps of PIAs. The suggestions of the US Bureau of Reclamation (1988) were used for the flood water depth classification.

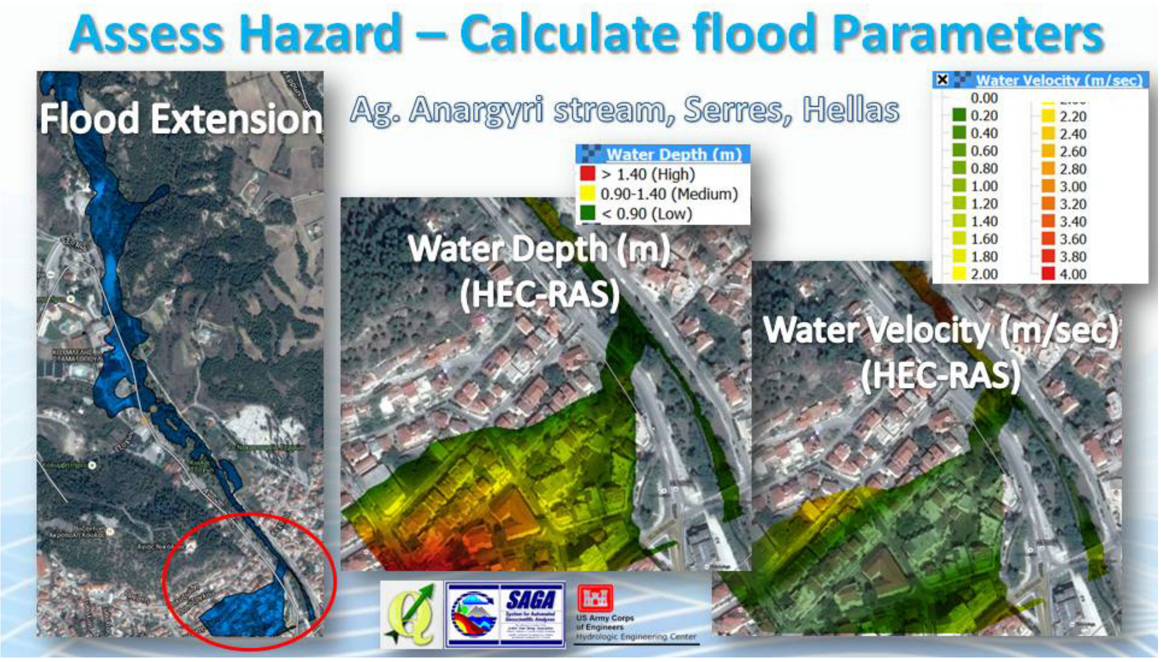


Fig38. Flood extend, water depth (m) and water velocity calculated for a 50 year reoccurrence flood in Agioi Anargyroi stream, Serres, Hellas.

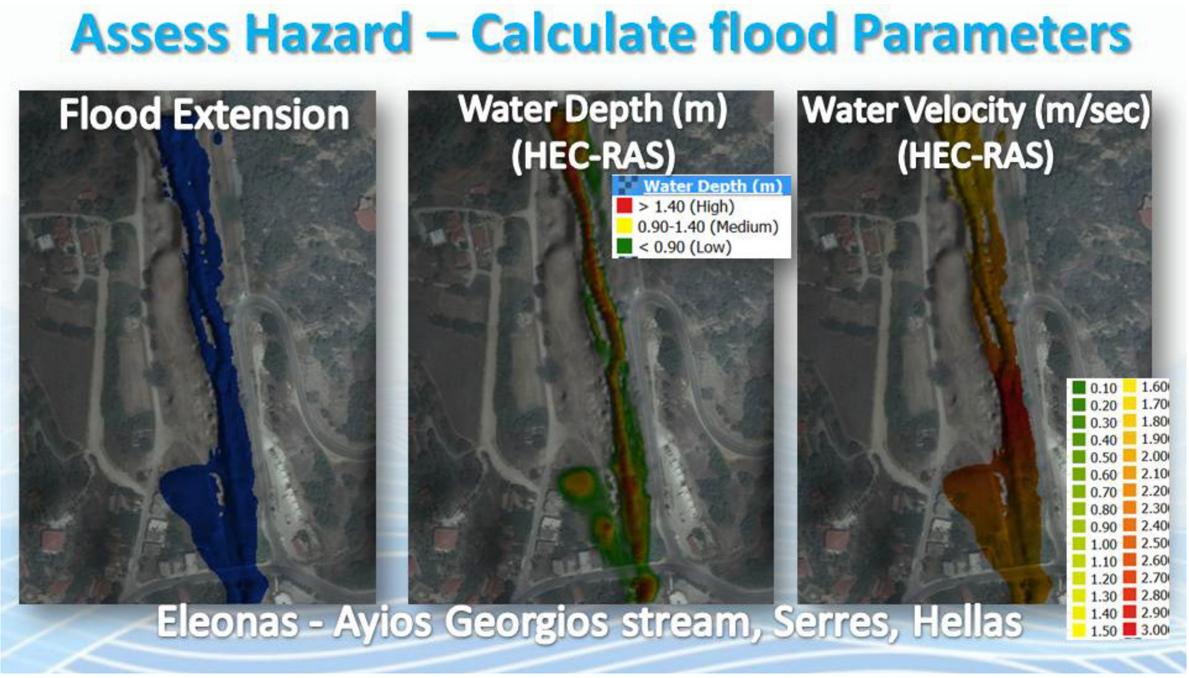


Fig39. Flood extend, water depth (m) and water velocity calculated for a 50 year reoccurrence flood in Eleonas stream, Serres, Hellas.

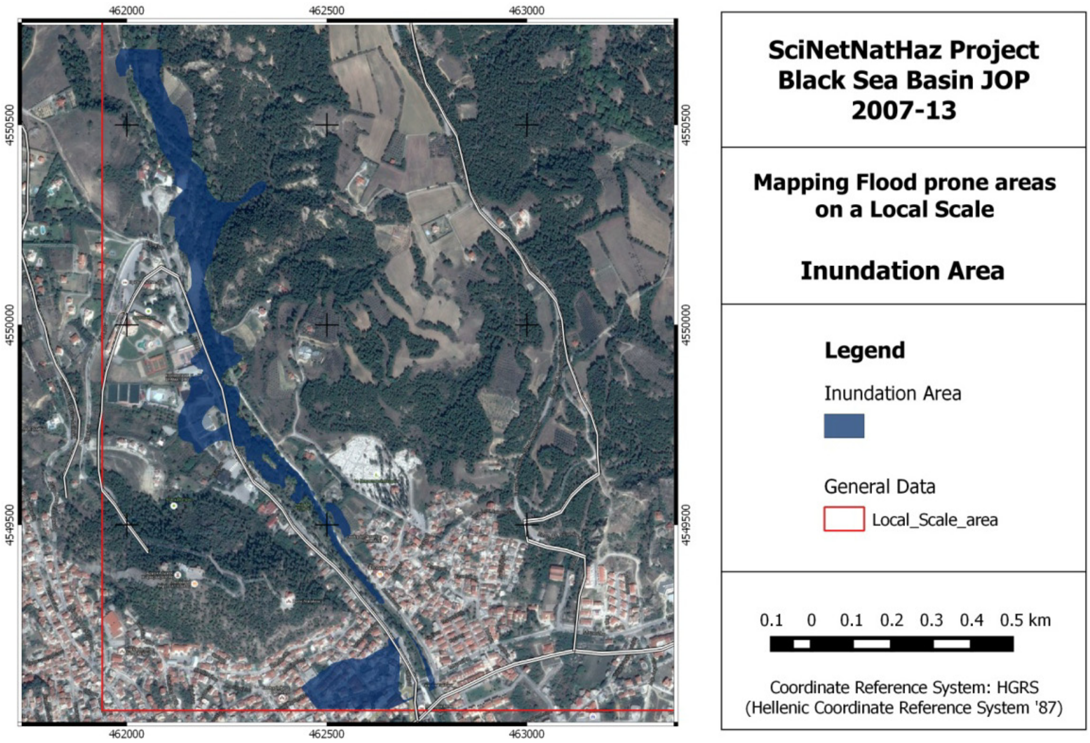


Fig40. Agioi Anargyroi stream. Innundation area (flood extend) for a 50 year flood return period.

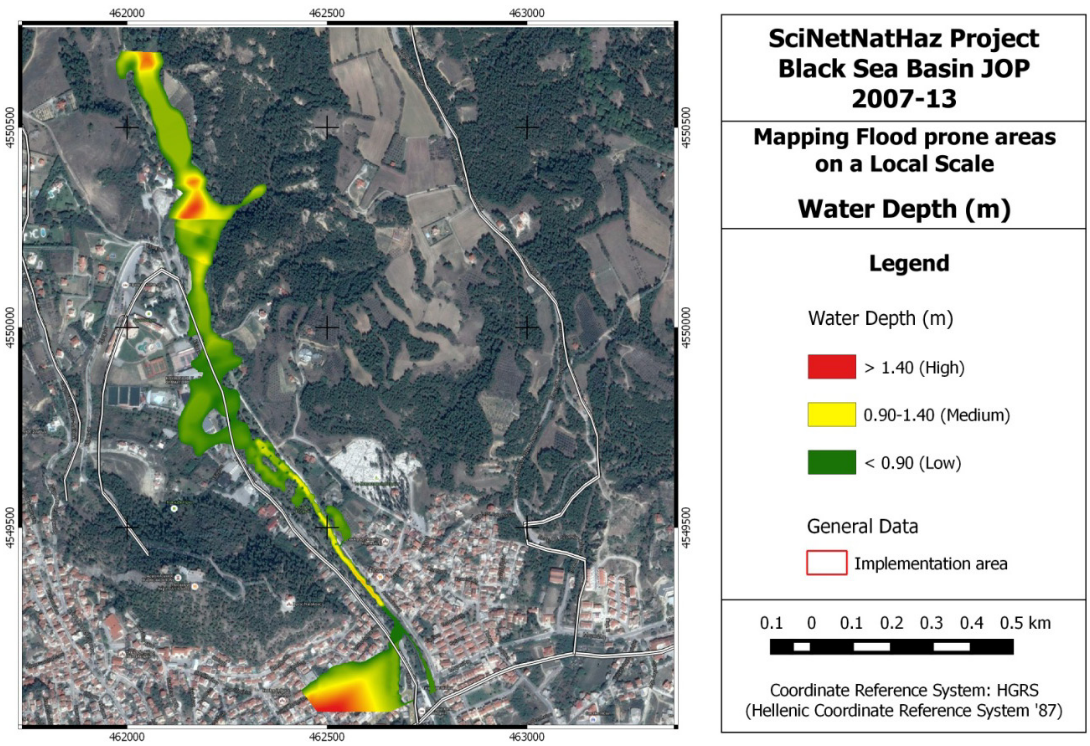


Fig41. Depth of water calculated for a 50 year flood return period.

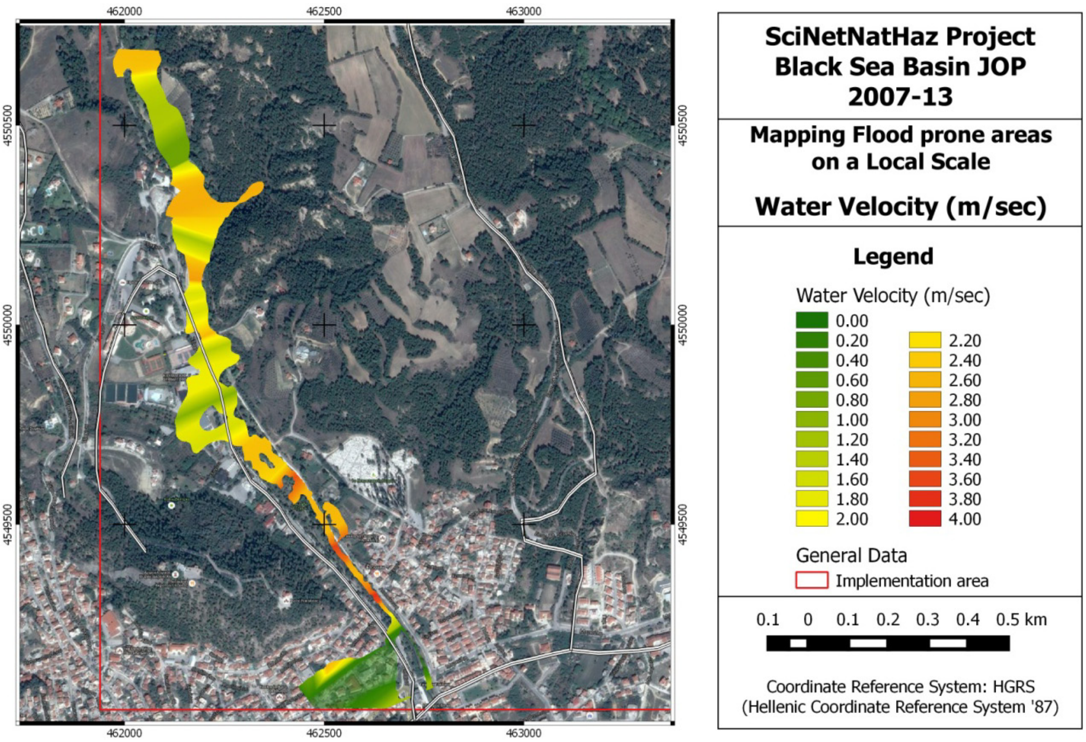


Fig42. Water velocity calculated for a 50 year flood return period.

4 OTMANLIYSKA RIVER/BURGAS REGION PILOT IMPLEMENTATION

4.1 INTRODUCTION

Floods are among the most dangerous natural phenomena causing severe damage to various branches of the economy and in many cases lead to casualties. Flooding occurs when areas that are not normally under water are inundated due to rising river levels and/or the level of groundwater due to rainfall and/or snowmelt, due to breaking of embankments, the dam breaks, temporary blockage of the river bed etc. [25].

The risk of flooding is determined by the frequency (probability) of their occurrence and exposure of the affected areas in terms of potential damage they may suffer. Damages in turn depend on the degree of hazard of the corresponding flood, as well as the vulnerability of exposed people and objects.

Exposure to floods is assessed on one hand through flood hazard zoning and on the other it is an important factor for vulnerability assessment. There are different systems (economic, social, ecological etc.) that can be exposed to flood hazard in particular area. Furthermore their exposure is different according to the flood risk zones where they belong to.

Vulnerability depends on the degree of flood hazard as well, but it also depends on many other factors such as the urbanization and buildings density, the type of threatened infrastructure, population characteristics such as density, age structure, mobility and health status, presence or absence of protective equipment in hazardous areas and early warning systems etc.

Flood hazard assessment on a regional scale can provide useful information which when combined with a preliminary risk assessment can support decision regarding strategic planning for disaster prevention. Flood Hazard maps can be used to assess the potential risks, prioritize areas in terms of the necessity to apply preventive measures and plan local investigations which require a more detailed planning for funding and implementation. S

uch a strategic planning can provide the State Regional and local administration the tool to plan effective flood disaster mitigation measures in both their financial and technical.

The accuracy in locating areas of a high flood hazard and the reliability of detecting them are of high importance since this information will be the basis for risk assessment, prioritization of high risk areas, decision making regarding the management of available funds and effective planning.

The area of interest in the terms of SciNetNatHaz Project from Bulgarian side is southern Black Sea cost in Burgas region. For the pilot implementation of the task we selected Otmanliyska river and its mouth in the area of "Ribarsko selishte" (Fisherman's village) (also known with its older name "Chengene skele").

Otmanliyska river is a relatively small watershed flowing directly to the Black Sea in the southern part of Burgas. The reason to aim this river as a local scale implementation area is the flooding occurred in 05 - 06 September 2014. This flooding event is the only one in the last 40 years to cause human casualties in Burgas region. Also, it affected the road connections. Flooded area included 400m around the main road amd Otmanliyska river bridge, cutting the access to southern parts of the Burgas region and Bulgarian - Turkish border without alternative connection. All the area between the road and the sea including the small wharf located in the river estuary was also flooded.

The Otmanliyska river is considered as non-dangerous in terms of flood risk due to the **low average water levels** (0.5 m). For long periods during summer, the river lacks any flow and is dry. The flooding events in the case of Otmanliyska river are the result of the intensive rainfall and the low filtration ability of the soils in the watershed. The **filtration properties** of gravel-sand layers in the alluvial deposits are about 50 m/d, and the conductivity is around 70 m^2/d.

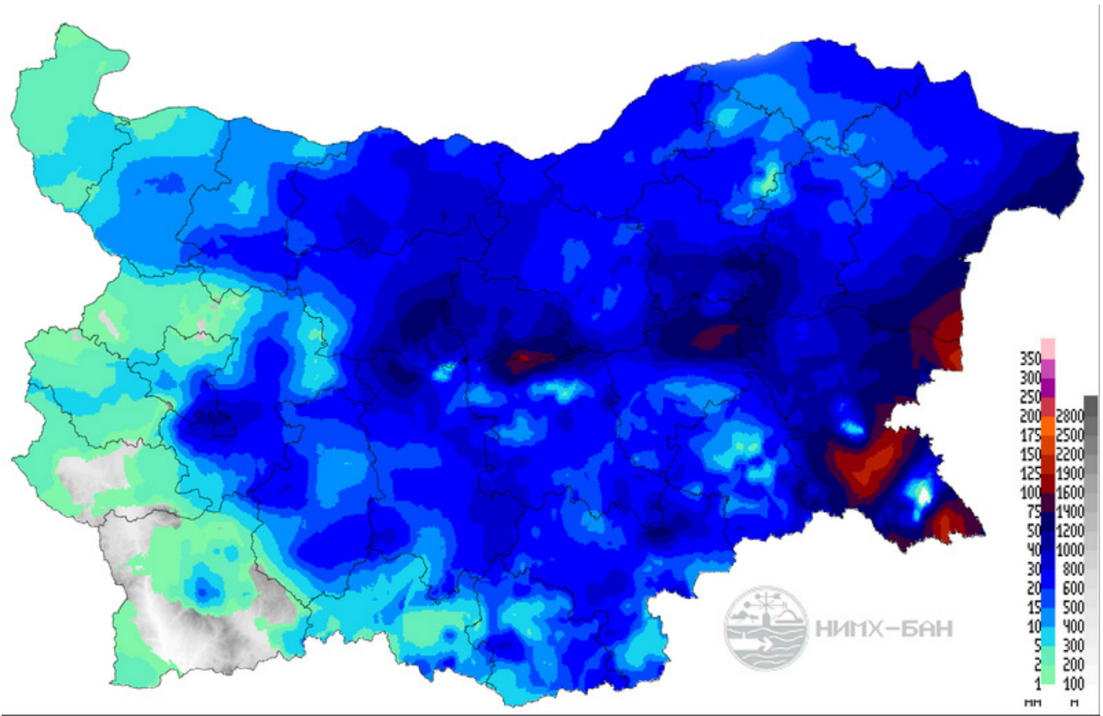


Fig43. Geographical distribution of the rainfall intensity 05-06 September 2014

The rainfall data analysis showed that the intensive rainfall is one of the main reason for the flooding event which occurred on 06.09.2014 in the lower catchment area and in the estuary of Otmansliyska river. The amount of 176 l concentrated in 12-15 hours, exceeds the average monthly rate with more than 250% which in combination with lower filtration properties exceeded the hydraulic characteristics of the riverbed.

The first step of the SciNetNatHaz project proposed procedure, is the implementation of FHA on a regional scale as a screening process aiming at detecting and mapping flood prone areas. This is actually a susceptibility assessment process and is followed by a preliminary risk assessment in order to prioritize those flood prone areas in terms of the importance of the assets at risk.

The Topographic Wetness Index (TWI) approach and its variant, the SAGA TW Index were selected to assess flash flood hazard on a regional scale.

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 [4],[5].

4.2 FLOOD HAZARD ASSESSMENT AT REGIONAL AND LOCAL SCALES

The approach applied in order to assess flood hazard is a two-step process, the first step involving the detection and mapping of flood prone areas, and after selecting the ones which are at risk, implement the HEC_RAS hydraulic model at the second step to assess flooding parameters.

The first step is actually a susceptibility assessment process and is followed by a preliminary risk assessment in order to prioritize those flood prone areas in terms of the importance of the assets at risk.

The second step is in fact the Flood Hazard Assessment stage, leading to results which can support decisions regarding the selection of preventive measures.

The Topographic Wetness Index (TWI) approach and its variant, the SAGA TW index were selected to map flash flood prone areas on a regional scale.

Additional data input and produced during the implementation phase included:

- Digitized geologic Maps
- Mean monthly rainfall (mm), max daily precipitations (mm) and peak rainfall intensity (mm/hour)
- Digital Elevation Model (DEM) with cell size of 2.0 x 2.0 m

Table 4.2.1 Rainfall data for Burgas region 01.09.2014 - 31.10.2014

Year	Month	Date	Rainfall /24 hours based mean value, mm/
2014	9	1	
2014	9	2	0.0
2014	9	3	
2014	9	4	18.9
2014	9	5	0.0
2014	9	6	176.0
2014	9	7	
2014	9	8	0.0
2014	9	9	0.0
2014	9	10	
2014	9	11	0.0
2014	9	12	0.0
2014	9	13	0.0
2014	9	14	0.0
2014	9	15	
2014	9	16	
2014	9	17	
2014	9	18	1.6
2014	9	19	0.3
2014	9	20	0.0
2014	9	21	
2014	9	22	
2014	9	23	3.4
2014	9	24	18.8
2014	9	25	0.0
2014	9	26	0.0
2014	9	27	27.8
2014	9	28	7.1
2014	9	29	0.0
2014	9	30	0.0

2014	10	1	0.0
2014	10	2	
2014	10	3	
2014	10	4	
2014	10	5	0.0
2014	10	6	0.0
2014	10	7	0.0
2014	10	8	0.0
2014	10	9	1.5
2014	10	10	
2014	10	11	0.0
2014	10	12	0.0
2014	10	13	0.0
2014	10	14	0.0
2014	10	15	0.0
2014	10	16	0.0
2014	10	17	0.0
2014	10	18	1.6
2014	10	19	2.3
2014	10	20	
2014	10	21	0.0
2014	10	22	0.0
2014	10	23	
2014	10	24	3.0
2014	10	25	24.2
2014	10	26	93.4
2014	10	27	5.8
2014	10	28	2.4
2014	10	29	0.1
2014	10	30	0.4
2014	10	31	7.6

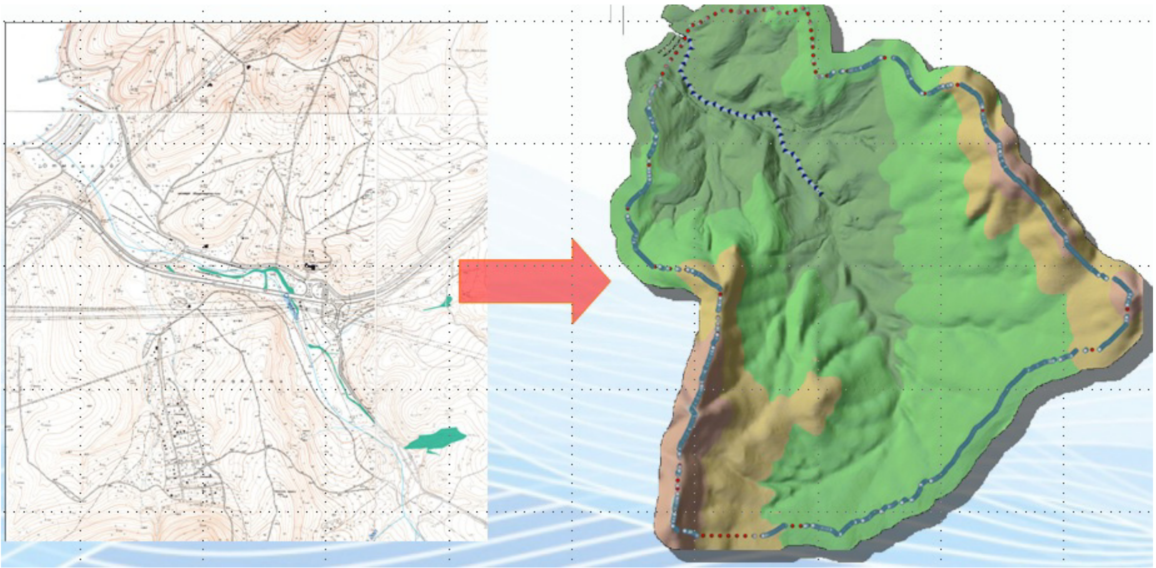


Fig44. Topographic map (1:10.000) of the Otmanliyska river catchment (left) and Digital Elevation Model (right)

4.3 MAPPING THE FLOOD PRONE AREAS ON A REGIONAL SCALE – PARAMETERS CALCULATED

The Topographic Wetness Index (TWI) can effectively be used to map the flooding susceptibility by mapping the flood prone areas.

The procedure to calculate the Topographic Wetness Index (TWI) and the SAGA-TWI in order to define the susceptibility to flooding (flood prone areas) is very straight forward since the selected Open Source software Quantum GIS (QGIS) incorporates the respective routines built into the SAGA GIS.

A model describing the entire procedure is presented in Fig. 45 (see previous paragraphs for more details).

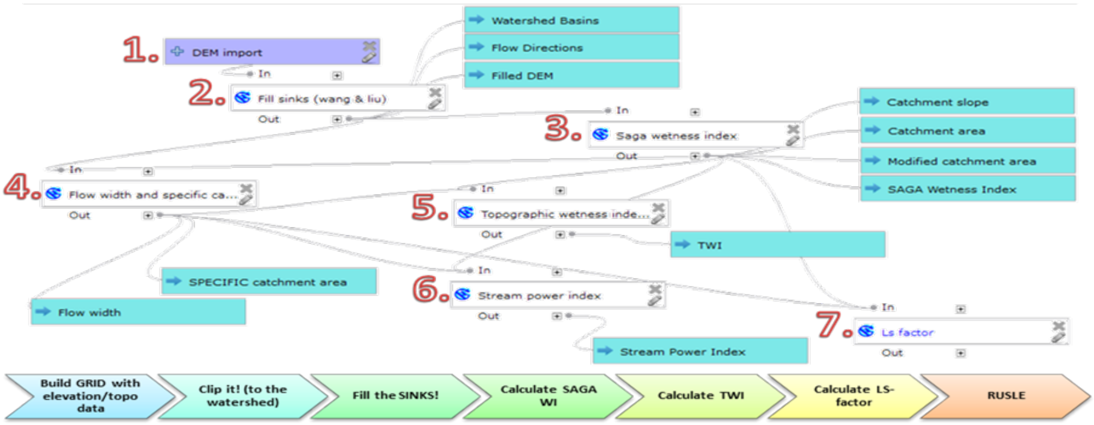


Fig45. Schematic representation of the entire process to develop TWI, SAGA WI and Stream Power spatial distribution maps. At the bottom, left to right, the consecutive steps are shown.

There are many variants of TWI based mainly on the way the upslope contributing (catchment) area is calculated. One of them is the SAGA TWI which is based on a "Modified Catchment Area"-MCA calculation which does not consider the flow as very thin film. As result, it predicts for cells situated in valley floors with a small vertical distance to a channel, a more realistic and with higher potential soil moisture as compared to the normal TWI value [5]. This fact is translated to a wider area calculated as potentially covered with water during a flood event (Fig. 46).

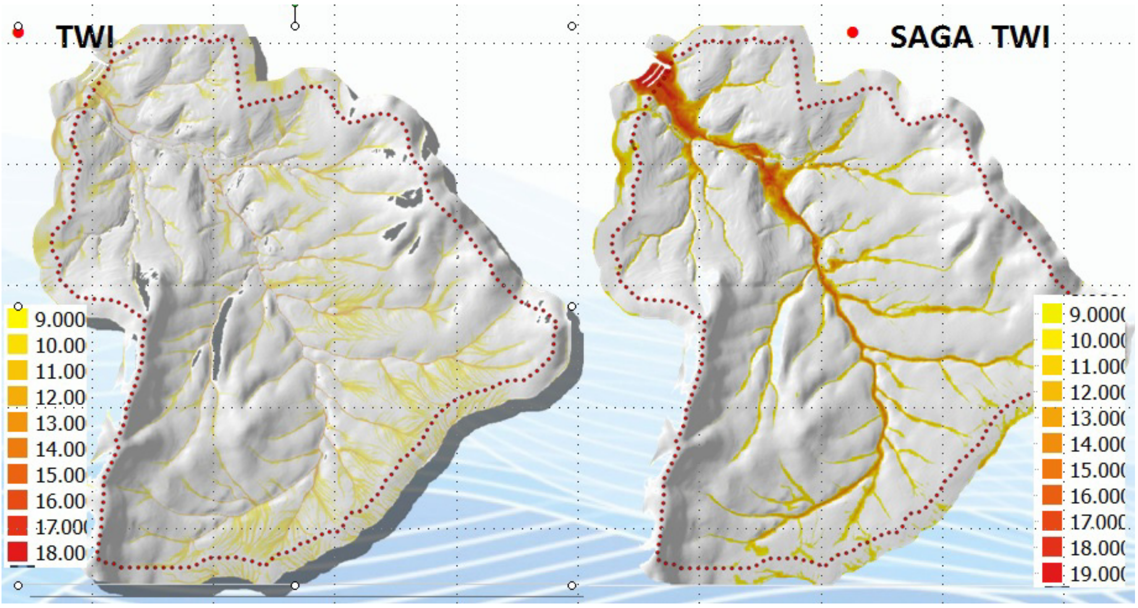


Fig46. The spatial distribution of Topographic Wetness Index (TWI) and SAGA- Topographic Wetness Index (SAGA-TWI) in the Otmanliyska river catchment.

According to the methodology these areas are considered as "flood prone" or areas of high susceptibility to flooding.

The superposition of the TWI on Google images as the evaluation of additional information about the location of important assets at risk, can be used to have a preliminary risk assessment and decide upon the exact location to which implement applied research on a local scale. At this point, the first "screening" step is concluded.

4.4 HYDRAULIC MODELING AND ANALYSIS IN HEC - RAS

Hydraulic Analysis and Modeling has shown extensive research effort to simulate flood propagation in rivers and this is expressed by numerous 1D and 2D simulation models including: HEC-RAS, Mike11, FLO-2D etc.

The outputs of these models, in flood hazard assessment, include: the level of inundation, the intersection of the flood level with the terrain (ground surface) to create the flood plain extent, the difference between the flood level and the terrain, which is used to calculate the depth and the distribution of velocity.

Hydraulic Analysis for assessing hydraulic behavior for the needs of this project has been implemented using HEC-RAS software. Details about the HEC-RAS methodology and software can be found in previous paragraphs.

Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section. Whether the computations proceed from upstream to downstream or vice versa, depend on the flow regime.

The dimensionless Froude number (Fr) is used to characterize flow regime, where: Fr < 1 denotes subcritical flow; Fr > 1 denotes supercritical flow and Fr = 1 denotes critical flow.

For a subcritical flow scenario, which is very common in natural and man-made channels, direct step computations would begin at the downstream end of the reach, and progress upstream between adjacent cross-sections (Fig. 47).

For supercritical flow, the computations would begin at the upstream end of the reach and proceed downstream.

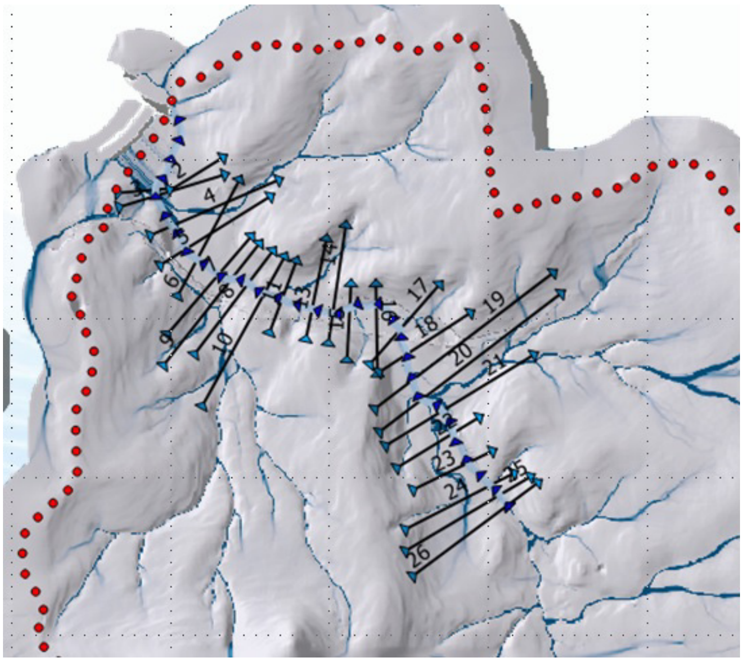


Fig47. Defining the channel geometry by cross sections of the Otmanliyska river catchment local scale FHA implementation area.

Once the computations are completed, output tables are instantly and automatically generated. Project may also be exported in GIS format as has been described in previous paragraphs. This way hydraulic data (water surface/profiles and geometry data may be inserted in other software for further mapping.

The main outputs of the HEC-RAS modelling are the flood parameters including the flood extent, the flood water velocity and the flood water depth and their spatial distribution in the flood prone areas (Fig 48).

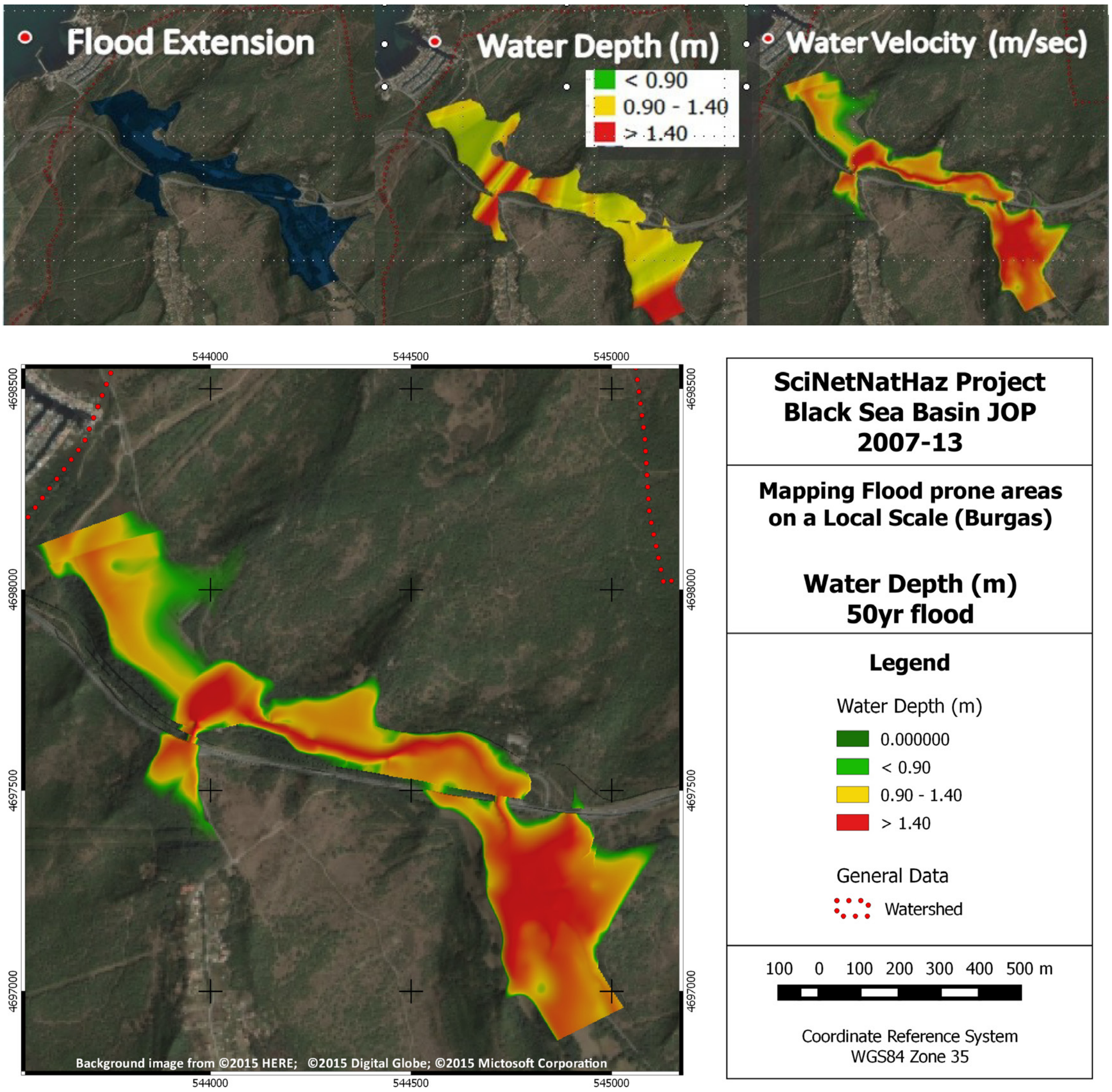


Fig48. Upper: Flood parameters calculated in the Otmanliyska river catchment for a 50yr flood; lower: Water depth map calculated for a 100 year flood. Note: all maps can be found at the end of this document in ANNEX I.

Going back to the flooding event occurred in the studied area in 2014**,** we can see a very good match of the modeling outputs with the real situation observed. This is a real life validation of the model and demonstration of the potential of the approach adopted in this project.

5 FLOOD HAZARD ASSESSMENT ON REGIONAL & LOCAL SCALES- PILOT IMPLEMENTATIONS IN TURKEY

Flood problems pose a serious threat to life, property and infrastructure across the northern Turkey. For that reason, two pilot implementation areas were chosen covering the cross border area to Greece and a part of the Turkish Black Sea coast. The areas of Tekirdağ province in eastern Thrace and the area of Samsun province. In the following sections, these implementation areas will be introduced from the view of flood hazard related characteristics. Then the regional scale and local scale Flood Hazard Assessment (FHA) applications will be presented and the conclusions of the implementation in Turkey will be drawn.

5.1 SAMSUN PILOT IMPLEMENTATION AREA

Samsun province is located in North, along the coast of Middle Black Sea Region in Turkey. As can be seen in Figure 49, Samsun is surrounded by Ordu province at the East, Sinop province at the West, Çorum province at the SouthWest, Amasya and Tokat provinces at the South. Samsun lies between 36^0 and 37^0 East latitudes and 41^0 and 42^0 North longitudes. The geographical features that border Samsun are Black Sea at the North, Derbent Creek at the West, Yeşilırmak River and Akçay Creek at the East and Canik Mountains at the South. Covering an area of approximately 9000 km^2, Samsun has the lowest altitude as far as the North Anatolian Mountains are concerned, which facilitates easier terrestrial outreach as compared to its neighbors (Fig. 50).

Fig49. The provincial map of Samsun with its districts.

Fig50. Geographic location and terrain view of Samsun (courtesy of GoogleEarth®).

Samsun has rich surface water resources including many rivers. The rivers like Yeşilırmak, Kızılırmak, Akçay, Mert and Kürtün are the major ones to name a few. Relatively high plateaus appear in between these rivers, most of which discharge directly to the Black Sea forming deltas of up to 1 km cross shore extent inner from the coast. Bafra and Çarşamba plateaus are examples of these land features.

There are numerous lakes in Samsun: Tuzlu Göl, Dumanlı Gölü, Dutdibi Gölü, Ladik Gölü, Balık Gölü, Simet Gölü, Kargalı Gölü, Akgöl, Silindir Gölü and Divanbaşı Gölü. Ladik Gölü, the largest lake in Samsun, covers an area of 870 ha and accommodates a great aqua-biodiversity.

Flood Hazard Assessment FHA pilot implementation in the area was carried out in two phases: a regional assessment of flood prone areas (flood susceptibility assessment) and an implementation on a local scale. Akçay Creek located in Samsun province was chosen as the area of the FHA implementation on a local scale. The downstream region of Akçay Creek comprises the Samsun-Ordu border as shown in Figure 50. Akçay Creek is located within the Terme district of Samsun, which is 56 km away from the Samsun city center. As shown in Figure 51, neighbors of Terme are Çarşamba district at the West and Salıpazarı district at the South West, Ünye and Çaybaşı districts at the East, Akkuş and İkizce at the South (the latter four are the districts of Ordu province). In addition to Akçay Creek, there are two other important rivers in Terme; Terme Creek and Milçay Creek. These rivers are being used for irrigation and for aquaculture. On the other hand, all these three rivers are known to be critical in terms of flash floods, causing losses and even casualties.

Fig51. Districts of Samsun, including Terme at the East.

Samsun province climate covers the coastal Black sea area including the Northern faces of the mountains and North east of Marmara region. The temperature difference between summer and winter is not sparse. Summers are relatively cool, whereas winters are relatively warmer in coastal lowlands and colder in higher ground with precipitation of snow.

Natural plant cover is humid and wide-leaved forest, turning to coniferous trees in higher lands. In the coastal areas along the river banks, there is an intense population of reeds.

The mean annual temperature is 14.2^{0}C, with the mean monthly summer temperatures of 23.3^{0}C, 23.2^{0}C and 20.0^{0}C in August, July and June, respectively. In the winter the mean monthly values drop down to 6.6^{0}C, 7.0^{0}C and 7.8^{0}C in February, January and March, respectively (Table 5.1.1). The mean annual precipitation is 683.2 mm. Maximum precipitation is seen in October, November and December with the values of 88.8 mm, 82.5 mm and 72.9 mm, respectively.

Further climatic parameters are manifested in Table 5.1.2. It may be of particular interest to mention that the maximum daily precipitation recorded in Samsun is 113.2 mm during 32 years of measurements. In the coastal region of Samsun (including Terme) the major type of encountered soil is clayey sand. The mean infiltration capacity of this soil type is measured to be 9 mm/hr, a quite low value.

The mean population density is 140 ind./km^2. This value rises to 155 ind./km^2 in Terme. The population is dependent on agriculture (mostly nuts) along with fundamental industries and fisheries (both marine and inland).

Table 5.1.1 Climatic conditions of Samsun province.

SAMSUN	Mean Temp (°C)	Mean Maximum Temp. (°C)	Mean Minimum Temp. (°C)	Mean Daylight Duration (hr)	Mean No. of Days Precipitated	Mean Monthly Cumulative Prec. (mm)	Maximum Temp. (°C)	Minimum Temp. (°C)
January	7.0	10.7	4.1	2.5	13.4	59.8	24.2	-6.6
February	6.9	10.9	3.7	3.2	13.4	50	26.2	-6.8
March	8.0	12.1	4.7	3.4	15	57.5	32.3	-7.0
April	11.2	15.2	7.8	4.4	14.8	59	37	-2.4
May	15.4	18.8	11.8	6.2	12.5	52	36.4	2.7
June	20.3	23.6	16.1	8.1	9.7	48.1	37.4	9.0
July	23.3	26.6	19.2	8.4	6.1	30.2	37.5	13.6
August	23.5	27.1	19.7	8.1	6.4	36.2	35.2	14.0
September	20.0	24.0	16.5	6.2	10.0	52.1	34.8	7.0
October	16.0	20.1	12.8	4.3	12.8	90.5	38.4	1.5
November	11.9	16.3	8.7	3.5	12.3	80.3	29.7	-2.2
December	9.0	12.7	6.0	2.4	13.5	76	28.9	-3.6

Table 5.1.2 Mean monthly climatic parameterrs recorded in Samsun in long term measurements

1975-2004	Months												Annual
	1	2	3	4	5	6	7	8	9	10	11	12	
Mean Temperature (ºC)	7.0	6.6	7.8	11.2	15.3	20	23.2	23.3	19.8	15.8	11.8	8.9	14.2
Mean Cumulative Precipitation Depth (mm)	60.4	49.0	53.0	59.9	48.8	49.7	32.0	34.9	51.3	88.8	82.5	72.9	683.2
Mean Cumulative Evaporation Depth (mm)	66.4	61.6	54.1	64.8	89.7	124.1	157.9	147.9	101.0	69.9	54.2	61.5	1053.1
Mean Relative Humidity (%)	68.0	70.0	75.0	79.0	79.0	73.0	70.0	72.0	75.0	76.0	70.0	67.0	72.0

5.2 TEKIRDAĞ PILOT IMPLEMENTATION AREA

Tekirdağ is located in the North West of Turkey, neighboring Istanbul. It is a part of the region historically known as Eastern Thrace (Figure 52). Its neighbors are Istanbul at the East, Kırklareli at the North, Edirne at the West and Çanakkale at the South West. It has a long coastline to Marmara Sea, as well as a short border to Black Sea.

Tekirdağ is a heavily industrialized city with a population of 150 000 people. There are two major highlands in Tekirdağ wider area, one of them is the Tekir Mountain located just at the North of city center and the other one is the Ganos Mountain located between the city center and Şarköy district. Tekirdağ is divided into 11 districts, including the city center (Figure 53).

Eregene river is the major river in Tekirdağ, unfortunately suffering from heavy pollution. The alluvial land that has been formed by Ergene through ages accommodated fertile land for agriculture. The land cover is generally trees with flat leaves, turning into coniferous plants in higher ground.

The summary of climate data for Tekirdağ is shown in Table 5.2.1. As can be seen here, the highest rainfalls are seen in October, November and December.

On the other hand, the most extreme rainfall and flood events have been recorded during September and October, such as the flash flood events in September 2009, which killed more than a dozen people in Tekirdağ.

Fig52. Geographic location and terrain view of Tekirdağ (courtesy of GoogleEarth®).

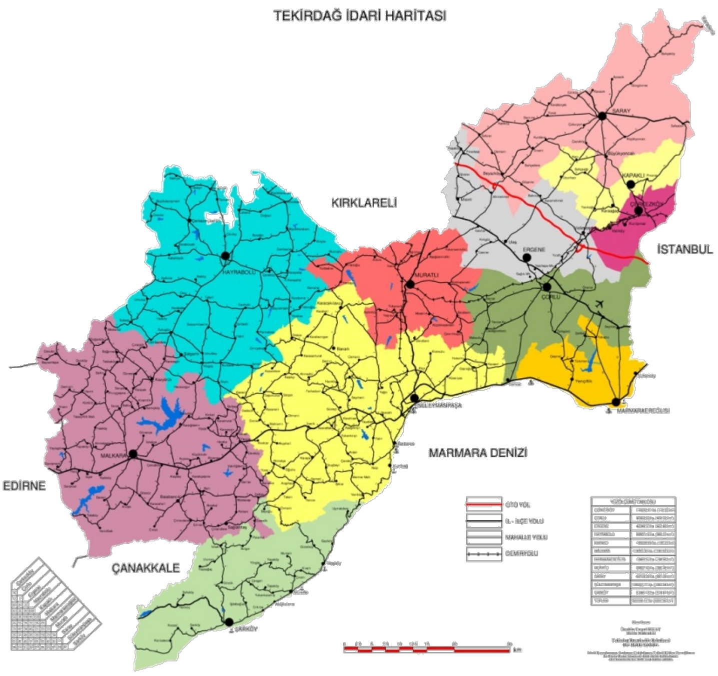


Fig53. General map of Tekirdağ showing its districts.

Table 5.2.1 Tekirdağ climatic data.

Climate data for Tekirdağ													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Record high °C (°F)	23.9 (75)	24.7 (76.5)	28.1 (82.6)	30.0 (86)	33.4 (92.1)			37.5 (99.5)	34.5 (94.1)	35.1 (95.2)	27.9 (82.2)	23.5 (74.3)	
Average high °C (°F)	8.1 (46.6)	8.7 (47.7)	11.0 (51.8)	15.7 (60.3)	20.5 (68.9)	25.3 (77.5)	27.9 (82.2)	27.9 (82.2)	24.3 (75.7)	19.7 (67.5)	14.8 (58.6)	10.5 (50.9)	17.87 (64.16)
Daily mean °C (°F)	4.8 (40.6)	5.1 (41.2)	7.3 (45.1)	11.9 (53.4)	16.8 (62.2)	21.4 (70.5)	23.8 (74.8)	23.6 (74.5)	19.9 (67.8)	15.4 (59.7)	11.0 (51.8)	7.2 (45)	14.02 (57.22)
Average low °C (°F)	2.0 (35.6)	2.2 (36)	4.1 (39.4)	8.1 (46.6)	12.5 (54.5)	16.5 (61.7)	18.8 (65.8)	19.1 (66.4)	15.8 (60.4)	12.0 (53.6)	7.9 (46.2)	4.2 (39.6)	10.27 (50.48)
Record low °C (°F)	−12.3 (9.9)	−11.5 (11.3)	−10.4 (13.3)	−1.2 (29.8)	3.5 (38.3)	8.6 (47.5)	10.9 (51.6)	12.0 (53.6)	3.7 (38.7)	−1.8 (28.8)	−5.3 (22.5)	−10.9 (12.4)	−12.3 (9.9)
Average precipitation mm (inches)	60.7 (2.39)	54.9 (2.161)	56.0 (2.205)	41.0 (1.614)	38.3 (1.508)	35.5 (1.398)	26.6 (1.047)	17.6 (0.693)	37.0 (1.457)	63.0 (2.48)	75.4 (2.969)	73.7 (2.902)	579.7 (22.824)
Average rainy days	11.9	10.8	10.5	10.0	8.2	6.9	3.8	2.8	4.9	7.4	9.4	12.1	98.7
Mean monthly sunshine hours	86.8	98	133.3	177	241.8	270	303.8	279	216	155	102		2,137.1

5.3 REGIONAL SCALE FHA IMPLEMENTATION IN SAMSUN AND TEKIRDAĞ

For the regional scale flood susceptibility assessment, the Topographic and the SAGA Wetness Indices were used. Those indices provide maps of the areas that are most likely to be flooded (flood prone areas) thus they are considered as flood susceptibility maps.

Open Source and freeware software was used (QGIS, SAGA-GIS and GRASS-GIS) for the entire implementation in order to effectively achieve easier dissemination conditions. For this implementation on a regional scale, the following data have been used:

These indices were converted into maps in order to depict the spatial distribution and the extent of the flood prone areas.

1. The 1/25000 scale digitized maps of the region obtained from the Turkish Army General Command of Maps.

2. The basin and sub-basin borders taken from the web-GIS database of Turkish Ministry of Forestry and Water (http://geodata.ormansu.gov.tr).

The following procedure was applied:

- The 1/25000 scale maps were converted to DEM (digital elevation model) format with a 10x10m pixel size.
- Using the sub-basin templates in http://geodata.ormansu.gov.tr, the DEM files were trimmed into sub-basins, such that each file is covering a single sub-basin (Figure 54).
- Once the sub-basin DEMs were generated, they were processed with the integrated computational steps using QGIS interface (as described above).
- The spatial distribution of various important parameters including the aspect, unit catchment area, Topographic Wetness Index (TWI) and SAGA Wetness Index (SAGA WI) indices were finally calculated (Figure 55).
- These indices were converted into maps in order to depict the spatial distribution and the extent of the flood prone areas.

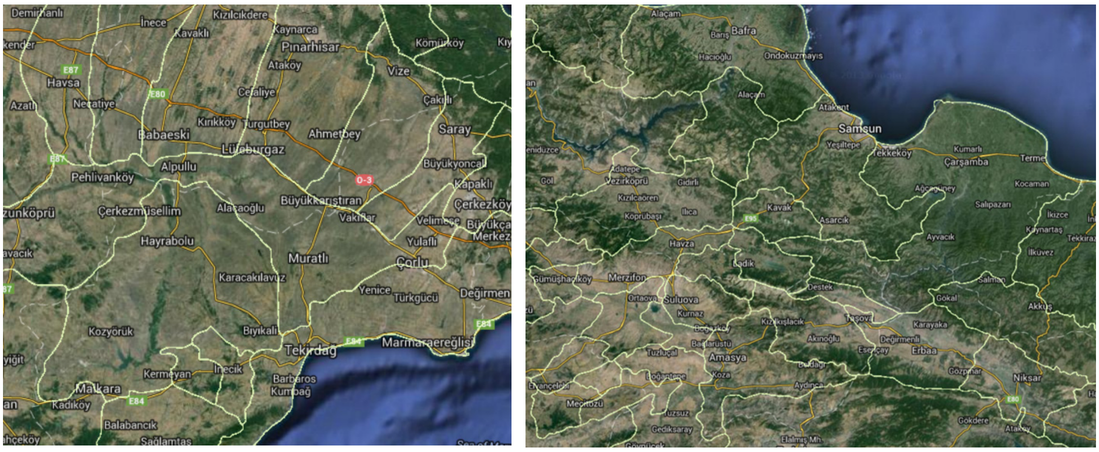


Fig54. The sub-basin borders taken from the http://geodata.ormansu.gov.tr web-GIS server for Tekirdağ (on the left) and Samsun (on the right).

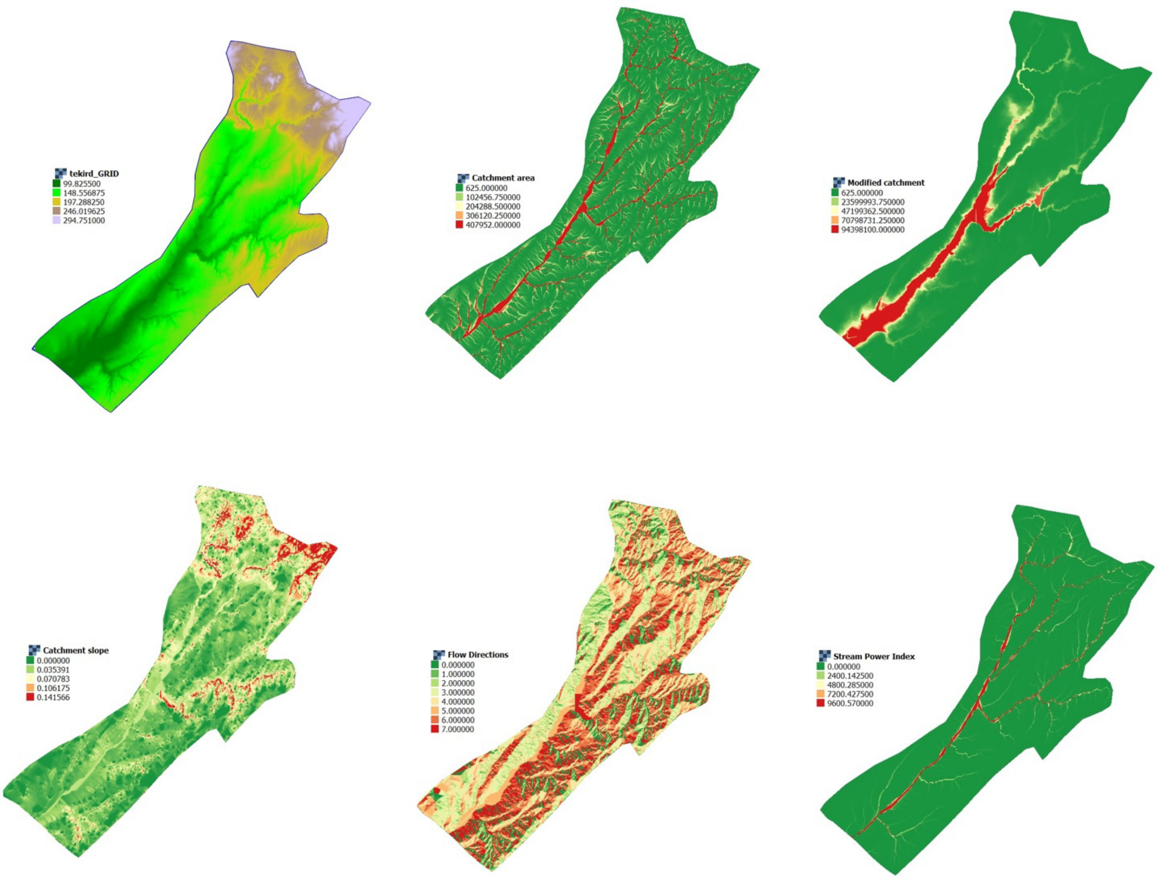


Fig55. An example application of the regional scale FHA assessment methodology. The figures refer to elevations, catchment area, modified catchment area, catchment slope, flow directions and stream power, respectively from top left to bottom right.

As part of the methodology both TWI and SAGA WI maps are produced for almost all the sub-basins of Tekirdağ and Samsun.

For the reasons of limited space, four of the modeled basins for regional scale FHA from each province are presented here, as shown in Table 5.3.1.

Table 5.3.1

Basins in Tekirdağ		Basins in Samsun	
Sub-basin Name	**Area (km^2)**	**Sub-basin Name**	**Area (km^2)**
Saray	454	Derbent	642
Yenice	118	Kavak	296
İnecik	165	Ladik	308
Hayrabolu	1800	Ünye-İkizce	3000

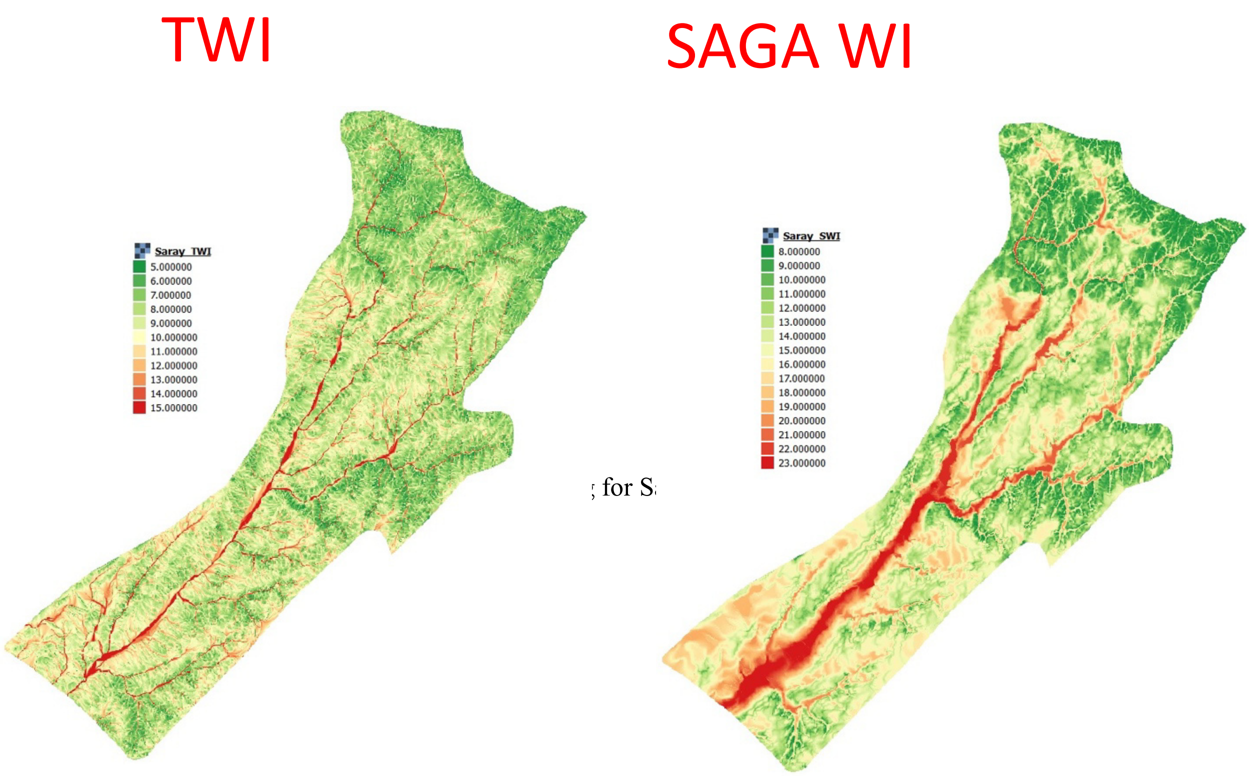
Although there is not a strict universal criterion to differentiate the flood-prone areas solely on the isolated values of the aforementioned indices, the distribution of the indices across the river basins give very crucial qualitative information about the flood susceptibility of any location of interest within the basin.

Figures 56-59 show the model results for the sub-basins in Tekirdağ.

In Figure 60, a close-up satellite view of Hayrabolu town center is shown, overlapped with SAGA Wetness Index results of the regional scale FHA model. It can be seen that the Eastern side of the town center came out to be prone to flooding, including the industrial complexes. This estimate of the model is very realistic that this exact region was flooded in February 2015 due to the intense and heavy rainfall (i.e. flash flood).

A photo from the newspaper inset is shown in Figure 61.

Figures 62-65 show the results of regional scale FHA in four sub-basins of Samsun province.



; for S

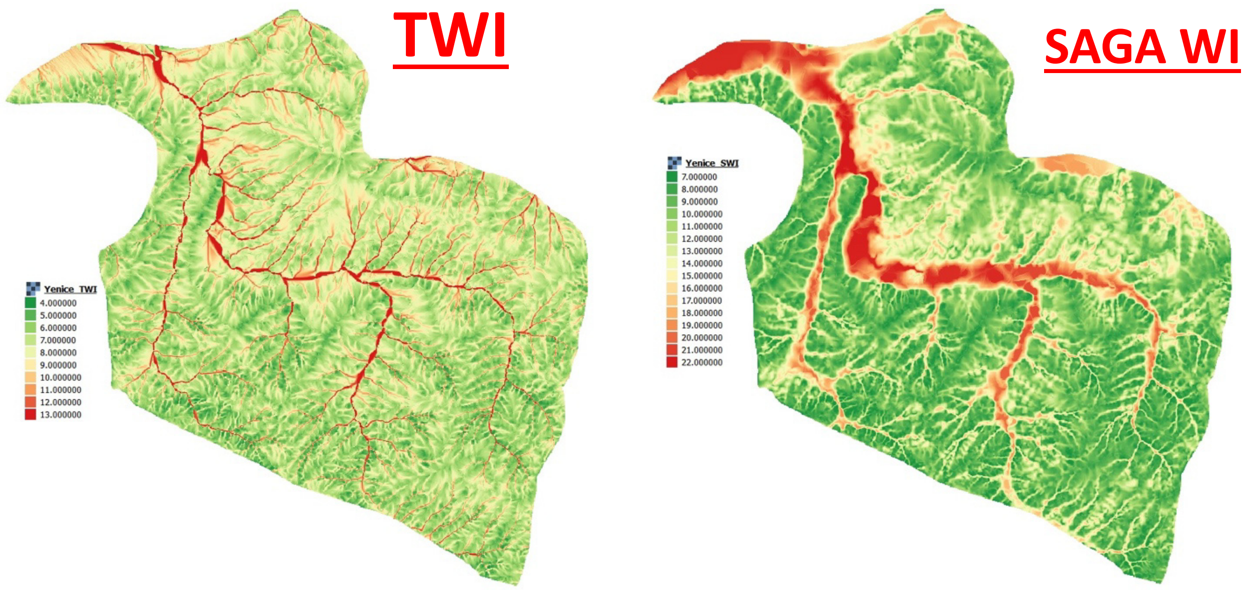


Fig57. The results of regional scale FHA modeling for Yenice basin, Tekirdağ.

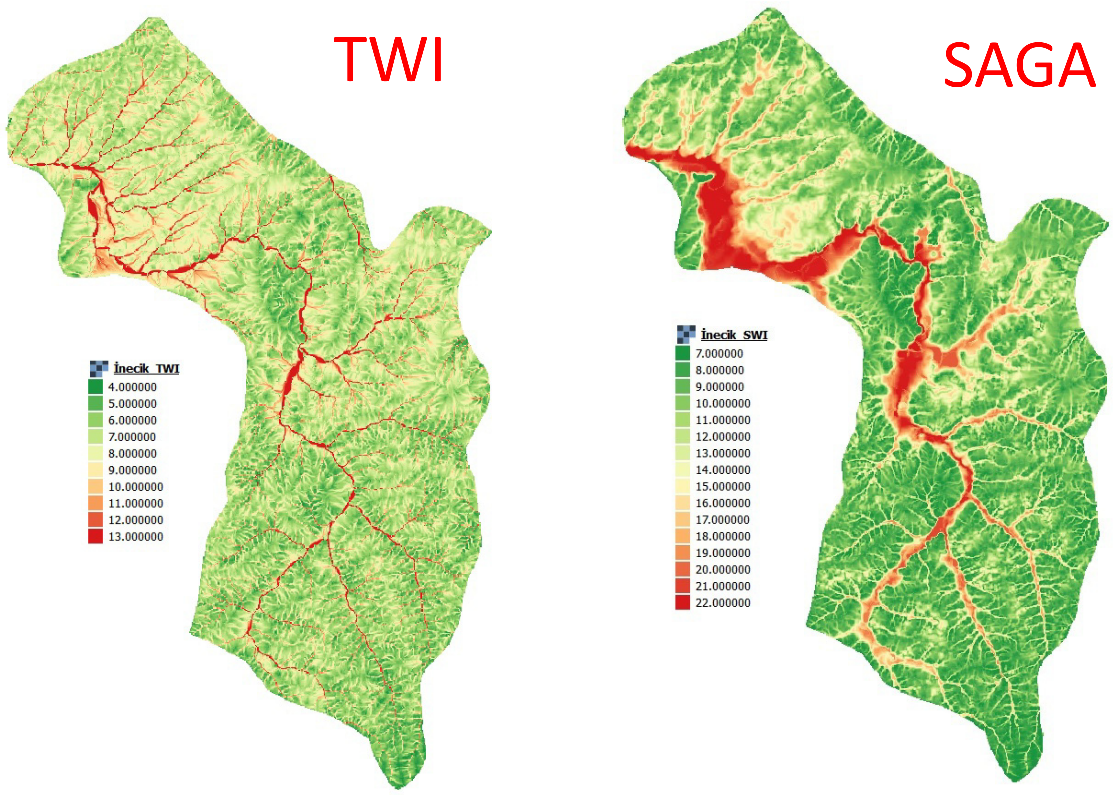


Fig58. The results of regional scale FHA modeling for İnecik basin, Tekirdağ.

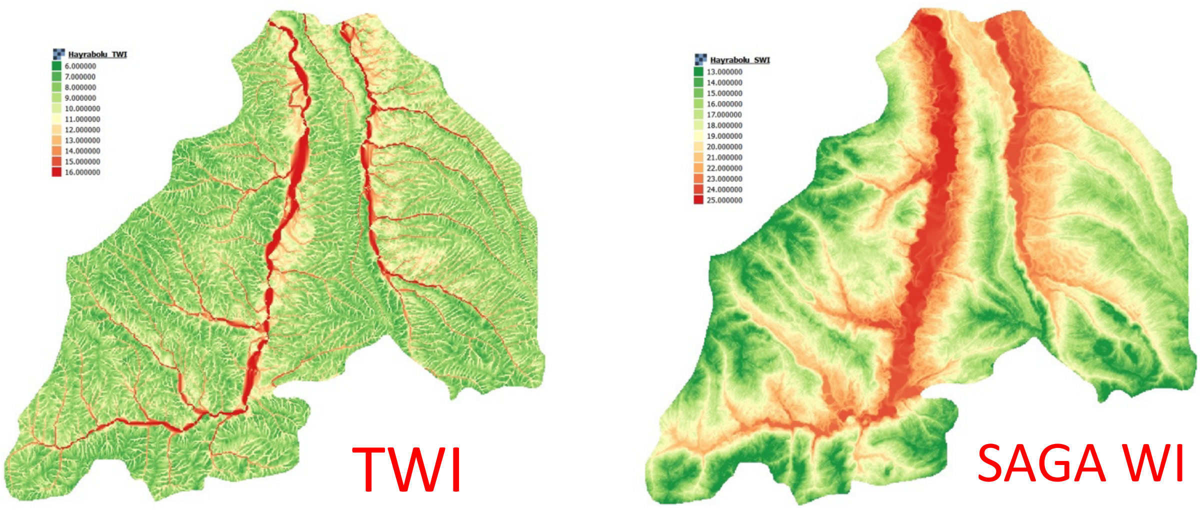


Fig59. The results of regional scale FHA modeling for Hayrabolu basin, Tekirdağ.

Fig60. Close-up view of Hayrabolu town center, showing that the industrial complex region is within the flood-prone area with respect to the SAGA Wetness Index results.

Fig61. Photos of the Hayrabolu industrial complex flooded in February 1st, 2015 **(**http://www.milliyet.com.tr/hayrabolu-deresi-saganak-dolayisiyla-tekirdag-yerelhaber-601938/**).**

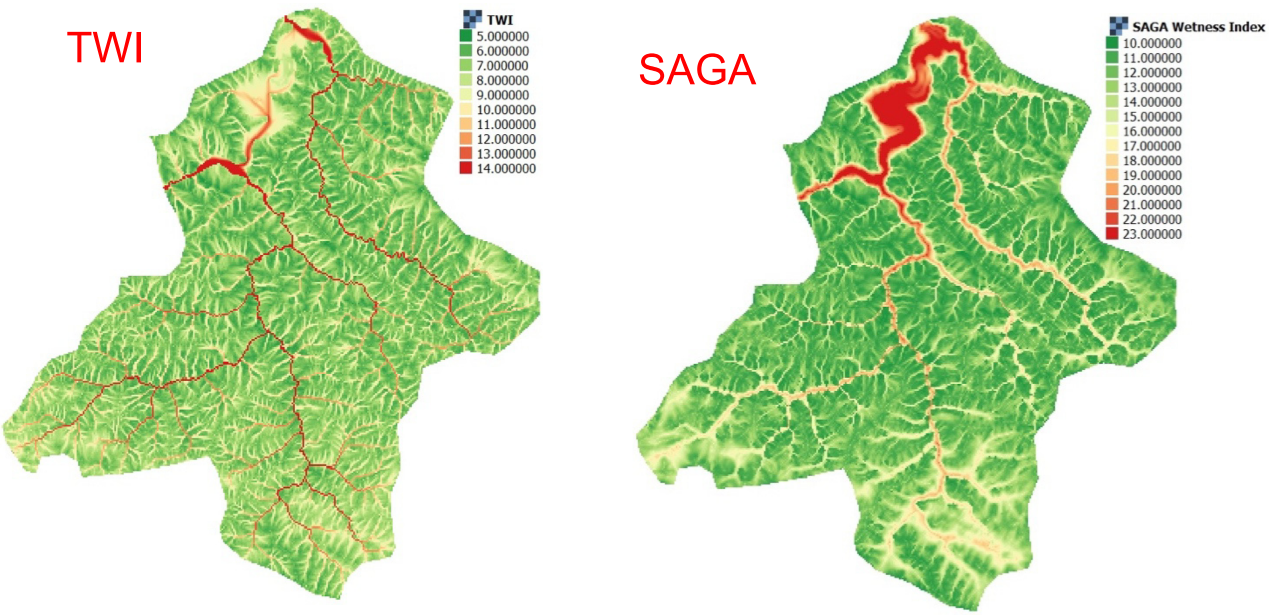


Fig62. The results of regional scale FHA modeling for Derbent basin, Samsun.

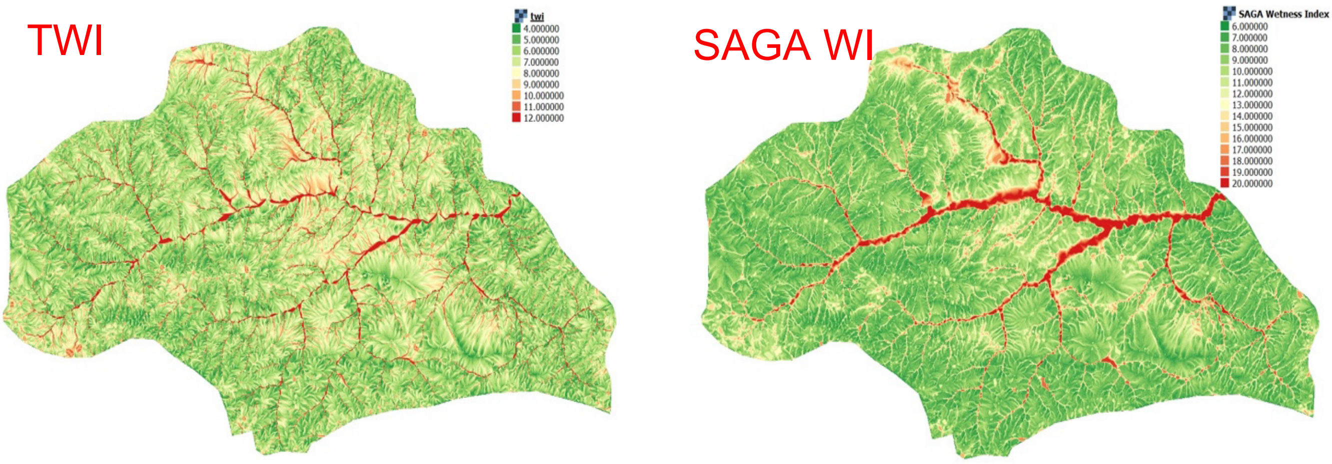


Fig63. The results of regional scale FHA modeling for Kavak basin, Samsun**.**

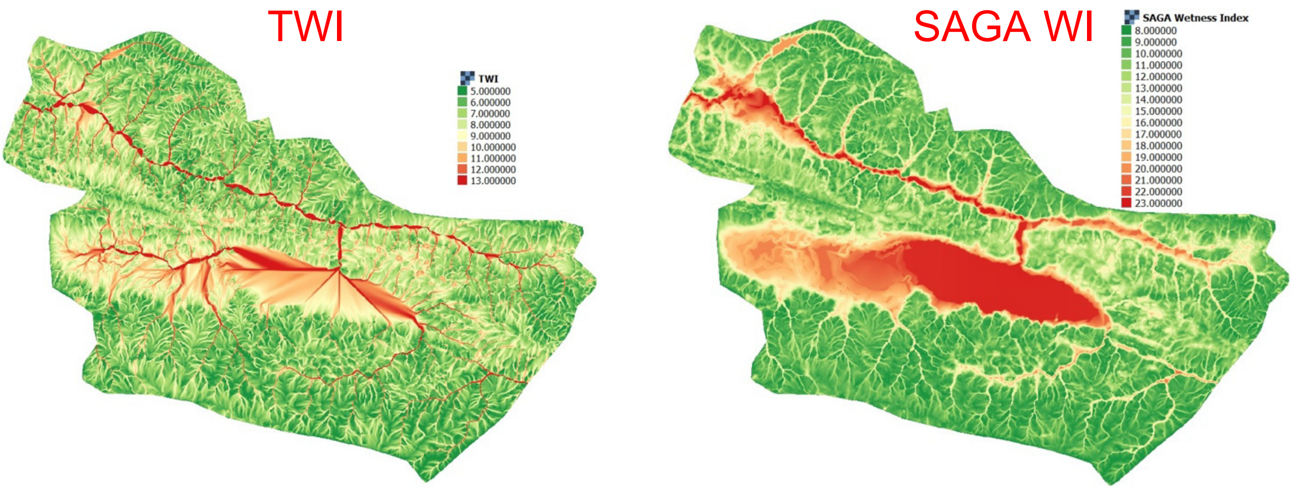


Fig64. The results of regional scale FHA modeling for Ladik basin, Samsun.

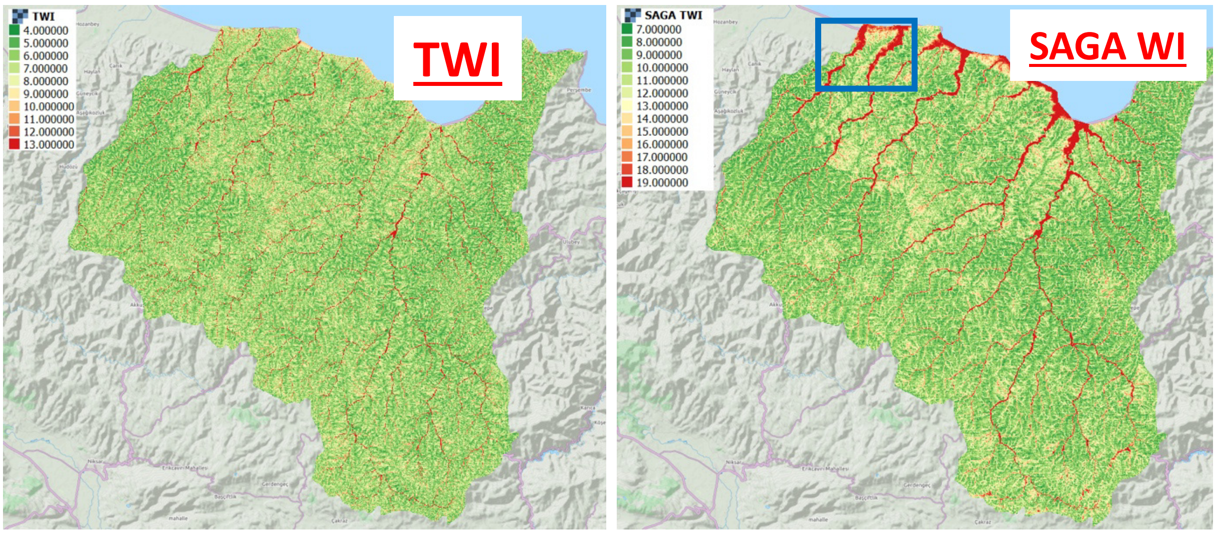


Fig65. The results of regional scale FHA modeling for Ünye-İkizce basin, Samsun.

The area marked by the dark blue rectangle in Figure 65 above is of particular importance since a local scale FHA model will be implemented in this area, as given in the next section.

5.4 LOCAL SCALE FHA IMPLEMENTATION IN AKÇAY, SAMSUN

The area chosen for local scale flood hazard assessment is the Akçay Creek in the Akçay village, which is located in the border of Samsun and Ordu provinces. In the output of the regional scale FHA model, the downstream area of Akçay came out to be a critically flood-prone zone (Figure 65). The close-up view of this location is presented in Figure 66 and 67. In Figure 66, the overlapped output from the regional FHA model can also be seen. The red-colored area is the most susceptible zone in the basin against flooding. Thereby, it is decided to model this region in local scale by means of 1D hydraulic modeling using HEC-RAS software.

Fig66. Close-up view of downstream area of Akçay Creek**.**

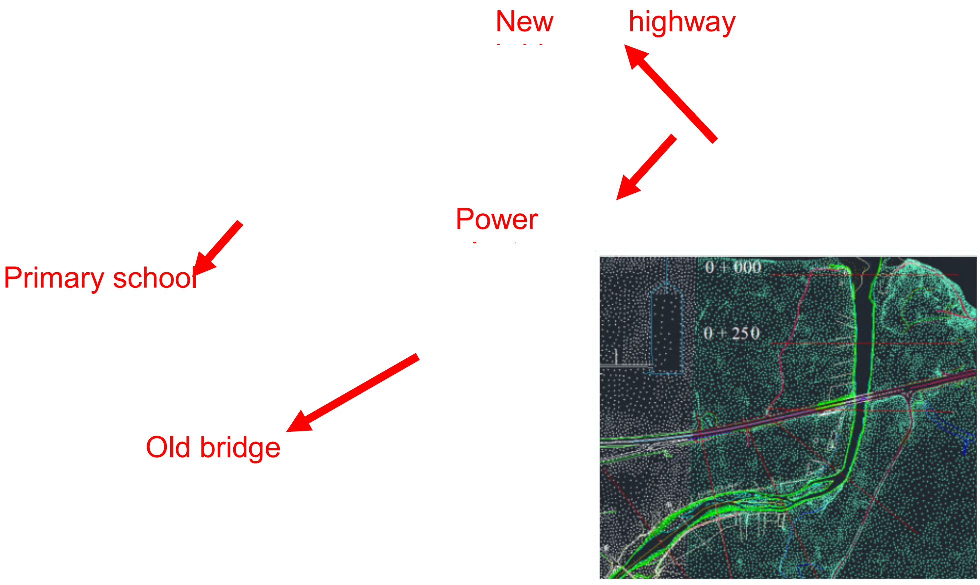


Fig67. The implementation area for local scale FHA modeling.

Akçay creek discharges directly to Black Sea (Figure 67). The downstream region of the creek is generally covered by agricultural area, as well as industrial facilities.

There is an LNG power plant, an ancient bridge and a primary school building in the close vicinity of this zone. The major intercity highway which connects Ordu to Samsun passes across the Akçay Creek with a new bridge (yellow line in Figure 67).

In July 2012, a flood event occurred which inundated this new highway bridge, killing a family in their car (http://www.guncelposta.com/MANSET_HABERLER/11017-Samsunda_ikinci_sel___1_olu_VIDEO.html, Figure 68). The critical structures are shown in Figure 67.

The data that has been used for the local scale flood modeling are:

- Maps of Samsun and Tekirdağ with 1/25000 scale (Turkish Army, General Command of Maps)
- Basin Borders – (Turkish Ministry of Forestry and Water) http://geodata.ormansu.gov.tr
- Samsun Akçay Orthophoto Maps with 1/500 Scale [26]
- In-Situ Topographic Data from Akçay [26]
- 2, 5, 10, 25, 50, 100 and 500 years flood hydrographs of Akçay Creek produced by DSİ method (obtained from State Hydraulic Works).

Fig68. Highway bridge on Akçay Creek was inundated by the flooded waters in July 2012. Implementation area for local scale FHA modeling.

As an inset to Figure 67, the point cloud from the orthophoto maps of 1/500 scale as well as in-situ topographic measurements can be seen.

The flood hydrographs of downstream segment Akçay Creek is plotted in Figure 69, also tabulated in Table 5.4.1.

The hydraulic model has been set and run in the HEC-RAS environment, the characteristics and capabilities of which was explained in the preceding sections. In the model, the peak discharge of the flood hydrograph (shown in red in Table 5.4.1) was entered in the model and the model was run for steady conditions, for in order to be on the "safe" side of the estimation.

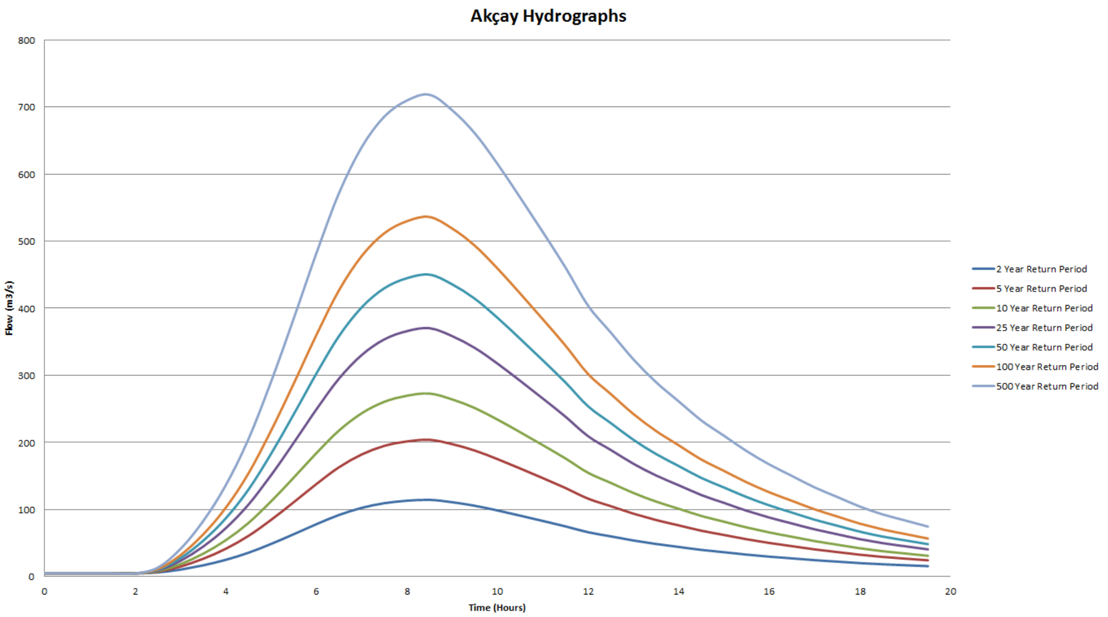


Fig69. The extreme flood hydrographs.

Table 5.4.1 The flood hydrohraphs of downstream segment Akçay Creek [26]

T hour	Q_2 m^3/s	Q_5 m^3/s	Q_{10} m^3/s	Q_{25} m^3/s	Q_{50} m^3/s	Q_{100} m^3/s	Q_{500} m^3/s
0.50	1.32	2.39	3.22	4.39	5.34	6.38	8.56
1.00	5.60	10.16	13.68	18.66	22.73	27.12	36.42
1.50	11.96	21.72	29.24	39.87	48.58	57.96	77.83
2.00	20.19	36.67	49.36	67.32	82.02	97.85	131.40
2.50	30.73	55.81	75.12	102.44	124.81	148.91	199.97
3.00	43.88	79.71	107.28	146.31	178.26	212.67	285.60
3.50	58.37	106.01	142.69	194.59	237.09	282.85	379.85
4.00	73.28	133.10	179.14	244.30	297.66	355.12	476.90
4.50	87.07	158.14	212.85	290.27	353.67	421.94	566.64
5.00	97.57	177.21	238.53	325.29	396.33	472.84	634.98
5.50	104.58	189.96	255.68	348.68	424.84	506.84	680.65

6.00	108.28	196.67	264.71	360.99	439.84	524.74	704.69
6.50	**109.57**	**199.02**	**267.87**	**365.30**	**445.09**	**531.01**	**713.10**
7.00	106.01	192.55	259.17	353.44	430.63	513.76	689.94
7.50	100.73	182.96	246.26	335.83	409.18	488.16	655.57
8.00	93.71	170.21	229.10	312.44	380.67	454.16	609.90
8.50	86.03	156.25	210.31	286.81	349.45	416.91	559.88
9.00	78.13	141.91	191.01	260.49	317.38	378.65	508.50
9.50	70.01	127.16	171.15	233.40	284.38	339.27	455.62
10.00	61.27	111.29	149.79	204.28	248.90	296.94	398.77
10.50	55.13	100.14	134.78	183.81	223.95	267.18	358.81
11.00	48.99	88.99	119.77	163.34	199.01	237.43	318.85
11.50	43.76	79.48	106.97	145.88	177.75	212.06	284.78
12.00	39.37	71.51	96.25	131.26	159.93	190.80	256.23
12.50	35.00	63.57	85.57	116.69	142.18	169.62	227.79
13.00	31.49	57.20	76.99	104.99	127.92	152.62	204.95
13.50	27.98	50.83	68.41	93.29	113.67	135.61	182.12
14.00	24.93	45.28	60.95	83.12	101.27	120.82	162.25
14.50	22.30	40.50	54.51	74.34	90.58	108.06	145.12
15.00	19.68	35.74	48.10	65.60	79.93	95.36	128.05
15.50	17.48	31.76	42.74	58.29	71.02	84.73	113.78
16.00	15.29	27.77	37.38	50.98	62.11	74.10	99.51
16.50	13.51	24.54	33.03	45.04	54.88	65.47	87.93
17.00	12.11	21.99	29.60	40.36	49.18	58.67	78.79
17.50	10.71	19.46	26.19	35.72	43.52	51.92	69.72

Cross sections with 20 m spacing were used to define the flow geometry in HEC-RAS (Figure 70). These cross sections are extracted from the DEM that was generated by use of the point cloud shown in Figure 67, resulted with a grid resolution of 2 m.

Model results are shown in Figures 71-73 for floods with return periods of 2, 5, 10, 25, 50 and 100 years.

As can be seen here, when the peak flood discharge exceeds the 10 years return period extreme value, the creek tends to overflow from its bed. This draws a parallel picture with what happens in reality.

Especially at the last 300m of the creek (i.e. downstream of the highway bridge) the inundation area is considerably high. In the modeling, it was seen that the highway bridge is flooded with return periods higher than 100 years.

The flood event of July 2012 was estimated to correspond to a (roughly) 85 years flood event.

If the storm surge that rises the sea level at the downstream (say, at the order of 0.5-1 m) is added on top of the model results, this observation is in agreement with the model results.

Fig70. Cross sections for local scale FHA modeling in Akçay Creek.

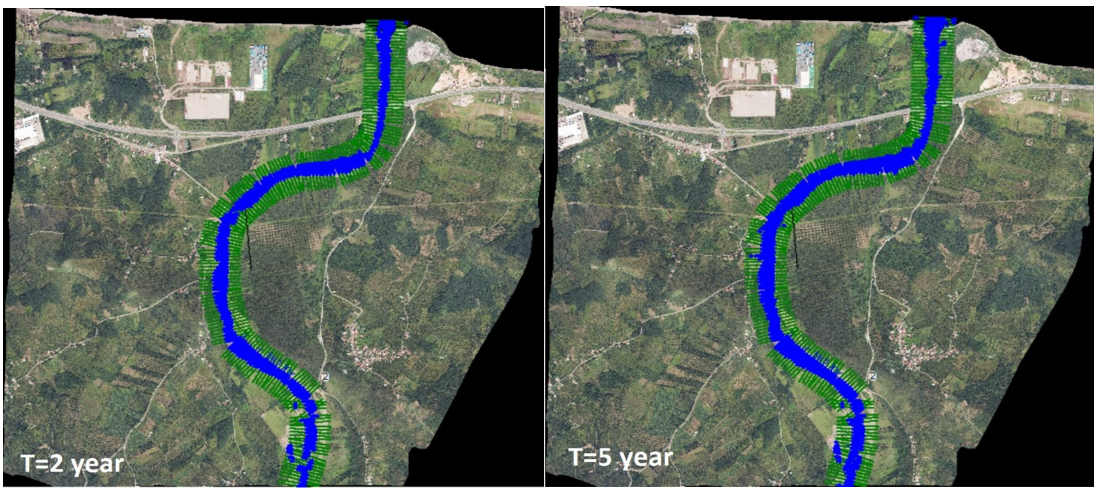


Fig71. Results of local scale FHA modeling for 2 and 5 year return period flood events.

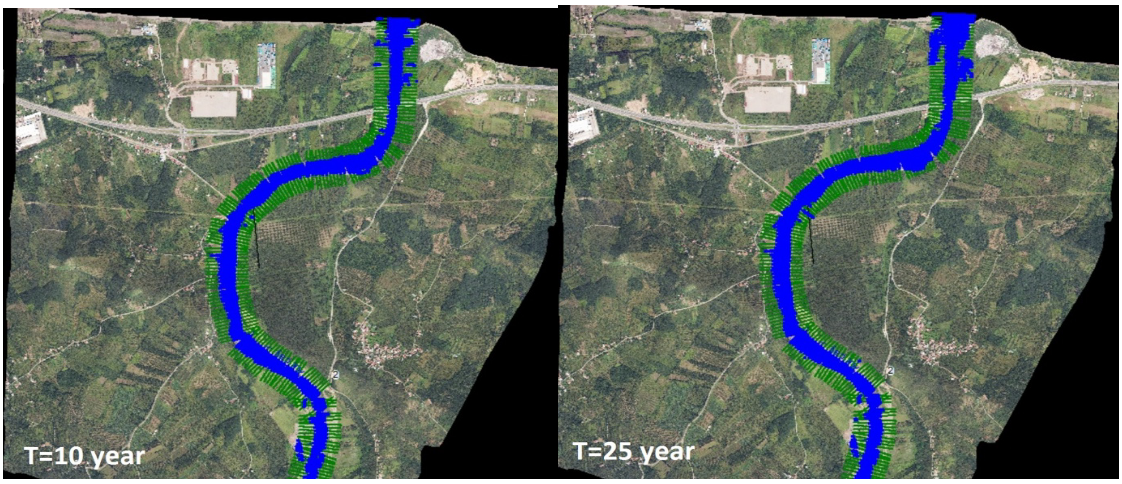


Fig72. Results (flood extend) of local scale FHA modeling for 10 and 25 year return period flood events.

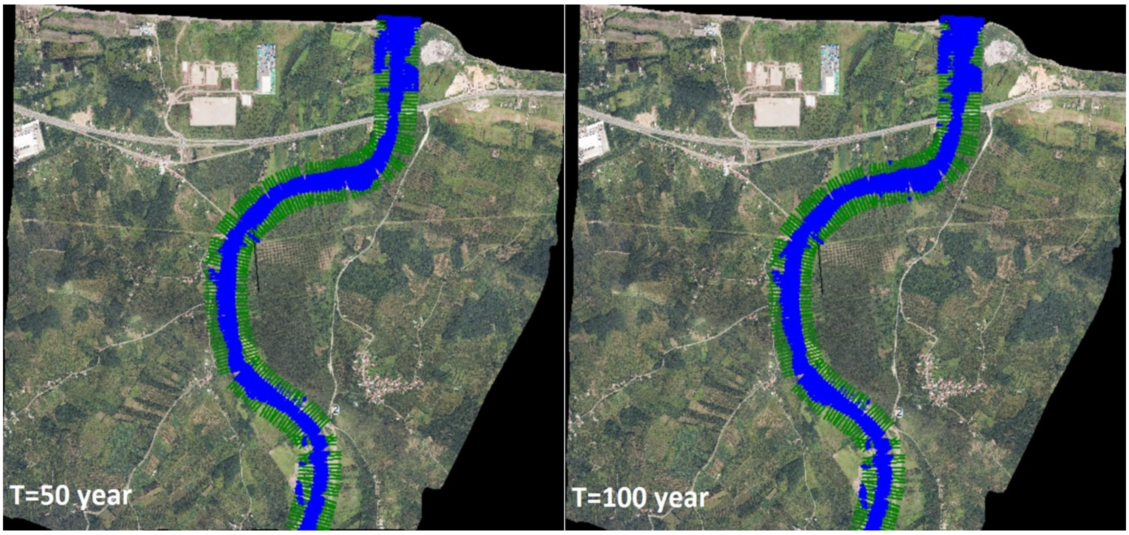


Fig73. Results(flood extend) of local scale FHA modeling for 50 and 100 year return period flood events.

5.5 CONCLUSION OF FHA STUDIES IMPLEMENTED IN TURKEY

The following conclusions can be drawn from the regional scale and local scale FHA modeling studies implemented in Turkey:

- The proposed regional scale FHA methodology is simple, easy and inexpensive (free software and minimum amount of data requirement); yet it is very effective in terms of pinpointing the flood prone locations in the modeled basin (watershed).
- Maps of 1/25000 scale are very convenient for application of this method yielding high resolution results. In this specific regional scale modeling practice, it was seen that an industrial region at the East of Hayrabolu town center (in Tekirdağ province) is prone to flooding. This very region was indeed inundated in February 2015 due to a flash flood event as a result of an intense and short-lasting rainfall. This indicates that the proposed methodology provides accurate and reliable enough outputs to support strategic planning for flood prevention actions on a regional scale. Moreover it helps locate flash flood prone areas in order to plan applied research on a local scale, aiming at designing preventive measures.
- An additional point is that the regional scale FHA model can be operated both with small basins (in size of a few hundred km^2) and relatively large basins (in size of a few thousand km^2). In any case, operating with smaller basins may be more practical since the precision of the results would be presumably higher.
- The local scale FHA model (1D hydraulic model) implemented by using the HEC-RAS model, yielded much more precise results for probable flood inundation areas (as well as flow velocities and water depth) for different return periods of occurrences. Local Scale Flood Hazard assessment outputs fit very well actual events recorded in the area a fact indicative of the reliability and accuracy of the methodology used.
- It was seen that Akçay Creek overflows its bed for return periods larger than 10 years and the event tends to become more catastrophic for events more extreme than 100 years return periods, since the highway bridge is inundated leading to further flooding upstream. In this case it should be noted that any possible sea level rise in Black Sea (i.e. due to storm surge, wind or wave setup) was not accounted for in the flood modeling. Such rises in the sea level are likely to increase the flooded areas due to the downstream-controlled flow regime in the river.
- HEC-RAS outputs can be used to plan effective flood prevention measures.

6 FLOOD HAZARD ASSESSMENT ON REGIONAL AND LOCAL SCALES-IMPLEMENTATION IN ROMANIA

The structure of the present scientific report comprises the following parts.

The introduction includes an overview of the problem which justifies the necessity of flood modeling, objectives of this research and a detailed description of the study area including physical, geomorphological, hydrological, soil conditions and existing land use conditions. Additional information regarding rainfall and runoff data is also presented.

A brief overview of methodologies and procedures used to model floods is presented with an emphasis given to comparing their requirements and their results in terms of reliability and accuracy. A classification of these models is shown as well.

Flood modeling methodologies were applied on **regional scales (1:25000)** in Taita river watershed (Dobrogea Region-Romania) and on **local scales (1:2500)** in a test area in Voinesti, catchment located in the Dambovita watershed (a primary tributary of the Danube, Romania). In particular, ANSWERS and TOPOG as physical-based distributed hydrological models, geomorphological models, unit hydrograph under MIKE, and HEC-RAS models were used. The pilot implementation of mapping flood prone areas will additionally provide information about the flood hazard in this area and can support decisions regarding the necessary preventive measures.

There are also some comments made regarding a few particularities of the functioning pattern of each model.

The report concludes with the recommendations concerning the usability and effectiveness of flood modeling and proposals for future research.

6.1 INTRODUCTION

6.1.1 Research context

Floods in Europe and especially flash floods in all the Mediterranean countries pose a serious threat to human life, property and infrastructure and block sustainable development. The problem has been recognized by the EU which has funded numerous research projects, has established bodies and Organizations and has issued the 2007/60 "Flood" Directive.

Reports of relevant European organizations as EEA (2012), show that global warming has led to an increase in the hydrological cycle and consequently, to the occurrence and frequency of extreme events in large parts of Europe. Temperature has risen by approximately one degree over the last century, higher than the global average. And as a result, evaporation has increased too. The effect is a change in atmospheric circulation. For this reason, annual precipitation has been generally increasing across most of northern Europe countries, most notably in winter, but decreasing in parts of southern Europe. At the same time, a serious increase in the aggressiveness of the rainfall has been recorded. There are cases in which, in a few hours, rainfall exceeded the monthly rainfall, leading to flood events, especially flash flood events. All over the world have been reported damages caused by flooding. According OFDA/CRED international data bases, during the last period (2000-2007), the number of floods has increased reaching almost 200 events in 2007. For the period 1998-2010 the most affected European countries in terms of economic damages were Germany and Italy. The flood damage costs for Germany only, during 2002, reached 11,600,000bn US$. Disaster statistics and additional data related to damages produced by natural disasters during the period 1980-2010 both for Romania and other European Countries, are given in the Prevention Web project's Web Site (http://www.preventionweb.net/english/). According to Prevention Web, during the studied period more than 50% of the disasters recorded were floods. Moreover, the greater losses in economic terms are also due to flooding (3,536,618x1000US$). Flood and storm disaster are those that affect a large number of people. During the aforementioned period, 96, 4% of the population was affected by floods and storm. Fatalities caused by floods cover around 50% of the total losses in life. Flood hazard maps are among the principal components of a watershed management plan. These maps offer information about the flood parameters and can be used to inform the public and to support the local authorities in order to take effective flood disaster prevention measures.

6.1.2 Research objective

Scope of this paper is to investigate the potential of easily adaptable and applicable methodologies to locate flood prone areas by combining them with widely accepted hydraulic models. In this way, preliminary data indicating flood prone areas will guide research to focus on certain areas thus minimizing the time and the cost of implementation since hydraulic models require a lot of highly detailed data, difficult or even expensive to acquire.

Effective Flood Disaster Mitigation requires Flood Hazard and Risk assessment and additionally the implementation of applied research on a local scale basis in the high risk areas, in order to support decisions regarding the required preventive measures.

Flood hazard maps are among the principal components of a watershed management plan. These maps offer information about the flood parameters and can be used to inform the public and to support the local authorities in order to take effective flood disaster prevention measures.

As has already been mentioned, there's a variety of different methodological approaches used to locate flood prone areas and to assess flood hazard with various data requirements and cost of implementation; each of them providing a range of results with different levels of reliability and accuracy.

Flood hazard maps provide information about the area affected by floods in terms of the probability and magnitude of a potential flood event. According to the Flood Directive (2007/60/EC), flood hazard assessment must be evaluated for three different hazard levels: frequent events (10 years Return Period), medium probability events (100 years Return Period) and extreme events (1000 years Return Period). For each scenario, the hazard map must provide the following results: flood extent, water surface depth/level, and water velocity if it is relevant.

In this context, research presented here helps to improve the knowledge on flood modeling. In this respect, the overall objective is to identify the proper methodology to floodplain modeling. To achieve the objective purposed in this chapter, the following specific objectives are proposed:

- The basic principles underlying the most commonly used model are reviewed in order to investigate the ability to incorporate flood modeling techniques into a GIS for generating flood hazard maps
- Basic criteria for the model evaluation are set.
- A pilot implementation of all selected models is carried out in the same river basin in order to provide comparable results.
- The results of the application of the different types of models used are compared.

6.2 OVERVIEW ON THE FLOOD MAPPING METHODOLOGY

Regardless of the methods used, the mapping of flood hazard can be achieved using all of or some the following procedures:

- Mapping the occurred historical events. This step is very important both in the identification of flood prone areas and in the calibration stage. Areas where floods have occurred repeatedly in the past pose a High flood Hazard and potential risk by future floods. Moreover, the location of past events can be used to calibrate methodologies used to assess flood hazard and to delineate flood prone areas. Advances in the use of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies, provide valuable tools to evaluate and use this kind of information.
- Estimate discharge for different return periods.
    - Data from gauging stations must exist to apply statistical analysis. The flood frequency analysis can be used to fit the best probability distribution. Computer programs for performing the analyses are

available from the U.S. Army Corps of Engineers (USACE) HEC-FFA Frequency Analysis [27] and the USGS PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines [28]. Guidance on frequency analysis can also be found in USACE Engineering Manual No.1110-2-1415 [27] or [29],

  - If the watershed is ungauged, other available data (rainfall, topographic, etc.) can be used with the regional model ([30], [31], [32]; [33]; [34]; [35]; [36]; [37]; [38]); with the index-flood relation ([39], [40], [41]) and with the area-altitude relation [42],

- Obtain discharge data using hydrological models. There are a couple of hydrological models which can be used to estimate discharge data and these include: i) the empirical model which consists of the rational model [43] and the unit hydrograph [44] and ii) the watershed model may be included; this model can be classified according to the type of simulation into two categories: single or continuous event. There is software available to apply the empirical model, provided by various sources including the U.S. Department of Agriculture, the US Natural Resources Conservation Service. HEC-HMS [45], SWMM [46] and MIKE 11 [47], [48]. The most widely applied hydrological models in Europe are the HBV- Hydrologiska Byråns Vattenbalansavdelningi - [49] proposed by Swedish Meteorological and Hydrologic Institute (SHMI) and used in 40 countries, the LISFLOOD [50], [51] and the TOPKAPI model [52]; [53].
- Use 1D or 2D hydrodynamic models in order to calculate the flood parameters, once the discharge for a return period is obtained. These models provide the water surface which is assessed by using each of: (i) normal-depth calculations using Manning's Equation (ii) highway culvert nomographs from Hydraulic Design of Highway Culverts [54]; there is a wide range of tools for this modeling. To be mentioned: Mike11 ([47], [48], [55]), Telemac [56], HEC-RAS [57].
- Delineation of the inundation (flooded) area by combining the flood parameters (water level) with Digital Elevation Models (DEM). FEMA recommended (2002) the implementation of a GIS tool to create cross-sections and insert data regarding structures which can block the free water flow during a flood event, for the HEC-RAS program in order to perform water surface elevation.

6.3 PILOT IMPLEMENTATION IN VOINESTI AND TAITA RIVERS

In order to assess flood hazard, a two-step procedure is proposed in order to save time, effort and money. The first step aims at locating flood prone areas where a detailed investigation using hydraulic models and requiring more time, effort and highly detailed data is required. This step will follow but assessment and requirements will be applied in certain limited areas located in the first step of the procedure.

In broad terms, the methodology proposed in this paper is described in Figure 1. If the basin is gauged, then a procedure based on frequency analysis and hydraulic models is proposed, in order to delineate the flood prone areas. If the basin is ungauged, a methodology based on geomorphological models is proposed.

The requirements to apply the hydraulic model (Fig. 74) include:

i. discharge estimation for different return periods;

ii. Application of 1D or 2D hydrodynamic models in order to obtain the parameters of flood.

The data needed include:

i. the maximum discharge time data series (to perform frequency analysis and obtain the maximum discharge for different return period);

ii. detailed topographic data;

iii. vegetation data (to obtain the roughness coefficient)

The hydraulic model software selected in the present study is the freeware HEC-RAS [58]. The preparation of the data input was carried out with HEC-GeoRAS. It must be pointed out that the use of HEC-GeoRAS reduces the time needed to input data in the HEC-RAS software and to perform the analysis but it's use is not compulsory; open source GIS software can be used to prepare the necessary data (ie. river bed cross sections, location of structures etc.) and then input the data manually into HEC-RAS in order to perform the analysis.

As already mentioned, HEC-RAS is a one-dimensional, water surface profiling application developed by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Centre.

In order to apply the proposed methodology, the following steps must be completed:

1. Data collection and development of digital spatial database of the hydrologic system in ArcGIS;
2. Generation of a Digital Elevation Model for the entire basin (raster and TIN). The TIN is going to be used as the Digital Elevation Model required in the

GeoRAS environment in order to prepare data sets required as input to the HEC-RAS simulation;

3. Hydraulic modeling: determination of flood peak discharge;
4. Flood plain analysis: It consists of three steps: (a) HEC-GeoRAS processing to generate HEC-RAS import files, (b) HEC-RAS application, (c) Post-processing of HEC-RAS results and flood plain mapping in ArcGIS.

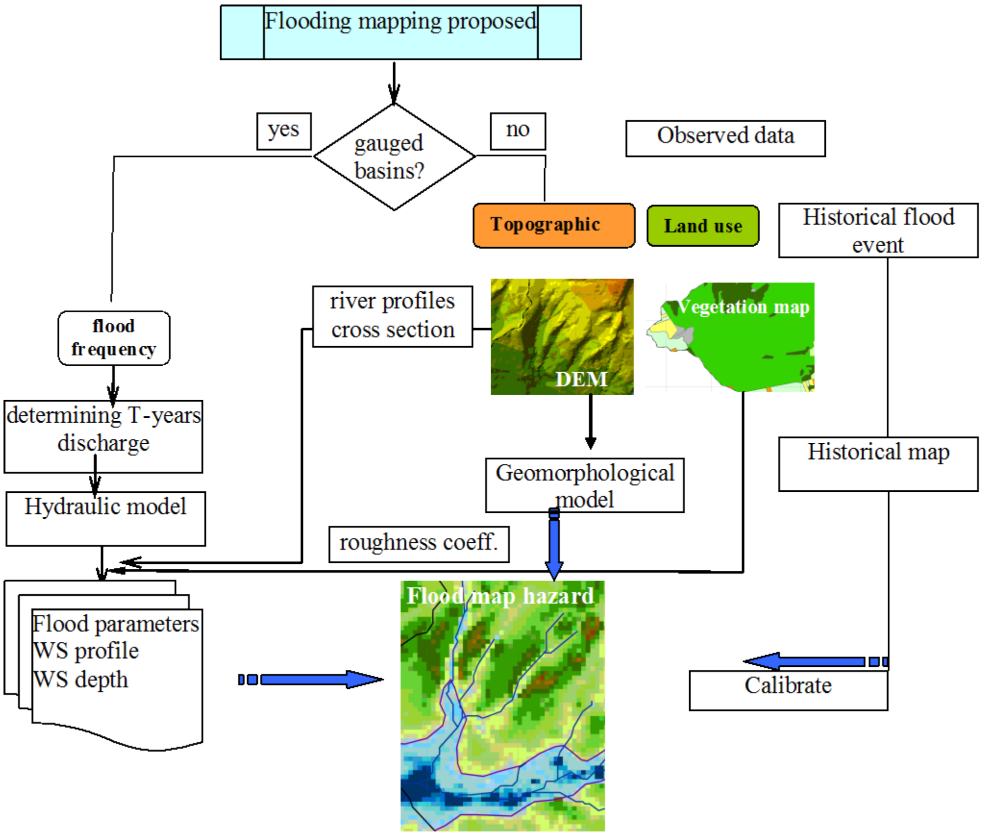


Fig74. Methodology proposed to delineate flood prone area

As far as the ungauged basins are concerned, the concept of topography controlling the hydrological process has been taken into consideration.

Beven and Kirby have suggested the Topographic Wetness Index (TWI) within TOPMODEL as a tool to predict quick response flow. It is defined as $TWI = ln [(A_e)/(tan\beta)]$ [1], where A_e represents the effective upslope contributing area per unit contour length (m^2/m) and β is local slope angle (in degrees). This index actually provides information about the spatial distribution of soil water content. In order to better evaluate the contributing area, some modifications were made. The SAGA Wetness Index [5] is a similar index as TWI, but this model is based on a modified procedure to evaluate the watershed area. Although the Topographic Wetness Index was proposed to predict quick response flow by using morphometric parameters ([1]; [3]; [4]), it has been used since then to delineate flood prone areas ([7]; [8]; [9]; [59]; [10]; [12]).

These two models were selected to obtain the extension of flood area. The most interesting part in applying those models is the fact that they have suggested to provide an accurate enough delineation of flood prone areas using only topographical data which are readily available. Moreover the use of open source software which provides extended functionality regarding the respective parameters minimizes the cost of implementation. Quantum GIS open source GIS software, which incorporates the SAGA GIS software, built in algorithms was used for the implementation. A model of the procedure followed in QGIS is shown in fig. 75.

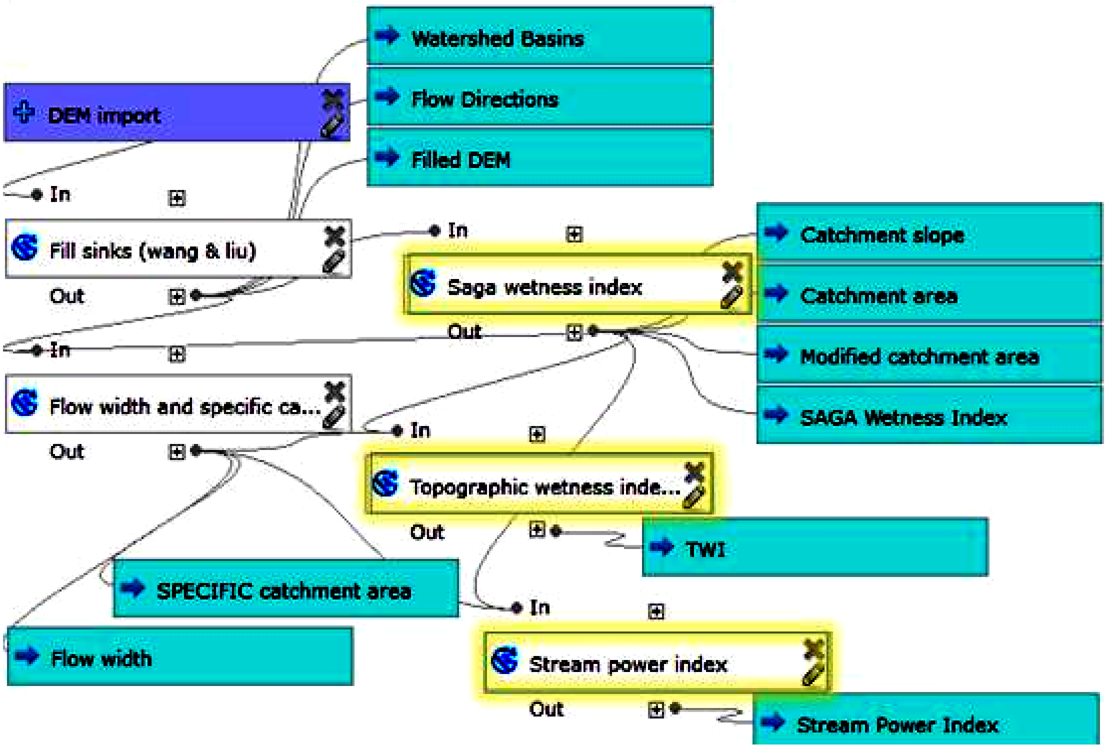


Fig75. Methodology proposed to delineate flood prone area with geomorphological model

6.4 MODEL IMPLEMENTATION AND RESULTS

6.4.1 Flood Hazard Assessment-FHA on regional scales (1:25000)

6.4.1.1 Study area and data

Dobrogea region is situated between lower Danube and the Black Sea (Figure 76).

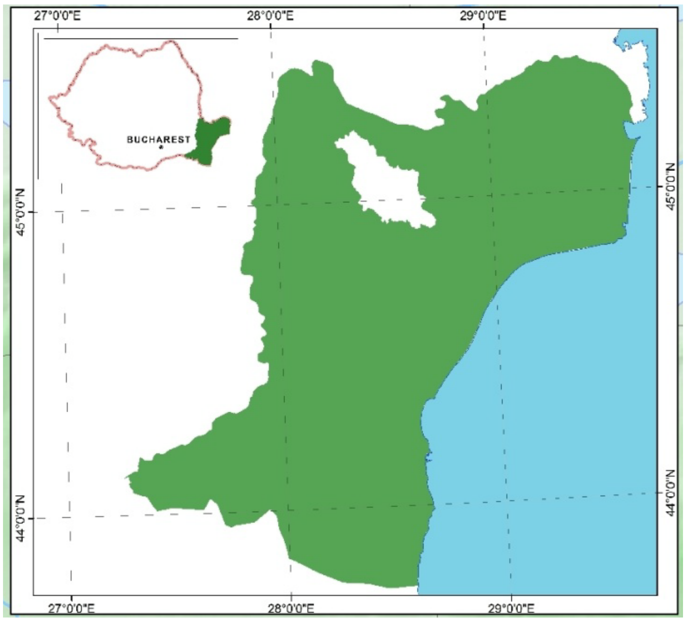


Fig76. Dobrogea region

From the geo-morphological point of view, Dobrogea contains four morpho-structural units: the Danube alluvial and deltaic plain, the mountainous – hilly Hercynian-Kimeric unit of the Northern Dobrogea, the green schist Casimcea plateau or the Central Dobrogea, the plateau with Sarmatian structure or the Southern Dobrogea.

Dobrogea's climate is temperate - continental and is divided in 2 units [60]: (I) the Eastern units which contains the Danube Delta, its south, two lagoons (Razim lake and Sinoe lake); whose extension varies from 20 to 50km to the littoral, depending on the warm/ cold season.

The climate of this unit is continental, influenced during the cold period of the year, by the Black Sea. The temperature remains positive up to an altitude of 100m during the whole year.

During the warm season, the climate is affected by sea breeze, (II) The Western units, which contain the rest of territory where thermal inversion regime is emphasized only on the low lands and where the climate is temperate continental.

The following observations are concluded from the analysis of temperature and precipitation time series data (Fig 77 and 78):

- As far as Temperature is concerned:
    - The multi-annual mean temperatures vary in small limits (10-12^{0}C approximately),
    - The highest temperature values are being recorded on the littoral area.
    - The smallest temperature was registered at Corugea – on the centre (9.9^{0}C at 219.2m), and the biggest at Constanta (11.7^{0}C at 12.8m) and Mangalia (11.6^{0}C at 6.0m) – on the coast, Tulcea and Sulina on the Danube Delta, respectively at Cernavoda (11.1^{0}C at 87.17m), on the Danube part (Fig. 77).
    - The temperature decreases from the coast towards the interior and from the Danube (seat on the West side of the region) towards the interior.
- As far as Precipitation is concerned:
    - The multi-annual mean precipitation varies between wide limits (260–500mm approximately), the highest values being registered in the North and center of the region.
    - The precipitation values increase with the altitude. The lowest precipitation was registered at Sulina (262 mm at elevation of +2m), Constanţa (423 mm at 12 m) and Mangalia (427 mm at 6 m) – on the coast, respectively at Harşova (408 mm at 37.31m), on the Danube, and the largest at Tulcea (462 mm at the North).

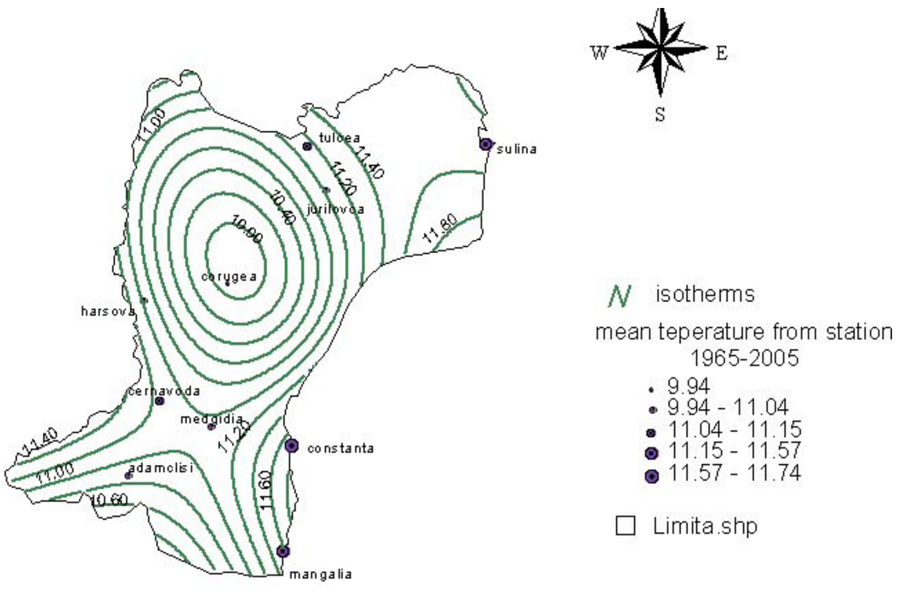


Fig77. Multi-annual mean temperature, [61]; [62]

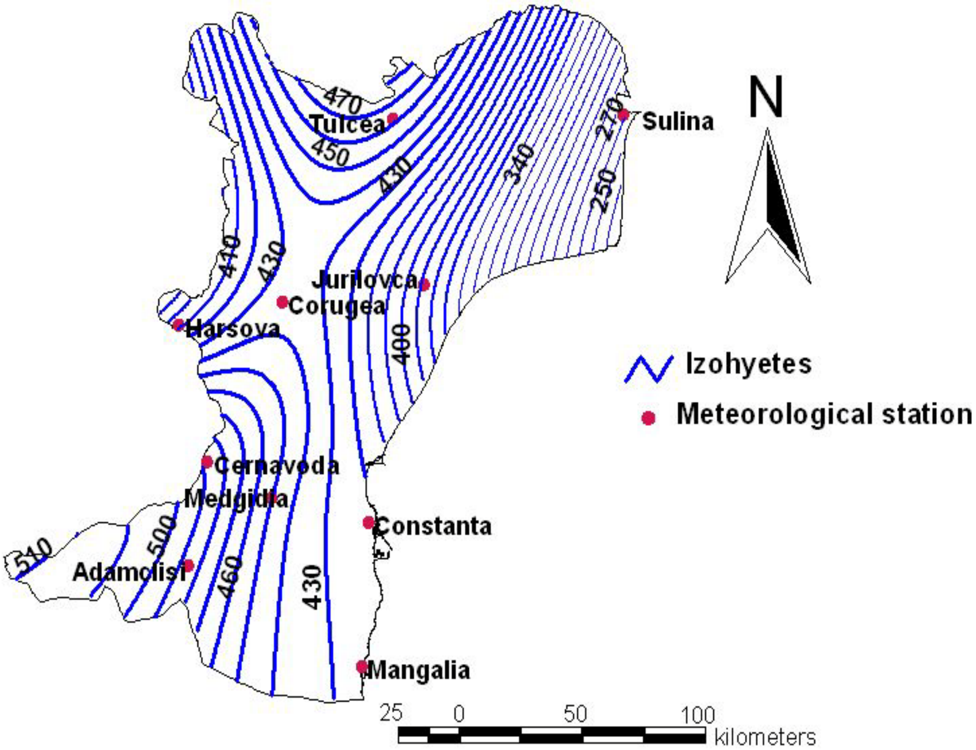


Fig77. Multi-annual mean precipitation, [61]; [62]

Dobrogea hydrographic area is not very extended; it consists of several rivers and lakes situated on the littoral and on the Danube River banks. Average annual discharge of rivers is about 145 mil.mc/year (4.59 m/s), which shows that Dobrogea is a poor region in surface water resources.

From the hydrological point of view, Dobrogea area is divided into two basins: one tributary to the Danube and other tributary to Black Sea basin (Fig. 78). Dobrogea's particular weather conditions cause max discharges being generated by the stream to appear during spring and summer (it rains for short periods with a high intensity).

The highest discharges in Dobrogea were registered on Casimcea River (Casian station, 442 m3/s, in September 1968), Teliţa River (64 m^3/s, in July 1975) and Taiţa River (Satu Nou station, 56,6 m^3/s, in March 1985), Topolog River(192 m^3/s, in October 1981), Hamangia River (Baia station, 221mc/s in November 1976).

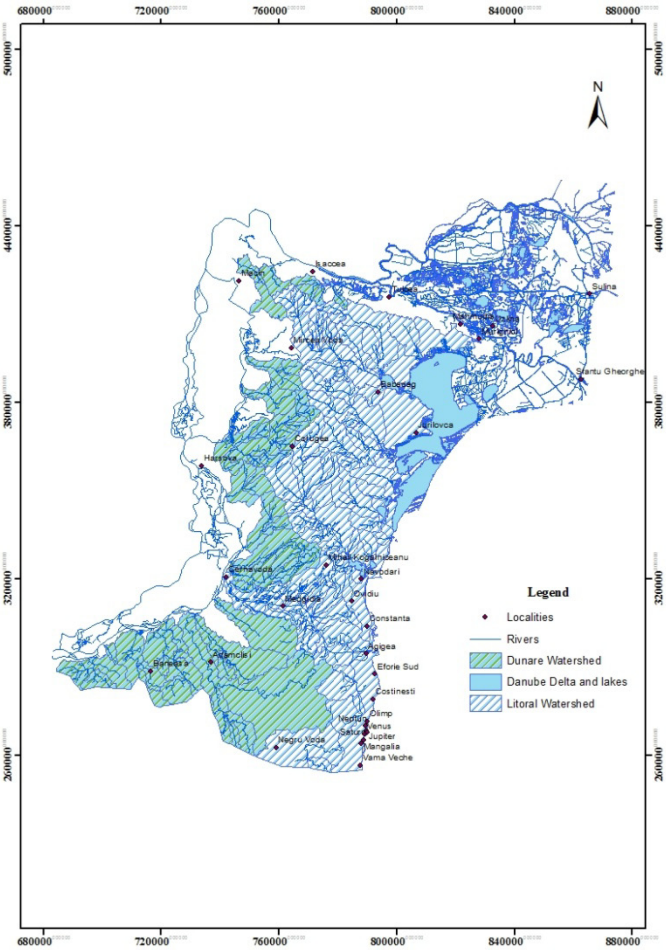


Fig78. The Dobrogea watersheds

During an extreme event which occurred on 28 August 2004, the amount of rainfall registered exceeded 300 mm over Casimcea plateau and 200 mm over the Eforie Sud town. A couple of days after that event (28 to 30 of August 2004) there has been extensive flooding in the hydrographic basin Casimcea (discharging in Tasaul lake) which caused heavy damage in the area. The water amount registered was 312 mm at Pantelimonu de Jos station and of 87 mm at Cheia station.

The flood registered at the hydrographic basin of Casimcea river, has resulted from the concourse of flood waters coming from the affluents Cartal and Râmnic. Records show that the maximum discharge registered on Râmnic tributary was on August the 28th 2004 at 17:00 hours, 50,0 mc/s. The maximum discharge registered on Cartal tributary was on August the 28th 2004 at 18:00 hours 102 mc/s. At 20:30 hours at Cheia station, the maximum discharge of 287 mc/s on Casimcea River was recorded. It should be noted that the mean annual discharge values in the respective gauging stations are: on Cartal tributary - 0,130 mc/s, on Râmnic tributary - 0,080 mc/s and on Casimcea tributary - 0,640 mc/s.

Another flood event has been recorded at Costineşti on 22-23 of September 2005. The flood spread in ascent on the ER from Biruinta village, where over 300 mm of rainfall were recorded during 24 hours.

During the same period, flooding had occured in another location, at Biruinţa station on the Valea Urlichioi course. It seems that the intensive rainfall of over 200 mm in 24 hours has led to the increase of Lake Techirghiol level.

Floods have also occurred in Tulcea during September 2013 after an amount of rainfall over 140mm. The most important flood events in the wider Dobrogea area, are presented in table 6.4.1.

Table 6.4.1 the most important flood events in the Dobrogea area.

No	Town, village	Date	Characteristics	Damages
1.	Garlița	1963;1971	-	30 household teared down and animals taken away by the floods
2.	Casian	24.09.1968	442mc/s*	Households and crops destroyed, human lives lost
3.	Lumina	1967	-	Flooded households and destroyed
4.	Runcu	11.06.1985	h apa=1.60 m	Households destroyed and 5 deaths
5.	Baia	16.07.1967	-	Households and gardens flooded
6.	Constanța	01.07.1992;28, 29.08.2004	rainfall >200 mm/12 h	Households flooded in the Western area , 3 deaths
7.	Nuntaşi/Nuntasi	01-11.09.1999	32.mc/s (fig.)	Households and gardens flooded, 1 death
8.	Cheia	02.-04.09.1999	-	Households and gardens flooded, school
9.	Costineşti	22-23.09.2005	Flood coming from upstream, at Biruinta registeredt>300mm/24 h	Damages to the railway, access roads, restaurants, households in Schitu
10.	Casimcea/Casimcea Cheia/Casimcea	30 - 31 V 2002 8 - 9 VIII 2002	398mc/s* 384mc/s*	Households and gardens flooded, access bridge damaged

11	Cuza Voda/Agi Cabul	2 - 4 IX 1999	57,8 *	
12	Negureni, Valea Marea	2-7 IX 1999	26,8 *	
13	Albesti	30 - 31 V 2000	153 mc/s*	
14	Sacele, raul Valea Sacele	8 - 9 VIII 2002	45mc/s*	
15	Saraiu, raul Topolog	2 - 20 VII 2005	214 mc/s*	
16	Biruinta,/ Valea Biruinta	20 - 25 IX 2005	131 mc/s*	
17	Urluia/V.Urluia	14-19 VI 1992	10.6mc/s*	

The Taita catchment covers 591 km^2 and is located in the North of the Dobrogea region. It's characterized by an asymmetrical shape, with a higher development on the left side. Maximum elevation is 261m.

An ASTER DEM (**resolution 30x30m**) was used in order to generate the Digital Elevation Model which has been used for the processing that followed.

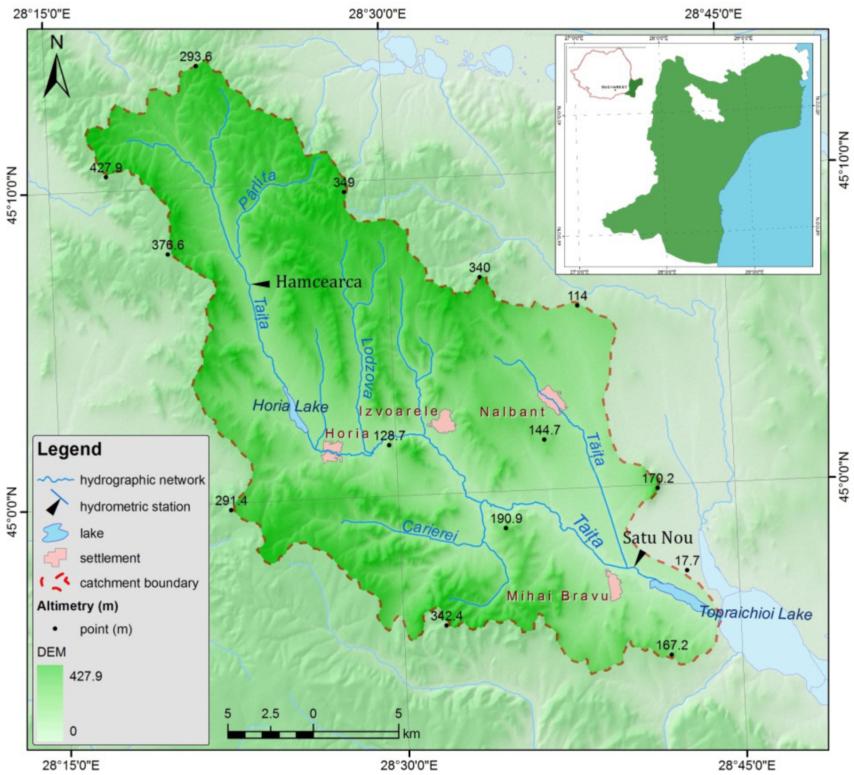


Fig79. Taita catchment

Taiţa river springs are located at the Northern area of Niculitel hills (altitude of 240 m) and discharges into Babadag Lake, draining first Toprachioi bog.

From a geomorphological point of view, Taita basin is part of the North Dobrogea Plateau.

Climate in the region is moderate continental belt: mean annual temperature is about 11°C and the precipitation of 400 mm. Precipitations are one of the main sources of supply of this river – 74%, compared to the underground supply – 24%.

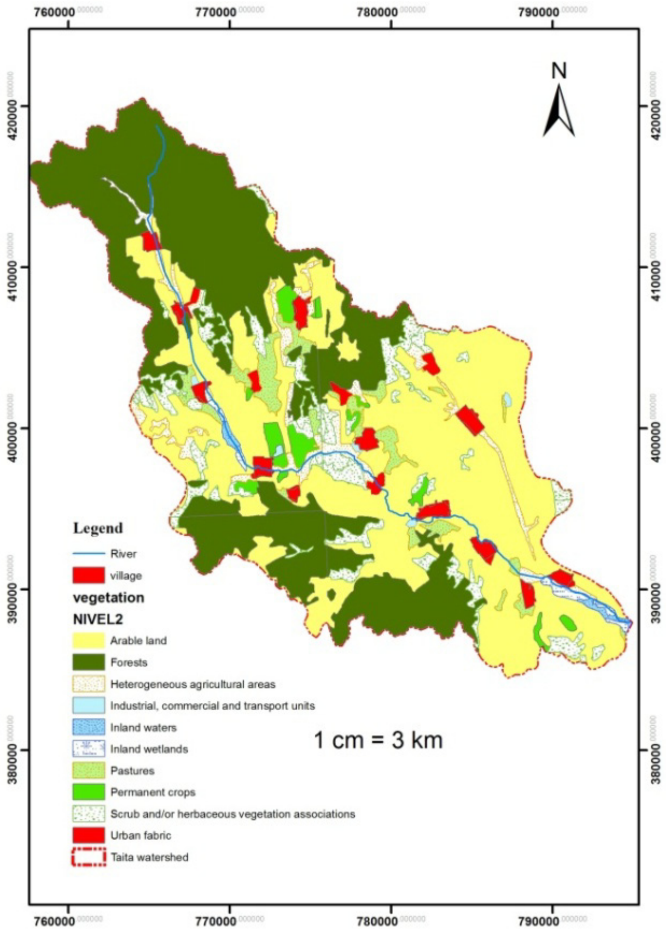


Fig80. Vegetation map for Taita catchement

Almost 33% of the Taita catchment is forested while in the lowlands, agriculture is the dominant land use (Fig. 80). Urbanized areas in the basin are largely concentrated in or around the population centers Horia, Nalbant, Izvoarele and Mihai Bravu (Fig. 80).

The Manning roughness coefficient for the area was calculated according to the vegetation map: forest - 0.15; arable land - 0.035; pasture - 0.03; wetlands- 0.04. The series of annual maximum stream flow, covering the period 1968 (1965)-2010 have been used to assess various stream flow parameters.

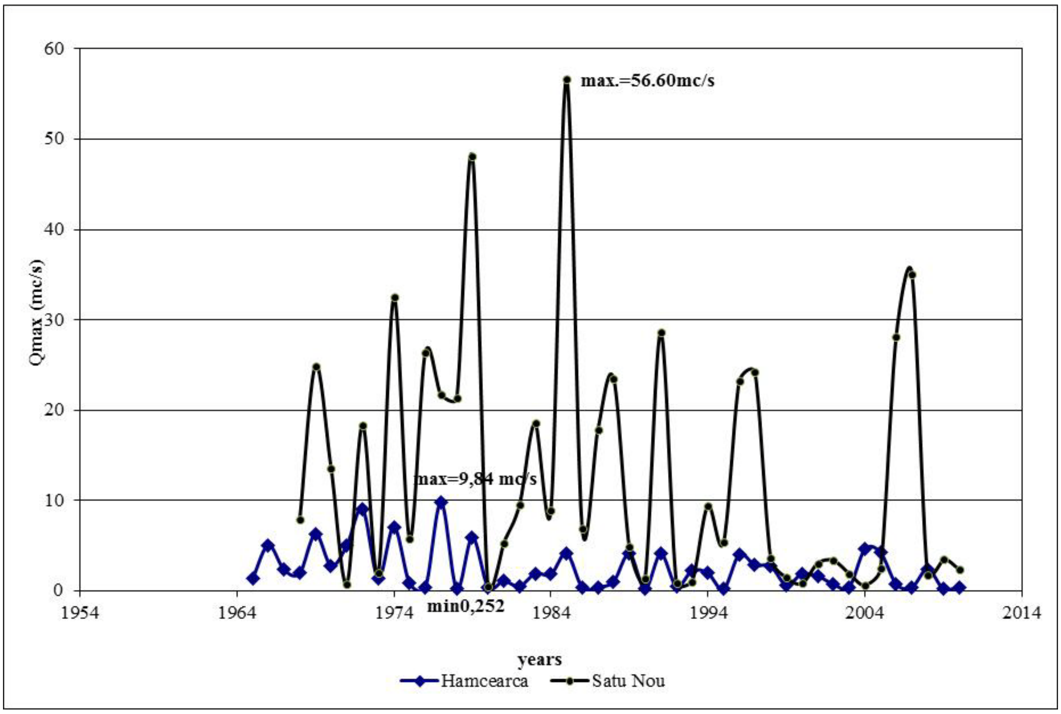


Fig81. Variation of maximum discharge at gauge stations for the study period

The hydrometric data are collected in two gauge stations: Hamcearca and Satu Nou (Fig. 81). Pearson III distribution function was selected to calculate the maximum discharge with different return periods. For Satu Nou gauge station, the values are:

- frequent event (low probability -10 and 50 return period) - 30mc/s, respectively 50mc/s;
- medium event (medium probability - 100 years) - 74 mc/s;
- extreme event (high probability - 1000 years) - 192 mc/s.

As it was mentioned in the previous paragraphs, an important flood event had occurred in 1985 (3-5 March) on Taita river (Fig. 82). The maximum discharge was 56.6 mc/s. At the Satu Nou gauge station, the water level increased by 2.50m during this event. The discharge value registered on 3-5March 1985 corresponds to a flood return period of 50 years.

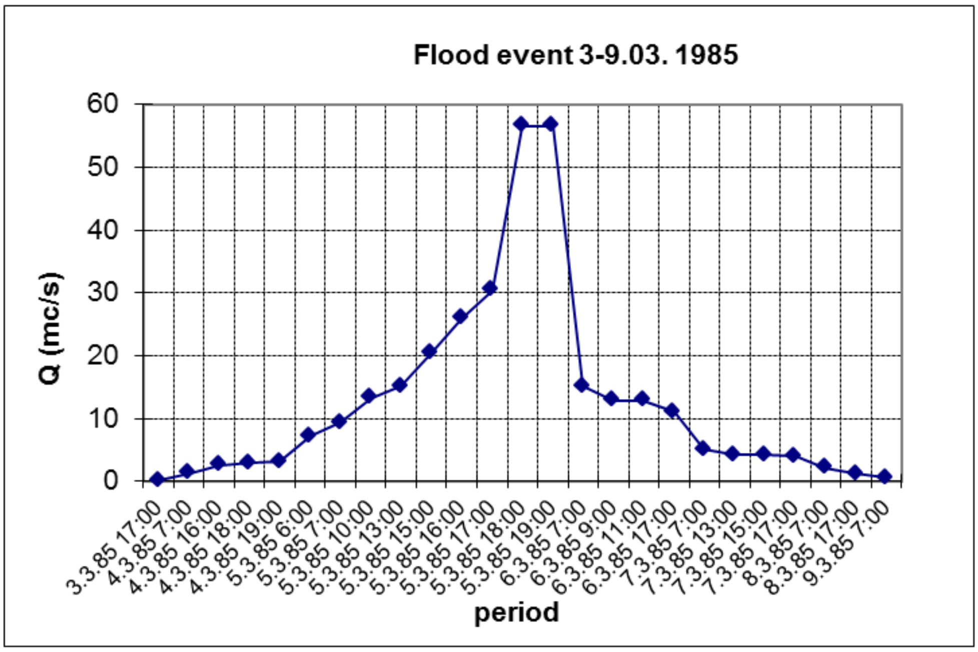


Fig82. Flood event in Taita river, Dobrogea, Romania (March 1985)

6.4.1.2 Geomorphologic and Hydraulic Model model implementation and results

A two-step approach was selected to assess flood hazard in Taita River. Geomorphological models TWI and SAGA were used in the first step in order to locate flood prone areas using readily available topographic data and the ASTER Digital Elevation Model (DEM).

Results of this process were compared to results produced by the use of the Hydraulic Model HEC-RAS which has also been applied in order to assess the flood parameters: the inundation (flooded) area for each of the scenarios created for 50, 100 and 50 and 1000 return period.

Under steady flow, the upstream boundary condition used is the discharge and downstream boundary condition used is "normal depth". Water surface profiles were computed from one cross section to the next by solving the energy equation. The normal depth option requires an energy slope to be entered by the user and the program back-calculates a starting water surface elevation using Manning's equation. The results (the flooding extension) for 50 and 1000 return period are presented in the following figures. For both scenarios presented in these figures, the villages situated in the lowland (e.g. Satu Nou) are flooded.

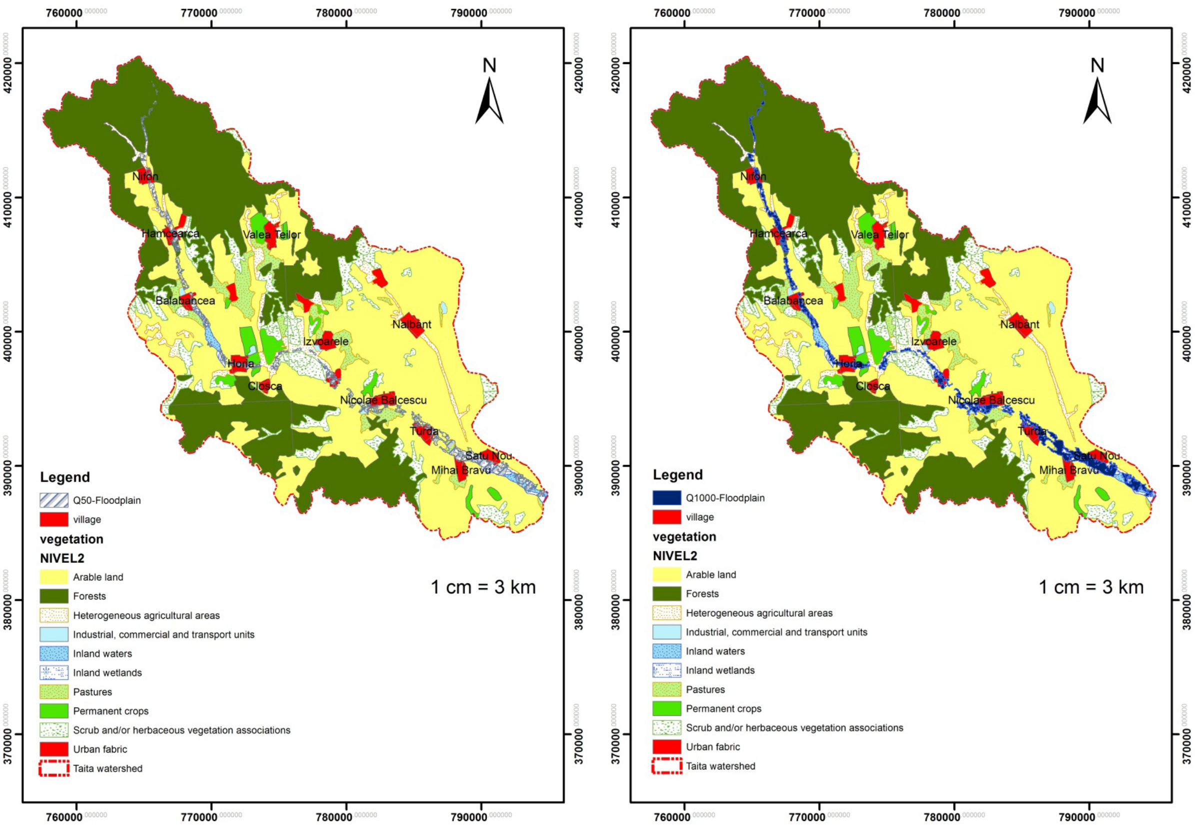


Fig83. Results of flood delineation

The water level in the same location (Satu Nou gauge station) increase only with 1.04m for the discharge corresponding to 50 years return period. The difference between the water level modeled (+1.04) and measured (+2.50) can be either due to the way the water level was measured – if it was measured after the trace (backwater) on the banks; and of course can be due to the resolution of the DEM which does not allow an accurate determination of the bank river location.

It must be noted though that the cost of implementation, including acquiring the necessary data is in many cases a restrictive factor for the implementation of various methodologies. In this case the use of the ASTER DEM provided the only possible source of accurate enough topographic data for implementing the methodologies on a regional scale.

The flood prone areas as delineated by the use of TWI and SAGA (SWI) wetness indices, is presented in figure 84. By comparing the results obtained by the use of the hydraulic model with the ones obtained by the geomorphological models, it can be seen that the geomorphological model can describe the flood prone area, though the SWI overestimates the results, especially in the lowland area. The TWI is very close to the simulated flood limit with the hydraulic model. But the TWI has a general tendency to underestimate the degree of wetness in the low- and wetland areas, because (i) in the flat (lowland) area the flow directions are not defined very well; (ii) the hydraulic gradient in the wetland is smaller than the surface slope; (iii) sensitivity to scale, quality and resolution of the DEM. A study of the TWI and SAGA sensitivity will be necessary in order to improve the quality of flood prone area evaluation.

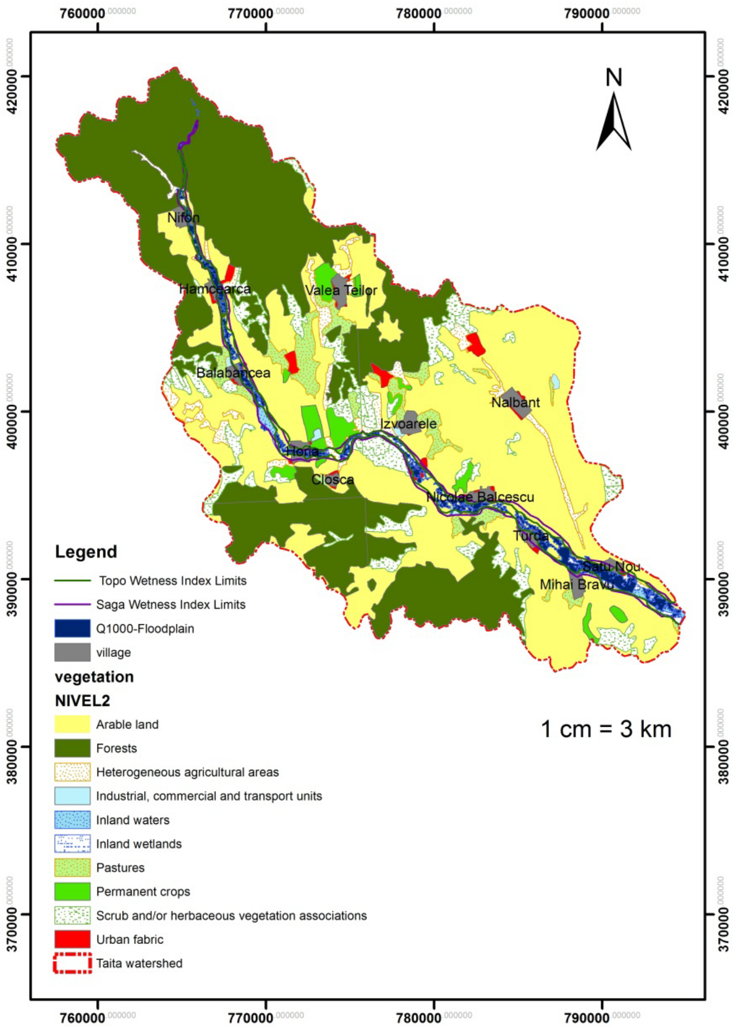


Fig84. TWI and SWI

Two completely different approaches to locate and delineate flood prone areas were applied in Taita river basin.

Geomorphologic based models with minimal data requirements were applied using Open Source software and the results were compared to results from the application of hydraulic models. Flash flood prone areas were delineated using the Topographic Wetness Index (based on TOPMODEL) and the SAGA WI geomorphological models and with the HEC-RAS hydraulic model by taking into consideration 10, 50, 100 and 1000 years return periods.

Comparison of the results of the different approaches and model types used (geomorphological and hydraulic), shows that there is a remarkable convergence in the location of flood prone areas and moreover in the delineation of the inundation (flooded) area despite the fact that these models have very different input data requirements and backgrounds. It must be noted though that the geomorphological models cannot provide hazard assessment but the hydraulic models can, so their application is absolutely necessary.

Taking into consideration that the geomorphological models have minimal data requirements as the required data are readily available (ASTER DEMs, topographical data), these models can be used to reliably delineate flood prone areas on a regional scale with minimal data requirements in order to proceed with Risk assessment in that scale.

At a next stage, hydraulic models can be used especially on site-specific (local) scales in order to accurately estimate the flooding parameters (inundation area, depth, flood water velocity etc.), thus helping make decisions about designing effective preventive measures. Data requirements in this case, especially for highly detailed topographic data of the area, are very demanding.

The one dimensional model, HEC RAS, was used to calculate single water surface elevations for a number of cross sections along the Taita River and to calculate the respective flood parameters. The results were compared to actual data recorder during various flooding events in the Taita river area. As it appears, flooding parameters are underestimated by 1.45m a fact mostly due to the relatively low resolution of the ASTER DEM used as the topographic base. This fact was already expected since ASTER DEM resolution is fit for applications (as the Flood Hazard Assessment-FHA) on regional scales (1:25000-1:100000) but the calculation of the flooding parameters requires data suitable for FHA on a local scale (1:500-1:5000).

To demonstrate the broad applicability of the selected methodologies, open source software was used to store, process data and create maps. As resulted, Quantum GIS (v.2.1), SAGA GIS (v.2.08) and HEC-RAS can be effectively used to fully apply the proposed methodological approach as they provide very reliable platforms at no cost thus restricting the cost of implementation to the cost of the necessary data.

6.4.2 Flood Hazard Assessment-FHA on local scales (1:2500)

Flood Hazard Assessment on local scale was carried out in Voinesti and Taitariver basins. Results of these implementations were communicated with the scientific society (published in books, Scientific Journals and presented in International

Conferences) in order to receive feedback. Additional FHA models were used in order to compare their processes and outputs with the ones provided by the proposed methodology.

6.4.2.1 Study area and data

The Voineşti catchment is located in the Dambovita watershed (a primary tributary of the Danube).

Geographically, Voinesti catchment is located in the extreme western part of the Ialomiţa Sub Carpathians (B), subdivision of Curvature Sub Carpathians Mountain (A) - Bărbuleţului Hills (Figure 85). The altitude varies between a minimum of 420 m and a maximum of 555.6 m, the average altitude is 481 m (Figure 85), height difference being of 120 meters.

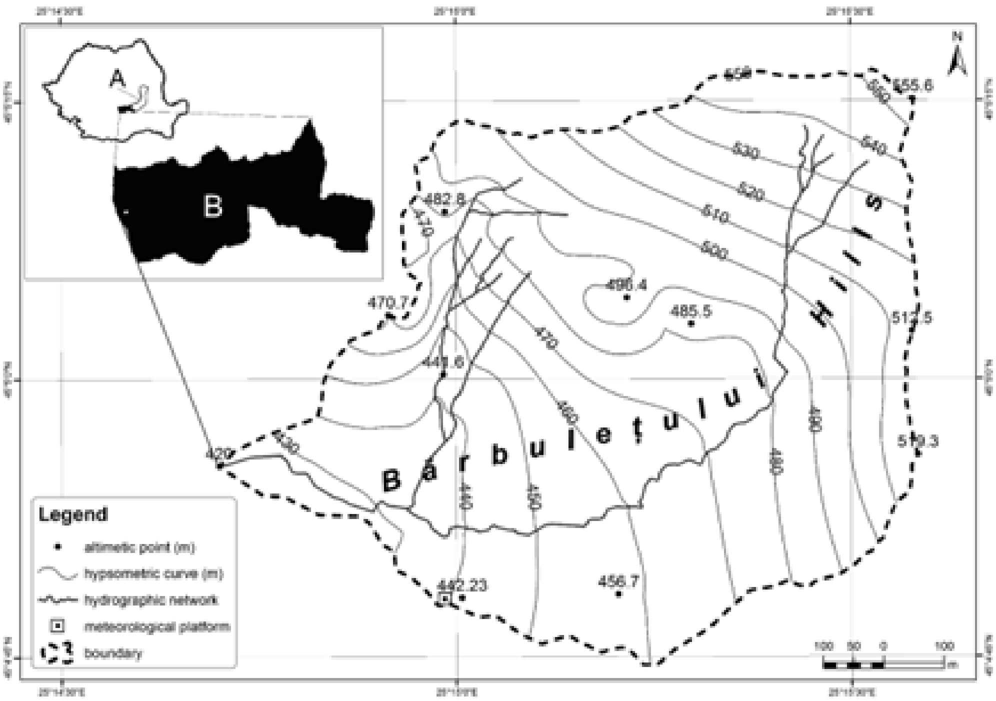


Fig85. Voinesti catchment

With a surface of 0.76km², this catchment is asymmetrically distributed with respect to its main channel, the Muret River Valley, located in the Eastern part of the basin. On its right bank, the Muret River receives a tributary, the Oak ("Stejarului") River Valley. From a geophysical point of view, we can identify two different zones of the catchment: the first one includes the higher altitude area, characterized by high slopes and an abrupt hillside, affected by intense erosion processes; the second one includes the lower altitude area of the basin and it is characterized by smoother slopes, but with a much more varied micro-landscape. The lower slope occurs in the lower half (2-10%) of the basin, but the terrain is quite varied due to frequent landslides. In the center of the watershed, one can distinguish a sliding layer well developed, bounded on the north by a sliding surface that has a circular plain appearance of a steep wall with a height between 10 and 20 meters. The greater slopes are in the upper half (15% or more). The slopes in the area are affected by major processes of erosion and landslides. They are also much gullied.

In respect to soil characteristics, the basin exhibits a brown soil, identified as preluvosol according to FAO 2003. From a pedological point of view, fifteen soil units (Figure 86) were identified and classified according to the degree of podzolization and erosion with different degrees of intensity.

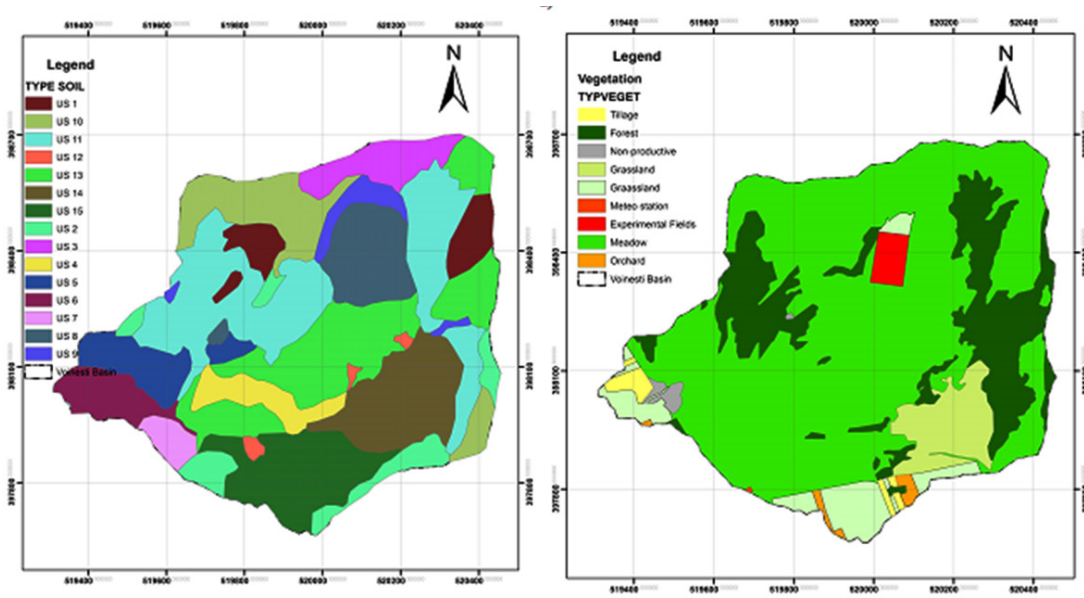


Fig86. Voinesti catchment - soils and land use maps

After a detailed analysis, the soils of the Voineşti catchment could be divided into two main units, corresponding roughly to the landscape:

1. For the first soil unit, US1, located in the steep slopes of the upper part of the basin, the texture of the soil profile is differentiated in the following way: sandy clay loam (LAS) in the upper 30 cm, loamy clay loam (LAL) between 30 and 60 cm of depth, clay (A) below 60 cm;

2. For the second soil unit, US2, located in the area of lower part of the basin, the texture is sandy clay loam (LAS) in the whole soil profile.

It is important to note that in the first soil unit there is a B_t horizon. The B_t horizon possesses a lower permeability which produces a temporary stagnation of the water in the soil profile, and determines the pseudo-gleying phenomenon.

An important property is the presence of argillaceous marl layer at 1-3m depth. An important property of this BH is the presence of an impermeable layer of clay marls which is found at approx.1-3m on the upper part of the basin and at 3-12 m on the bottom part.

The Voineşti catchment has a vegetation land cover composed of the following groups (Figure 15): (a) grassland area 59,10% of the basin (46,09 ha); (b) forest area covering 33,10 % of the basin (25,82 ha); (c) natural meadow area 3,79 % of the basin (2,96 ha); (d) other land cover 4,01 % of the basin (3.13 ha) representing: constructions, route, tillable and orchard.

The rainfall distribution shows a conspicuous seasonality. In particular, a concentration of significant events in May (31/05/97 and 16/05/98) and August (02/08/97) is evident. The average rainfall intensities vary from 0.23 mm/min in 1997 to 0.32 mm/min in 1998. Maximum intensities vary from 2.00mm/min in 1997 to 1.24mm/min in 1998.

The average discharge at the catchment outlet was about 3.81mc/s in 1997 and 1.59mc/s in 1998. It is noteworthy that the maximum discharge of 1997 (16.08 mc/s) is also roughly two times higher than the one recorded in 1998 (7.72 mc/s). The duration of floods is quite varied; about 50% of the events last between 180 and 600minutes with a rising time (time-to-peak) between 5 and 60 minutes. The surface flow volume of each event ranges between 0.22 and 87.2mm during the entire period, with an average value of 11.42 mm. The computed average runoff coefficient is 0.53.

The rainfall – runoff analysis led to a rough description of the main hydrological processes in this small basin when significant rainfall is preceded by several days without precipitation, very little surface runoff takes place. This occurs as a consequence of the dry soil conditions which allow infiltration to become predominant. On the other hand, even moderate rainfall on saturated soil can produce significantly strong surface runoff.

The analysis of the maximum rainfall values allows the establishment of a rainfall threshold of 9.6mm, in order to affect channel runoff. However, the observation period might be too short to accurately estimate this limit.

The analysis of the rainfall data leads to the following observations:

- The existence of a large temporal variability of the rainfall amount and of the rainfall intensity at a daily and at a monthly time step;
- The presence of rather significant surface flow (on average, 51% of the total precipitation);
- Single-event cumulated rainfall exceeding 9.6 mm generates a discharge in the hydrological network; nevertheless, the rainfall-runoff analysis shows that

there are rainfall events, which although they do not exceed this limit, they may produce surface flow. This situation is characteristic of rainfall events with lower precipitation amounts, but concentrated over short time intervals, and having high intensities (0.36 – 0.86 mm/min); on the other hand, there is a case where significant daily amount rainfalls have fallen on dry soil for a long duration, but no significant surface flow was produced (e.g. 27 mm in 12 hours - 04/06/97).

6.4.2.2 Geomorphologic indices - model implementation and results

The performance of the Topographic Wetness Index (TWI) and the SAGA Wetness Index in predicting the spatial distribution of wetland zones is presented in the following paragraph.

A DEM-Digital Elevation Model (**resolution 3x3m**) was developed using topographic maps of a 1:2500 scale.

The DEM TWI calculations are highly dependent on the spatial resolution of the Digital Elevation Model (DEM) of the studied topography [9].

The SAGA Wetness Index which is 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 [5].

The SAGA Wetness Index [5] is 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 was also calculated and mapped.

The two models selected were implemented using the Quantum GIS and the SAGA GIS algorithms. These models are based solely on topography, so the only input data required were elevation data created has a pixel size (spatial resolution) of 10m.

Multilevel B-spline algorithm [63] was used for the spatial interpolation of the scattered elevation data and the construction of the DEM.

The results obtained (the TWI index map and SAGA wetness index m) are presented in Fig 87.

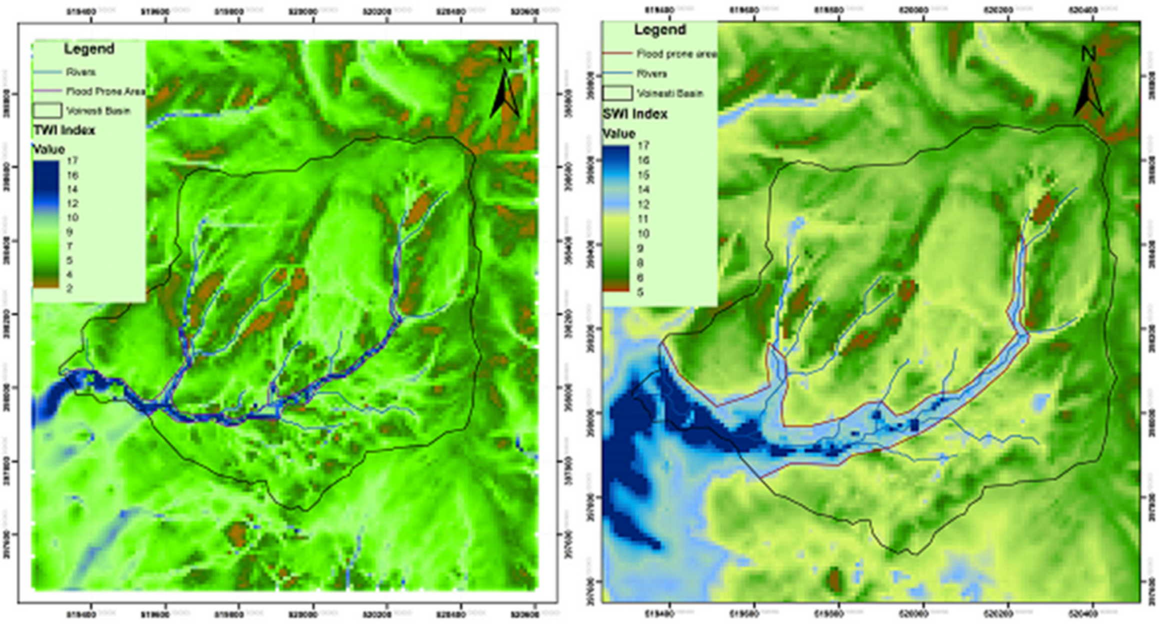


Fig87. TWI index (a) and SAGA Wetness Index (b) spatial distribution in Stereo 70 projection

In the first case TWI index values vary between 2 and 17 (Figure 87). As expected, most exposed areas are situated along the river valley and correspond to the higher value (12, 17). For the other flat area this index varies between 2 and 7. SAGA wetness index (SWI) values (Figure 87) vary between 5 and 17.

Both of these indices have a qualitative character when considering floods: they can be used to detect the flood prone areas or the areas which are going to be the first ones to flood ([7]; [8]; [9]; [10]; [11]).

The interpretation of these results shows that the most likely to flood areas are located at the low altitude, low slope areas around the basin outlet (dark blue areas). The actual inundation area can only be assessed when using rainfall data so the use of this methodology aims at defining the "hot spots" in order to proceed with a more detailed analysis based on hydraulic models at those of the "Hot Spots" where valuable assets are at risk. It is therefore evident that these methodologies can be effectively used for a preliminary flood susceptibility assessment.

As already mentioned, the Voinesti catchment soil has some important characteristics which influence the flow genesis. Firstly the soil texture is between medium and fine. The presence of the alluvial B horizon (in the upper third of the basin), enriched in clay, causes a poor drainage of soil. When the rain intensity exceeds the infiltration capacity of soil, the overland flow appears immediately as a thin film. When the rain intensity is low, the saturated areas are formed first. If the rainfall continues, the water cannot infiltrate and flows on the surface, in areas where the soil profile is already saturated and the amount of precipitated water is greater than the lateral transmission level. The flow on the saturated surface is facilitated not only by precipitation, but also by a lateral flow of shallow water. The presence of clay marl at a small depth in the lower part of catchment, especially on the flat zone, leads to stagnation of water and to the appearance of surface flows. To conclude, the areas where the SAGA index values varies between 10-11 (Figure 87) are saturated zones while areas where the index is between 12 and 17 are considered as flood prone areas.

It must be noted that the area located in the South Western part of the catchment outlet is an urban area.

As already mentioned, the geomorphologic indexes spatial distribution can be considered as a qualitative approach to locating flood prone areas and less as a quantitative tool to accurately delineate them. The use of this kind of models should be done carefully and only after a careful interpretation of soil conditions in respect to hydrological terms.

6.4.2.3 TOPOG model implementation and results

The beauty and strength of TOPOG model is it's "terrain analysis" module. This is based on a grid, built on the topography, with contour lines perpendicular to the lines of largest slope (CSIRO, 1999). This allows the implicit representation of the convergent and divergent zones in the studied catchment area. The catchment area is divided into irregular elements (cells), inter-connected according to the concept of stream lines.

In order to simulate the surface storm flow runoff, TOPOG uses the following information: the topographic layout given by the digital elevation model, state physical data (vegetation, soil), hydro-meteorological data (precipitation) and climatic data (radiation, water vapor pressure deficit, minimum and maximum temperatures). The vegetation and the soil parameters are spatially distributed. To represent the vertical flow in the unsaturated zone, a diagram similar as the one used in TOPMODEL [1] was used. The SBM (Simplified Bucket Model) (CSIRO, 1999) module considers only one layer of soil (assumed internally homogeneous) in which saturated hydraulic conductivity decreases with the depth, following an exponential law:

$$q = k_0 \cdot \tan(\beta) \cdot \exp\left(\frac{S_i}{m}\right)$$

Where: *tan (β)* is the surface slope; k_0 is the hydraulic conductivity of each cell; *Si/m* is the saturation deficit of each cell.

The expression varies in interval (0, 1). If =1, $q = k_0 \cdot \tan(\beta)$

In this case, the storm flow mode was used. The evapotranspiration is not calculated and the surface flow is simulated with the kinematic wave equation. The kinematic wave velocity is calculated by the Manning-Strickler equation:

$$v = k \cdot s^{1/2} \cdot h^{2/3}$$

Where: *s* is the surface slope; *h* is the flow depth; *k* is the Manning-Strickler coefficient, which decreases with increasing roughness.

The terrain analysis of the TOPOG model applied in the catchment led to the following conclusions:

- the catchment surface was estimated at $0.75km^2$ (with TOPOG) and it's a bit different than the calculated surface in ArcView® and the surface of $0.78km^2$ determined through topographic measures;
- the average elevation of the catchment is about 483m, as compared with the measured value of 481m;
- the average slope is about 25%, comparing well with the measured value of at 17.7%.

Previous results indicate [64] that the TOPOG model could be an excellent tool for a good representation of the catchment topography.

The analysis and evaluation of results, involved comparing the cumulated surface flow simulated with actual measurements, using as criteria: (a) the correlation coefficient (R2); (b) the Nash criterion, (c) and the non-dimensional regression slope. Half of the 27 rainfall-runoff records used were used to calibrate the model and the other half was used to validate it.

For a Manning-Strickler coefficient value of 0.2 $m^{1/3} s^{-1}$, we observe that TOPOG has a tendency to underestimate the surface flow values and that it isn't accurate simulating strong rainfall. For example, for the rainfall observed on August 3rd, 1997, the estimated value was 16.34mm, whereas the measured value was 40.00mm. The lowest surface flows were computed satisfactorily, with errors varying between 1 and 5%. The determination coefficient (fraction of explained variance) was 73%, while the Nash criterion had a rather low value (0.55). Since the above results weren't completely satisfactory, Manning - Strickler coefficient was increasing to test the following values: 0.35 and 1.10 $m^{1/3} s^{-1}$. The results are presented in Figure 88. Manning coefficient values of 1.10 $m^{1/3} s^{-1}$, presented a better correlation coefficient of the regression analysis. The correlation coefficient (R^2) increases from 0.73 to 0.90 for this latter value of the Manning-Strickler coefficient. The value of the Nash criterion increased from 0.83 to 0.90.

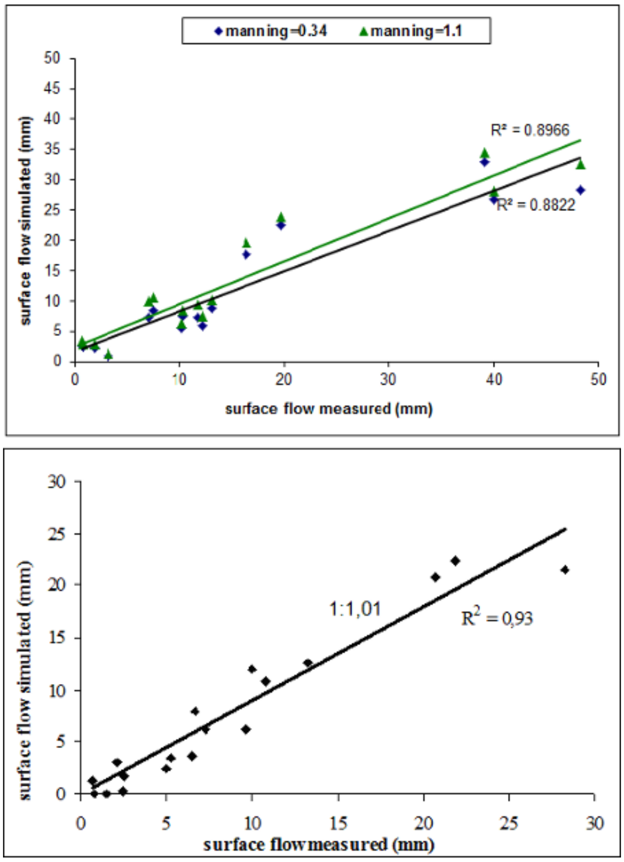


Fig88. Comparison of the surface flow measured and simulated in calibration stage (top) and in validation stage (bottom)

Under these conditions, the value of 1.10 $m^{1/3} s^{-1}$for the Manning - Strickler coefficient was adopted. In order to validate the calibration procedure, this value should be tested for events during the year 1998. The testing results are shown in Figure 3.

The regression line has its origin close to zero, and the slope doesn't significantly differ from 1 (the Manning - Strickler is 1.01). It is evident that, for very low rainfall values (like those observed on 18/06/1998 and 14/09/1998); the model calculates a zero surface runoff, which means that during such rainfall events the basin does not produce surface runoff.

This value matches the Manning-Strickler coefficient specified in the literature - for the vegetated areas the coefficient can set to 1 $m^{1/3} s^{-1}$according to information by [65]; [66] and [67]). Taking in account the fact that 70% of land cover of the Voineşti catchment is of this type, it may be considered that the roughness coefficient obtained through the model is well verified.

Since there are not sufficient observations to validate the operation diagram of the basin, classical calibration and validation procedures could not be used. An effort has been made to determine a Manning coefficient. The effort was based on a sub-daily time step, which gives the best results for a given data set and then on comparing this coefficient with another data set. Within the limit of the criteria that were used, it may be concluded that, in terms of cumulated surface flow, the results obtained with TOPOG model are close enough to reality.

Since there are not sufficient observations to validate the operation diagram of the basin, classical calibration and validation procedures could not be used. An effort has been made to determine a Manning coefficient. The effort was based on a sub-daily time step, which gives the best results for a given data set and then on comparing this coefficient with another data set. Within the limit of the criteria that were used, it may be concluded that, in terms of cumulated surface flow, the results obtained with TOPOG model are close enough to reality.

The importance of the Manning-Strickler factor in the TOPOG modeling approach was also discussed by Carluer & de Marsily [68], who underestimated the role of the artificial surface hydrological network. There is also recent research which proposes remote-sensing methods in order to improve the description of such networks [69].

6.4.2.4 ANSWERS model implementation and results

ANSWERS is an event oriented, distributed parameter model, which adopts some simplifying assumptions: (a) the evapotranspiration is neglected on the sub-daily step; (b) subsurface drainage begins when soil moisture exceeds field capacity; (c) the steady state is reached when the soil is saturated i.e. that the intensity of infiltration equalizes the saturated hydraulic conductivity; (d) the coefficient of sub-surface drainage is equal to the permanent coefficient of infiltration when the soil is saturated.

To estimate overland flow ANSWERS GRASS GIS oriented model is used. The following information was necessary: topographic layout given by the digital elevation model, vegetation, and soil map (as state variables), rainfall intensity (as data input). The ANSWERS model is limited to a total number of 1700 cells, so the DEM's resolution used was 25m.

The vegetation and the soil parameters are spatially distributed and effect: total porosity (TP), field capacity (FP), steady state infiltration rate (FC), infiltration exponent (P), control zone depth (DF), antecedent soil moisture (ASM) which quantifies the starting point for the soil moisture-based infiltration equation for soil characterization, and respectively potential interception (PIT) and percent covers (PER) that are used to describe the interception of rainfall whereas Manning's (N) describes the surface roughness. Some of the aforementioned parameters are measurable: total porosity (TP), field capacity (FP), steady state infiltration rate (FC). Other parameters as the percentage of land covered with vegetation - PER are deduced with GIS and the values are presented in the general presentation of the study area. Ritter (1983) indicated that the most significant parameters are the parameters concerning the infiltration (FC and DF) and the soil initial moisture (ASM). The FC parameters cannot be modified but as it is comparable with the saturated hydraulic conductivity, its value was determined experimentally. With regard to parameter DF, the user's manual mentioned that the values of this parameter can vary from 0,25 to 0,75 the depth of horizon A. The soil of Voinesti catchment presents widely spread erosion phenomena and sometimes horizon A does not exist or is reduced considerably. For this reason, the value of the parameter DF selected was 0,25 the for the respective depth of horizon A. The soil analysis shows that the soil has a behavior of a clay soil. Clays have the property to retain infiltrated water. The soil quickly becomes saturated and water in excess runs out on the surface of the slope. Taking this fact into account, coefficient P was increased from the 0,55 to 0,8 (0,9). The potential interception volume (PIT-mm) describes the volume of moisture that could be removed if the area was completely covered by that some land use. PIT was selected between 0 mm for the naked ground and 2 mm for the forested areas (according to user's manual).

In order to calibrate the model and validate it's results, 27 recorded events were used. The Nash criterion the correlation coefficient (R^2) and the non-dimensional regression slope were used to calibrate the model.

With the assumptions suggested above, the results of simulations show an improved correlation (Figure 89). The correlation coefficient and the coefficient of determination were increases from 0,90 to 0,94 and from 0,80 to 0,87 respectively. The Nash criterion value calculated was 0,87.

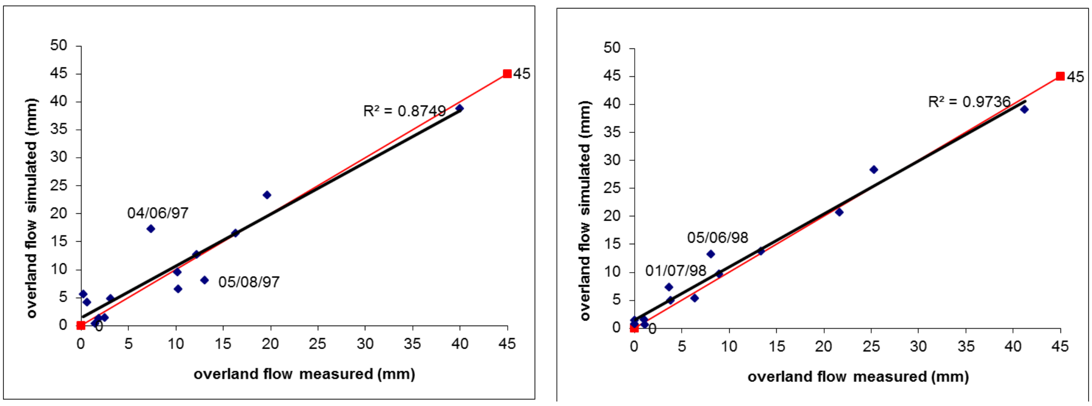


Fig89. Comparison of the surface flow measured and simulated in the calibration stage and in validation stage.

In order to test the validity of the model, the data that were not used for the calibration, were simulated with the parameters tested previously. To estimate the quality of the reconstitution, overland flow values were successively studied. Figure 18 depicts the overland flow values calculated by the model and the same variables observed. The scatter plot (simulated and measured overland flow) shows a good correlation between the two variables represented. Moreover, the Nash coefficient has a higher value that the calculated one in the calibration stage (0,96 as compared to 0,87). The correlation coefficient increased from 0,94 to 0,98. The coefficient of determination was 97,3%. The slope and the ordinate at the origin of linear regression are not significantly different from 1and 0 respectively.

The following figures (Figure 90) present the hydrographs simulated and observed on the basin for two specific events: single hydrograph and complex hydrograph.

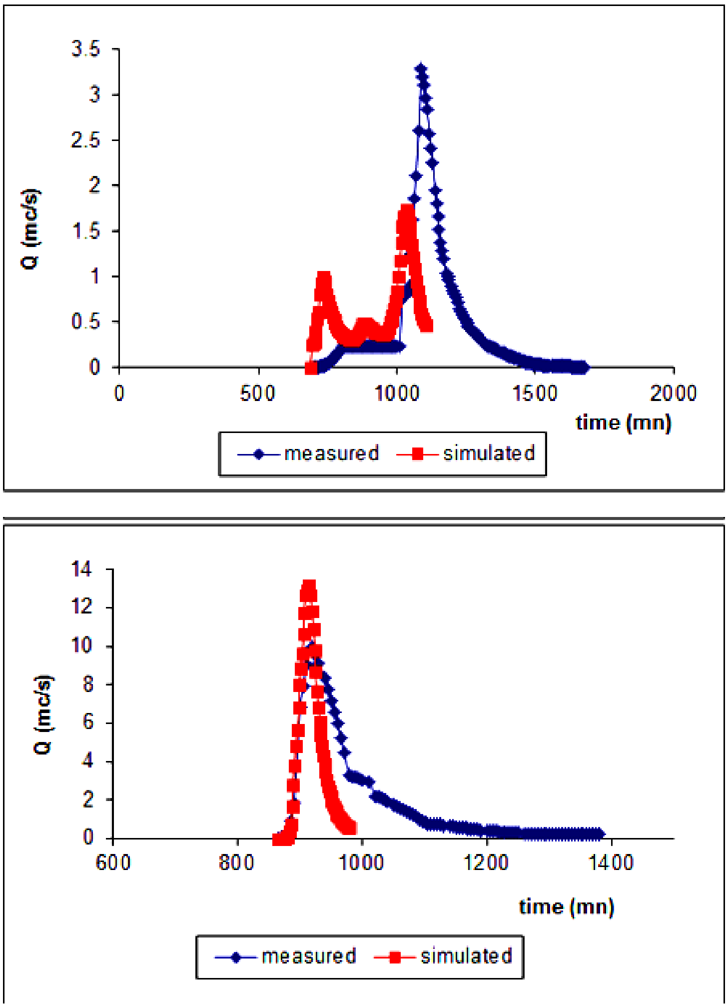


Fig90. Comparison of the simulated and measured discharge for a single hydrograph (top) and complex hydrograph (bottom).

The model simulates the first phase of hydrograph but not the second one, which explains the over estimation of the calculated overland flow. Surface flow stopped at the end of the rainfall, a fact which means that the model does not simulate the depletion phase of the catchment.

It seems that the ANSWERS model can simulate complex hydrographs but in a rather unsatisfactory way. The overland flow calculated by the model is close to the measured flow but the form of the simulated hydrograph is rather different than the one measured. The rain histogram form that takes a rather irregular form (with two peaks of the strong intensities) is the reason for this problem.

6.4.2.5 UH model implementation and results

MIKE is a software package developed by DHI Water & Environment to model the water flow. MIKE also possesses the ability to run rainfall-runoff hydrological models and the users can choose one of the several hydrological models available: UHM (Unit Hydrograph Model), NAM (Nedbor-Afstromnings-Model), SMAP (Soil Moisture Active-Passive), URBAN, FEC, DriFT. In the present study the UHM model was chosen. The UHM MIKE model proposes three methods to estimate the hydrograph: the triangular SCS method, the SCS - UH dimensionless method and the specified UH method.

The UH model selected includes several methods for estimating precipitation loss: (1) constant losses, (2) proportional loss method that takes into account the runoff coefficient, (3) SCS method based the moisture conditions up to and (4) a method based SCS generalized dimensionless parameter called " Curve Number" , denoted by CN , $0 < CN < 100$ and the initial loss Ia.

The first method (constant losses) assumes that the infiltration is described by an initial loss, followed by a constant rate of infiltration.

In the second (proportional loss) method, losses are distributed proportionally to the precipitation. The values of rainfall amounts are reduced by a value equal to the runoff coefficient.

The SCS method is based on previous soil moisture conditions (AMC - Previous Moisture Conditions); the AMC value represents the soil moisture at beginning of a rainfall and its calculation is based on the cumulative rainfall in the preceding five days (McCuen 1982). The model was applied with three AMC types: AMC II - average conditions - relative soil humidity is close to the field capacity of soil, AMC I - low humidity conditions - relative soil humidity is close to wilting capacity of soil and AMC III - high humidity - the soil humidity is closed to saturation moisture of soil. Given the previous humidity rainfall index (AMC), it is possible to define several values of the CN (Curve Number) parameter.

The SCS generalized method suggests that the initial loss, Ia., represents the water losses by interception and/or retention. If the soil is saturated, Ia can be considered zero, and in any case the variation of this parameter depends on the vegetation and soil type.

Properties of soil influence the flow generation processes on slopes. Soil classification in terms of its potential to generate flows is based on the following factors: transmissivity, hydraulic conductivity, depth at which the layer is waterproof, groundwater presence. The kind of classification is not used in Romania. Textural classification is only used. For this reason, a harmonization of the two types of soil classification has been carried out, based on both hydric soil properties and it's texture.

From a hydrological point of view, BH Voineşti soil can be classified as type "C" – soil with high potential flow (moderate transmissivity). Taking into account that the soil is showing an alluvial horizon which allows a temporary standstill of rain water, this type of soil can be classified as type „D" due to it's low hydraulic conductivity. D-type soils present a powerful flood potential (low transmissivity) considering the fact that they contain an impermeable horizon at a small depth.

Additional data required to running the model are: catchment surface (0.78km2), the generally slope of the river (17.7%), the length of principal river (1.5km) the CN number and the rainfall-runoff events. The slope, river length and CN number are necessary to establish the response time Tlag. Basic geometric and topographic parameters as the catchment area, slope and length of various parts of the hydrologic network were calculated by GIS software.

The CN number is calculated as a weighted average of CN numbers corresponding to different land uses. The main land uses in Voinesti catchment are: grass land (59.10%), forest (33.10%), meadow (3.79%) and others (4,01 %). For each land use a CN interval was established according with Drobot (2007). Weighted average is 77, and the interval used is 74-80.

To calibrate the model, 11 rainfall-runoff events were used and to assess the performance of model both graphics and features such RMSE (root mean square error) and Nash-Sutcliffe coefficient were also used.

Regarding the value of maximum discharge simulated, it is considered that the model used, simulates well these values as is evident by the correlation coefficient between measured and simulated values which is 0.99, the RMSE which is 0.08 and Nash-Sutcliffe which is 0.99.

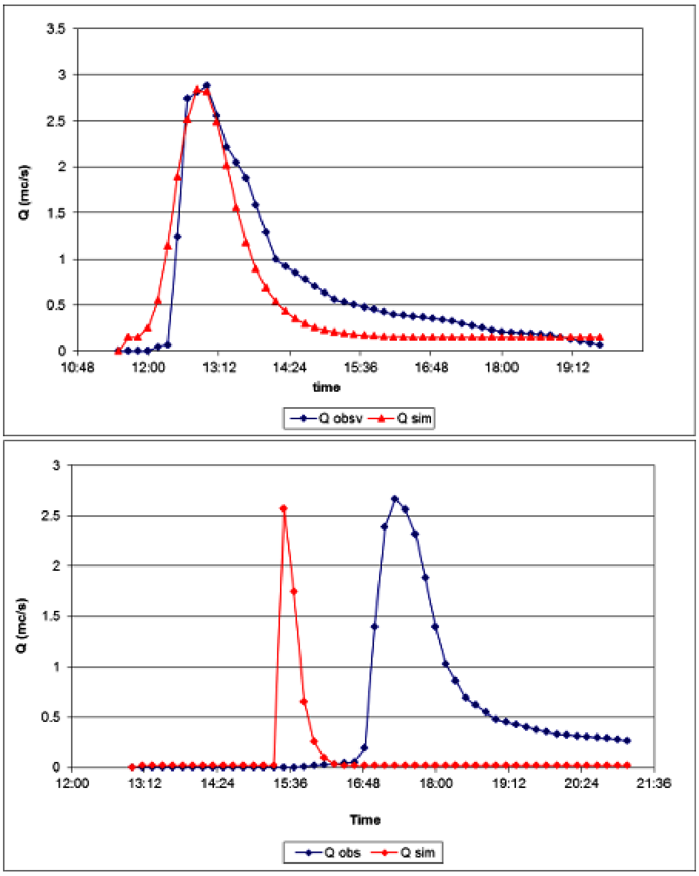


Fig91 Comparison of the simulated and measured hydrographs (type I and type II).

Concerning the simulated hydrograph, two different statuses are evident (Figure 91). The shape of the hydrograph (simulated vs measured) is similar in both types observed. The moment of maximum discharge in type I is about the same in both the measured and the simulated flow series. The moment of maximum discharge for the second type (type II), differs. The difference varies from 30 minutes to more than one hour. In any case, the depletion phase of catchment is not very well modeled. From this reason, the volume of runoff is not very well simulated.

Although a sensitivity test to response time (T_{lag}) was not carried out, it is evident that the model is extremely sensitive to response time.

To conclude, the biggest shortcoming of the UH model seems to be its inability to process distributed parameters. Although a weighted average of the CN number determined by vegetation structure has been used, GIS soil and vegetation maps could not be used. Most probably, the use of the dimensionless UH may improve the performance of this model. Using a CN number grid could improve also the results.

6.4.2.6 Local scale implementation and results

Implementation of the methodology requires the use of two software platforms: ArcGIS for geospatial applications and HEC-RAS for the hydraulic part. Linking the two software packages is being performed by the HEC-GeoRAS. The HEC-GeoRAS is actually an ArcGIS extension. This application allows the design of the components of the topographical model and the automated export to HEC-RAS and then imports the results of the hydraulic simulation into ArcGIS.

In order to apply this methodology the following steps were taken:

(1) Detailed topographic and auxiliary data and the development of digital spatial database of the entire hydrologic system in ArcGIS;

(2) Digital Elevation Model generation for the entire basin (raster and TIN). TIN is used as Digital Elevation Model required in GeoRAS environment in order to prepare data sets required as input to the HEC-RAS simulation.

(3) Creation of entities like: river, banks, flow path, cross section;

(4) Flood plain analysis: It consists of three steps: (a) HECGeoRAS processing to generate HEC-RAS import files, (b) HEC-RAS application, (c) Post-processing of HEC-RAS results and flood plain mapping in ArcGIS.

HEC-RAS is capable to perform steady- and unsteady state hydraulic computations. In steady state conditions, the energy equation is used to compute the water level for a given discharge and geometry.

Boundary conditions are required to establish the water initial level at the limits of the analyzed river sectors. In the case of the subcritical flow regime, only boundary conditions at the downstream part of the river are required. If the flow regime is supercritical, it is necessary to introduce boundary conditions only at the upstream part of the river. For mixed flow regime, boundary conditions at both ends of the river are necessary.

In a subcritical flow regime, one of following boundary conditions must be known: (a) known water surface; (b) critical depth; (c) normal depth and (d) rating curve. The main parameter to calculate is the Manning's, n, coefficient.

Scope of the implementation is the creation of a floodplain model for the Voinesti catchment. The basic assumption made is that there are steady flow conditions. Under steady flow conditions, the subcritical regime is related to normal depth as boundary condition. For this boundary condition, the energy slope must be calculated. In this application, the general slope of the river bed is used e.g. 17.7%. Values of Manning's coefficient for bank and river channel are range between 0.015 and 0.07 according with land use characteristics. The Manning's values are derived from tables.

The hydraulic geometry of the Muret Valley River is based on a 5m DEM resolution. Flood maps were created considering two different scenarios: 100 and 1000 years return period (16.8m^3/s and respectively 47.6m^3/s). It is obvious that the riverbed transport capacity is exceeded for both scenarios considered.

Maps created with the methodologies applied in Voinesti catchment were compared by superposition in a GIS application. HEC-RAS maps were used as a reference and compared with maps created by the rest of the methodologies used.

In this modeling approach the calibration step is omitted due to the fact the observed data of post-flooding events missed. Secondly the goal of this chapter is to explore the capability of this model to offer a representation of floodplain.

It must be pointed out that the models based on morphological parameters actually show the flood prone areas so they are used for this purpose only and their results must be considered as qualitative in respect to flood hazard. They cannot be used to delineate inundation areas due to the lack of basic hydrologic and rainfall information. Despite that fact, a comparison of the TWI and SWI with HEC-RAS results was attempted.

From a general perspective it seems that the flood prone areas derived from the TWI index model are in close agreement to the inundation area derived from the HEC-RAS model. Exceptions occur in the flat areas of the catchment, especially on the outlet section area and this fact can be attributed to the different way those models approach the flood issue in terms of detailed analysis. The comparison of the flood prone areas derived by SWI and HEC-RAS, shows that SWI overestimates flood prone zones, especially in the lower third of the catchment where there is a smooth, low relief (Figure 92).

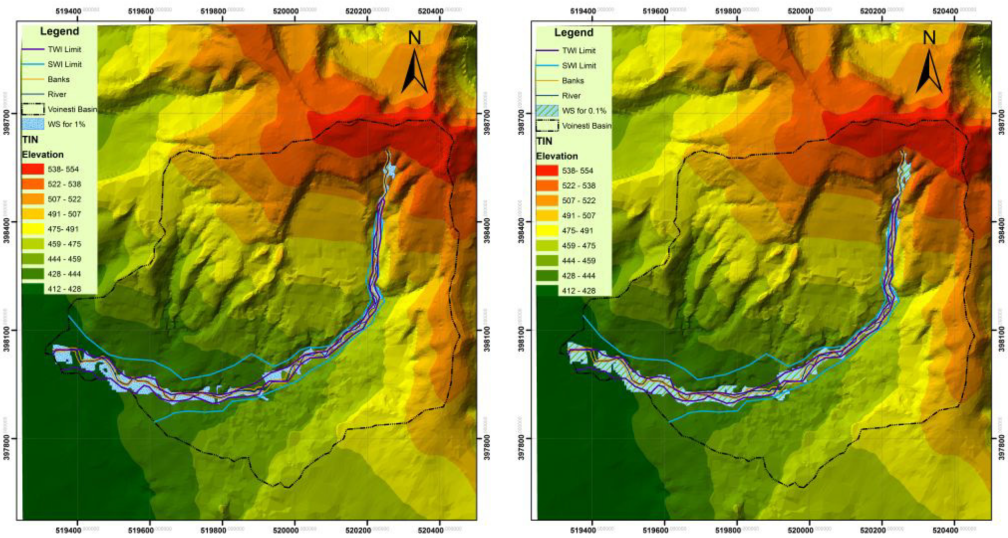


Fig92. The water surface extend delineate with HEC-RAS for 100 and 1000 years return period, TWI and SWI limits in STERO 70 projection**.**

Based on the comparison results presented above and considering that the morphology based methodologies are extremely easy to use because of their limited data requirements and the availability of open source tools as Quantum GIS, GRASS GIS and SAGA GIS), we may conclude that they can be used to provide a reliable location of flood prone zones at a preliminary stage in order to help assess the flood risk in stream catchments. The use of hydraulic models as the HEC-RAS presented here will provide at the next stage, accurate information regarding the flooding parameters (inundation area, depth of water etc.).

6.5 EVALUATION OF THE MODELS USED - CONCLUSIONS

The implementations on regional and local scales in Tata and Voinesti river basins in Romania, have led to the following conclusions as far as their data requirements, the completeness, the reliability and the accuracy of their outputs is concerned.

- All models take into account the spatial variability of the watershed through its main morphological characteristics;
- the majority of the models tested, offers good results in terms of simulated and measured hydrographs;
- the models tested predict only the runoff and stream flow but cannot predict hydraulic flow variables such as depth, velocity, etc.;
- the rainfall-runoff models can provide the data input necessary to calibrate models able to predict the flood extent;
- a good representation of topography is necessary in order to improve the distribution and flux of water into the watershed; DEMs (Digital Elevation model) are often used to derive topographic data for distributed hydrological models, and the quality of a DEM depends highly on the data sources and on the interpolation techniques.

6.6 DISCUSSION

Some basic considerations related to the hydrological research are discussed. Scientific research activities are often interested in several issues relating to:

- generating flowing mechanisms,
- validation of certain software or tools which overcomes the empirical approach and achieve a scientific approach to the water cycle and related flows;

- Modeling long-term parameters that control the hydrological processes and identify any developments related to the anthropogenic/or climatic variability.

In all these cases, a deterministic physically-based hydrological model may be used.

In engineering practice, to design a hydraulic work, the peak discharge with different return period might be enough and the results of a black-box model are acceptable (self-assured). These models can be used successfully to compute the peak flow for small ungauged basin. Their results can be used as input in other models, such HEC-RAS, to perform the floodplain delineation.

When is necessary to design/operate outlet structures, storm drain systems, culverts, small drainage ditches, open channels and energy dissipaters the hydrograph knowledge is necessary. In this case a very useful model is UHM (Unit Hydrograph Model). The most known models which have incorporated UH model used a set of parameters already standardized for different areas.

When considering the watershed plan management and especially the flood plan management, the Flood Directive recommends the use of "the best practice" and "the best available technologies" which do not involve excessive costs. In respect with these recommendations HEC-RAS is a solution.

This software is free and friendly to use. Moreover it performs not only flood modeling in terms on depth, velocity, or discharge, but also the impact of hydraulics works.

The issue that remains is “where to apply” the model since the “information gap” problems restrict implementation since the lack of required data leads to high demand time and funds. This is where the use of the geomorfological model comes. Itsimplementation helps accurately and reliably locate and delineate flood prone areas thus limiting the total investigation area extend and permitting for strategic planning through prioritization of areas under high flood risk.

The geomorfological model results can be improved using higher scale topographic maps and ancillary data that lead to mapping the spatial distribution of parameters which control the runoff, as Manning's coefficient.

The use of Open Source and/or freeware software can promote the use of these methodologies thus increasing the number of potential users and providing to state authorities/administration essential tools to promote flood disaster prevention.

7 FLOOD HAZARD ASSESSMENT ON A REGIONAL SCALE – IMPLEMENTATION IN MOLDOVA

Moldova is facing flood problems on a regular basis and in many areas mainly adjacent to large rivers (Fig.93).

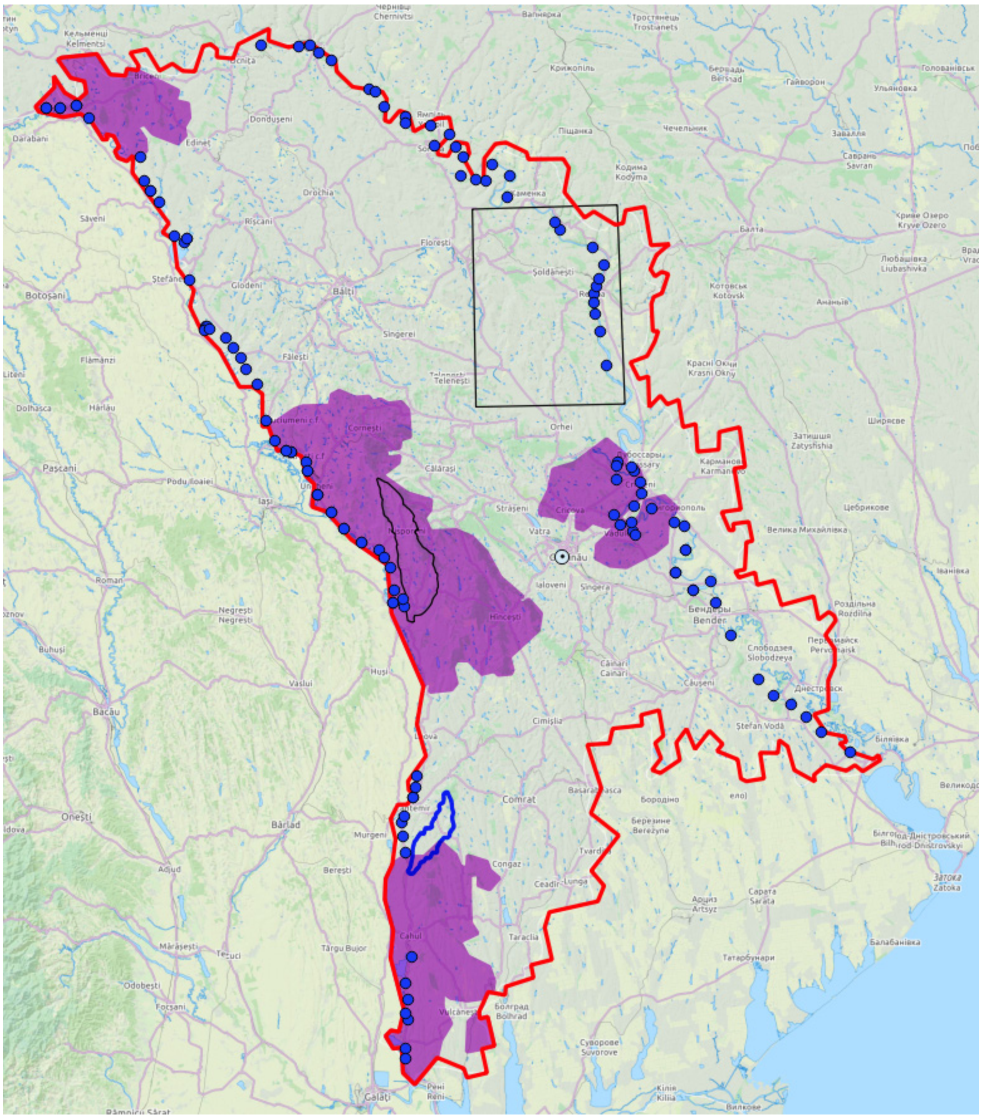


Fig93. Moldova: areas of high flood risk (purple polygons), flood locations (blue dots), areas of regional scale assessment (black polygons) and pilot implementation area (blue polygon).

A number of attempts to locate flood prone areas and compare the outputs to actual flood events (shown in fig.94) was carried out using ASTER DEMs. The attempts have revealed weaknesses in accurately locating flood prone areas due to the poor quality of the elevation information combined with the extremely low maximum relief. ASTER DEMs have a pixel size of 30x30m and usually can easily depict elevation changes in a way respective to a topographic map of an about 1/75000 scale. The maximum relief in large parts of Moldova does not exceed a 300m so the hydrologic model algorithms produce low quality outputs.

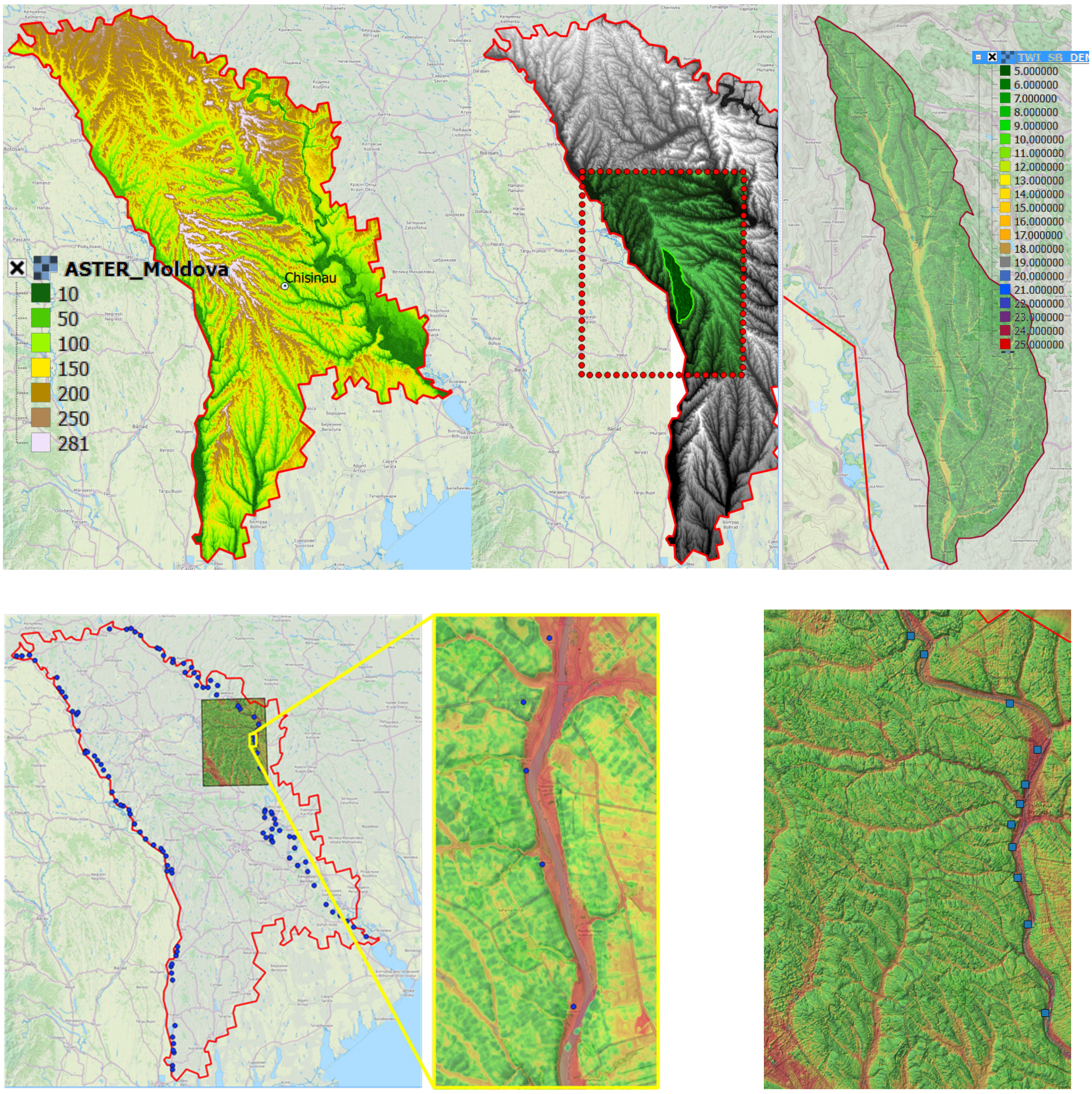


Fig94. Implementation of the geomorphologic model to locate flood prone areas on a regional scale in various areas of Moldova: past flood events (blue dots) compared with TWI and SAGA WI maps.

Due to the restrictions imposed by the area morphology combined with the relatively coarse resolution of ASTER DEMs, and in order to produce as reliable and as accurate as possible outputs, topographic maps of 1/10.000 scale were used. The proposed methodologies were thus implemented on a small size river basin, in order to demonstrate its potential towards flood disaster prevention.

7.1 AREA OF PILOT IMPLEMENTATION: LARGA RIVER

Larga River basin is situated in 80 km from the city of Chisinau and it falls into within two administrative districts. Most of the basin is in Cantemir district, whereas a smaller part (mouth part and the southeastern part of the watershed) – is located in Cahul district.

Larga River source is located near the village Lărguţa. The river length is more than 32 km, and the basin area covers more than 14.600 hectares. The flow velocity is 0.1-0.2 m/sec and discharge near 0.08 cubic km/year. The river has a relatively large tributary that flows into Larga River near village Cîrpeşti.

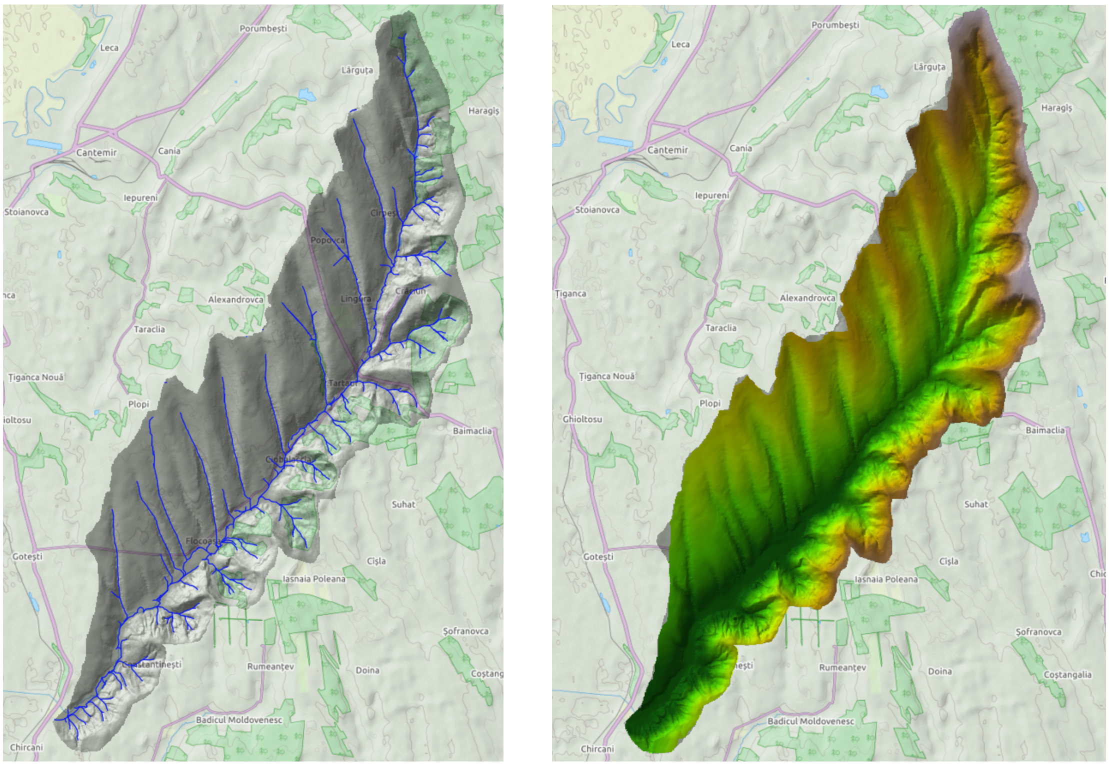


Fig95. Larga river (Moldova). Drainage network (left) and digital elevation model (right).

Larga River basin is situated at left slope of Tigheci plateau. The highest altitude is 302 m (hill Larguta), lowest altitude is at river mouth, 10 m, and the middle altitude is

145 m. The hill inclination is changed from 0 up to 35 degrees with middle value 5 degree. Maximal inclination is characterized for landslide areas, the minimal for watershed and flood plains.

Only about 1.5 percent of the territory is occupied by forests. The rest of the territory is occupied by different agricultural land uses (arable land, pastures, orchards and vineyards), man-made form (settlements, roads, artificial reservoirs).

The annual average temperature is 10 degrees, a few changing in the latitudinal direction (from 9.9 in the northern part of the basin in the south to 10.2). The average annual precipitation varies from 512 to 535 mm. More than 50% of the wind is from south-west direction and have average speed of 3.2 m/sec.

The geological structure of the basin is attended mostly by sand and clay deposits of Kherson layer of upper Sarmatian age (about 6% of the territory), Meotic layer of Miocene (about 57%) and Pontian stage.

These rocks are overlapped by colluvial deposits (mainly on the left slope of the valley), deluvial and eluvial deposits (mainly on the right side of the valley), eluvial-deluvial deposits in the headwaters, and alluvial deposits of high terraces on watersheds in the middle and lower part of the basin. The bank part of the basin is represented by the modern alluvium.

Flood events in the wider area are often and cause serious damage. Recently (2010) there were catastrophic flood events on river Prut where more than 30 villages were flashed out completely. Similar events on a much smaller scale had also occurred in smaller rivers. At river Larga, the level of the water had risen for about 220 cm above the normal level. During this event, very serious damage was caused especially in agriculture (installations, crops etc), on infrastructure and on property

To assess the flood prone areas, a detailed digital elevation model was produced using topographic maps of 1/10.000 scale (contours and elevation points).

Topographic Wetness and SAGA topographic wetness indices were calculated using the respective geomorphologic model (Fig. 96).

Outputs of both indices show a considerable coincidence with actual events recorded in the area although SAGA TWI depicts as "flood prone area" a much larger area that thee TWI does. This fact is attributed to the very low slopes characterizing the lowest (downstream) parts of the basin and most of its part along the main stream bed.

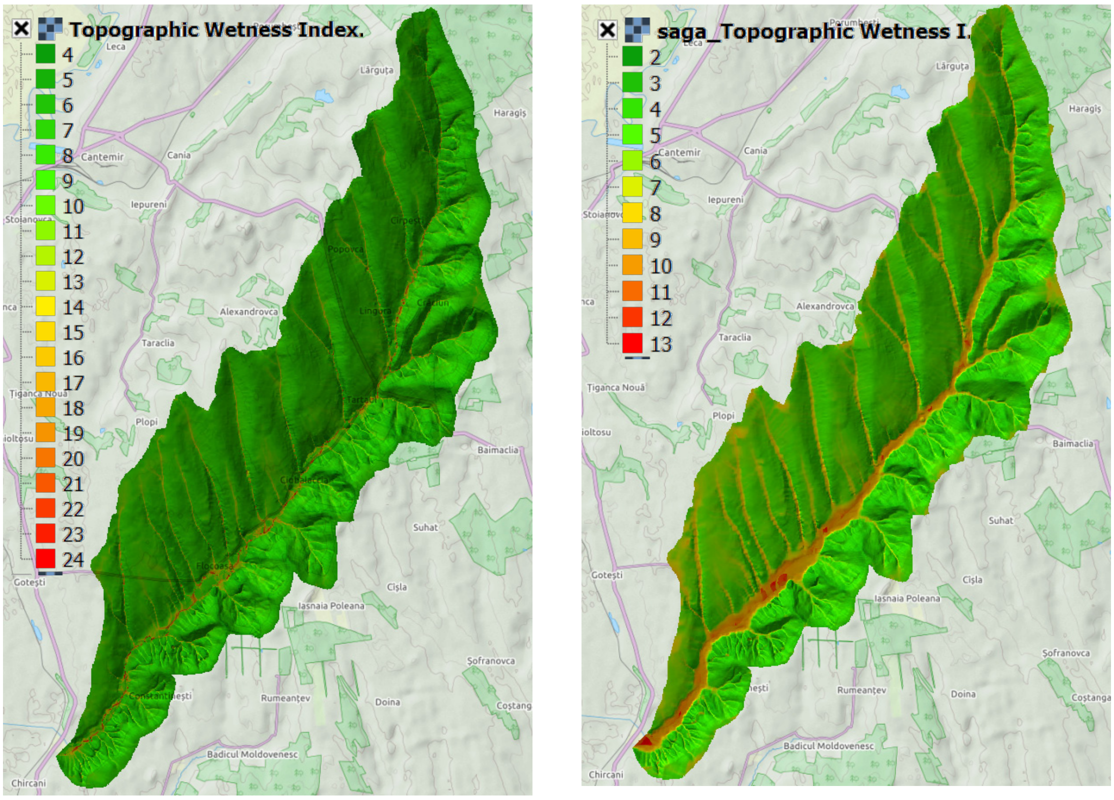


Fig96. Larga river (Moldova). Drainage network (left) and digital elevation model (right).

The lowest part of the Larga river basin near the mouth of the river, was selected as the area of the hydraulic model implementation in order to calculate the flood parameters (Fig. 97).

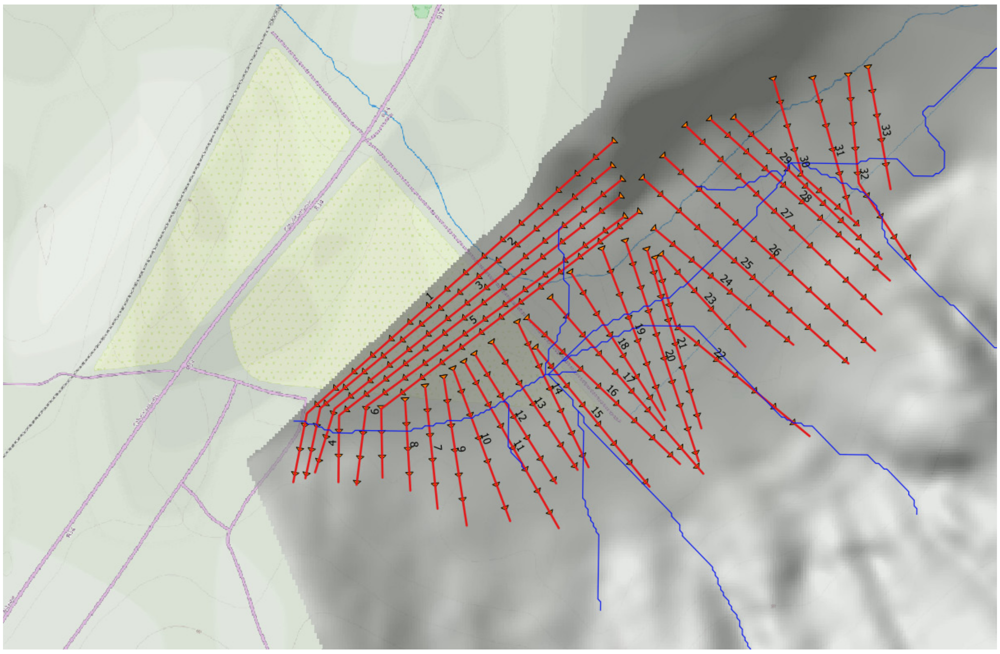
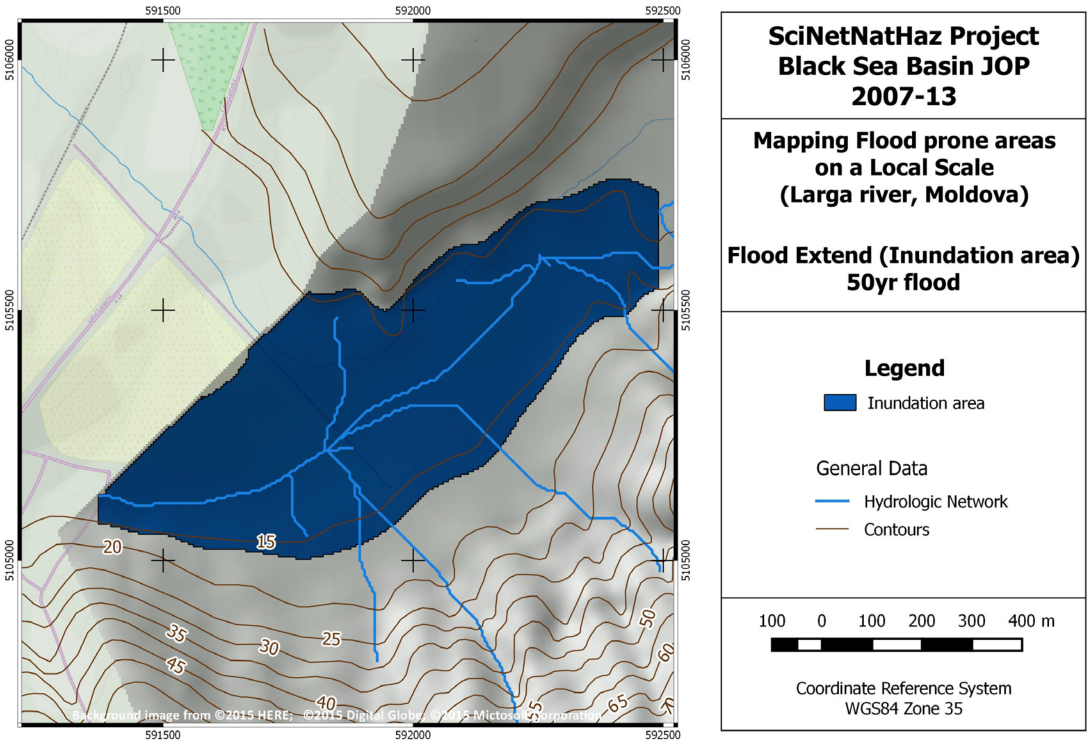


Fig97. Area of local scale implementation and cross sections analyzed (right).



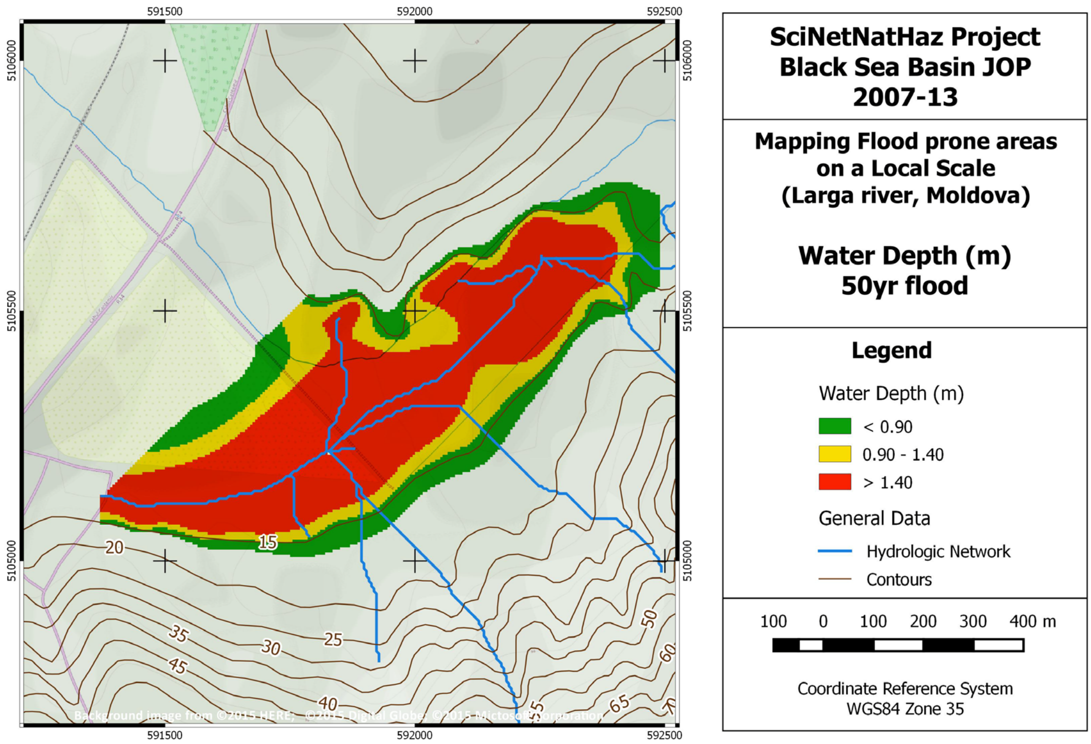


Fig97. Flood extend (top) and flood water depth (bottom maps of Larga river basin.

The entire set of maps is given in the ANNEX A – FHA maps of pilot implementation areas.

8 PILOT IMPLEMENTATION IN UKRAINE: DANUBE DELTA REGION

Roman Sizo (sizo.roman@gmail.com), Yevgen Gazetov (gazetov@gmail.com)

8.1 INTRODUCTION

Flood risk depends on the several factors

- Orographic conditions: catchment area, slope rate, etc.
- Intensity and quantity of precipitation
- Potential water volume that can be accumulated
- Floodplain width and configuration, type of vegetation
- Location of settlements
- Obstacles: bridges, dams, etc.

The main task of this study was to roughly locate and assess the potential areas that can be influenced by flash floods. Assessment of above mentioned factors were made using open source software: QGIS, SAGA GIS and GRASS GIS

The study was based on the following data:

- Shuttle Radar Topography (SRTM)
- ASTER DEM
- ENSEMBLES precipitation database (1950-2010 years)
- Topographic maps 1:50.000 and 1:100.000
- WorldView & Pleiades remote sensing data (some areas)
- Google Earth

Results of the project “Joint environmental monitoring, assessment and exchange of information for integrated management of the Danube delta region” were partly used for this study.

8.2 METHODOLOGY

Flood hazard assessment on a regional scale was implemented on the Aliyaga river basin which forms a part of Danube delta wider area (fig. 98).

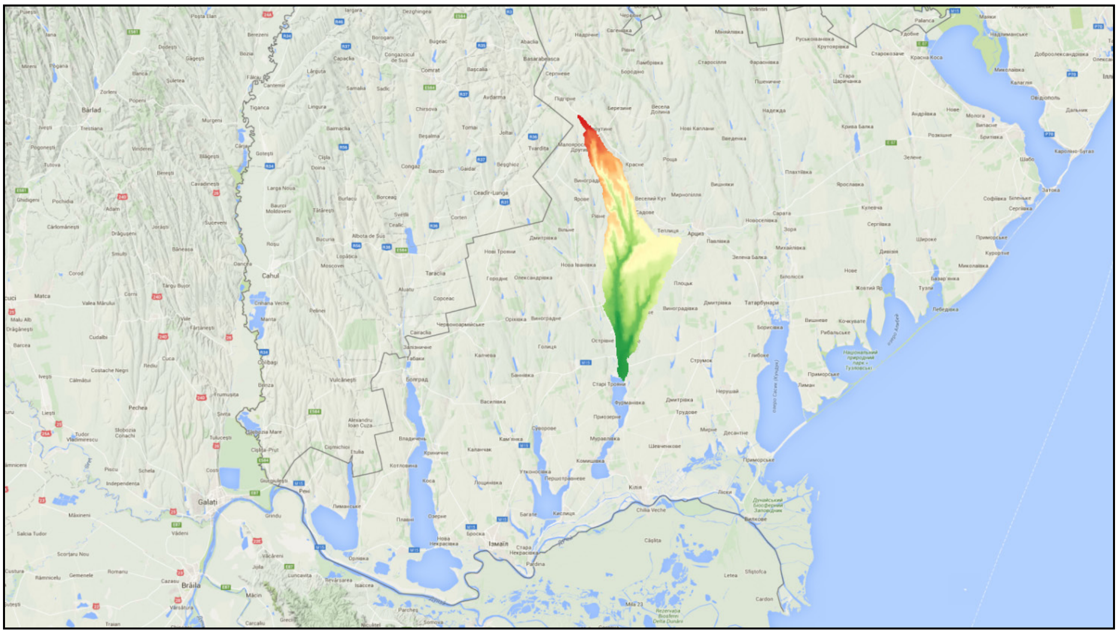


Fig 98. Aliyage river basin.

Digitized topographic maps of a 1/50000 scale were used as input data and the geomorphologic models were implemented using QGIS and SAGA GIS. The SAGA Wetness Index (SWI) is, as the name says, similar to the 'Topographic Wetness Index', but it is based on a modified catchment area calculation ('Modified Catchment Area'), which does consider water flow as very thin film. As a result, it predicts for cells situated in valley floors with a small vertical distance to a channel a more "realistic", higher potential soil moisture as compared to the standard TWI calculation." This leads to overestimating the flood prone areas extend which means a biased prediction towards a safer estimation of the areas which are prone to flooding.

The calculated values and the respective maps depicting the spatial distribution of TWI and Saga WI are given below. Flood prone areas are classified into "low" (yellow to green areas), and "high" (brown to red).

As can be seen, TWI and Saga WI values show similar areas with high flood "prone-ness". However due to above mentioned differences between Topographic Wetness

Index and SAGA Wetness Index methodology approaches in the case of SWI wider area is high flood probability which is, from our point of view, more realistic (fig. 99).

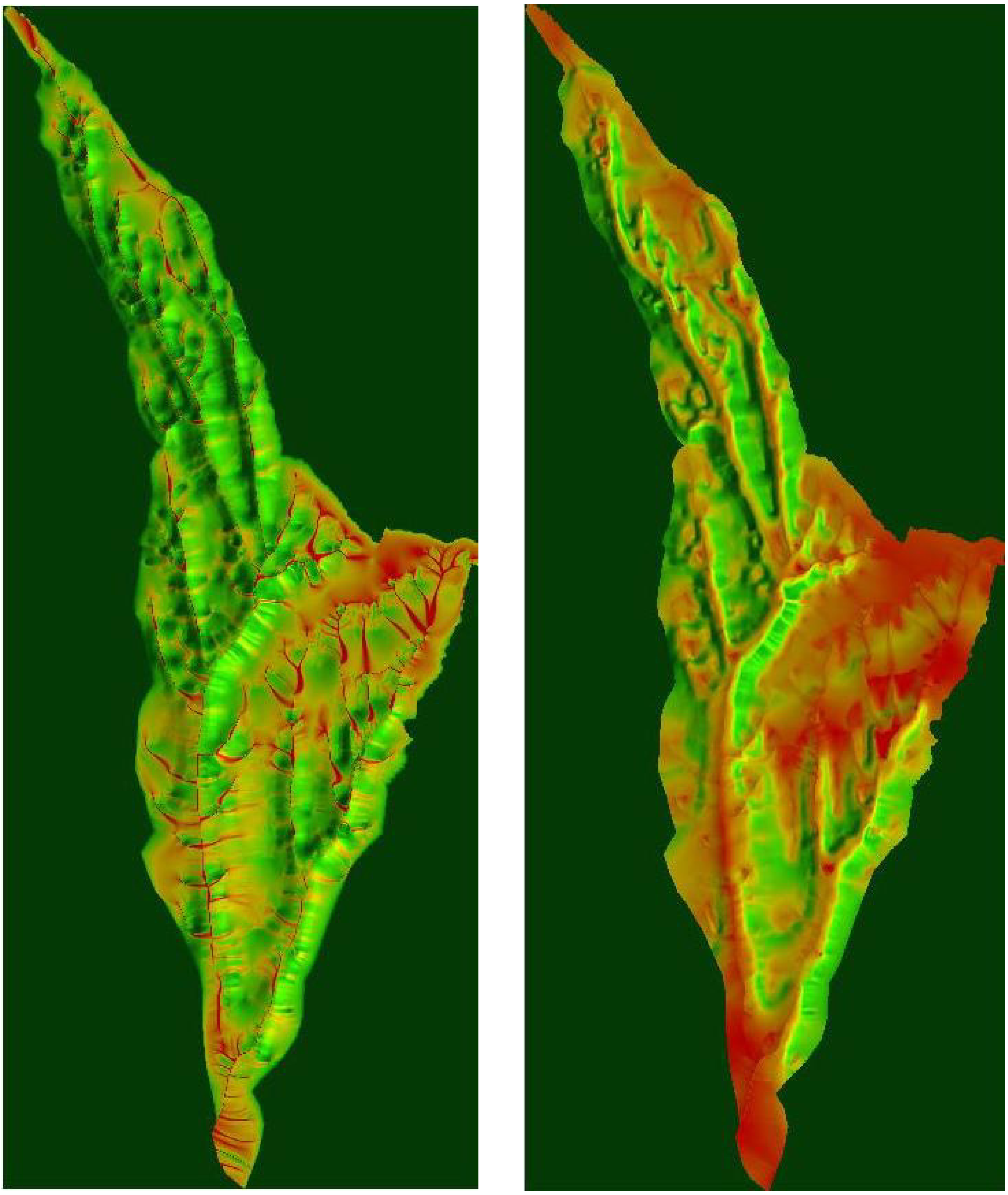


Fig 99. Geomorfologic model run at Aliyage river basin. Topographic Wetness Index (left) and SAGA TWI (right) of the river basin.

Another issue which has not been taken into consideration but may affect the final results is the fact that factors as obstacles, reservoirs etc have not been taken into account at the moment. It can be done after the field studies in order to receive up-to-date information about the area. However TWI and SWI modeling provides the ability to define areas with the high flooding potential (prone-ness) and take measures to reduce the potential flood damage.

In addition to the proposed methodology for regional scale FHA, the following methodology was also implemented.

For the regional flood risk assessment we used two of the most important concepts in terrain analysis: flow directions and flow accumulation. Flow accumulation quantifies how much water flows through each point of the terrain. Flow directions and flow accumulation can be used for evaluation of topographic convergence, drainage network, and watersheds (Fig. 100, 101 & 102).

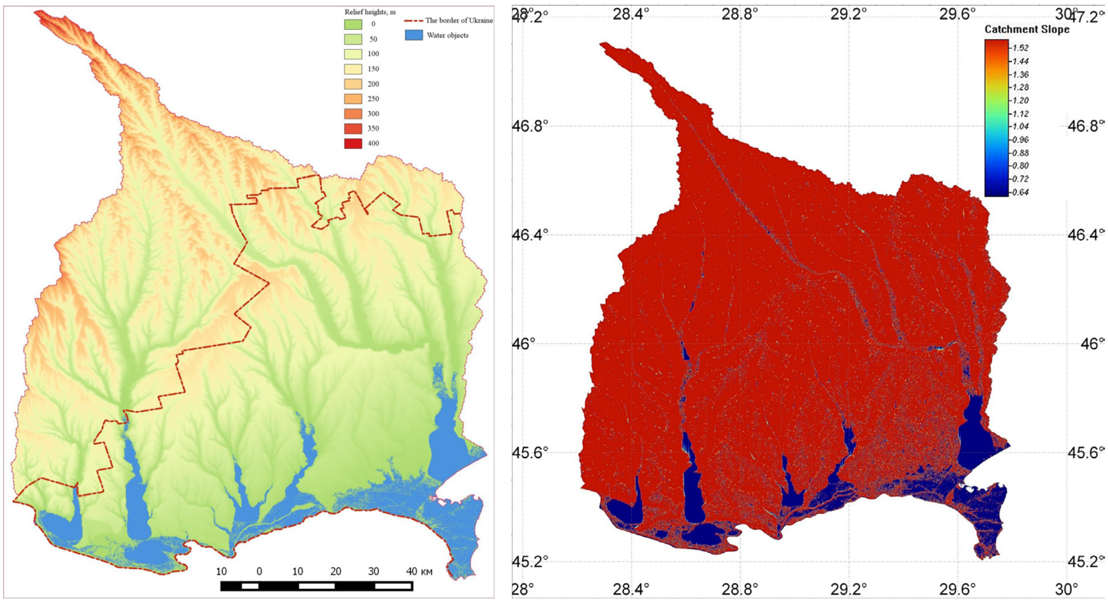


Fig 100. Digital elevation model of Danube Delta sub-basin which was based on SRTM data (left) and catchment slope map produced in SAGA GIS (right).

Flow direction was calculated using the GRASS GIS module «Flow computation for massive grids (integer version)» (r.terraflow.short) [http://grass.osgeo.org/grass64/manuals/r.terraflow.html]. «r.terraflow.short». This module takes as input a digital elevation model (DEM) and computes the flow direction raster and the flow accumulation raster, as well as the flooded elevation raster, sink-watershed raster (partition into watersheds around sinks) and tci (topographic convergence index) raster.

«r.terraflow» computes these rasters using well-known approaches, with the difference that it emphases on the computational complexity of the algorithms, rather than on modeling realistic flow.

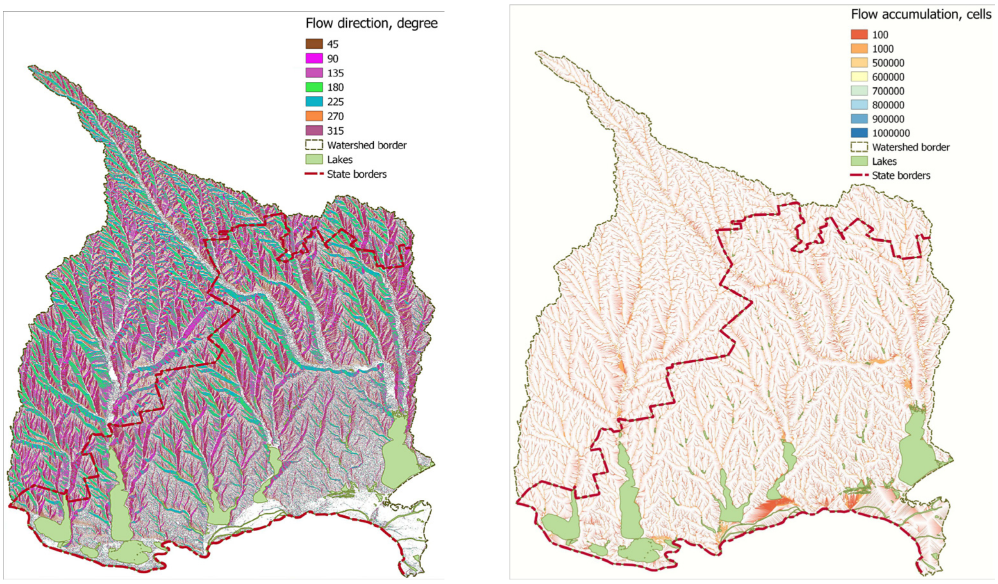


Fig 101. Flow direction (left) and flow accumulation (right) calculated using GRASS GIS routines.

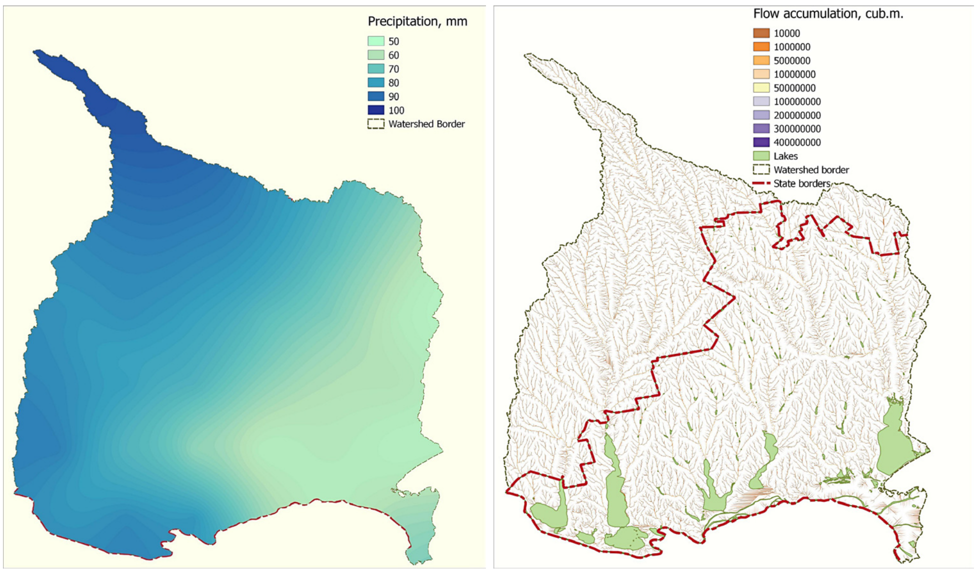


Fig 102. Precipitation in mm based on ENSEMBLES data (left) and potential flash flood water accumulation based on flow accumulation and precipitation used as weight coefficient (right).

Obstacles: bridges, dams, etc. were identified based on satellite images and Google Earth data. As resulted, areas where critical volume of water potentially can be stored were found. Finally, four classes of risk for settlements and infrastructure were identified based on the time of potential volume of water transmission (Fig. 103).

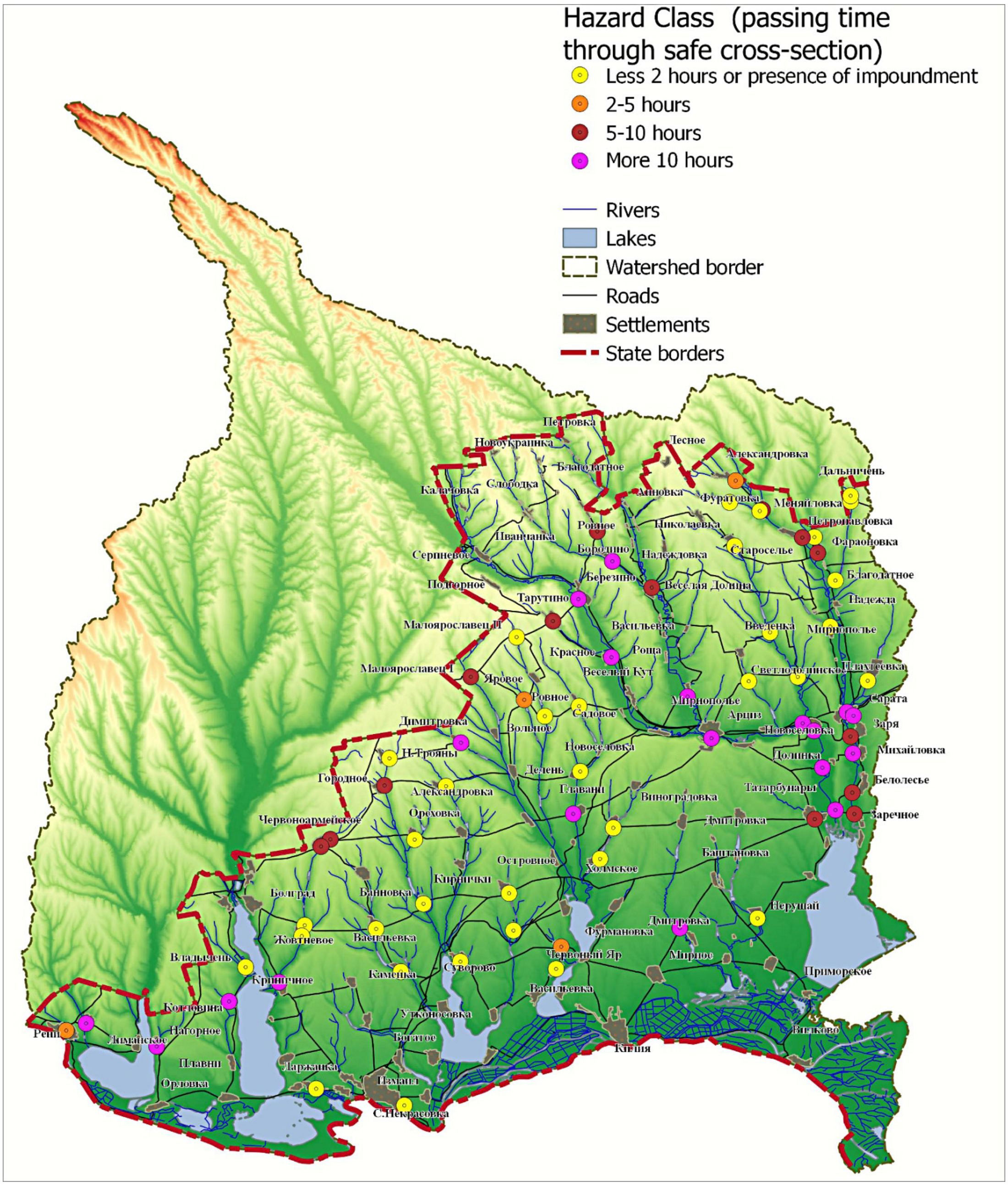


Fig 103. Flood Hazard classes based on flow accumulation, precipitation and the location of flow affecting structures (dams, bridges etc) of part of the Danube delta wider area.

9 EVALUATION OF THE PROPOSED METHODOLOGIES AND PROCEDURES

As in any case, reliability and accuracy of outputs is strongly dependent on the quality of data input and of course, on the methodologies used.

Having that in mind, every effort was made to ensure the maximum data input quality in order to be able to evaluate the performance of the methodologies used.

Coordinate Reference Systems transformations, digitization of the topographic maps 1:50.000 used in the regional FHA rainfall data processing, quality of surveying with GPS (quality of measurements and density of points measured) and all the respective to both the regional and the local FH assessments procedures, were conducted with maximum caution in order to impose the minimum possible errors into the calculations; always within the limits set by the respective specifications.

Evaluation of the proposed procedures is a twofold issue involving both the regional scale assessment which refers to the flood susceptibility and when combined with a preliminary risk assessment is used for strategic planning; and the local scale implementation which refers to the flood hazard and aims at providing support for planning preventive measures.

The final evaluation was based on the comparison of the proposed procedure outputs to actual flood event parameters both from a qualitative and a quantitative point of view.

Local Scale Flood Hazard Assessment is based on the world wide used HEC-RAS 1D hydraulic analysis model and software which allows to perform one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling (http://www.hec.usace.army.mil/software/hec-ras/features.aspx). The fact that the outputs of this model have been applied in numerous cases over the entire world in flood plain management and flood insurance studies, indicates the reliability and accuracy of the outputs it provides.

HEC-RAS analysis takes into consideration a number of additional parameters including rainfall and water flow for various re-occurrence periods and thus provides quantitative outputs regarding the flood extend (inundation area), flood water velocity and flood depth.

HEC-RAS outputs were compared to actual events recorded in the city of Serres at least four times during the past thirty years and twice during the last ten. In this specific case, HEC-RAS outputs fit exactly to actual facts as the flood progress which did not follow the stream bed but broke into the city through a specific city street, and the flood extend corresponding to a flood between the 25-year and the 50-year floods. A very tight fit between HEC-RAS outputs and flood events was also recorded in Eleonas stream (Serres, Greece).

The same conclusion is evident in the case of the Lovno-Ribarsko flood (Burgas, Bulgaria) where flood parameters calculated (flood extend, flood velocity) fit the flood event of October 2014 (Fig. 105).

Other cases of successful HEC-RAS calculation of the flood parameters is in the cases of Voinesti and Taita river cases in Dobrogea, Romania where the local scale flood hazard assessment (flood parameters calculated) assessed using the HEC-RAS hydraulic model, fit very well with those mapped in previous flood events.

Equally close estimations of the flood parameters to actual facts were found during the pilot implementations in Samsun area, Turkey.

As is therefore evident, the proposed methodology to calculate flood parameters on a local scale presents an excellent performance and can be used to reliably and accurately calculate flood parameters and thus support decisions regarding preventive measures.

The regional scale flood susceptibility assessment on the other hand, is based on a physically based model and on topography. The fact that it looks like a simple if not "simplistic" approach, immediately raises questions about the reliability and accuracy of its outputs.

The Topographic Wetness Index (TWI) has been proposed to predict quick response flow by using morphometric parameters ([1]; [3]; [4]) but has been used since to delineate flood prone areas ([7]; [8]; [9]; [10]; [59]). The same stands for SAGA Wetness Index [5] which is very similar to TWI but it is consider to predict for areas (cells in a GIS), a more realistic and higher potential soil moisture than TWI; thus a more extended flood prone area.

Both indices provide **qualitative information** since they do not take into consideration any qualitative data (rainfall, flow etc.). They do in fact indicate, with their highest values, which areas are going to be the first to flood. In that respect, they present a gradation of areas which are going to flood consequently (higher to lower Index values) in respect to different rainfall and flow conditions. This very interesting fact has been shown in this project and in previous research [70] by comparing TWI outputs for entire river basins (pilot implementations in Serres, Burgas, Taita and Voinesti rivers in Romania, Tekirdag and Samsun in Turkey) to the respective outputs of hydraulic models as the HEC-RAS.

TWI has shown an impressively good performance to indicating the flood progress (direction) as in all the aforementioned cases and especially and especially in Agioi Anargyroi stream (Fig. 104) where flooding was indicated to break out of the river bed and follow a different direction towards the city of Serres.

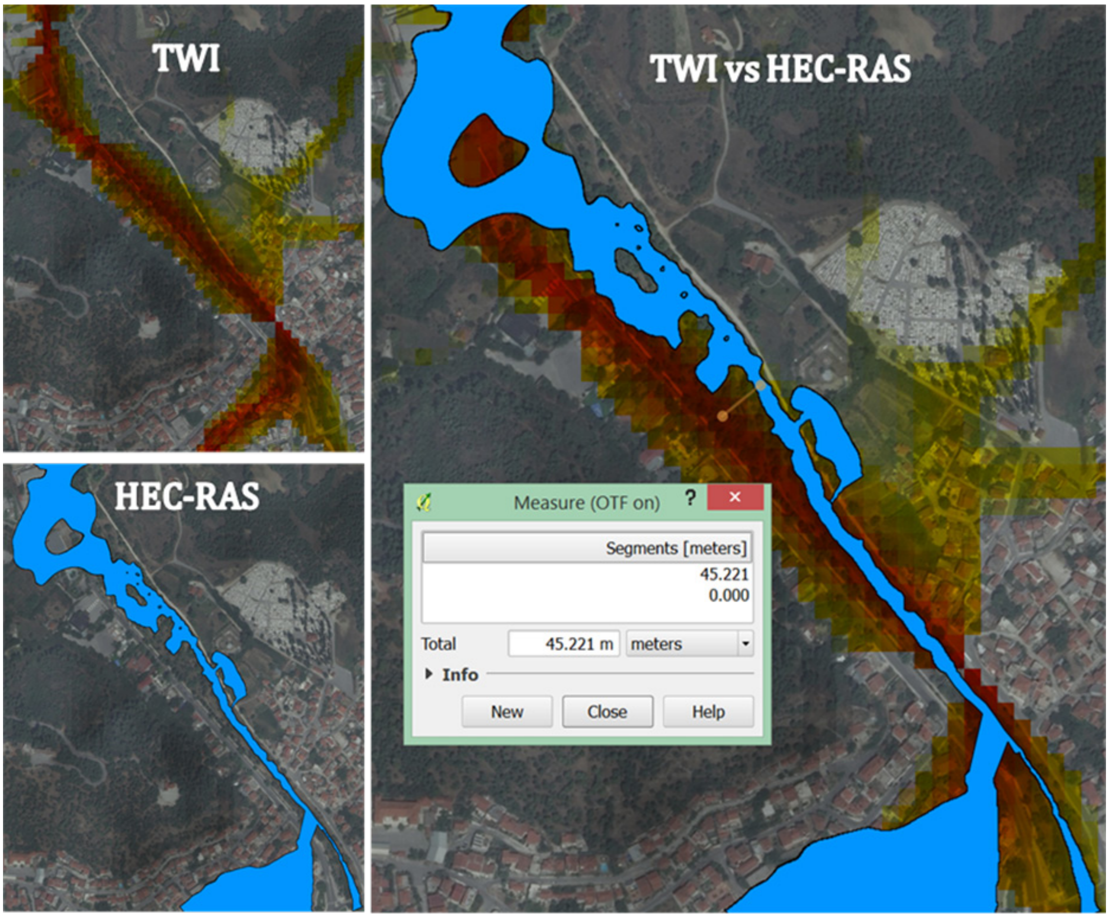


Fig 104. Comparison of TWI to HEC-RAS outputs for the 50-year flood. From the superposition of outputs it is evident that the TWI defines as flood prone area the city instead of the stream bed as does the HEC-RAS hydraulic model. These assessments fully agree with actual facts repeated twice during the last 10 years**.**

As shown in Fig. 104 (right image) the maximum distance between the assessed TWI flood prone area and the flood extend for the 50-year flood is 45m, which to a 1:50.000 topographic map corresponds to less than 1mm. This is considered as impressively close estimation since the digitized topographic maps of the area had to be transformed from European 1950 Coordinate Reference System to GGRS 1987, a procedure which alone imposes an error of 10-12m. Most impressive is the fact that the TWI calculation is based on topographic data only (1:50.000) whereas the HEC-RAS assessment is based on topographic map of 1:500 scale and rainfall data analysis.

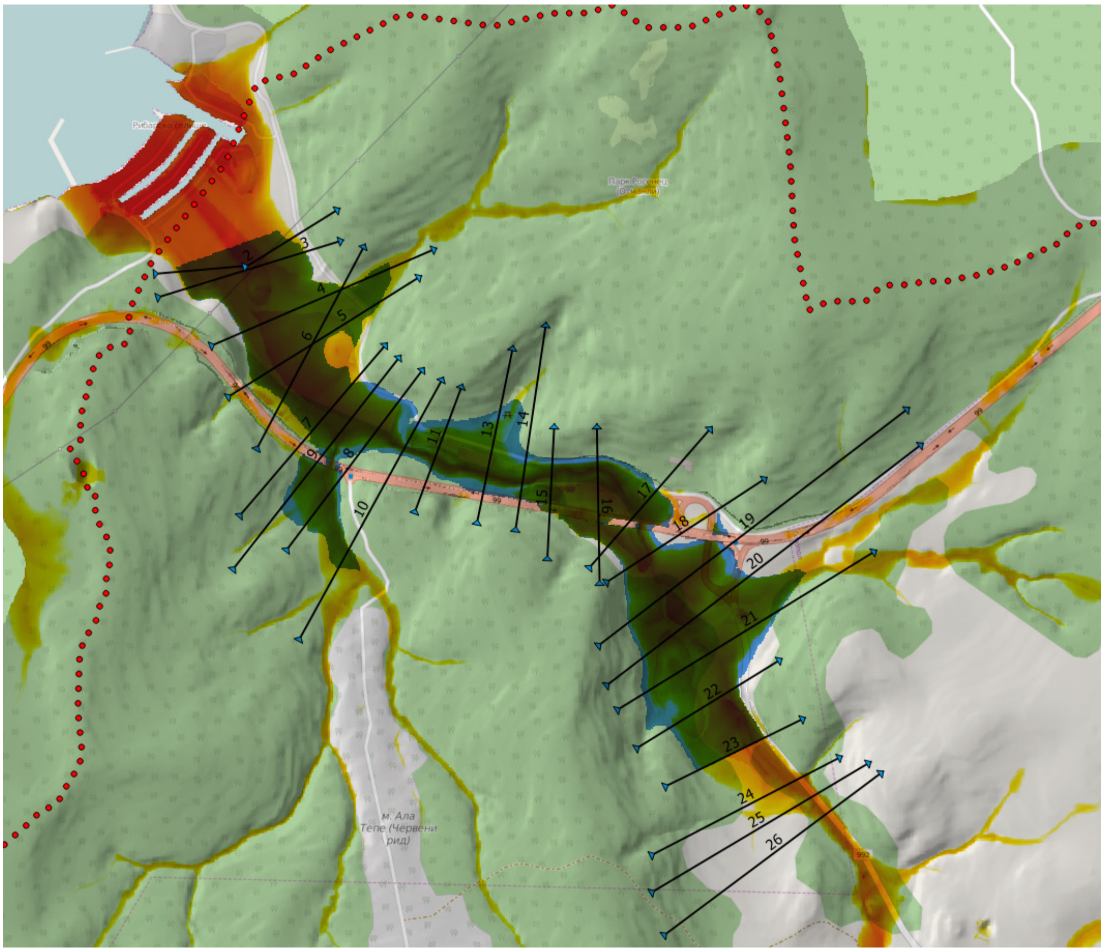


Fig 105. Flood extend for a 50-year flood calculated using HEC-RAS (blue area) superimposed over SAGA Wetness Index, in Park Rosenets, Ribarsko, Burgas. The same scale (1:2500) maps were used for both assessments.

As is therefore evident, the use of TWI can help reliably define the flood prone areas at a regional scale. A preliminary risk assessment can then be carried out by combining this information with ancillary data regarding important installations and other assets at risk as well as by using freely available aerial photos and satellite images.

Having said the above, TWI can by no means replace the implementation of the hydraulic model on a local scale.

Flood parameters have to be quantitatively defined using rainfall and hydrologic data and a very accurate surface model including all potential blocks to flood water.

10 COMPLIANCE TO STANDING REGULATIONS/THE "FLOOD" DRECTIVE

An additional important aspect to be considered when proposing a methodology to be used, is its compliance to standing regulations. In respect to floods, the most current regulations have been set by the 2007/60/EC "Flood" Directive (European Parliament and Council, 2007).

According to the "flood" directive, all Member States will, by 2011, undertake a preliminary flood risk assessment of their river basins and associated coastal zones, in order to identify areas of potential significant flood risk.

At a second stage, they must by 2013, develop Flood Hazard (FH) maps and Flood Risk (FR) maps for those areas in order to identify areas with a medium likelihood of flooding (100-year event) as well as for extreme event (low likelihood events), in which expected water depths should be indicated.

At a next step, the number of inhabitants at risk, the economic activity and the environmental damage potential should be indicated at those areas at risk.

Finally, by 2015, Flood Risk management plans must be drawn for these zones. These plans should include measures to reduce the probability of flooding and its potential consequences and should address all phases of the flood risk management cycle particularly focusing on **Prevention** (land use management, spatial development), protection (taking measures to reduce the likelihood of flooding and the impact of floods) and **preparedness**.

What has actually been done regarding the implementation of the "Flood" Directive, is presented in the Commission Staff Working Document: Report on the progress in implementation of the Floods Directive, issued on 09.03.2015 (European Commission, 2015). In brief, instead of a common approach to solve a common problem which could lead to a sustainable and transparent cooperation among them, each EU member state has opted for its own individual approach. Eighteen of them followed the "Flood" Directive provisions and the rest have presented existing reports or have followed different approaches. Twenty two of the member countries have used flood inventories and created flood hazard maps mainly for floods in rivers whereas some took into consideration flood causes which are not included in the Directive (European Commission, 2015).

As far as the inventories created is concerned, most of the historic data are very recent (60% of the entire number of reported floods were recorded from 2000 onwards and an additional percentage of around 30% was recorded during 1950-1999 (data from the European Commission Report, 2015). Floods recorded were river water floods (66% of events), surface water flooding from heavy rainfall (20%) and coastal floods (16%). As is evident from the above, floods in rivers and moreover, flood events of the last 15 years were mostly taken into consideration.

This fact shows that flash floods, which are the prominent type of floods around the Mediterranean and the Black Sea countries causing serious damage every year thus affecting people’s lives, property and infrastructure, were not really taken into account. Flash floods mostly occur in ephemeral streams so no gauge data are available.

The proposed methodology responds exactly to the “flood” directive demands: preliminary risk assessment based on a regional scale assessment of flood prone areas regardless of the type of flood hazard examined (riverine or flash flood in ephemeral streams). Moreover it can fulfil this task with minimal data requirements thus overcoming the “information gap” or lack of data. The use of Open Source/Freeware software and the use of topographic data (and freely available ancillary data as high resolution satellite images and aerial photographs) minimize both time and cost of implementation providing a common platform on which the preliminary flood risk assessment can be based.

Results of this stage are reliable and accurate enough to lead to decisions regarding the prioritization of areas needing applied research on local scales; where additional data (implying cost in time and money) are necessary.

State authorities (including regional and local administration) can benefit from these outputs for strategic planning (ie. local scale implementation; land use planning etc) flood disaster prevention actions.

The final stage of applied research on a local scale leads to calculating all important flood related parameters including flood extend (inundation area delineation), flood water depth mapping, flood water velocity mapping and flood risk assessment so that typical effective preventive measures can be designed.

11 CONCLUSIONS

The overview (D.01.02) on the main methodologies used worldwide has provided a scientific base necessary to improve the understanding of the flood hazard mapping and the implementation of the respective methodologies. The implementation of the selected methodologies on regional scales and especially the applied research on local scale, have led to the following conclusions presented herein and discussed in chapter 12 of the present deliverable.

Two supplementary approaches to assess Flood Hazard on Regional and on Local scales and calculate important flood parameters including the flood extent (inundation area), the flood water depth and the flood water velocity in order to design preventive measures, were fully applied in seven different river basins in six different countries (two in Greece, one in Bulgaria, one in Romania, one in Moldova and one in Turkey). Based on the evaluation of the reliability and accuracy assessment of the FHA on regional scales, flood prone areas (regional scale assessment) were delineated in nine **additional** river basins (one in Romania, one in Ukraine and eight in Turkey).

The supplementary methodologies used to locate and delineate flood prone areas include the:

- Topographic Wetness Index (based on TOPMODEL) and the SAGA WI geomorphological models.
- HEC-RAS hydraulic model by taking into consideration 10, 50, 100 and 1000 years return periods.

Comparison of the results of the models used, showed a remarkable convergence in the delineation of the inundation (flooded) area despite the fact that these two models have very different input data requirements and more importantly the fact that the geomorphological model provides only qualitative outputs whereas the hydraulic provides both qualitative and most importantly, quantitative outputs.

As it appears, the geomorphological model can be used to provide a reliable location of flood prone areas at a preliminary stage of assessing the Flood Hazard, in order to help focus on the areas within stream catchments, where it's necessary to assess the flood risk at a second stage.

Taking into consideration that the geomorphological model used has minimal data requirements and moreover that the required data are readily available (topographic maps at various scales or even ASTER DEMs), this model can be used to reliably delineate flood prone areas on a regional scale in order to proceed with Risk assessment on a local scale to selected (high risk) areas.

State authorities (including regional and local administration) can benefit from these outputs for strategic planning (ie. local scale implementation; land use planning etc) flood disaster prevention actions.

This first stage of "flood susceptibility assessment" covers the first step of the "Floods" directive (Chapter II, Articles 4 & 5), overcoming the issue of "non-existent" information regarding flash floods (since inventories mostly refer to riverine floods). Moreover, it can be applied anywhere since it requires a minimum amount of data (just topographic maps) and provides a consistent way of assessing this parameter.

The development of a flexible Geographic Information System and the adoption of Open Source software (Quantum GIS) for the entire process, provide easy access and processing to additional information regarding demographic and economic data, high risk installations etc so that the entire procedure can be concluded using only one tool.

At the second stage, the HEC-RAS hydraulic model is implemented on site-specific (local) scale in order to accurately estimate the flooding parameters (inundation area, depth, flood water velocity, flood risk etc.), thus helping make decisions about designing effective preventive measures. These exact parameters calculated for various re-occurrence periods are the ones required by the "Flood" Directive (Chapter III, Article 6), thus the proposed methodology fully covers this part too.

The entire proposed procedure helps focus from a "Regional" FHA, useful for strategic planning (including land use planning and flood disaster prevention planning) to a "local", which can support decisions regarding planning preventive measures. Therefore, the outputs of the proposed methodology fully cover the principles of "Prevention" and "Protection" which are the main targets set by the Flood Directive and also positively affects "preparedness" (the third one).

As the cost of implementation is minimized by using open source software and already available data, experts working in the respective field can produce outputs in a very limited time. State, regional and local authorities, the scientific community and experts can form a team which can work together sharing competencies and supporting each other to provide Flood Susceptibility, Flood Hazard and Risk maps covering large areas in a very short period with a very low cost restricted in rainfall data and large scale topographic maps for the areas selected for FHA on a local scale.

As is therefore evident, the methodology proposed completely covers the requirements of the Flood Directive and can form a common platform to reliably and accurately assess Flood Hazard and effectively design typical preventive measures. Given the progress made regarding the implementation of the "flood" directive so far, the proposed methodology can support a harmonized implementation which will lead to a closer cooperation among member states and neighbouring countries, in order to address, especially in cross border areas, common problems using common solutions.

11.1 DISCUSSION

Concerning the geomorphological models, further studies are necessary in order to minimize the errors of supra- sub estimation. This methodology can be used in areas where detailed information about the floods extension exists. The indices used by the geomorphological model are very sensitive to the DEM resolution. Further analysis of this impact in terms of using elevation data of different scales (1:5000, 1:50,000, ASTER DEM and STRMs) will provide valuable information regarding this issue. LiDAR and high spatial resolution remote sensing images can be a solution in order to improve the DEM's resolution and thus the accuracy of their outputs.

The deterministic physical-based hydrological models have proven their value especially in research activities in order to better understand the hydrologic processes or how the climatic and anthropogenic changes can influence the hydrological response of the catchment.

For ungauged basins these models can be used as far as some the data can be transferred from gauged basins. Undoubtedly, the existing technologies (such the radar rainfall estimator or satellite observations systems) offer rainfall data which can be used in hydrological modeling in "data-lacking" regions. Advances in thermal imagery technology provide the capability of obtaining data regarding soil moisture. Remote Sensing techniques can be used to effectively obtain data in order to estimate evapotranspiration parameters. In the bottom line, all of these models can provide assistance in understanding the hydrological functioning of a basin and less in the actual floodplain modeling.

The hydrodynamic models require discharge data in order to provide boundary conditions. For ungauged basins, discharge data are unavailable. In this case, the conceptual hydrological models can provide solutions and information as the maximum discharge or the hydrograph for a given cross-section. Further studies must be focused on the Unit Hydrograph model calibration/validation, on the Curve Number (CN) control of the rainfall-runoff transformation. In order to improve the results obtained, a grid CN modified for Romanian conditions will be performed in GIS environment.

The roughness coefficient is another important parameter for hydrodynamic models. The spatial distribution of the roughness coefficient is necessary in order to improve the accuracy of the implemented hydraulic model results. The future studies shall focus on the use of LiDAR, orthophotos and CORINE land cover in order to obtain this parameter.

High-quality topographic data are an absolute necessity in site-specific implementations of hydraulic/hydrodynamic models in order to accurately assess the flood parameters (inundation area, depth of water, etc.). The use of LiDAR data and drones (photogrammetric surveying using aerial photography and GPS measurements) can reduce acquisition time and provide very accurate data.

12 PRELIMINARY PUBLICATIONS

Papatheodorou K., Tzanou E., Ntouros K. "Flash Flood Hazard Prevention using Morphometric and Hydraulic models. An example implementation." *International Congress on "Green Infrastructure and Sustainable Socities/Cities" GreInSus' 14*. May 2014.

Maftei C., Papatheodorou K., Mapping the flash flood prone area in the Taita watershed (Romania) using topographic indexes and hydraulic model, Second International Conference on NATURAL AND ANTHROPIC RISKS ICNAR2014 04-07 June 2014.

Aksoy H, Kirca VSO, Papatheodorou K (2014) Flood hazard assessment and modelling practices in Turkey. Proceedings of the Mediterranean Meeting on 'Monitoring , modelling and early warning of extreme events triggered by heavy rainfall', University of Calabria, Cosenza, Italy, June 26-28, 2014, pp.205-214.

Papatheodorou K., Tzanou E., Maftei C., Kirca O. and Aksoy H., Towards flash flood disaster prevention: the SciNetNat Haz proposal, Geophysical Research Abstracts Vol. 17, EGU2015-15176, 2015

Maftei C., Papatheodorou K., Flash flood prone area assessment using geomorphologic and hydraulic models, Journal of Environmental Protection and Ecology (JEPE), Vol. 16(1), pp. 63-75, ISSN 1311-5065, 2015

Maftei C., Papatheodorou K., Mathematical models used for hydrological floodplain modeling in Maftei, Carmen (Ed). "Extreme Weather and Impacts of Climate Change on Water Resources in the Dobrogea Region." IGI Global, 2015.

Stepanova K., Rubel O. Methodolody used in Ukraine for natural hazards assessment (Sarata river case study). International U.A.B. – B.EN.A. Conference on Environmental Engineering and Sustainable Development, Alba Iulia, May 28-30, 2015

Ermis IS (2015) Determination of flood-prone areas with topographic wetness indices in the river basins. Istanbul Technical University, Institute of Science and Technology, Istanbul, June 2015, 65 p. (in Turkish).

Aksoy H, Kirca VSO, Burgan HI, Kellecioglu D, Ermis IS (2015) Determination of flood-prone areas by soil wetness index in river basins. 8th National Hydrology Congress, Şanlıurfa, October 8-10, 2015, pp. 424-429 (in Turkish).

Burgan HI, Kellecioglu D, Aksoy H, Kirca VSO (2015) GIS-supported flood hydraulic model. 4th Water Structures Symposium, Antalya, November 19-21, 2015, pp. 260-267 (in Turkish).

Stepanov V., Stepanova K., Cheroy A. Flood management and mitigation practices for coastal regions of Ukraine. Scientific Bulletin of International Humanitarian University. Series Economic and management. № 9, pp. 37-42, 2015

13 REFFERENCES

[1] Beven, K. J., and M. J. Kirkby. "A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant." *Hydrological Sciences Journal* 24.1 (1979): 43-69.

[2] Beven, K., Warren R., Zaqui J. (1980): "SHE: towards a methodology for physically-based distributed forecasting in hydrology." IAHS Publ 129 (1980): 133-137.

[3] Moore, I. D., Burch, G. J., and Mackenzie, D. H.: 'Topographic effects on the distribution of surface soil water and the location of ephemeral gullies', Trans. Am. Soc. Agr. Engrs., 31 (1988):1098- 1107

[4] Sørensen, R., U. Zinko, and J. Seibert. "On the calculation of the topographic wetness index: evaluation of different methods based on field observations." *Hydrology and Earth System Sciences Discussions Discussions* 2.4 (2005): 1807-1834.

[5] Boehner, J., Koethe, R. Conrad, O., Gross, J., Ringeler, A., Selige, T.: Soil Regionalisation by Means of Terrain Analysis and Process Parameterisation. In: Micheli, E., Nachtergaele, F., Montanarella, L. [Ed.]: Soil Classification 2001. European Soil Bureau, Research Report No. 7, EUR 20398 EN, Luxembourg. pp.213-222, (2002)

[6] Böhner, Jürgen, and Thomas Selige. "Spatial prediction of soil attributes using terrain analysis and climate regionalisation." *Gottinger Geographische Abhandlungen* 115 (2006): 13-28.

[7] Dong, Lu. *Evaluation of high quality topographic data for geomorphological and flood impact studies in upland area: North York Moors, UK*. Diss. Durham University, 2006.

[8] Versini, P-A., E. Gaume, and H. Andrieu. "Assessment of the susceptibility of roads to flooding based on geographical information–test in a flash flood prone area (the Gard region, France)." *Nat. Hazards Earth Syst. Sci* 10 (2010): 793-803.

[9] Manfreda S., Di Leo M., Sole A.: Detection of Flood-Prone Areas Using Digital Elevation Models. Journal of Hydrologic Engineering, 16 (10):781-790, 2011, (2011).

[10] Rafael De Risi (2013): “A Probabilistic bi-scale framework for Urban Flood Risk Assessment, PhD Thesis, Dept. of Structures for Engineering and Architecture, University of Naples Federico II, p.198, Naples.

[11] De Risi, Raffaele, et al. "Delineation of flood-prone areas and the identification of residential hotspots for two African cities." *EGU General Assembly Conference Abstracts*. Vol. 15. 2013.

[12] Papatheodorou K., Tzanou E., Ntouros K. "Flash Flood Hazard Prevention using Morphometric and Hydraulic models. An example implementation." *International Congress on “Green Infrastructure and Sustainable Socities/Cities” GreInSus’ 14*. 2014.

[13] European Commission: Research and innovation: Workshop on “RESEARCH: Floods!: Managing the risks of flooding in Europe. Conference Proceedings, (2006)

[14] European Commission DG Environment (2008): “Assessing the Potential for a Comprehensive Community Strategy for the prevention of Natural and Manmade Disasters”. Final Report, March 2008.

[15] Council of the European Union (2009): Council Conclusions on a Community framework on disaster prevention within the EU 2979th JUSTICE and HOME AFFAIRS Council meeting, Brussels, 30 November 2009

[16] Clark Ian, (European Commission): Towards an EU Policy on Disaster Management, Brussels 2012.

[17] K. Papatheodorou, N. Klimis, B. Margaris, K. Ntouros, K. Evangelidis, A. Konstantinidis. “An Overview of the EU Actions towards Natural Hazard Prevention and Management: Current Status and Future Trends”. *Journal of Environmental Protection and Ecology* 15.2 (2014): 433-444.

[18] Al Hassoun, Saleh A. "Developing an empirical formulae to estimate rainfall intensity in Riyadh region." Journal of King Saud University-Engineering Sciences 23.2 (2011): 81-88.

[19] V.T. Chow, D.R. Maidment, L.W. Mays, Applied Hydrology, McGraw-Hill, New York (1988).

[20] Keifer, Clint J., and Henry Hsien Chu. "Synthetic storm pattern for drainage design." Journal of the hydraulics division 83.4 (1957): 1-25.

[21] Nguyen, V. T. V., T. D. Nguyen, and H. Wang. "Regional estimation of short duration rainfall extremes." Water science and technology 37.11 (1998): 15-19.

[22] E.M. Castrogiovanni, G. La Loggia, L.V. Noto. "Design storm prediction and hydrologic modeling using a web-GIS approach on a free-software platform." Atmospheric Research 77.1 (2005): 367-377.

[23] Gumbel, E. J. "Statistical theory of floods and droughts." Journal of the Institution of Water Enigneers and Scientists 12 (1958): 157-184.

[24] Kuichling, Emil. "The relation between the rainfall and the discharge of sewers in populous districts." Transactions of the American Society of Civil Engineers 20.1 (1889): 1-56.

[25] Nikolova, M., and Nedkov, S., 2102. Flood Risk. GIS modeling of Environmental Changes for Flood Risk Assessment. TerArt, 247 pp.

[26] Onoz, B., Kabdasli, S, Varol, O.E., YUce, A., Bora, O.: 'Report on assessment of flood characteristics and risks due to Akc¸ay River for OMV Gas & Power'. Technical report by ITU and CEC, NO. C-1209047, (2012).

[27] U.S. Department of the Army, Corps of Engineers, Engineering Manual No.1110-1-1415, Hydrologic Frequency Analysis, 1993.

[28] U.S. Department of the Interior, Geological Survey, PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines, 1998.

[29] WMO, 2013, Integrated Flood Management Tools Series: Flood Mapping No.20 retrieved from, http://www.apfm.info/publications/tools/APFM_Tool_20.pdf

[30] Kite, G.W., Frequency and Risk Analysis, New York: Water Resources Publications, 1999.

[31] Maidment, D.R. (Editor in Chief), Handbook of Hydrology, New York: McGraw-Hill, Inc., 1993.

[32] Riggs H.C., 1973. Regional analyses of streamflow characteristics: Technique of Water Resources Investigation of the U.S. Geological Survey, Book 4, chapter B3, 15p, av. on http://pubs.usgs.gov/twri/twri4b3

[33] Tasker GD., 1982, Simplified testing of hydrologic regression regions., Journal of Hydraulic Division, Proceedings of the American Society of Civil engineering, v. 108. no HY10, p.1218-1222.

[34] Tasker G.D., Stendinger J.R., 1989, An operational GLS model for hydrologic regression, Journal of Hydroogy 111, 361-375.

[35] Tasker GD., Slade R.M., 1994, An interactive regional regression approach to estimating flood quantiles, in Fontaine DG and Tuvel HN eds. Water policy and management, solving the problems, Proceeding of the 21 Annual Conference, May 23-26, 1994: Denver Society of ASCE, p 782-785.

[36] Tasker G.D., Hodge SA, Barks CS, 1996, Region of influence regression for estimating the 50-year flood at ungaged sites: Water Resource Bulletin 32, 163-170.

[37] Law GS, Tasker GD, 2003, Flood frequency prediction methods for unregulated streams of Tennessee, 2000, US Geological Survey Water Resources Investigation Report 03-4176, 79p, av. on http://pubs.usgs.gov.wri/wri034176.

[38] Law GS, Tasker GD, Gladd DE, 2009, Stream Flow Characteristic Estimation methods for Unregulated Streams of Tennessee, US Geological Survey Scientific Investigation Report 2009-5159, 212 p., av. on: http://pubs.usgs.gov/sir/2009/5159

[39] Kennon, F.W., 1954, Magnitude and frequency of summer floods in western New Mexico and eastern Arizona: U.S. Geological Survey open-file report, 15 p.

[40] Dalrymple, Tate, 1960, Flood-frequency analyses: U.S. Geological Survey Water-Supply Paper 1543-A, 80 p.

[41] Butler, Elmer, Reid, J.K., and Berwick, V.K., 1966, Magnitude and frequency of floods in the United States part 10. The Great Basin: U.S. Geological Survey Water-Supply Paper 1684,256 p.

[42] Moore, D.O., 1976, Estimating peak discharge from small drainages in Nevada according to basin areas within elevation zones: Nevada Highway Department Hydrologic Report 3, 17 p.

[43] Mulvaney, T.J., 1850. On the use of self-registering rain and flood gauges. Trans. Inst. Civ. Eng. Ireland, 4(2): 1-8.

[44] Sherman, L.K., 1932. Streamflow from rainfall by the unit-graph method. Engineering News Record, 108: 501-505.

[45] U.S. Army Corps of Engineers. (2013 December). Hydrological Modeling System, HEC-HMS. User's Manual. Retrieved from http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Users_Manual_4.0.pdf.

[46] Metcalf and Eddy, 1971, Water Resources Engineers, and University of Florida. Storm Water Management Model, US EPA, Washington, D.C. Vol. I - Final Report, 11024DOC 7/71. Vol. II - Verification and Testing, 11024DOC 8/71. Vol. III - User's Manual, 11024DOC 9/71. Vol. IV - Program Listing, 11024DOC 10/71.

[47] DHI, 2000a, MIKE 11 a modelling system for rivers and channels. DHI Water and Environment, 82 p.

[48] DHI, 2000b, MIKE SHE Flow Modules, Technical Reference. DHI Water and Environment, 174 p.

[49] Lindström, G., Johansson, B., Persson, M., Gardelin, M., Bergström, S. (1997). Development and test of the distributed HBV-96 hydrological model. Journal of Hydrology 201, pp.272-288.

[50] De Roo, A.P.J., Wesseling, C.G. and Van Deursen, W.P.A. (2000) Physically based river basin modelling within a GIS: The LISFLOOD model. Hydrological Processes, 14, pp. 1981–1992.

[51] Van der Knijff J.M., J. Younis and A.P.J. De Roo (2010) LISFLOOD: a GIS-based distributed model for river-basin scale water balance and flood simulation. International Journal of Geographical Information Science, Vol. 24, No.2, 189-212.

[52] Todini, E. Ciarapica L., The TOPKAPI model. In V. P. Singh et al. (eds.) Mathematical Models of Large Watershed Hydrology (Ch. 12). Water Resources Publications, Littleton, Colorado, 2001.

[53] Ciarapica L., Todini E., 2002, TOPKAPI: a model for the representation of the rainfall-runoff process at different scales, Hydrol. Proc., 16, 2, 207–229

[54] U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-IP-85-15, Hydraulic Design of Highway Culverts, 1985.

[55] DHI, 2003, DHI Software. Modeling the world of water. URL: http://www.dhisoftware.com/index.htm

[56] Galland, J.C.; Goutal, N.; Hervouet, J.M., 1991, "TELEMAC: A New Numerical Model for Solving Shallow Water Equations", Advances in Water Resources AWREDI 14 (3): 138–148, doi:10.1016/0309-1708(91)90006-A

[57] U.S. Army Corps of Engineers. (2010 January). HEC-RAS River Analysis System, User's Manual, Retrieved http://www.hec.usace.army.mil/software/hec-ras/documentation.

[58] US Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS, River Analysis System, User's Manual Version 2.0, April 1997 and HEC-RAS computer program, Version 2.2.

[59] Qin C.Z., Zhu A.X., Pei T., Li B.L., Scholten T., Behrens T., Zhou C.H.: An approach to computing topographic wetness index based on maximum downslope gradient. Precision Agric, 12:32–43, DOI 10.1007/s11119-009- 9152-y, (2011).

[60] Păltineanu, CR., Mihăilescu, I.F., Seceleanu, I., 2000, Dobrogea - condiţiile pedoclimatice, consumul şi necesarul apei de irigaţii pentru principalele culturi agricole, Edit. ExPonto, Constanţa.

[61] Maftei C., Bărbulescu A., 2008, *Statistical analysis of climate evolution in Dobrudja region*, Lecture Notes in Engineering and Computer Sciences, vol.II, pp. 1082 – 1087

[62] Maftei C., Barbulescu A., Hubert P., Dobrica G., 2012, Statistical Analysis of the Precipitation from Consțan (Romania) Meteorological Station, in Recent Researches in Applied Computers and Computational Science, the 11th WSEAS

International Conference on Applied Computer and Applied Computational Science (ACACOS '12), Rovaniemi Finlanda, pp. 52-57., ISBN: 978-1-61804-084-8.

[63] Lee, Seungyong, George Wolberg, and Sung Yong Shin. "Scattered data interpolation with multilevel B-splines." Visualization and Computer Graphics, IEEE Transactions on 3.3 (1997): 228-244.

[64] Carluer, Nadia. Vers une modélisation hydrologique adaptée à l'évaluation des pollutions diffuses: prise en compte du réseau anthropique. Application au bassin versant de Naizin(Morbihan). Diss. 1998.

[65] Engman, Edwin T. "Roughness coefficients for routing surface runoff." *Journal of Irrigation and Drainage Engineering* 112.1 (1986): 39-53.

[66] Wicks, J. M., J. C. Bathurst, and C. W. Johnson. "Calibrating SHE soil-erosion model for different land covers." *Journal of irrigation and drainage engineering* 118.5 (1992): 708-723.

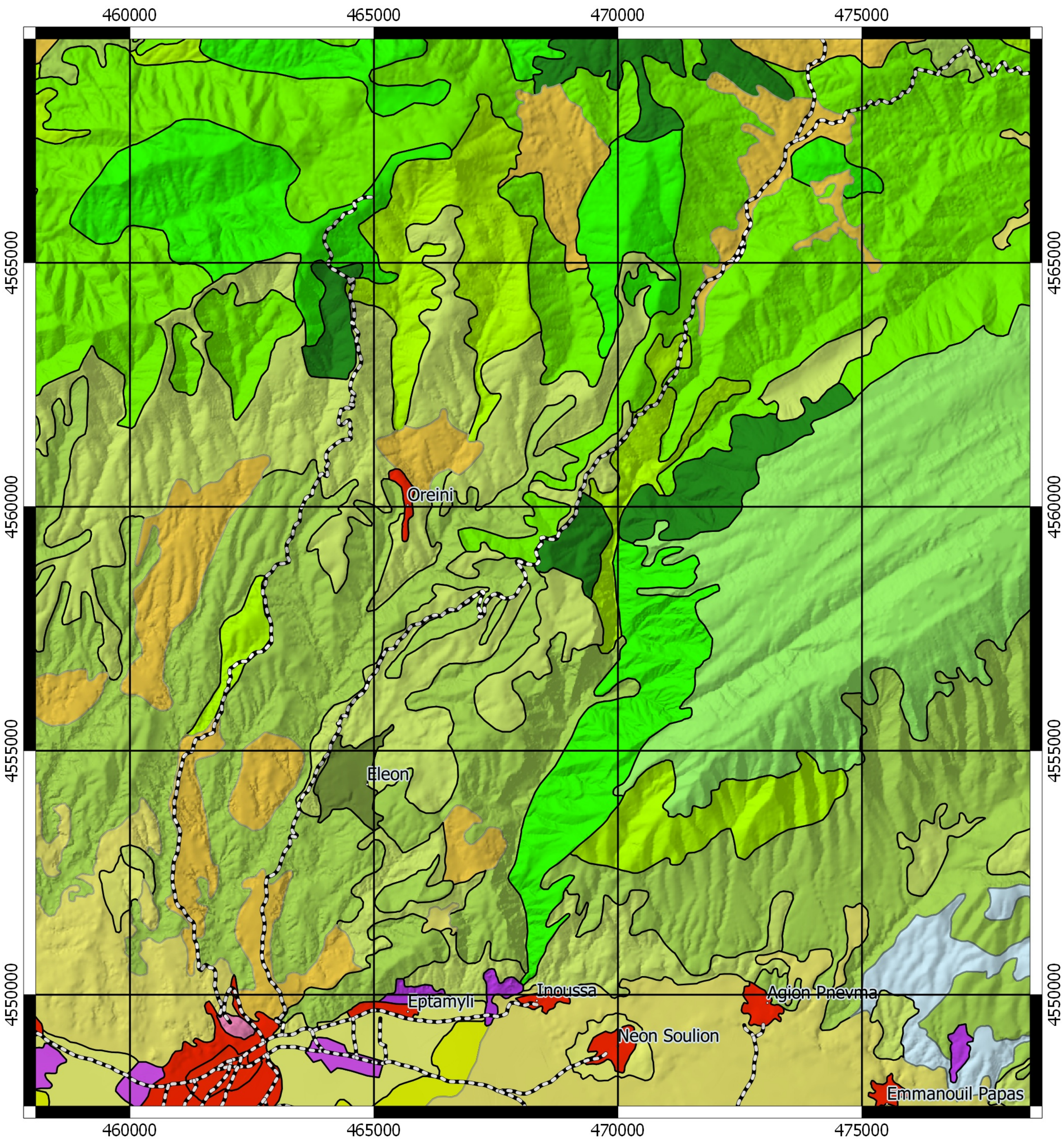
[67] Chow, Ven Te, 1959, Open-channel hydraulics: New York, McGraw-Hill, 680 p

[68] Carluer, Nadia, and Ghislain De Marsily. "Assessment and modelling of the influence of man-made networks on the hydrology of a small watershed: implications for fast flow components, water quality and landscape management." *Journal of Hydrology* 285.1 (2004): 76-95.

[69] Bailly, J. S., et al. "Agrarian landscapes linear features detection from LiDAR: application to artificial drainage networks." International Journal of Remote Sensing 29.12 (2008): 3489-3508.

[70] Maftei C., Papatheodorou K., Mapping the flash flood prone area in the Taita watershed (Romania) using topographic indexes and hydraulic model, Second International Conference on NATURAL AND ANTHROPIC RISKS ICNAR2014 04-07 June 2014.

14 ANNEX I – FLOOD HAZARD MAPS



SciNetNatHaz Project
Black Sea Basin JOP 2007-13

Corine 2000 Land Cover map

Legend

Land Cover

- Broad-leaved forest
- Complex cultivation patterns
- Coniferous forest
- Continuous urban fabric
- Discontinuous urban fabric
- Green urban areas
- Industrial or commercial units
- Land principally occupied by agriculture
- Mineral extraction sites
- Mixed forest
- Moors and heathland
- Natural grasslands
- Non-irrigated arable land
- Olive groves
- Permanently irrigated land
- Sclerophyllous vegetation
- Sparsely vegetated areas
- Transitional woodland-shrub

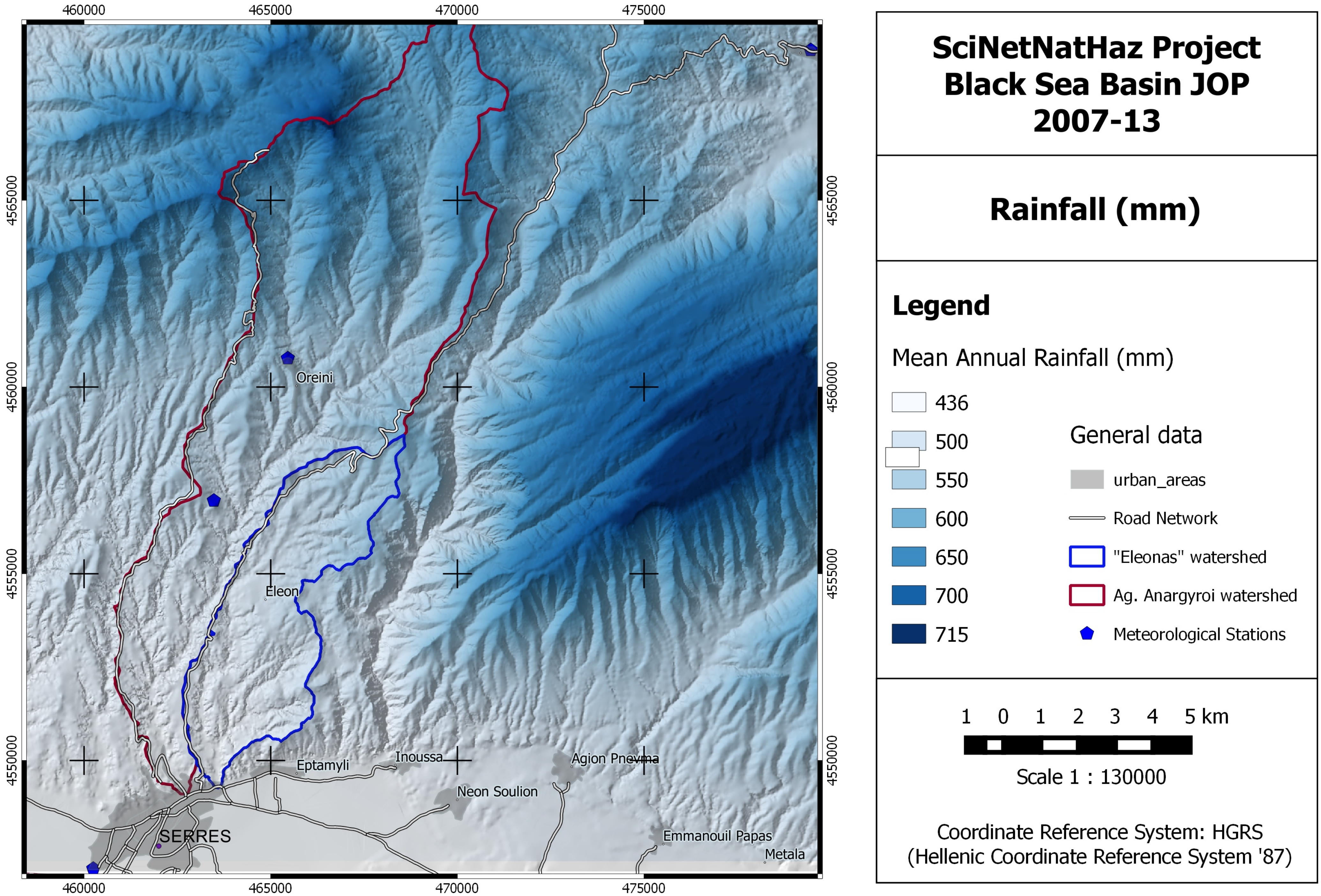
General data

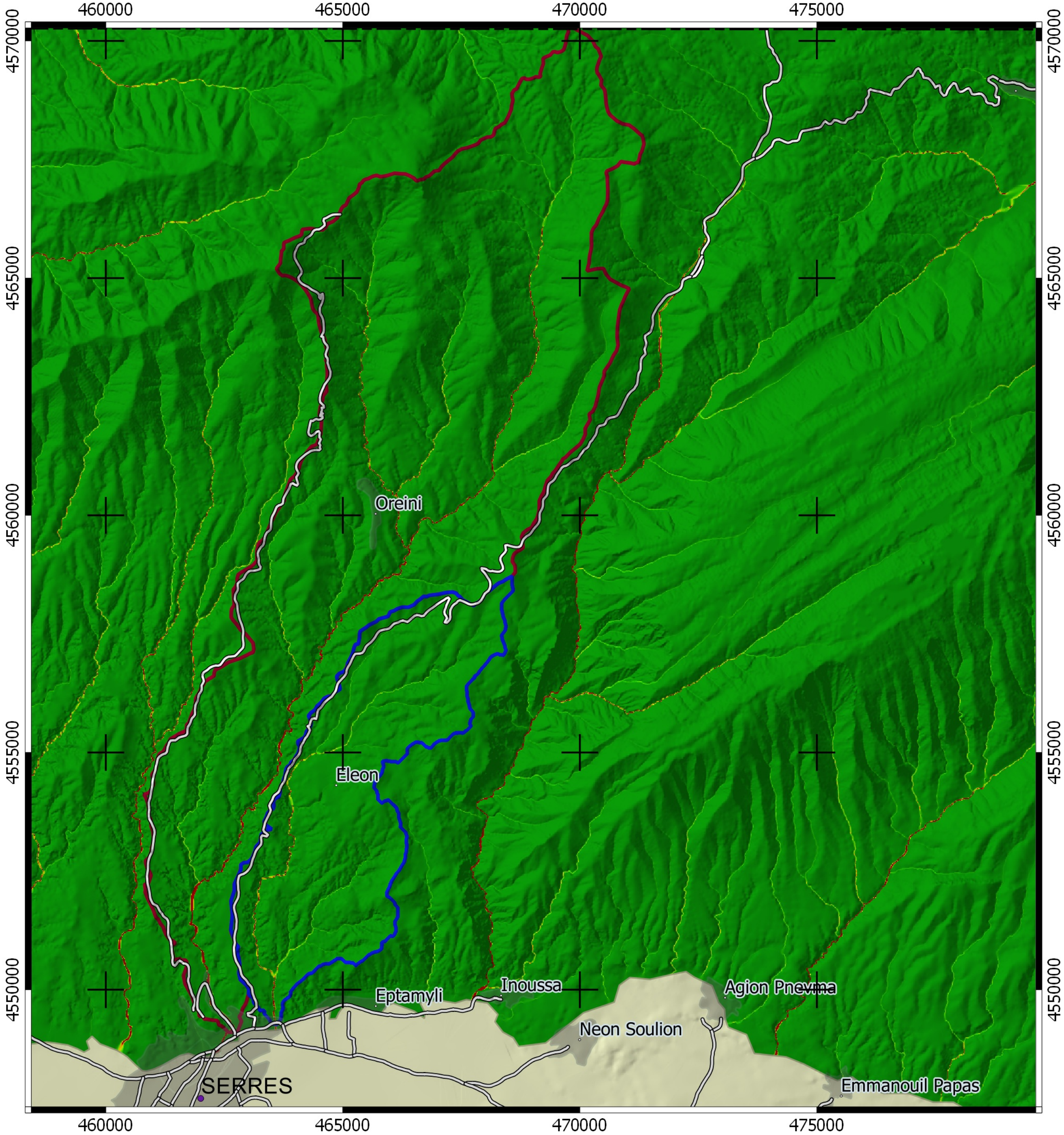
- Urban areas
- Road Network

1 0 1 2 3 4 5 km

Scale 1 : 125000

Coordinate Reference System: HGRS (Hellenic Coordinate Reference System '87)


SciNetNatHaz Project
Black Sea Basin JOP
2007-13
Rainfall (mm)
Legend
Mean Annual Rainfall (mm)
436
500
550
600
650
700
715
General data
urban_areas
Road Network
"Eleonas" watershed
Ag. Anargyroi watershed
Meteorological Stations
1 0 1 2 3 4 5 km
Scale 1 : 130000
Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)
460000
465000
470000
475000
4565000
4560000
4555000
4550000
Oreini
Eleon
Eptamyli
Inoussa
Agion Pnevma
Neon Soulion
SERRES
Emmanouil Papas
Metala



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Potential Flow Erosion on a Regional Scale

Stream Power Index

Legend

Stream Power Index (Moore et.al, 1991)

- 0
- 30000
- 60000
- 90000
- 120000
- 150000
- 170000

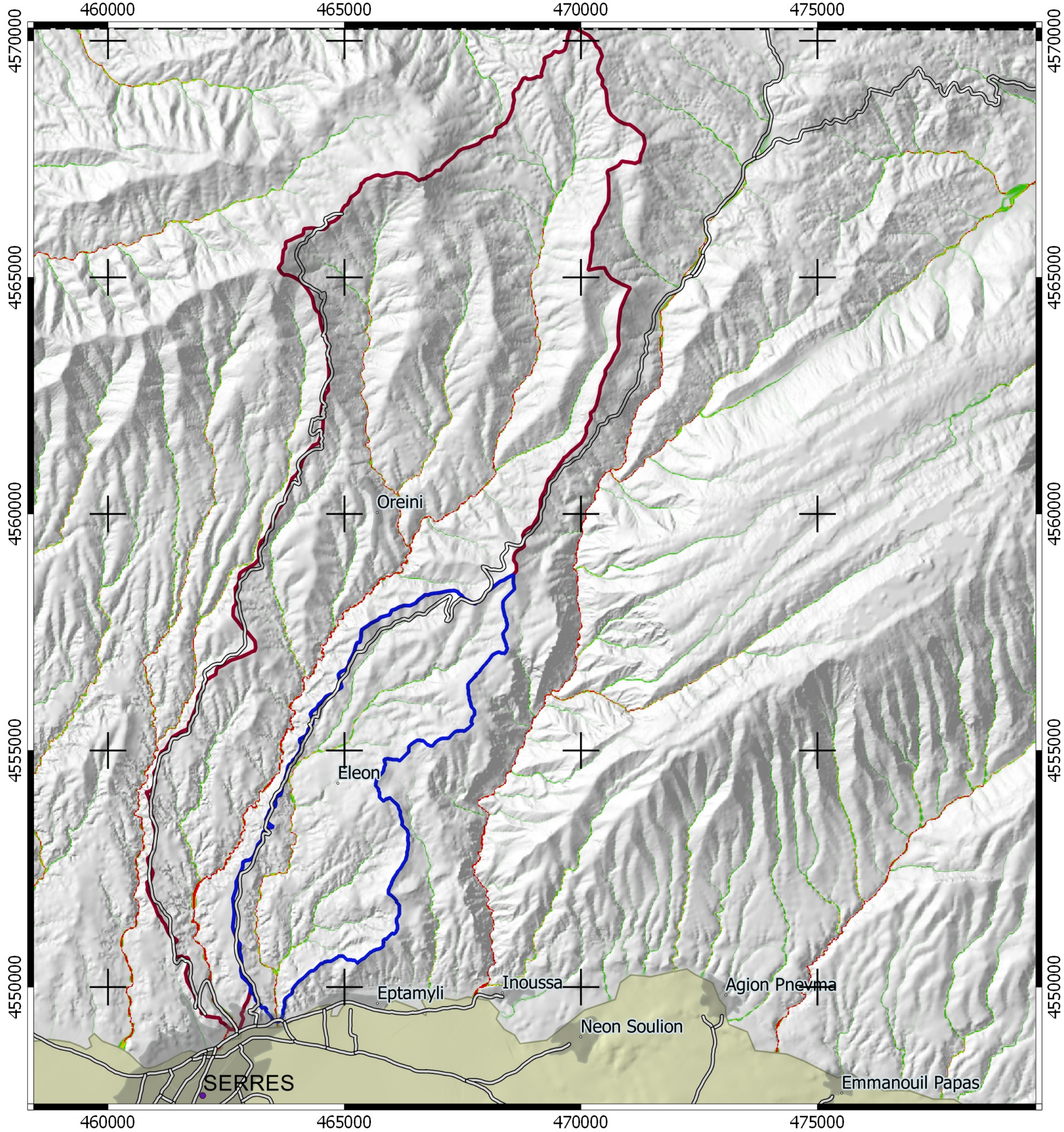
General data

- urban_areas
- Road Network
- "Eleonas" watershed
- Ag. Anargyroi watershed
- Non computable

1 0 1 2 3 4 5 km

Scale 1 : 130000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Potential Flow Erosion on a Regional Scale

Stream Power Index

Legend

Stream Power Index_Model

- 0
- 30000
- 60000
- 90000
- 120000
- 150000
- 170000

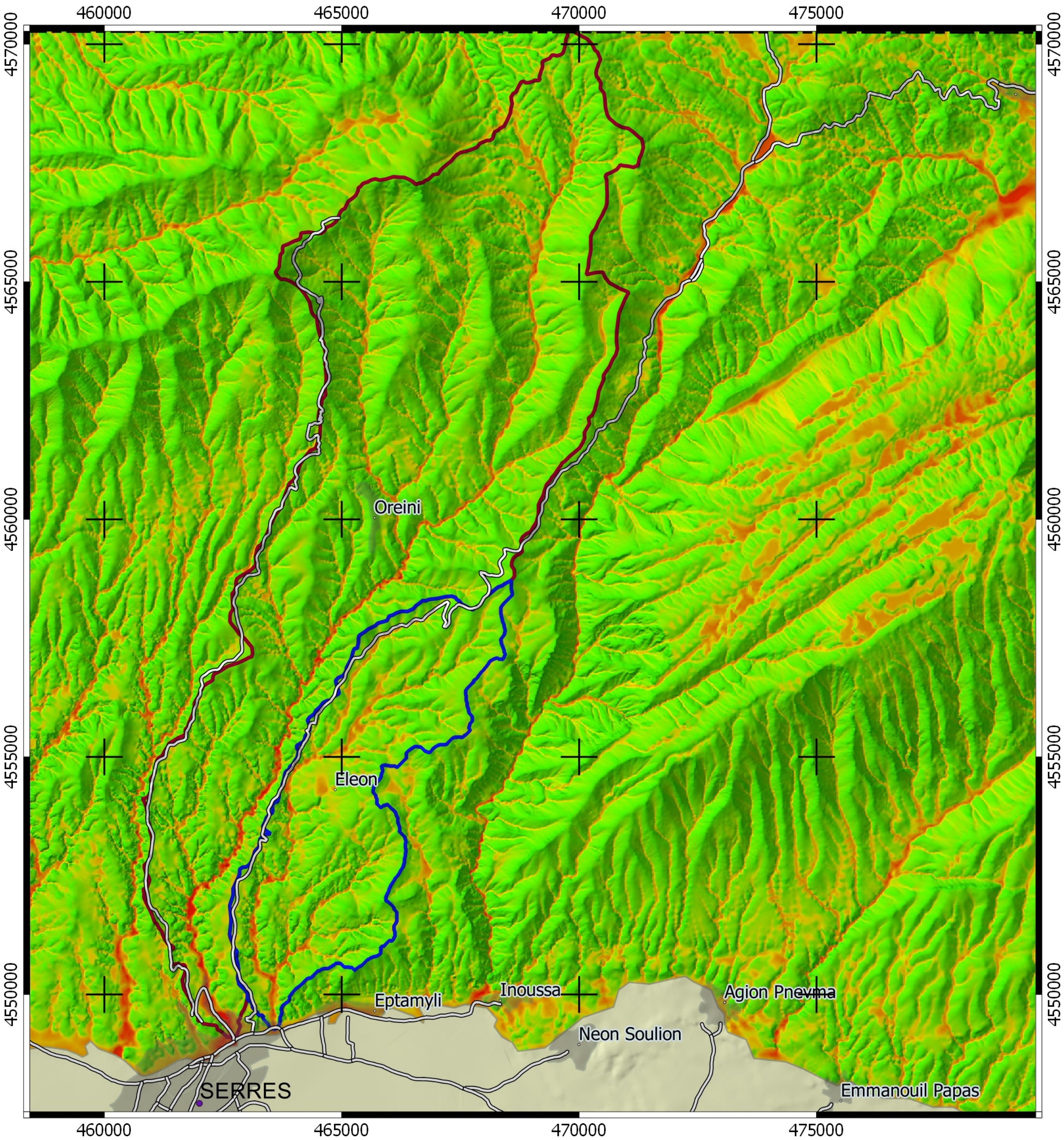
General data

- urban_areas
- Road Network
- "Eleonas" watershed
- Ag. Anargyroi watershed
- Non computable

1 0 1 2 3 4 5 km

Scale 1 : 130000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale

SAGA Topographic Wetness Index

Legend

SAGA Topographic Wetness Index

2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23

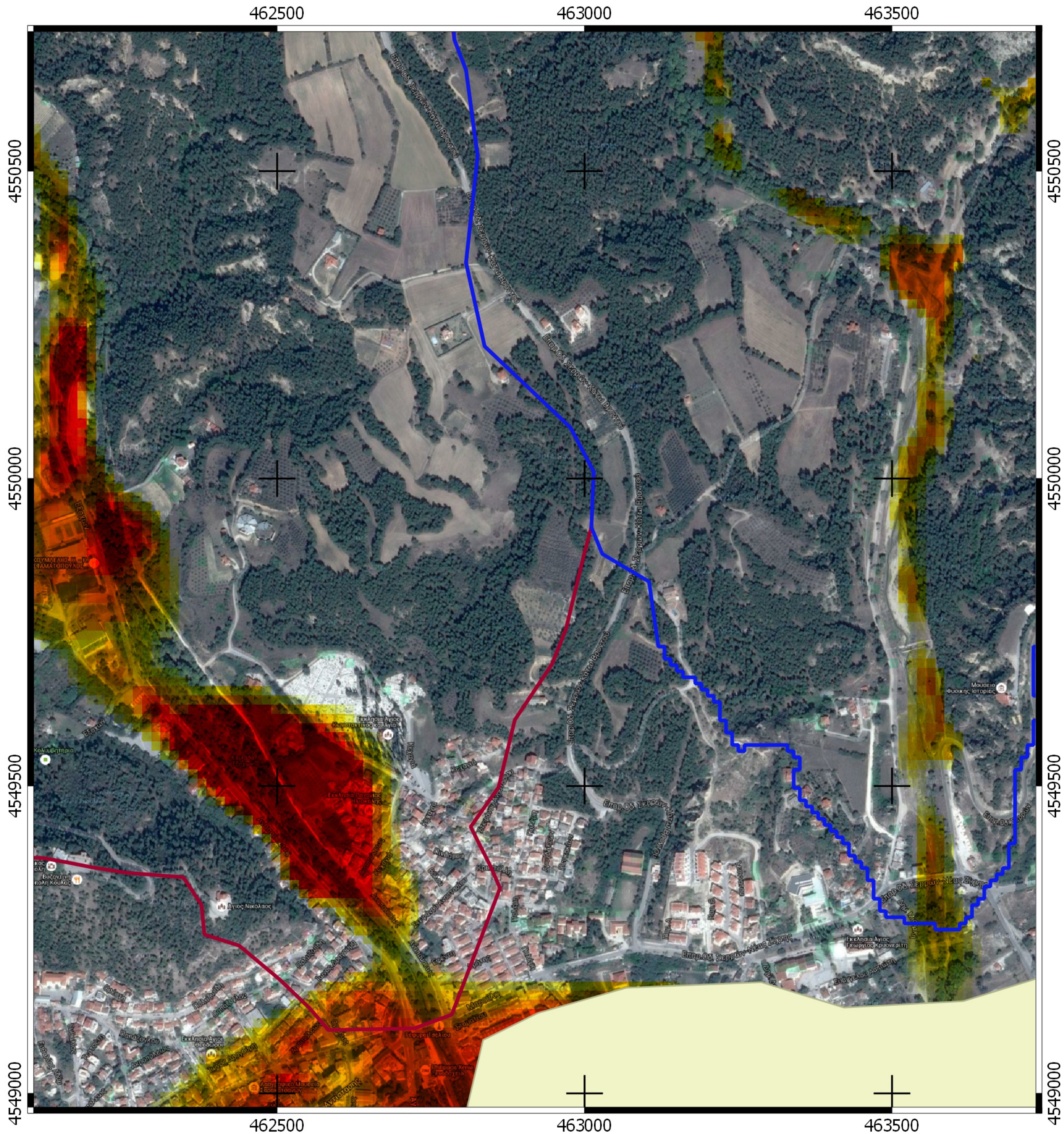
General data

- urban_areas
- Road Network
- "Eleonas" watershed
- Ag. Anargyroi watershed
- Non computable

1 0 1 2 3 4 5 km

Scale 1 : 130000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale

SAGA Topographic Wetness Index

Legend

SAGA Topographic Wetness Index

- 19
- 20
- 21
- 22

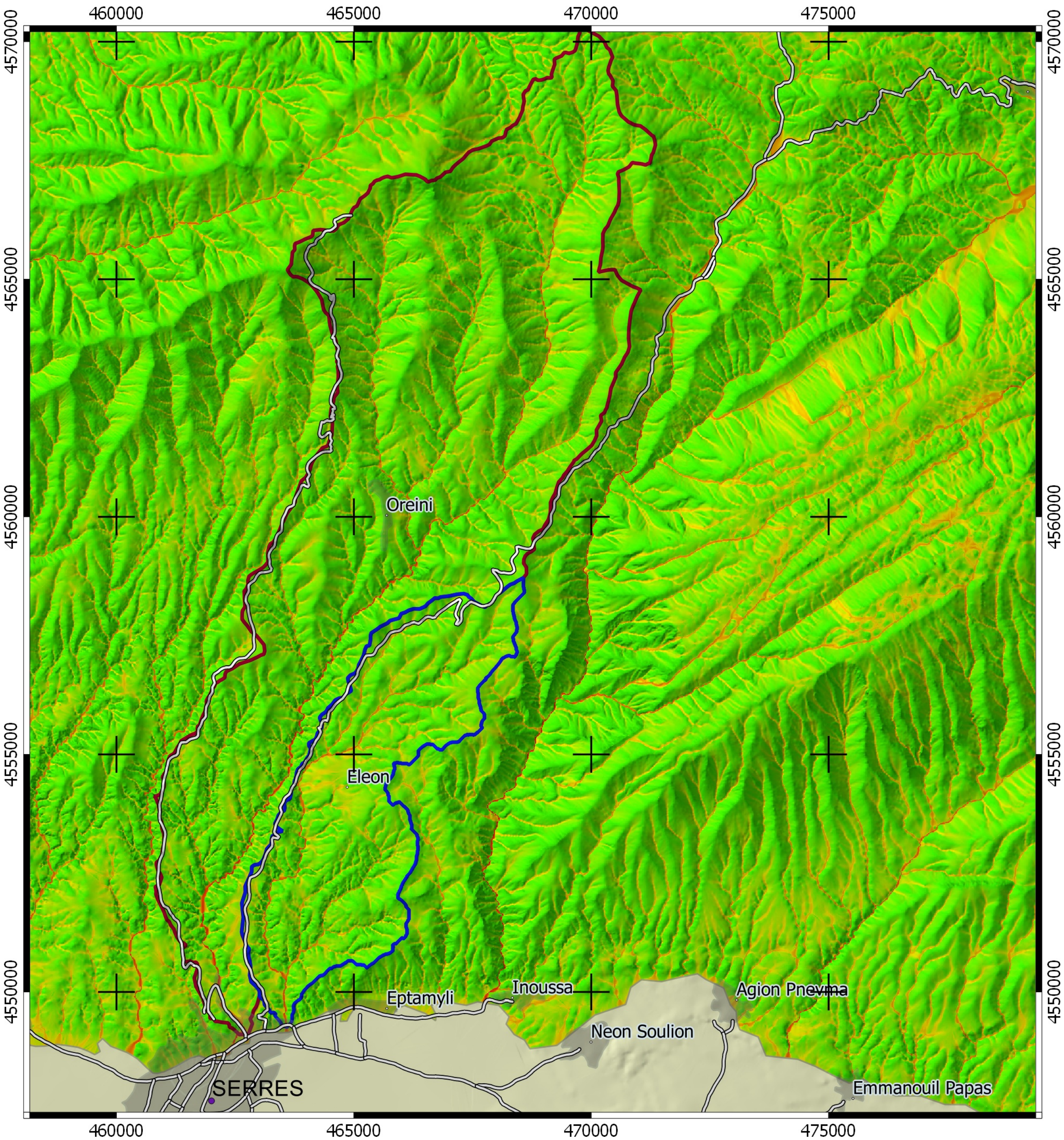
General data

- urban_areas
- Road Network
- "Eleonas" watershed
- Ag. Anargyroi watershed
- Non computable

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Scale 1 : 10000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale

Topographic Wetness Index

Legend

Topographic Wetness Index-TWI

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

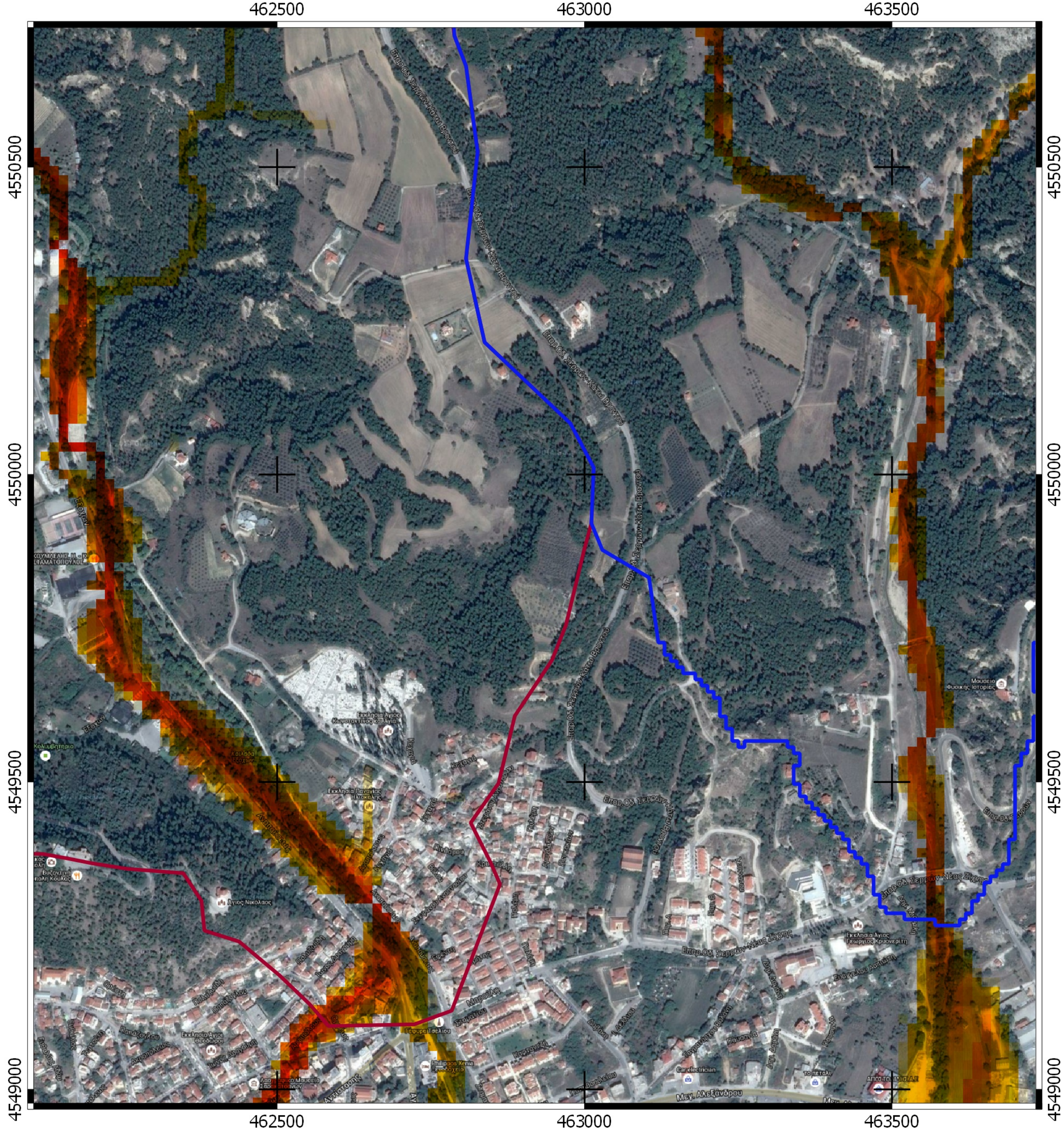
General data

urban_areas
Road Network
"Eleonas" watershed
Ag. Anargyroi watershed
Non computable

1 0 1 2 3 4 5 km

Scale 1 : 130000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale

Topographic Wetness Index

Legend

Topographic Wetness Index

- 11
- 12
- 13
- 14
- 15
- 16
- 17

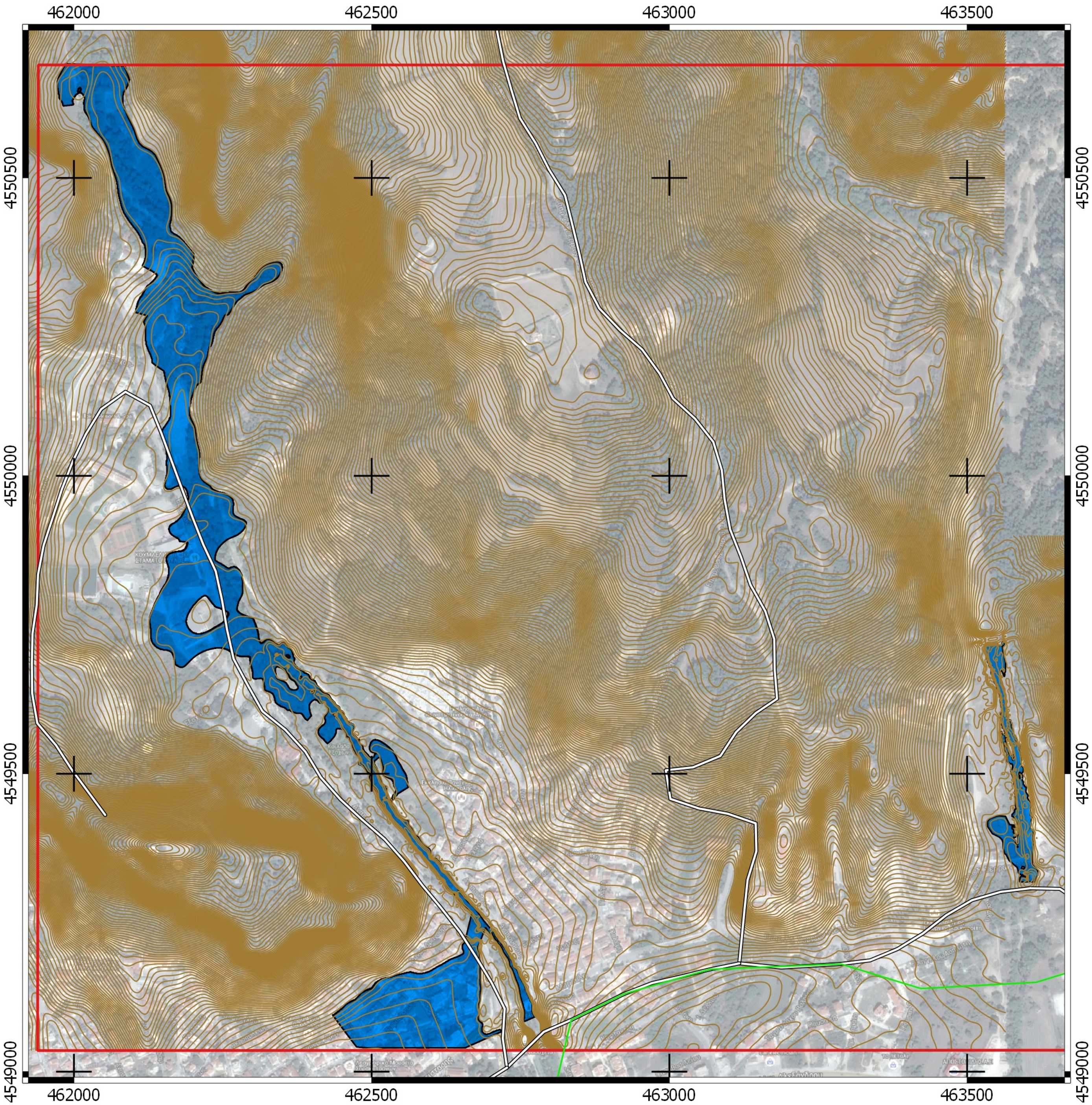
General data

- urban_areas
- Road Network
- "Eleonas" watershed
- Ag. Anargyroi watershed
- Non computable

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Scale 1 : 10000

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale

Inundation Area

Legend

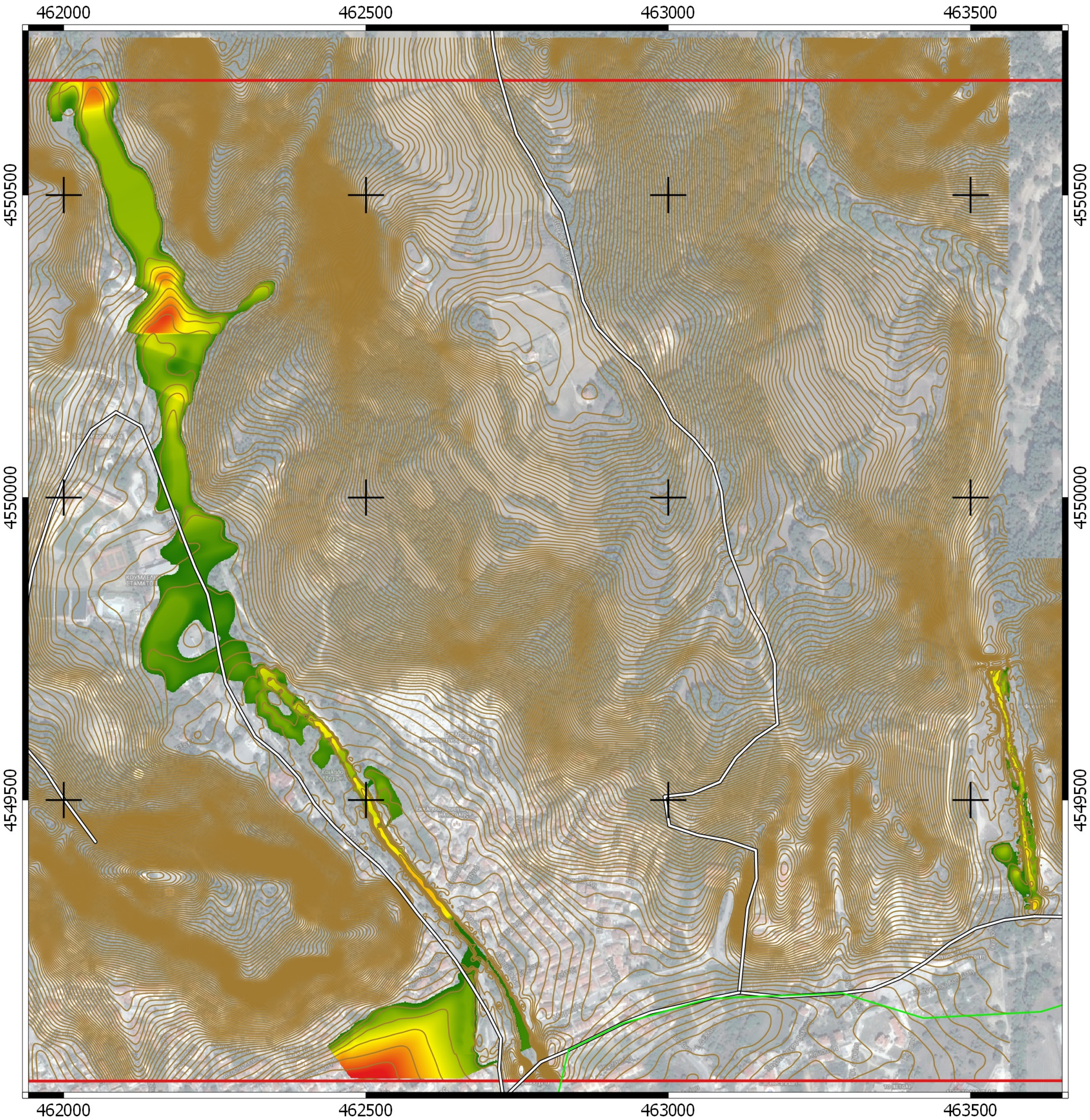
Inundation Area

General Data

Local_Scale_area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Local Scale

Water Depth (m)

Legend

Water Depth (m)

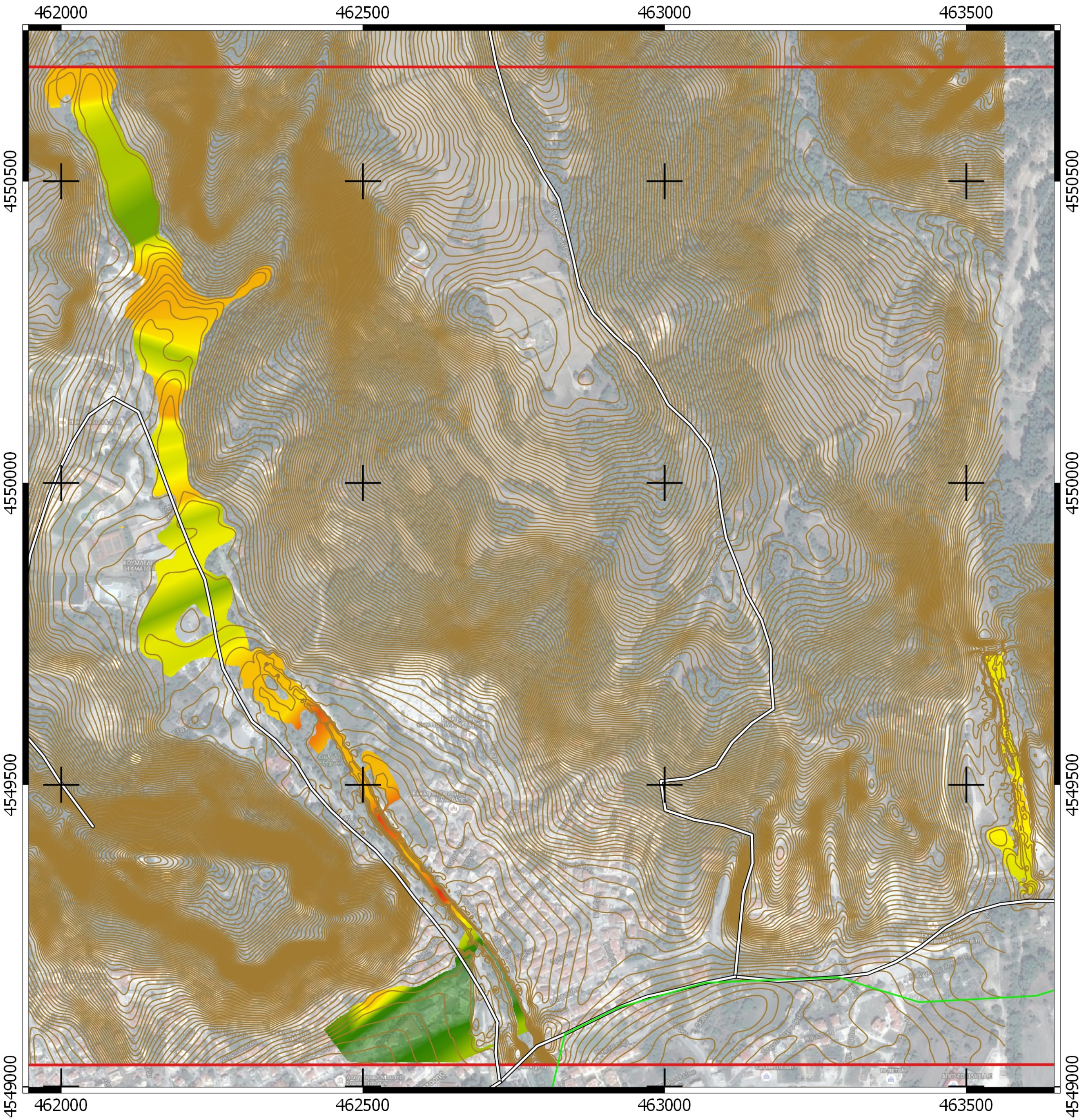
- > 1.40 (High)
- 0.90-1.40 (Medium)
- < 0.90 (Low)

General Data

- Implementation area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale

Water Velocity (m/sec)

Legend

Water Velocity (m/sec)

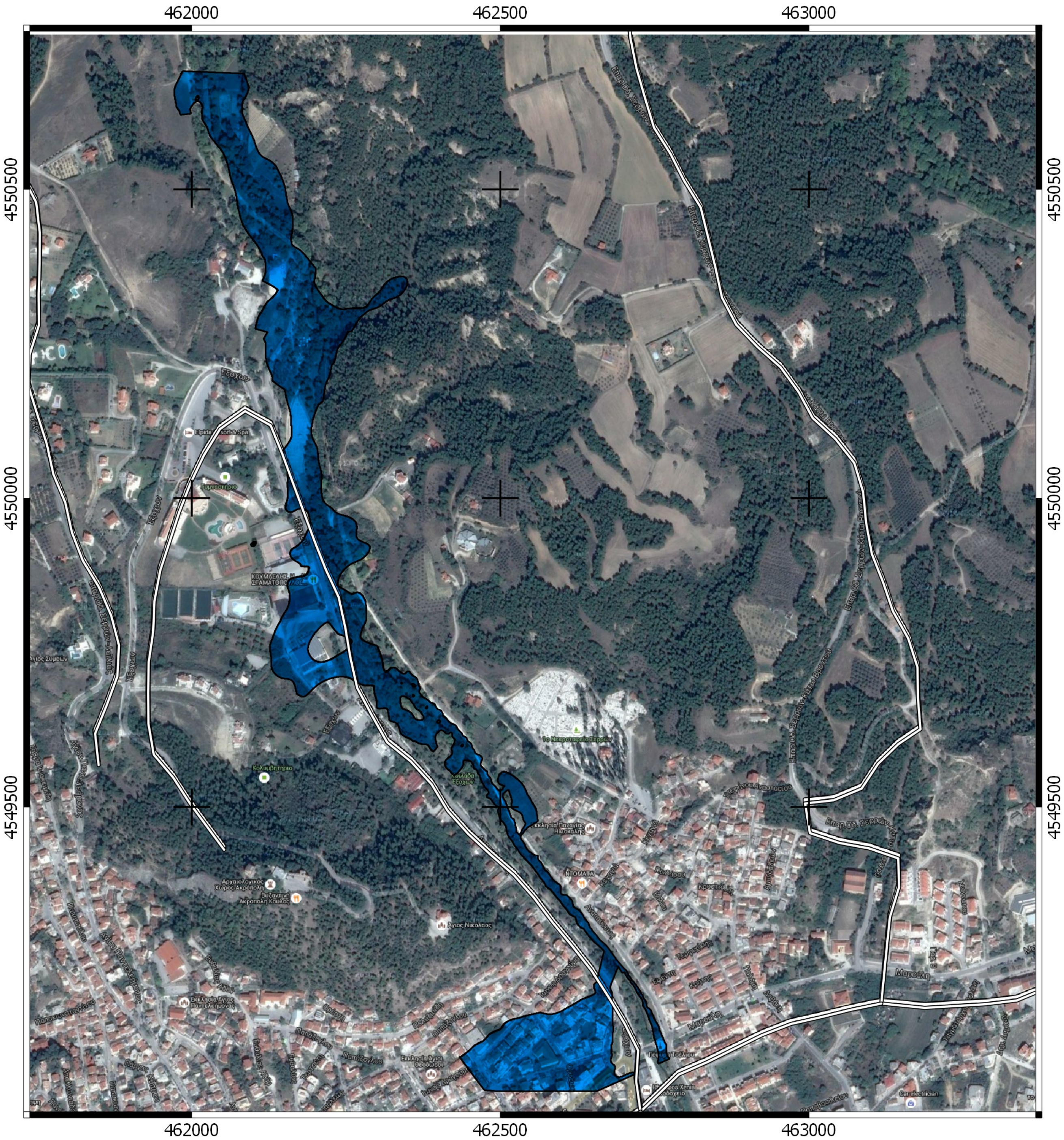
0.00	
0.20	2.20
0.40	2.40
0.60	2.60
0.80	2.80
1.00	3.00
1.20	3.20
1.40	3.40
1.60	3.60
1.80	3.80
2.00	4.00

General Data

Implementation area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale

Inundation Area

Legend

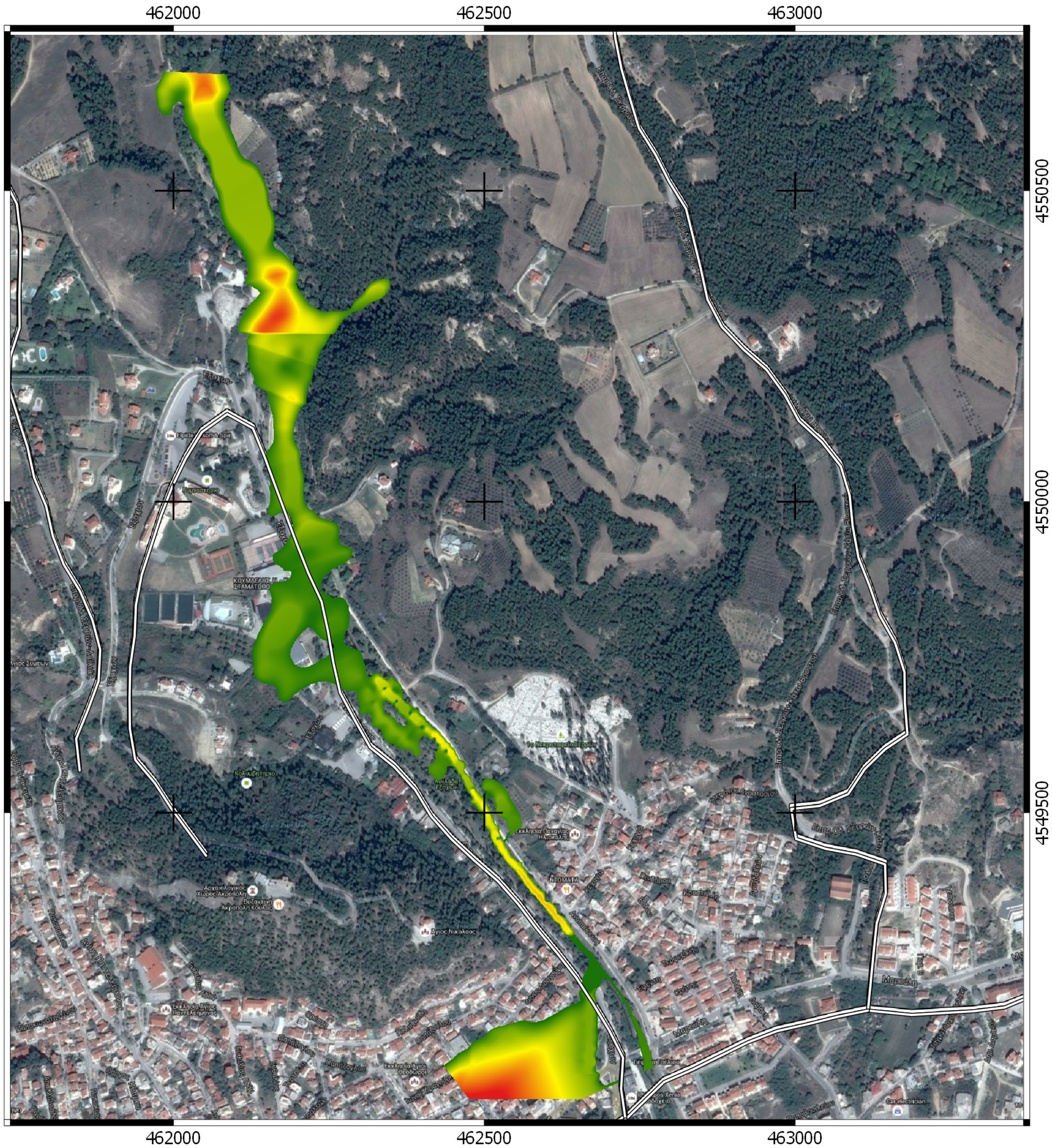
Inundation Area

General Data

Local_Scale_area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Local Scale

Water Depth (m)

Legend

Water Depth (m)

> 1.40 (High)

0.90-1.40 (Medium)

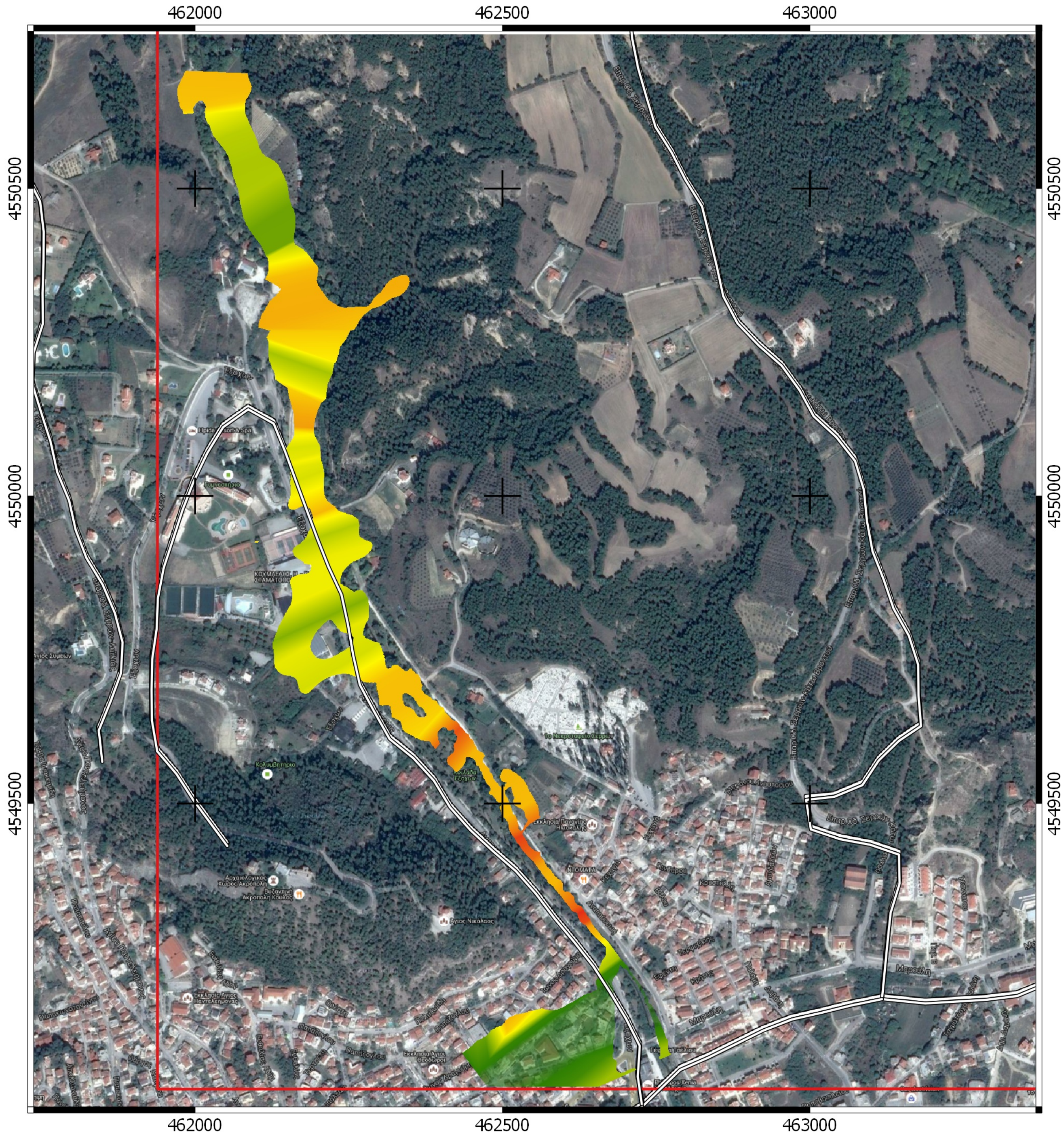
< 0.90 (Low)

General Data

Implementation area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS (Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale

Water Velocity (m/sec)

Legend

Water Velocity (m/sec)

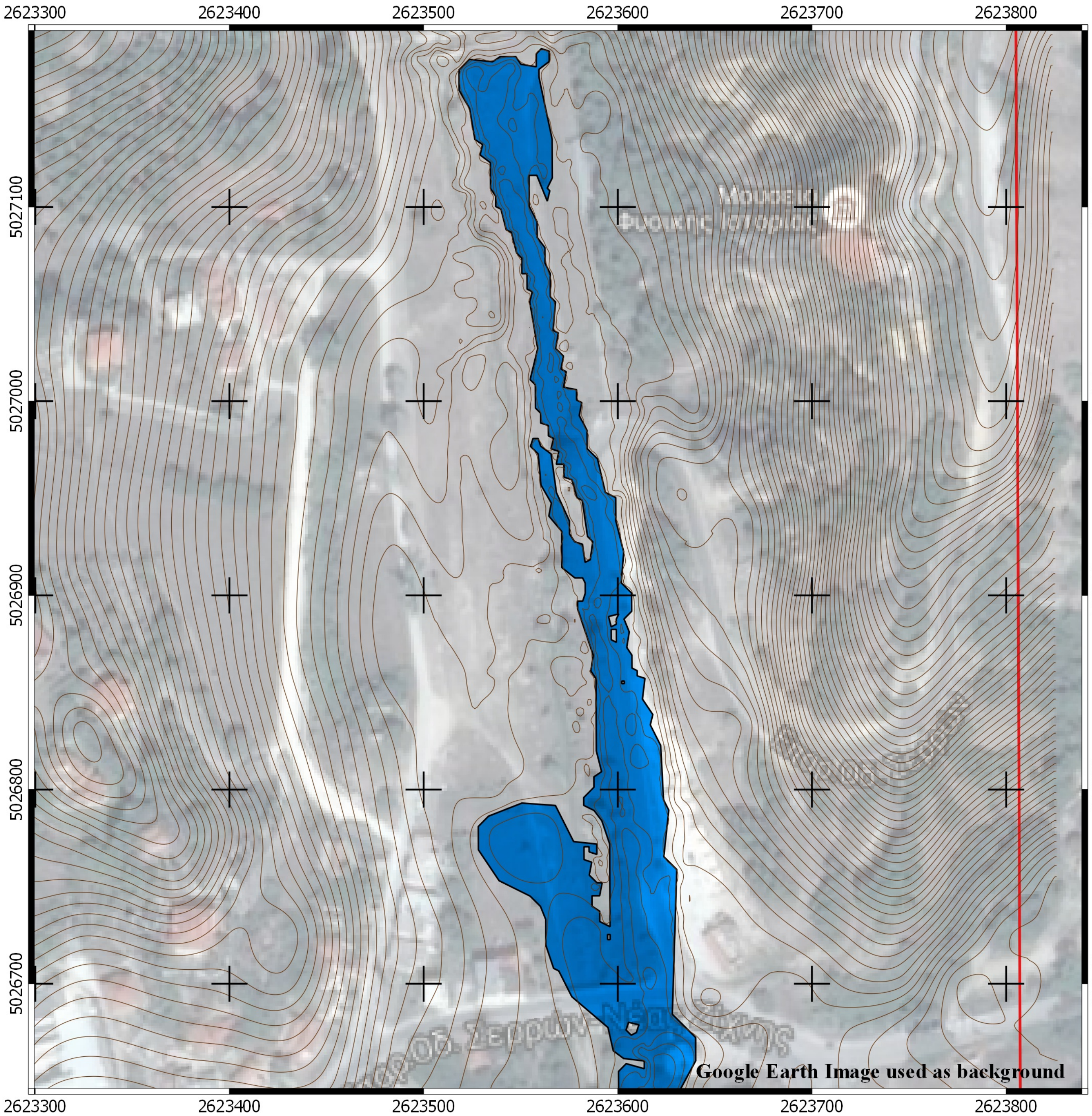
0.00	
0.20	2.20
0.40	2.40
0.60	2.60
0.80	2.80
1.00	3.00
1.20	3.20
1.40	3.40
1.60	3.60
1.80	3.80
2.00	4.00

General Data

Implementation area

0.1 0 0.1 0.2 0.3 0.4 0.5 km

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale
Eleonas stream

Inundation Area
50yr flood

Legend

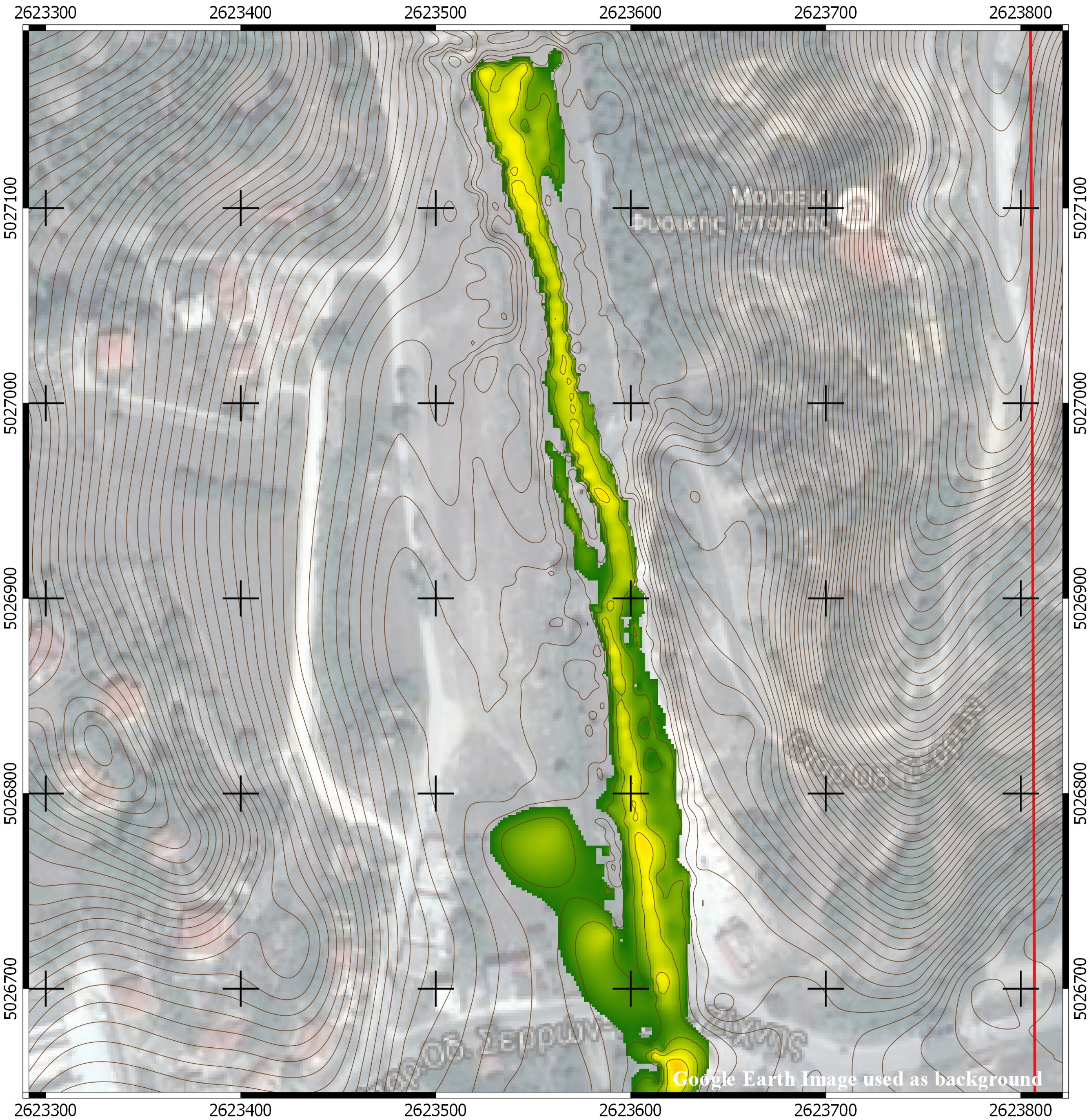
Inundation Area

General Data

Local_Scale_area

0 50 100 150 m

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale
Eleonas stream

Water Depth (m)
50yr flood

Legend

Water Depth (m)

> 1.40 (High)

0.90-1.40 (Medium)

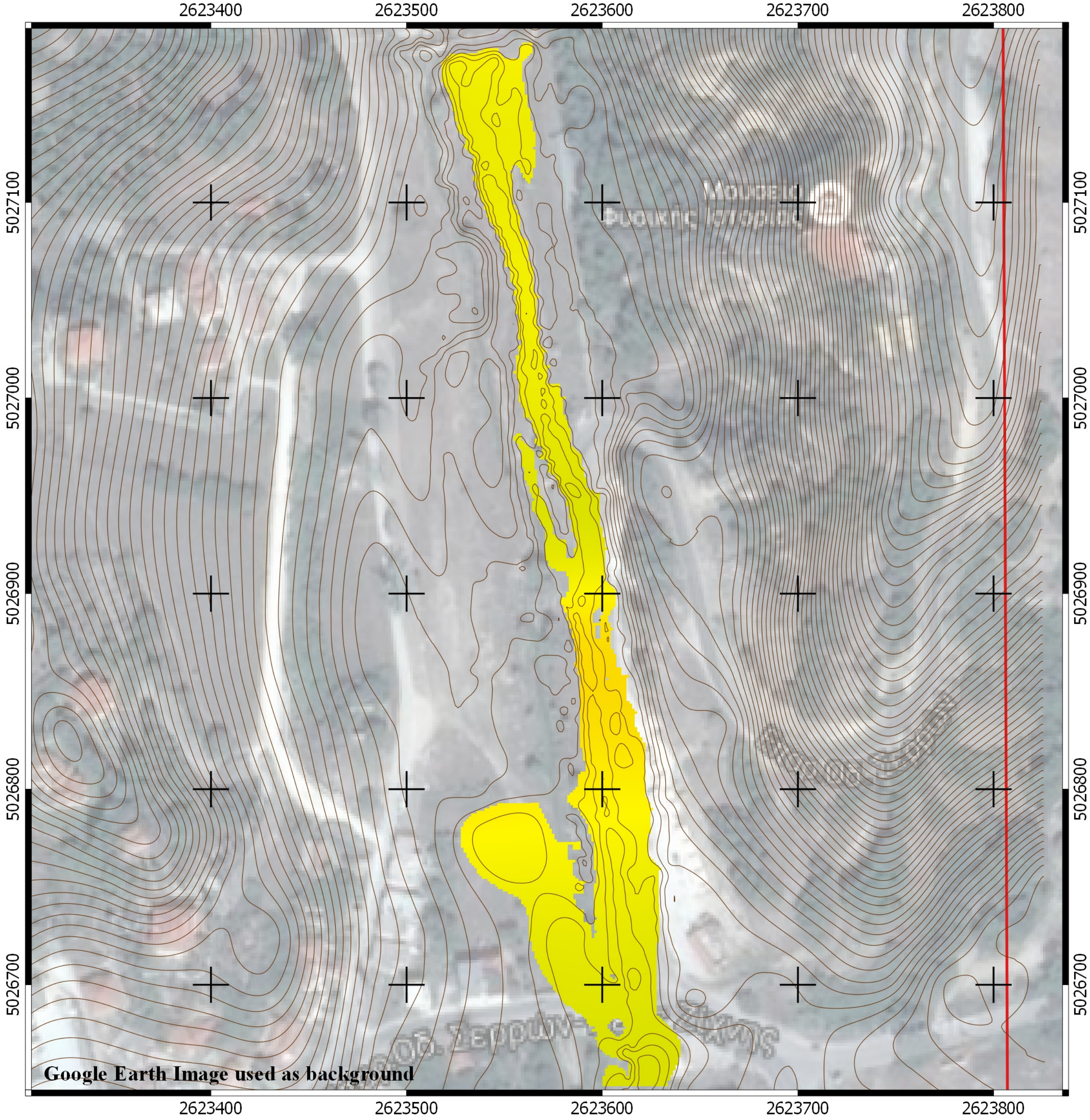
< 0.90 (Low)

General Data

Implementation area

50 0 50 100 m

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale
Eleonas stream

Water Velocity (m/sec)
50yr flood

Legend

Water Velocity (m/sec)

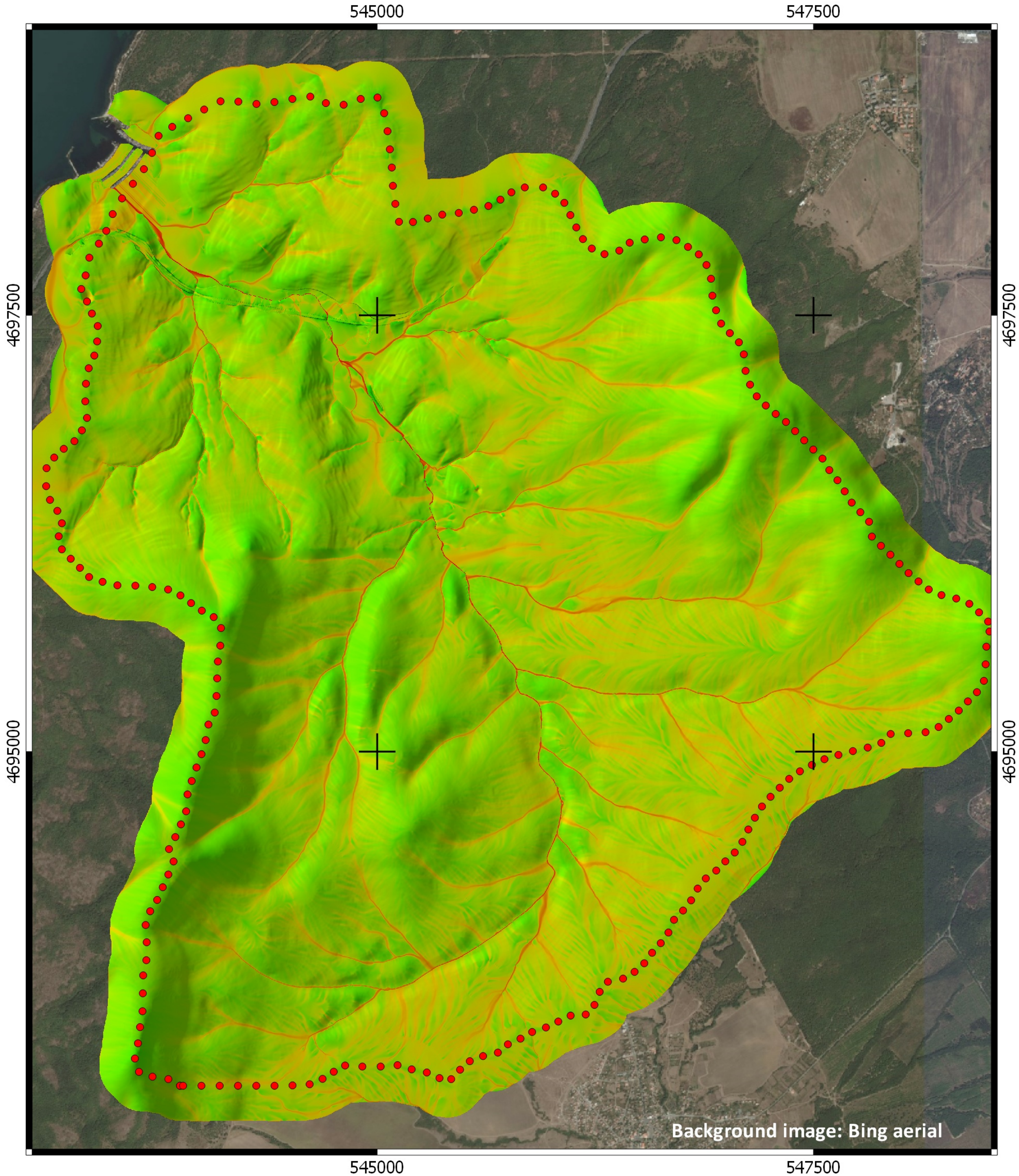
0.00	
0.20	2.20
0.40	2.40
0.60	2.60
0.80	2.80
1.00	3.00
1.20	3.20
1.40	3.40
1.60	3.60
1.80	3.80
2.00	4.00

General Data

Implementation area

50 0 50 100 m

Coordinate Reference System: HGRS
(Hellenic Coordinate Reference System '87)



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale (Burgas)

Topographic Wetness Index (TWI)

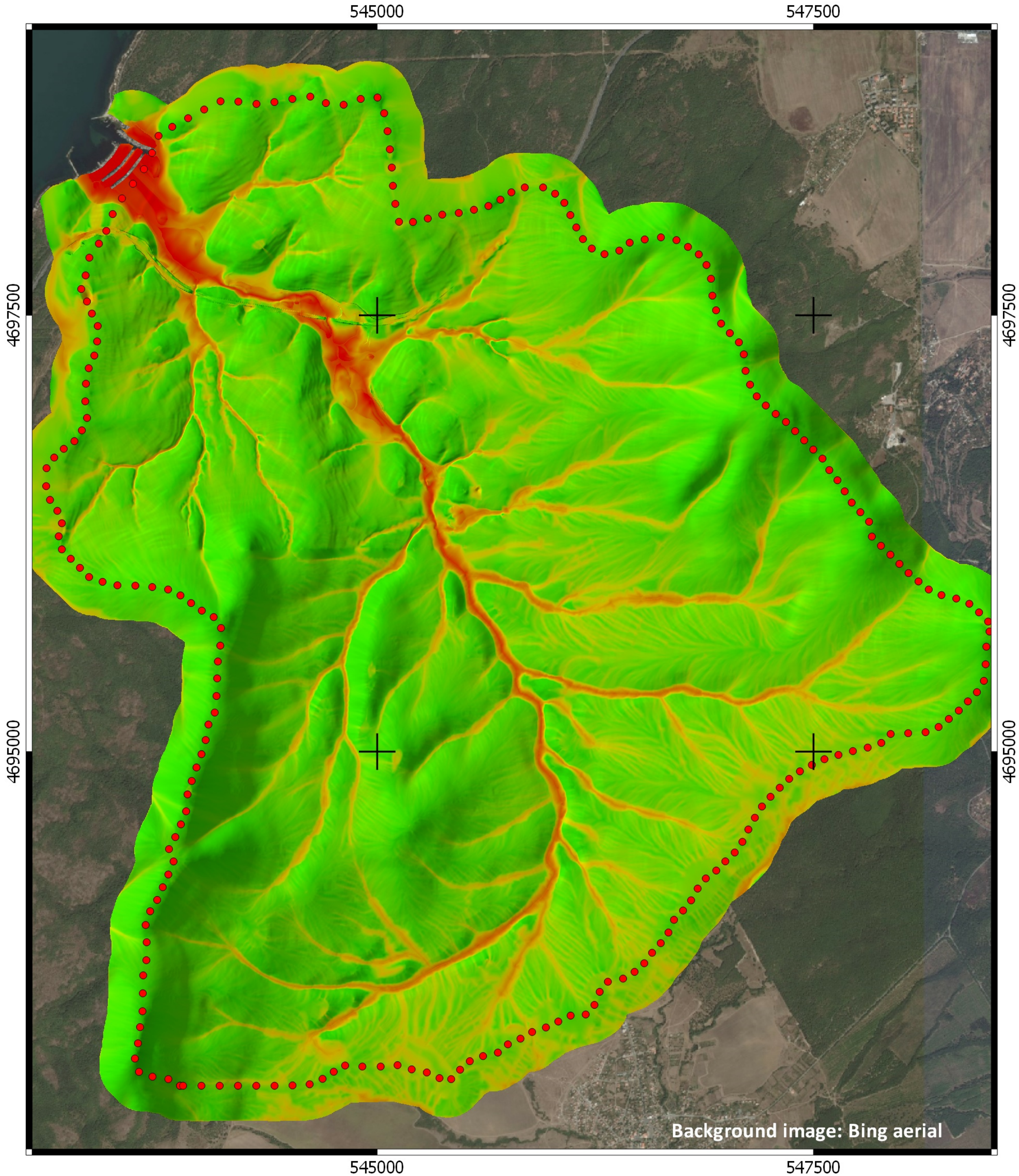
Legend

Topographic Wetness Index_TWI

- 0.0
- 2.0
- 4.0
- 6.0
- 8.0
- 10.0
- 12.0
- 14.0
- 16.0
- 18.0

0.5 0 0.5 1 1.5 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale (Burgas)

SAGA Topographic Wetness Index (TWI)

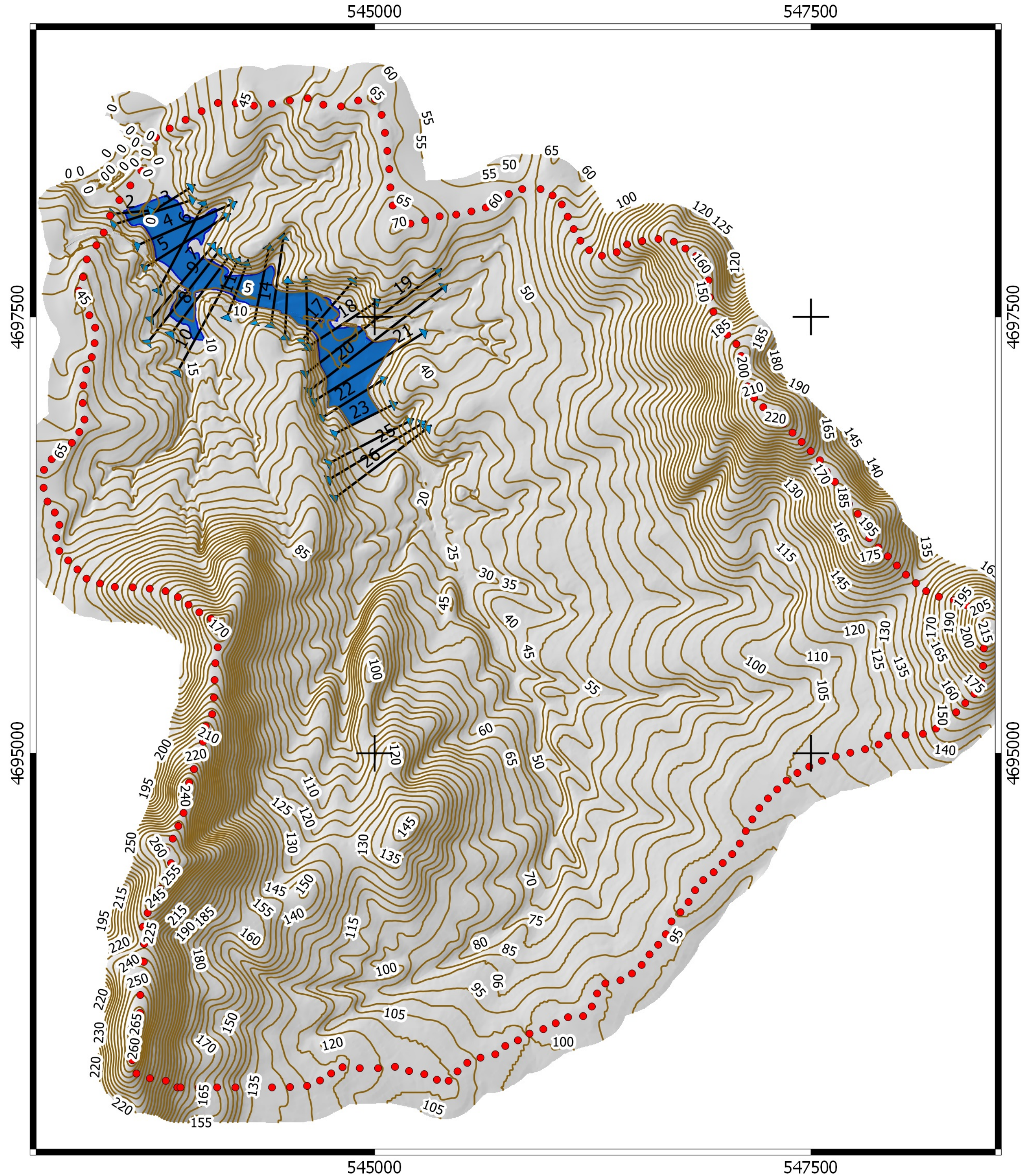
Legend

SAGA TWI

- 0.0
- 2.0
- 4.0
- 6.0
- 8.0
- 10.0
- 12.0
- 14.0
- 16.0
- 18.0

0.5 0 0.5 1 1.5 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale (Burgas)

From regional to local scale

Legend

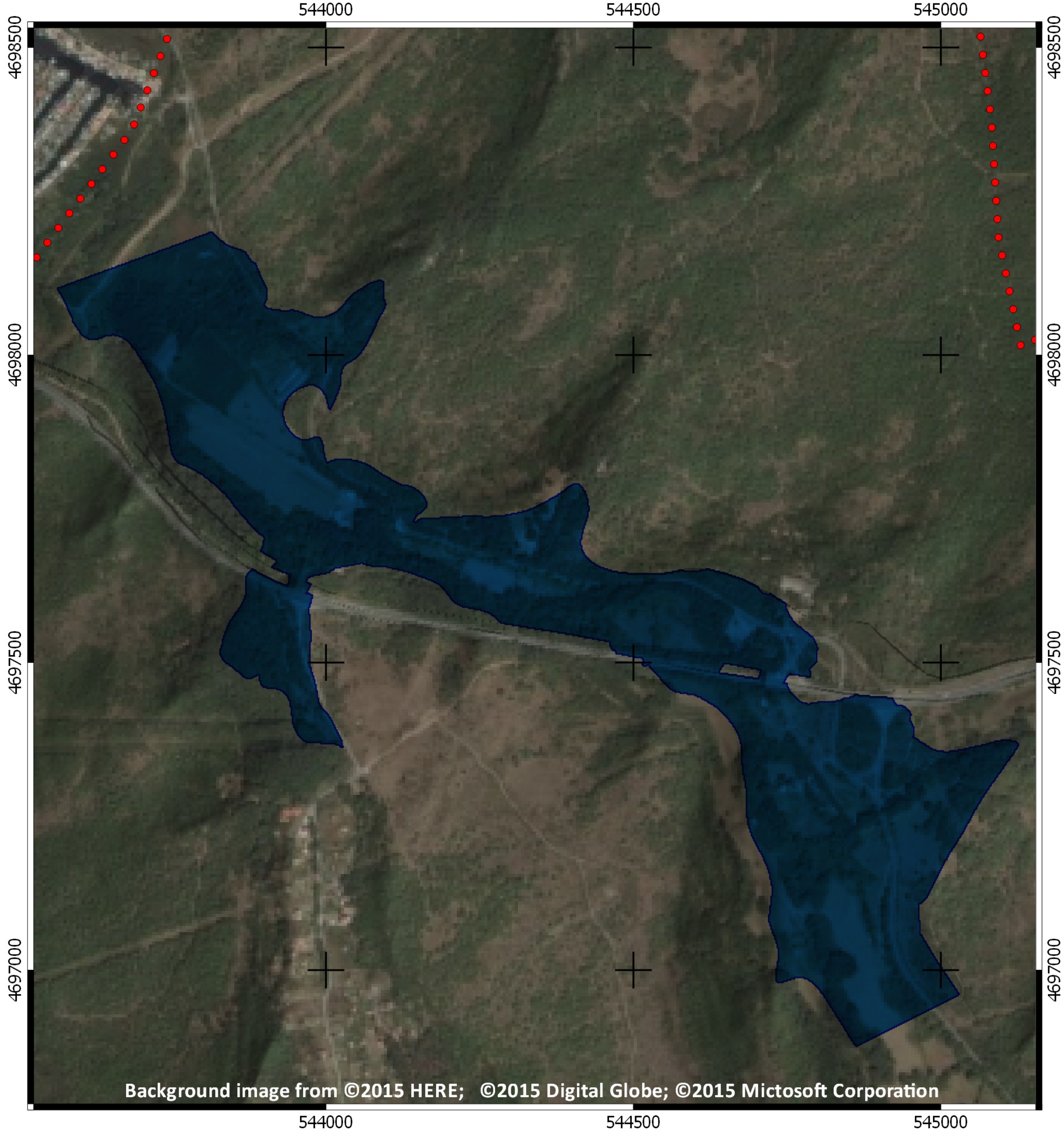
Inundation area (flood extend)

Cross Sections used

Watershed

0.5 0 0.5 1 1.5 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Local Scale (Burgas)

Inundation Area 50yr flood

Legend

Inundation Area

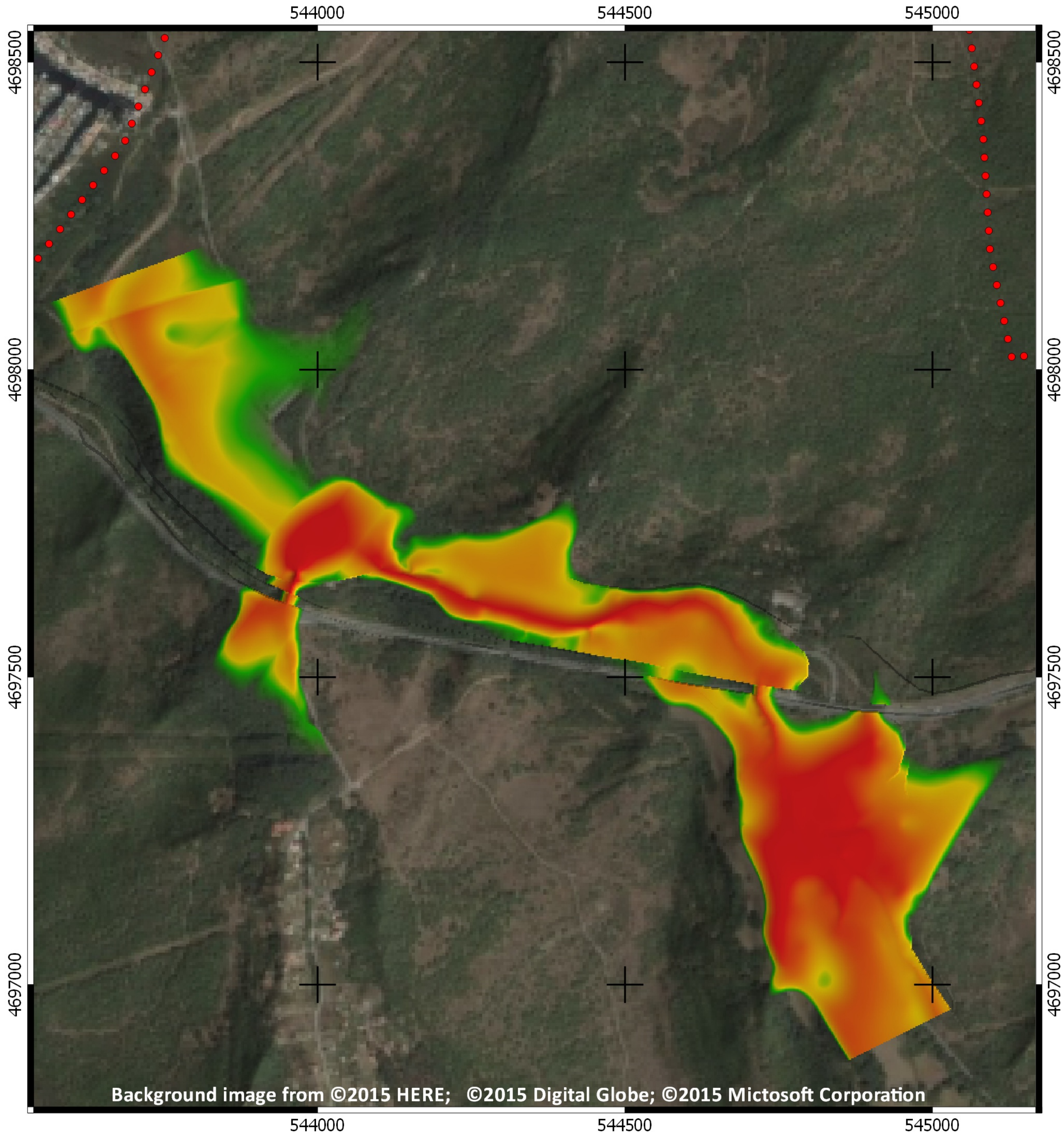
Inundation area

General Data

Watershed

100 0 100 200 300 400 500 m

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale (Burgas)

Water Depth (m)
50yr flood

Legend

Water Depth (m)

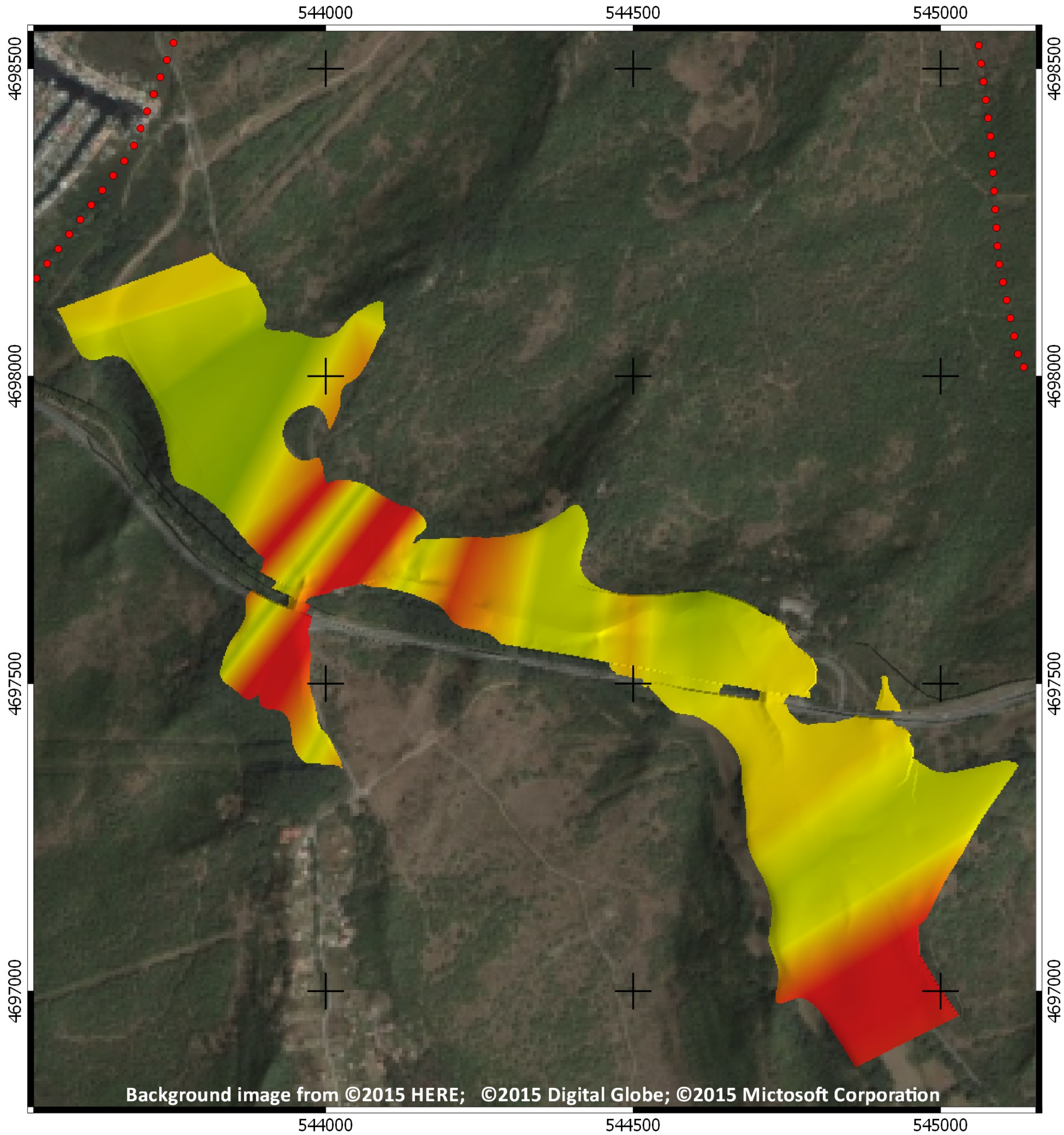
- 0.000000
- < 0.90
- 0.90 - 1.40
- > 1.40

General Data

- Watershed

100 0 100 200 300 400 500 m

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Local Scale (Burgas)

Water Velocity (m/sec) 50yr flood

Legend

Water Velocity (m/sec)

0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80

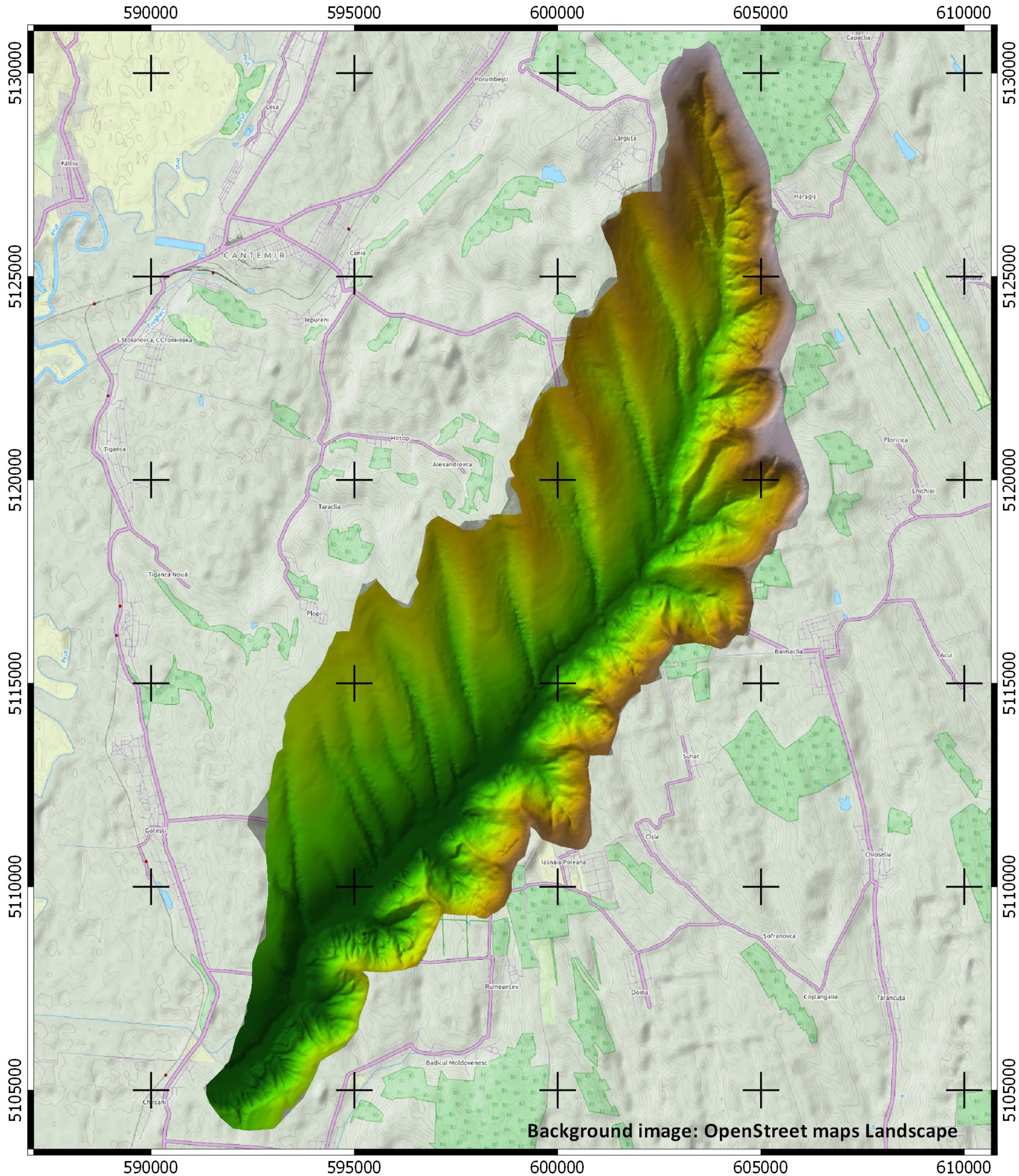
General Data

Implementation area

Watershed

100 0 100 200 300 400 500 m

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale (Moldova)

Relief Map (Elevation)

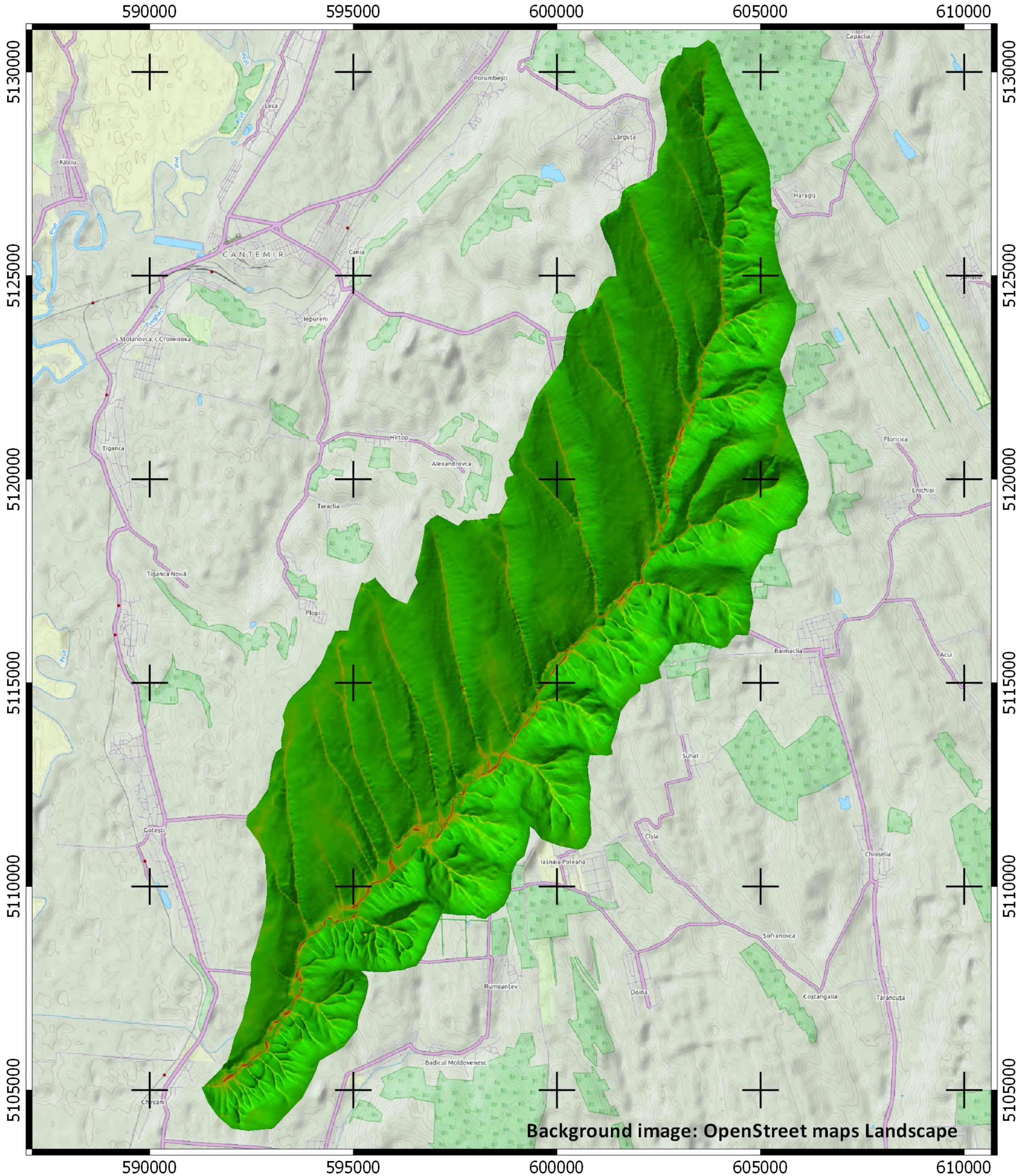
Legend

Elevation (m)

- 50
- 100
- 150
- 200
- 250
- 300

4 0 4 8 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Regional Scale (Moldova)

Topographic Wetness Index (TWI)

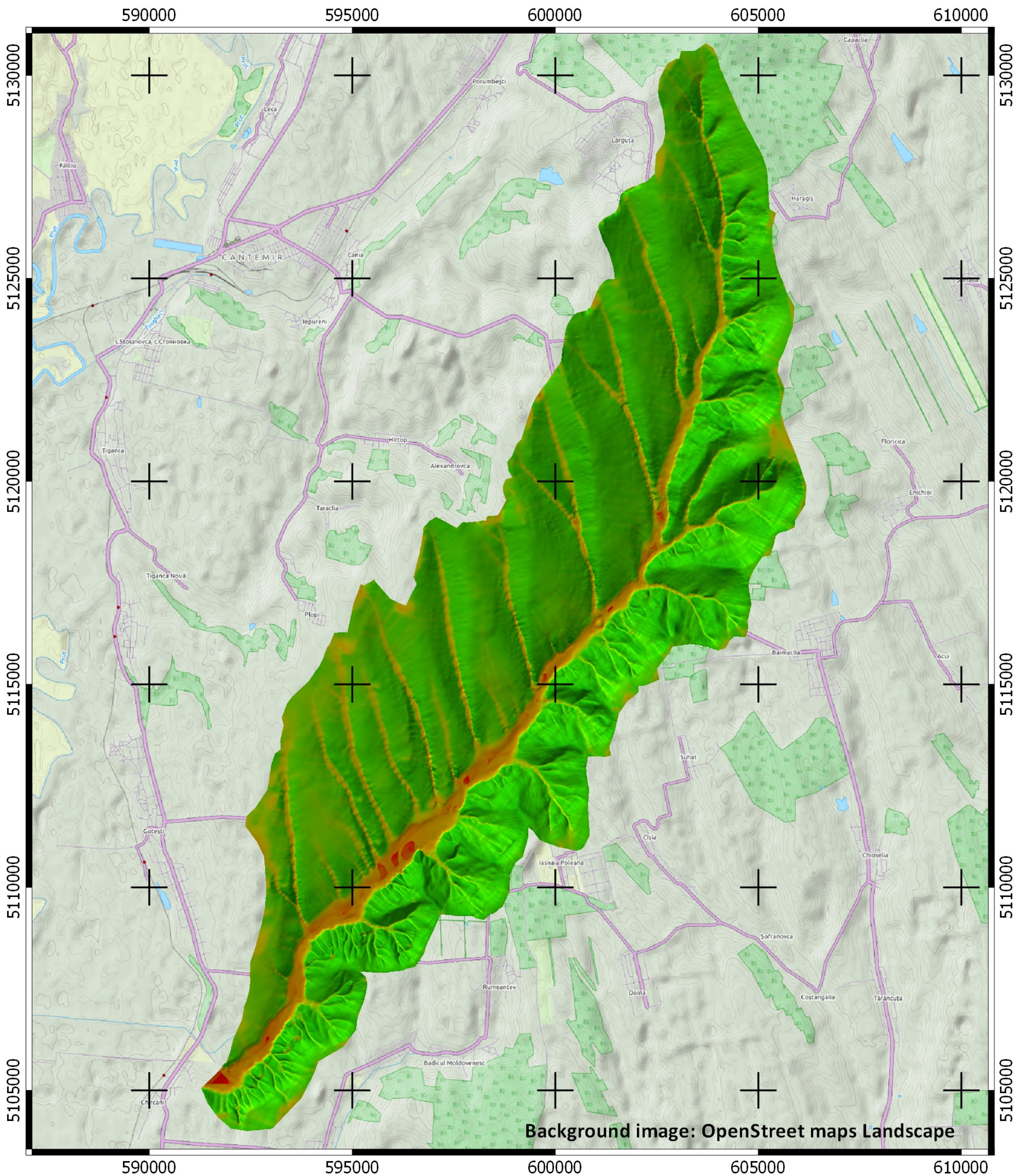
Legend

Topographic Wetness Index (TWI)

4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

4 0 4 8 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Regional Scale (Moldova)

SAGA Topographic Wetness Index

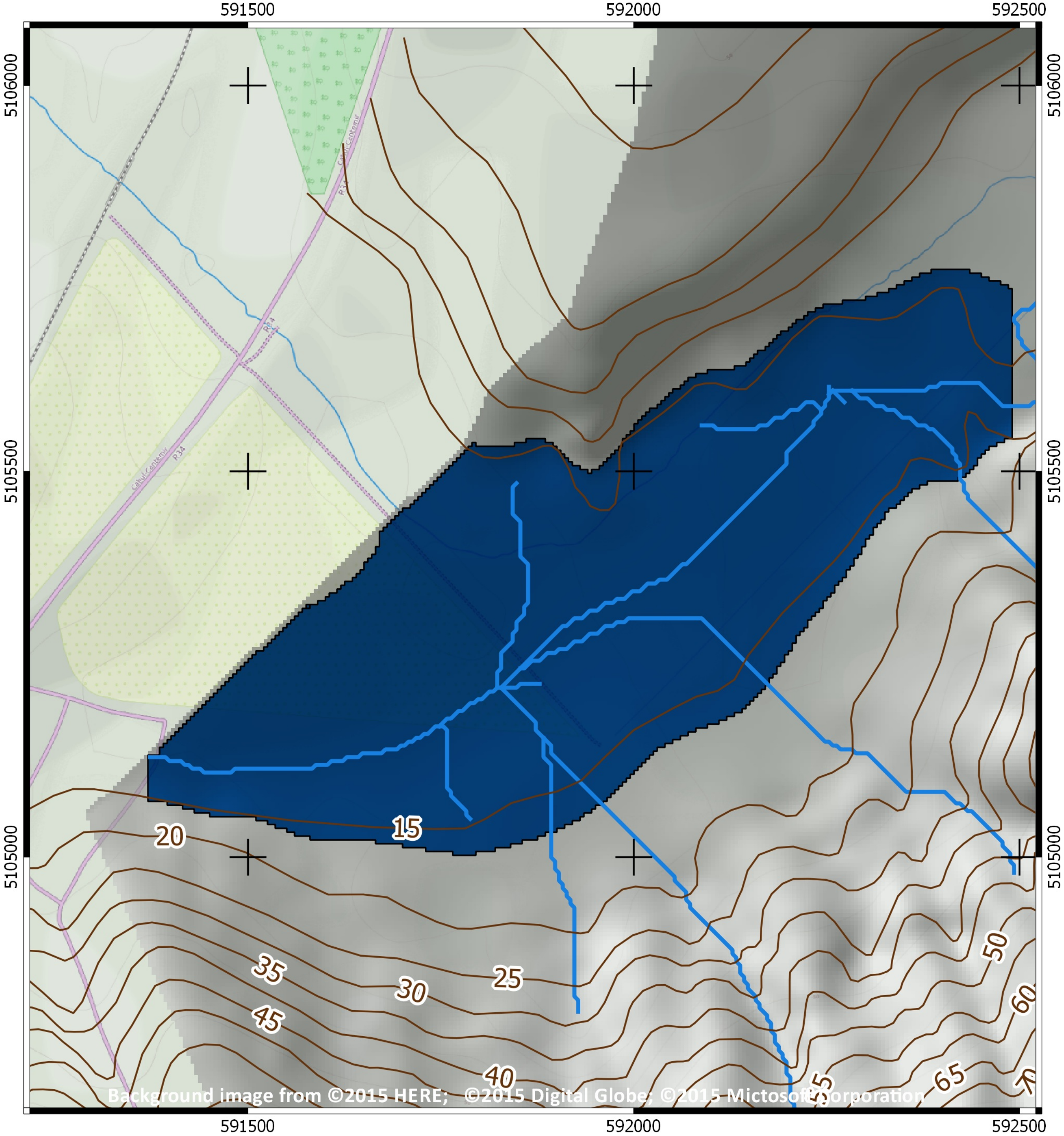
Legend

SAGA Topo Wetness Index

2	8
3	9
4	10
5	11
6	12
7	13

4 0 4 8 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale (Larga river, Moldova)

Flood Extend (Inundation area) 50yr flood

Legend

Inundation area

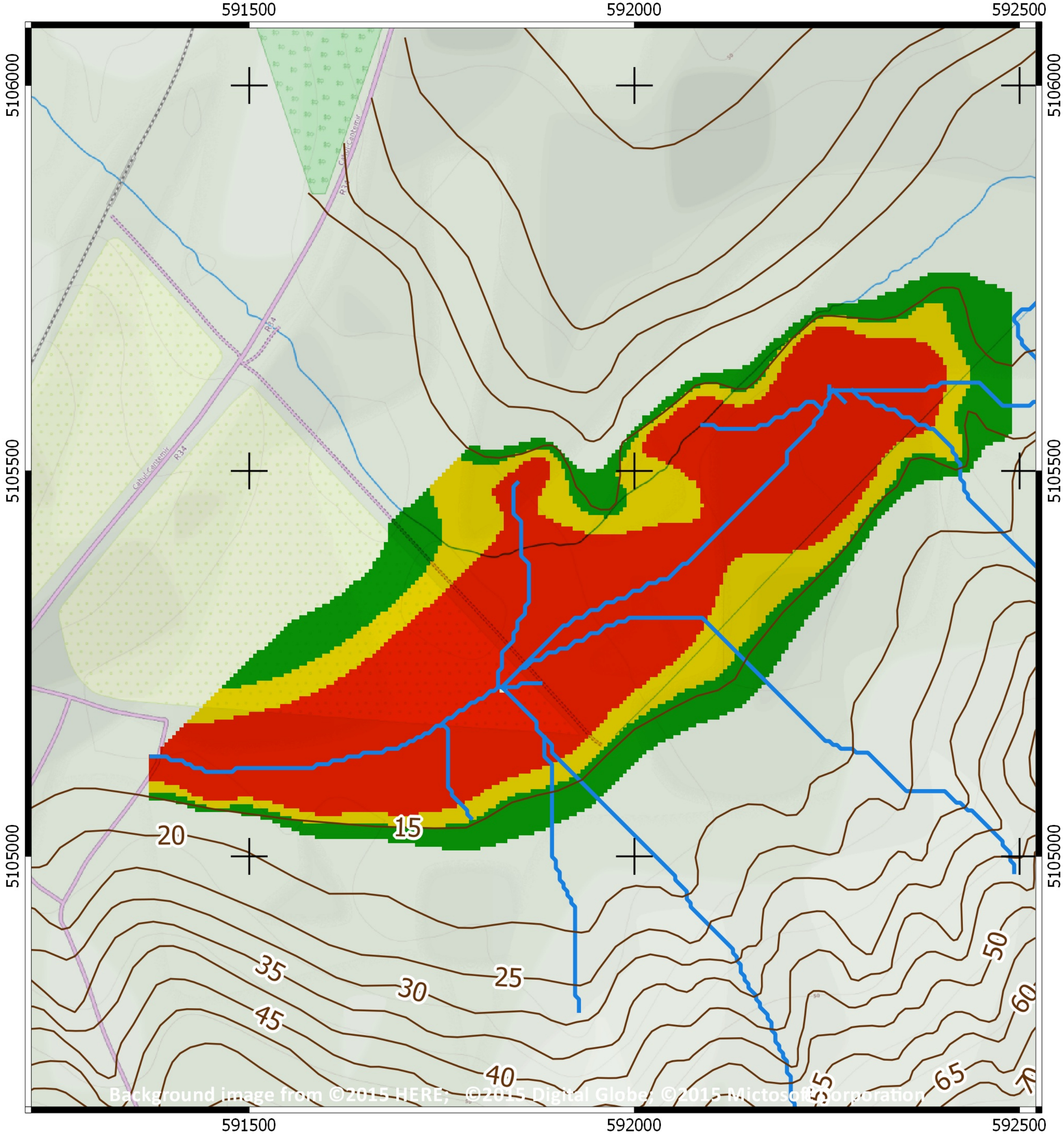
General Data

Hydrologic Network

Contours

100 0 100 200 300 400 m

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale (Larga river, Moldova)

Water Depth (m)
50yr flood

Legend

Water Depth (m)

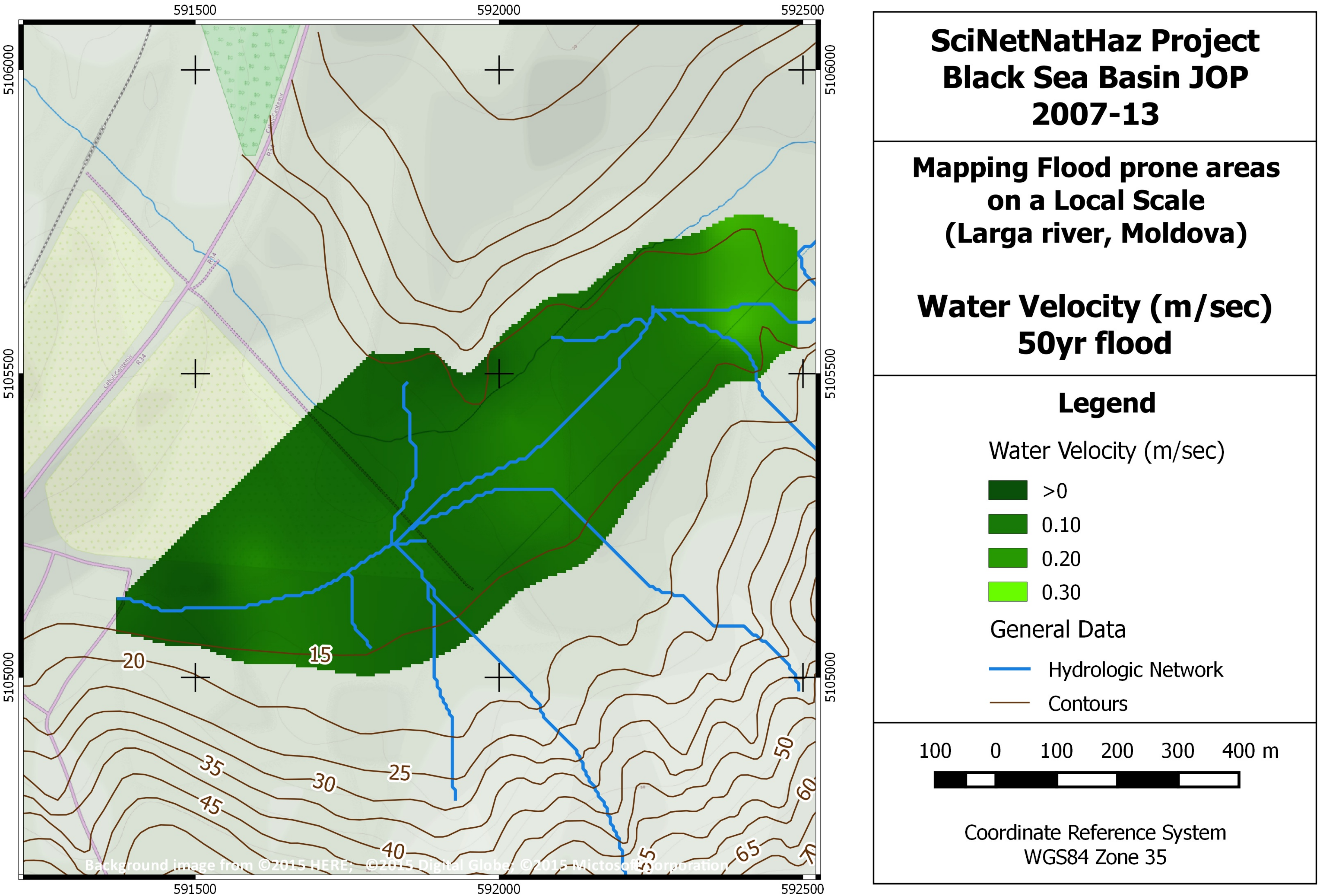
- < 0.90
- 0.90 - 1.40
- > 1.40

General Data

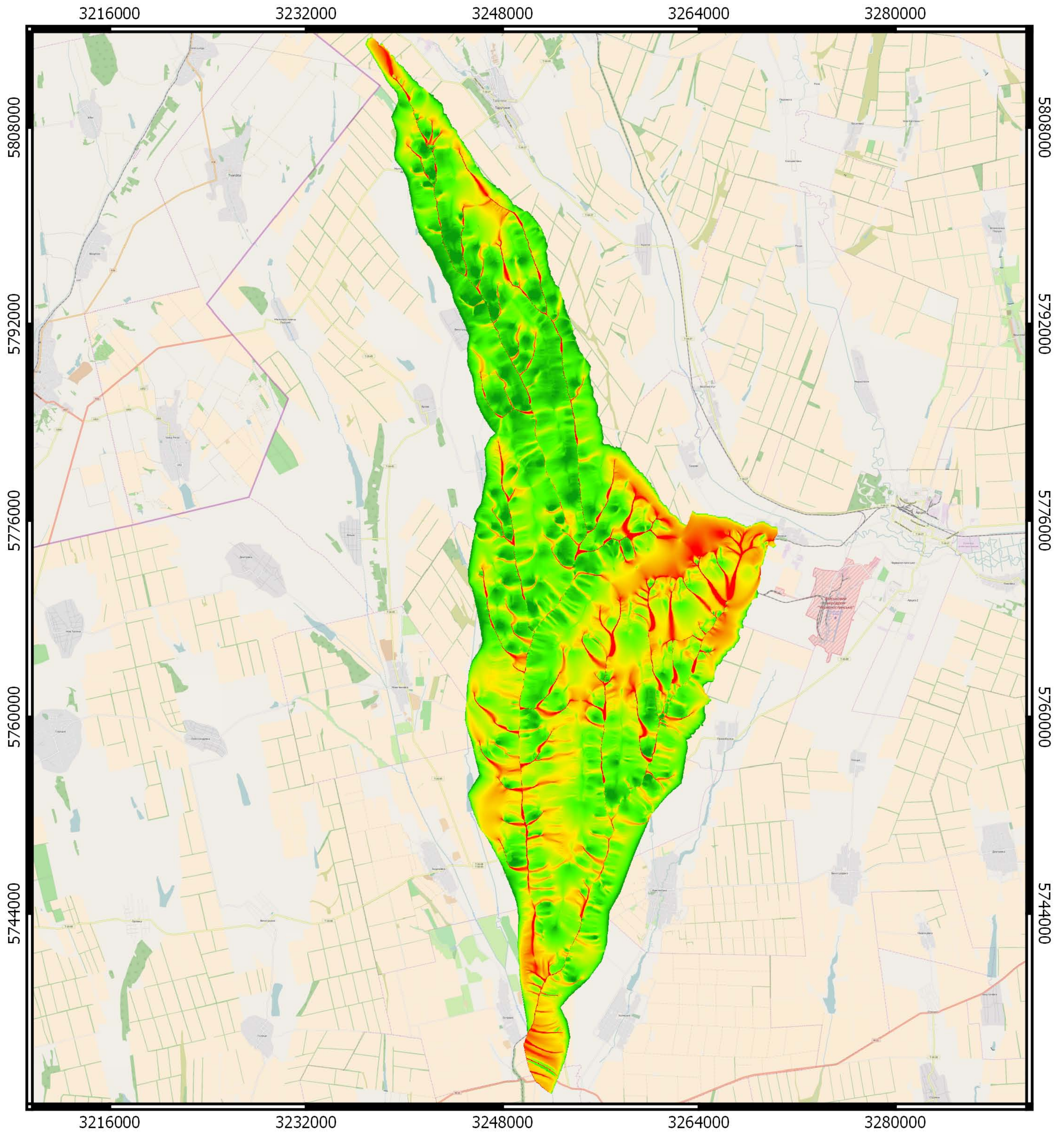
- Hydrologic Network
- Contours

100 0 100 200 300 400 m

Coordinate Reference System
WGS84 Zone 35



591500
592000
592500
5106000
5105500
5105000
20
15
25
30
35
40
45
50
55
60
65
70
Background image from ©2015 HERE; ©2015 Digital Globe; ©2015 Microsoft Corporation
SciNetNatHaz Project
Black Sea Basin JOP
2007-13
Mapping Flood prone areas
on a Local Scale
(Larga river, Moldova)
Water Velocity (m/sec)
50yr flood
Legend
Water Velocity (m/sec)
>0
0.10
0.20
0.30
General Data
Hydrologic Network
Contours
100 0 100 200 300 400 m
Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project
Black Sea Basin JOP
2007-13

Mapping Flood prone areas on a Local Scale (Ukraine)

Topographic Wetness Index
Aliyaga River Catchment

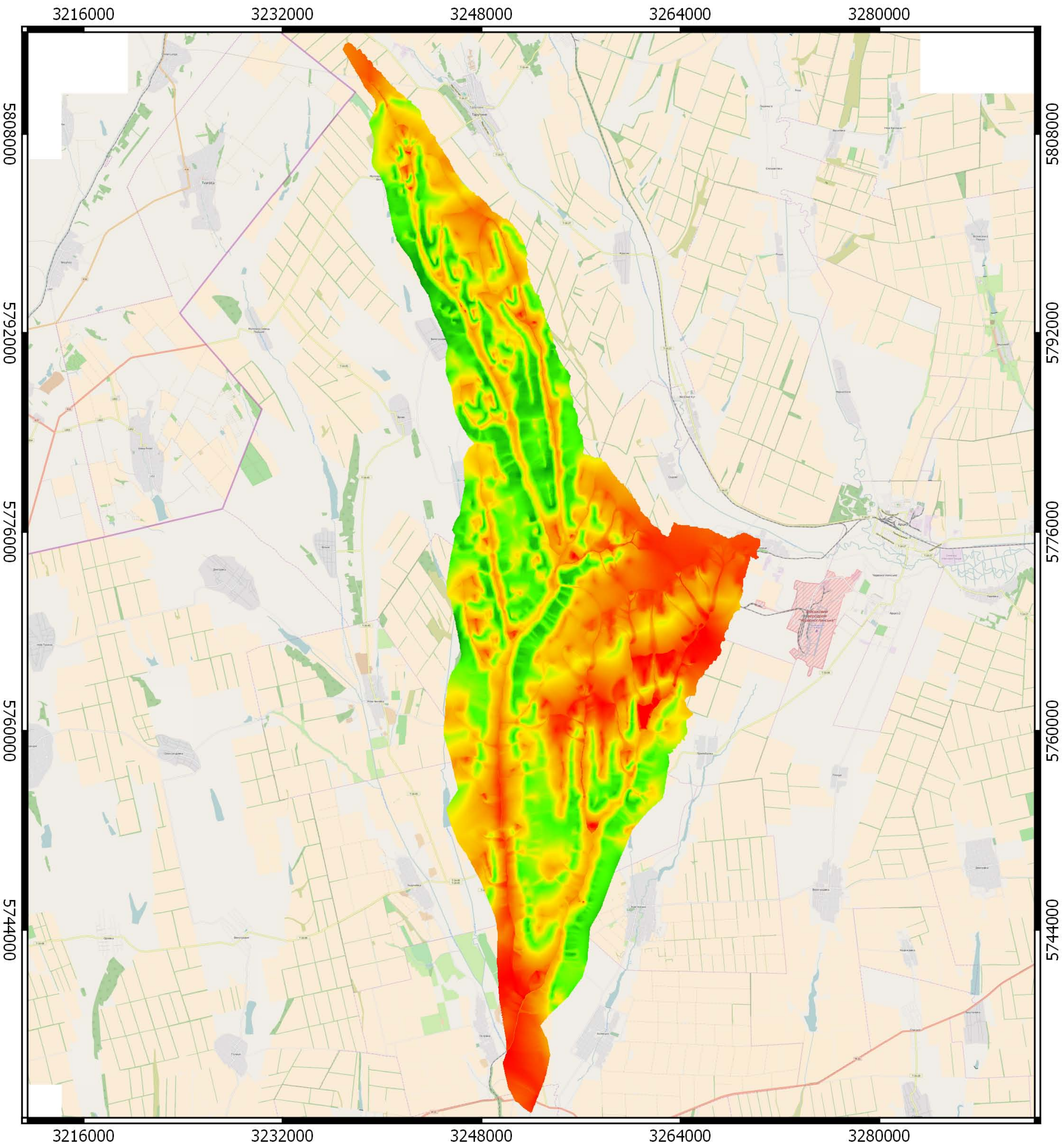
Legend

Topographic Wetness Index

8
10
11
13
14

6 0 6 12 18 24 km

Coordinate Reference System
WGS84 Zone 35



SciNetNatHaz Project Black Sea Basin JOP 2007-13

Mapping Flood prone areas on a Local Scale (Ukraine)

SAGA Wetness Index Aliyaga River Catchment

Legend

SAGA Wetness Index

5
6
8
10
12

6 0 6 12 18 24 km

Coordinate Reference System
WGS84 Zone 35