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Greece - Republic of North Macedonia

Preven-T

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PREVEN-T Project Profile

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Partners

INTERNATIONAL HELLENIC UNIVERSITY	International Hellenic University (IHU)	Greece
	Military Academy "General Mihailo Apostolski" (MAGMA)	RNM
	National Park Pelister	RNM

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Version	Date	Author (Partner)	Remarks/Changes
4.2.1	20/07/2022	Kalliopi Kravari (IHU)	Table of Contents
4.2.2	22/07/2022	Elissavet Feloni (IHU)	1st Report
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4.2			FINAL VERSION TO BE SUBMITTED

Abbreviations and acronyms

Deliverable	D
Expected Outcomes	EO
International Hellenic University	IHU
Non-governmental organization	NGO
Digital Terrain Model	DTM
Digital Elevation Model	DEM
Geographical Information Systems	GIS
Curve Number	CN
Corine Land Cover	CLC
Time – area diagram	TAD
Unit Hydrograph	UH
Flood Early Warning System	FEWS

Executive Summary

PREVEN-T is a 18 month duration project funding from the Interreg IPA Cross-border Cooperation Programme: PREVEN-T – CN2 – SO2.4 – SC049.

The overarching objective of the PREVEN-T project is to provide "Modern Tools for wildfires' and Floods' Risk punctual forecast and monitoring and innovative techniques for citizens' safeguard awareness and preparedness". The main purpose of this document is to a report the progress of the PREVEN-T project during the deliverable of WP 4.2 titled: "Local hydrological model for basin's run - off and torrent's discharge estimation on Pelister's Park area". Simultaneously with the implementation of the atmospheric forecast model of the entire Pelister's Park area (WP 4.1), we proceed to the implementation of the local hydrological model according to the following steps, together with the installation of Automatic hydrometeorological and hydrometric in the above region.

As this was an ungauged basin, freely available Digital Elevation Model (DEM) and other datasets for the study area are incorporated in a GIS-based approach to finally perform a hydrological analysis and the following hydraulic simulation to produce the corresponding inundation map, as a way to quantify the flood risk for Bitola city.

The combined results from the WP 4.1 model and WP 4.2 model could be used for the implementation of an AH (Atmospheric Hydrological) model which will be able to inform both the authorities and local population of Bitola (around 24h prior to an event of high risk), for any forthcoming threat by presenting precise estimations. Overall results will also allow the policy makers to prepare an organized and smooth evacuation plan, by displaying active flood risk maps, incorporating real time information, in order to find the safest and easiest way to protecting local population.

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List of Figures & Tables

1 Introduction

1.1 PREVEN-T | Specific research visits on the study

In the frame of WP 3 & WP 4, several visits took place for the study area's screening and for the preparation of the model scheme. In-situ observations in the study areas (i.e., Pelister National Park, Dragor river basin), installation and calibration of instruments for air pollution monitoring, sampling regarding water quality, and technical meeting with the research team meambers from the International Hellenic University (Lead Partner), local partners from the Military Academy "General Mihailo Apostolski", Skopje, N. Macedonia, and the National Park Pelister, Bitola, N. Macedonia and the INTERREG GREECE – NORTH MACEDONIA Joint secretariat.

1.2 Research activities during our visit

1.2.1 Activities in the frame of WP 3.3 "Surface water and fragile vegetation pollution model, due to acid rain caused by air pollutants": Sensors

Installation and calibration of instruments regarding air quality monitoring (Figure 1).

Calibration of water quality instruments that measure electrical conductivity (EC), water temperature, pH, etc (Figure 2). Sampling (Figure 3) and analysis of samples using the laboratory equipment of the Laboratory of Climatology and Atmospheric Environment (LACAE), UOA.

Figure 4 depicts the form that was created for in-situ records during sampling, while Table 1 summarizes the locations of sampling.

Figure 1 Installation of instruments at Molika (Pelister)

Figure 2 Calibration of instruments

Figure 3 Sampling across Dragor river and at the Baba (Pelister) Mountain lakes mountain lakes named Pelister's Eyes

ΔΕΛΤΙΟ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ SAMPLING EVIDENCE SHEET			**ΔΕΙΓΜΑ** SAMPLE
ΚΩΔΙΚΟΣ ΟΜΑΔΑΣ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ (SAMPLING TEAM IDENTIFICATION) : **ΟΝΟΜΑΤΕΠΩΝΥΜΟ ΔΕΙΓΜΑΤΟΛΗΠΤΗ** (SAMPLER NAME):			**ΚΩΔΙΚΟΣ ΔΕΙΓΜΑΤΟΣ** SAMPLE NUMBER : **#1A**
ΤΟΠΟΣ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ LOCATION :	**ΦΥΛΛΟ ΧΑΡΤΗ** / MAP NUMBER : **1** **ΣΥΝΤΕΤΑΓΜΕΝΕΣ** / GRID : **41.04, 21.30** **ΔΙΕΥΘΥΝΣΗ** / ADRESS : **after InfoCenter**		
ΣΗΜΕΙΟ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ SAMPLING SPOT :	**Dragor/upstream pnt**		**MEDIA :** **ΝΑΙ** YES - ~~**ΟΧΙ** NO~~
ΩΡΑ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ TIME OF SAMPLING :	**13 :16**		**(ΤΟΠΙΚΗ** / Local - **Zoulou)**
ΕΙΔΟΣ ΔΕΙΓΜΑΤΟΣ TYPE OF SAMPLE:	~~**ΑΕΡΙΟ** / ΓΑΖ~~ - **ΥΓΡΟ**/ LIQUID - ~~**ΣΤΕΡΕΟ** /SOLID~~ **ΑΛΛΟ** / OTHER : **-**		
ΠΕΡΙΓΡΑΦΗ ΤΟΥ ΔΕΙΓΜΑΤΟΣ DESCRIPTION (NATURE OF THE SAMPLE):	**In situ measurements & sample of water in a bottle**		
ΜΕΓΕΘΟΣ & ΟΓΚΟΣ ΔΕΙΓΜΑΤΟΣ VOLUME / SIZE :	**ΑΡΧΙΚΗ ΕΥΡΕΘΕΙΣΑ ΠΟΣΟΤΗΤΑ** (INITIAL) : **riverflow**	**ΠΟΣΟΤΗΤΑ ΔΕΙΓΜΑΤΟΣ ΠΟΥ ΣΥΛΛΕΧΘΗΚΕ**(TAKEN): **500ml**	
ΕΝΔΕΙΞΕΙΣ ΦΟΡΗΤΩΝ ΑΝΙΧΝΕΥΤΩΝ ON SCENE MEASUREMENTS :	**ΧΗΜΙΚΑ** / CHEMICAL : **Cond 103 μS – pH 7.96 – Temp 16.6°C**		
ΣΥΣΚΕΥΗ ΤΑΥΤΟΠΟΙΗΣΗΣ RELATED MEDIA IDENTIFICATION :	**Laboratory's instruments**		
ΑΛΛΕΣ ΠΑΡΑΤΗΡΗΣΕΙΣ OTHER RELEVANT INFORMATION :	**-**		
ΑΡΙΘΜΟΣ ΔΕΙΓΜΑΤΩΝ ΠΟΥ ΣΥΛΛΕΧΘΗΚΑΝ CONTROL SAMPLE NUMBER	**Three [3]** **Codes (1A, 1B, 1C)**		

Figure 4 Sample's record example

Table 1 Measurements' summary table)

Conductivity (μS)	*pH*	*T(°C)*		*Latitude (°)*	*Longitude (°)*	*Altitude (m a.s.l.)*
site #1 (41.04, 21.30)						
103.00	7.96	16.60		41.04	21.30	685.00
98.00	7.56	15.20				
63.00	7.48	15.30				
site #2 (41.034, 21.317)						
105.00	7.69	16.10		41.03	21.32	649.00
114.00	7.67	16.00				

1.2.2 Activities in the frame of WP 4.1 "High resolution weather forecast model " and the WP 4.2 "Local hydrological model for basin's run - off and torrent's discharge estimation on Pelister's Park area": in-situ observations across river and actions regarding spatial data acquisition

In-situ observations in vulnerable hotspots in the Dragor river basin were required in order to define suitable locations for stations' installation, as well as to locate the positions across river where the hydrological model will be developed and implemented. Collaboration with local partners also offered critical information regarding several hydraulic parameters of the channel in Bitola city, such as the peak discharge values, which are among the input requirements for the hydraulic simulation. Finally, observations regarding stage were compared in a seasonal basis with the ones observed during a previous visit in May, 2022 (Figure 5).

Dragor river in Bitola city - May, 2022

Dragor river in Bitola city - July, 2022

Figure 5 In-situ observations across Dragor river

Finally, as several geospatial data are necessary in order to perform the hydrologic and hydraulic modelling, an initial planning regarding data acquisition, analysis and pre-processing was done. Particularly, the datasets for which we were applied concern the Dragor river basing (Figure 6) and are listed as follows:

i. High Resolution Digital Elevation Model (DEM)

ii. Soil map

iii. Geology/lithology map

iv. Land use/land cover map

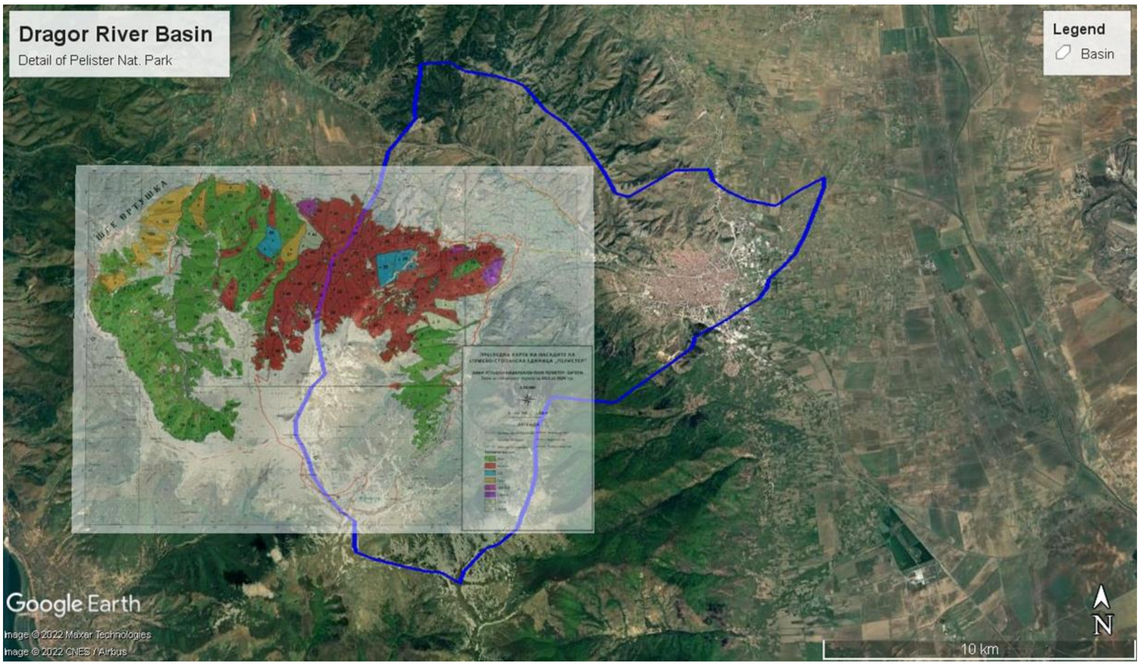


Figure 6 Dragor river basin

Finally, the research team searched out any available hydro-meteorological data, and, more specifically, regarding historical precipitation timeseries of fine temporal scale and the local intensity-duration-frequency (IDF) curves, which are also among requirements in the frame of rainfall-runoff modelling. The lack of any available datasets contributes to the implementation of a GIS-based methodology that may incorporate freely-available datasets.

2 Station network design

Among the main objectives of the WP 4.2 entitled "Local hydrological model for basin's run - off and torrent's discharge estimation on Pelister's Park area" are the implementation of an atmospheric forecast model for the entire Pelister's Park area, as well as of a hydrological model oriented towards the local geomorphological and hydrological characteristics of the study area.

One of most crucial factors contributing to a reliable approach is the existence of a hydrometric-hydrometeorological network of stations to monitor rainfall-runoff events and, finally, to obtain records valuable for the model calibration and verification. As study area is a case of ungauged basin, this work package also includes the installation of an automatic hydrometric station on the gorge of Dragor's river, near Bitola city. This paragraph includes the description of the main guidelines that were taken into consideration in order to select a proper location for the station installation. Additionally, the characteristics of the location and the technical specifications of the instrument are also presented.

2.1 Site selection guidelines

Hydrometric information constitute the primary information for the design of various water resources projects, such as reservoirs, water distribution systems, irrigation networks, flood warning systems and the study of hydrological impact of climate change (Mishra and Coulibaly, 2009). However, establishing and maintaining an adequate hydrometric network remains a major challenge in most countries around the world, due to the limited number of stream gauges installed (Samuel et al., 2013). For this reason, research concerning optimal site selection for a stream gauging network design is important.

The general location of a hydrometric/ stream gauging station depends on the specific purpose of the hydrometric record (Hong et al., 2016). According to the World Meteorological Organization (WMO, 2010), certain data for regional flood frequency studies that are essential for the designing of dam spillways, bridges, culverts and for delineation of flood plains, are mainly records of annual peak discharge at specific stream locations. However, regional studies of low flow magnitude and frequency are also useful for the planning, designing, and management of water supply facilities. Low flow data can be supplemented by establishing a more comprehensive network of low flow partial record sites, which should measure natural flow streams in the region and include a wide range of drainage, physiographic and climatological characteristics.

The hydrological principles in selecting the general locations of the individual stations in the network should be applied in a way that optimal information could be obtained regarding the cost required for the data collection (Hong et al., 2016). After the selection of the general location of the stream gauging station, a specific site for its installation must be set, satisfying further criteria, many of which are defined by the ISO 1100-1:1996 (WMO, 2010) and its revision ISO 18365:2013. In order to determine suitable stream gauges locations, an analysis is required to evaluate whether eligible locations meet specific criteria. The most common criteria that are considered are described as follows (Sơn and Phượng, 2003; Hong et al. 2016; Feloni et al., 2018; Theochari et al., 2019):

i. The general course of the stream should be straight for about ten (10) times the stream width, upstream and downstream from the gauge site.

ii. The gauge site should be far enough upstream from the confluence with another stream to avoid any variable influence from another stream.

iii. The gauge site should be far enough upstream and downstream from sites vulnerable to tidal effect.

iv. The total flow should be confined to one channel at all stages and no flow bypasses the site as subsurface flow.

v. The stream-bed should be relatively free of aquatic vegetation. Banks are permanent, high enough to contain floods, and are free of brush.

vi. Upstream of the station location, a pool should be formed in order to ensure the stage recording at extremely low flow, and to avoid high velocities at the stream ward end of stage recorder intakes, transducers, or manometer orifice during periods of high flow. V

ii. In this work, an additional criterion, which can be enforced after in-situ observation, explains that the site of installation should not be affected by intense scour and fill, which is ensured by maintaining a steady slope upstream and downstream of the site, given the fact that the station is located in a straight enough part of the river. Very low stream slope is preferred.

2.2 Hydrometric station location description

As one can note, the majority of a hydrologic network design criteria can be validated only after in site observations, as the GIS-based procedure can only nominate some candidate positions according to a team of criteria (e.g., i-ii-vii or i-ii-v-vi-vii), as in general the potential of GIS procedure is strictly affected by the quality of available geographical data (detailed network, high-resolution digital elevation model, etc.). For this reason, study area is study for two periods of different flows; during May 2022, a period after extensive rainfall events in the region and also a period characterized by high snow melting rates, and during July 2022, when Dragor river appears low flows (Figure 7).

Figure 7 Focused field exploration across Dragor River;
May 2022 [upper panel] and July 2022 [lower panel]

After taking into consideration the above-mentioned criteria as well as the hydrologic behaviour of the gorge, a suitable location is proposed close to the upper limit of Bitola city (Figure 8; Latitude: 41.03°, Longitude: 21.32°), a location that can also be used as a reference station in case an early warning system operates in the area. The existence of a bridge in this location ensures the low cost of installation and the proper operation of the instrument. Furthermore, the ease of access that describes this location, is another important characteristic.

Figure 8 Hydrometric station site selection

2.3 Hydrometric station specifications

The RQ-30 radar sensor was selected for Dragor river monitoring (Figure 9). This instrument continuously measures directly the discharge of rivers and channels. The device combines two contact-free radar measurement methods to determine the surface velocity and water level. It is a contact-free measurement, which is its main advantage as in this way it cannot be harmed by sediments and floating refuse. The result requires very low maintenance and is characterised by an increased reliability, especially in flood water situations.

(a) (b)

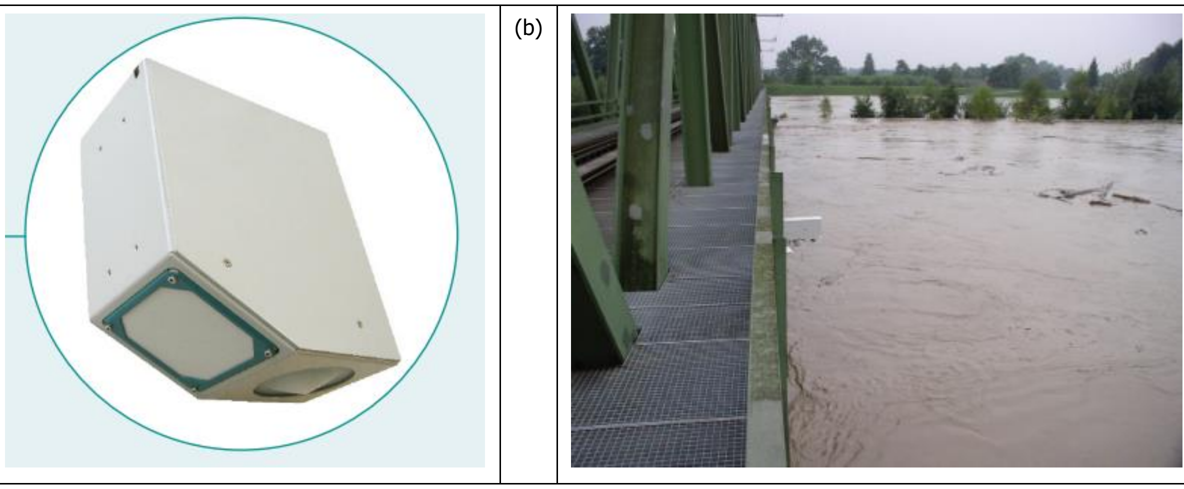


Figure 9 The RQ-30 radar sensor; (a) image of the sensor, (b) indicative way of the sensor's installation on a bridge (Sommer, 2017)

As shown in Figure 3(b), the sensor can be easily mounted on bridges, superstructures of channels or the ceilings of closed channels. Installation at measurement locations that was previously too difficult to realize, is now possible.

The main criteria for measurement sites are in general in agreement with the WMO guidelines, and more specifically they are related to the properties of the riverbed, the water surface and the flow conditions:

i. The riverbed must not change to ensure a consistent measurement.
ii. The water surface must not be flat.
iii. Wavelets should be visible.
iv. Stones, maelstroms or standing waves should not occur within the measuring area.

The variety of sites where a RQ-30 sensor already operates is shown in Figure 10. Depending on the properties of the water surface the device can be installed in a height of 0.5 to 35 m. The measurable velocity range is between 0.10 and 15 m/s.

Figure 10 Various cases of RQ-30 sensor installation

Additionally, the direction of flow is detected, enabling the operation in tide influenced rivers. Figure 11 presents the scanner range on the river flow as a function of the height of installation.

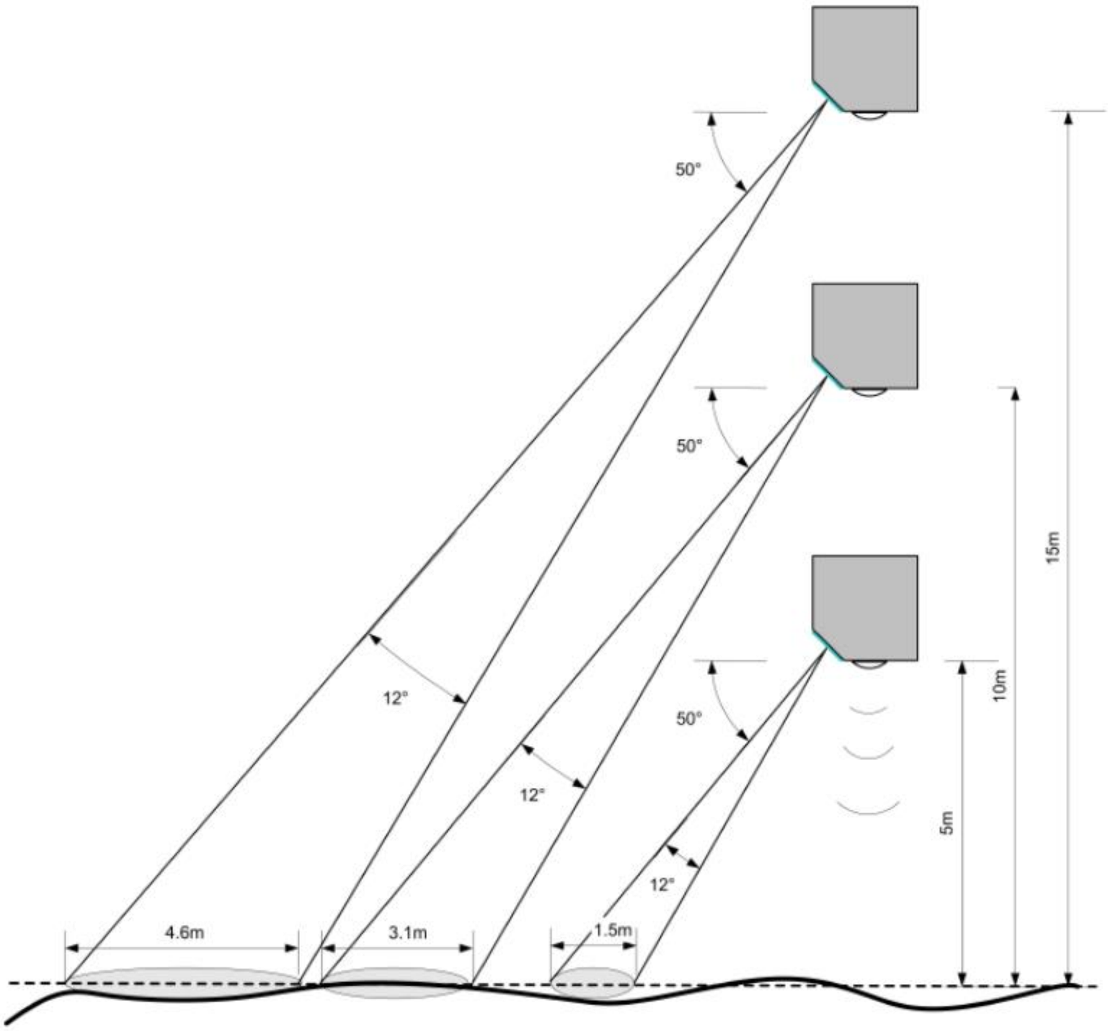


Figure 11 Scanner range as a function of its installation height (Sommer, 2017)

The in-situ calculation of discharge is based on several principles, which are summarized as follows:

- Flow velocity determination

The flow velocity is measured using the Doppler effect. A radar signal with a frequency of 24 GHz is transmitted towards the water surface. The signal is partially reflected, the moving water causes a frequency change due to the Doppler effect. A spectral analysis is performed on the reflected signal and the water's surface velocity is calculated. The signal has to be transmitted at an angle to the water surface. This angle is internally measured to automatically correct the calculated velocity.

- Water depth

The water level is calculated using a term measurement. The radar device sends short pulses perpendicular to the water surface (Figure 5). To conclude the distance to the water surface and thus the water level, the time between transmission and reception of these pulses is measured.

- Discharge

The discharge Q is determined by the continuity equation:

$$Q = v_m \cdot A(h)$$

The moistened cross-sectional area A(h) as a function of the water level is determined by the cross-sectional profile of the measuring point. The RQ-30 does not measure the mean velocity v_m but the local surface velocity v_l. The mean velocity is calculated with the conversion factor k:

$$v_m = v_l \cdot k$$

The k-factor k can either be determined by a reference measurement or by modeling using the RQ-Commander Modeling for example and can vary across the section (Figure 12). The surface level, the k factors and cross-sectional areas can be stored on the device. This enables the RQ-30 to calculate and output the discharge directly from the measured speed and water level. The RQ-Commander finally uses the following equation to calculate the discharge:

$$Q = A(h) \cdot v_l \cdot k$$

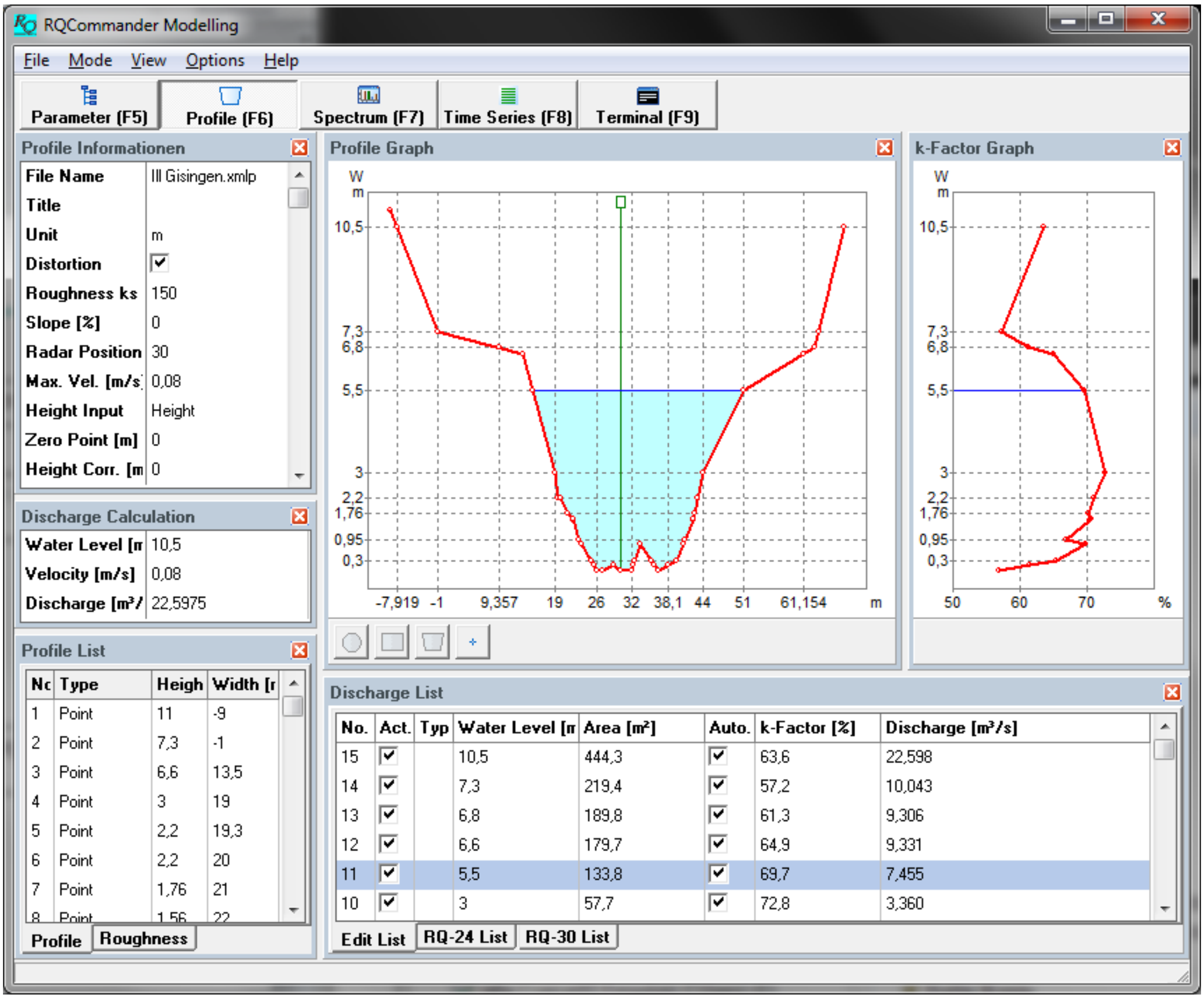


Figure 12 RQ-Commander Modeling scheme

Figure 13 presents the flowchart that summarizes the abovementioned procedure.

Table 2 summarizes the technical characteristics of the RQ-30 sensor.

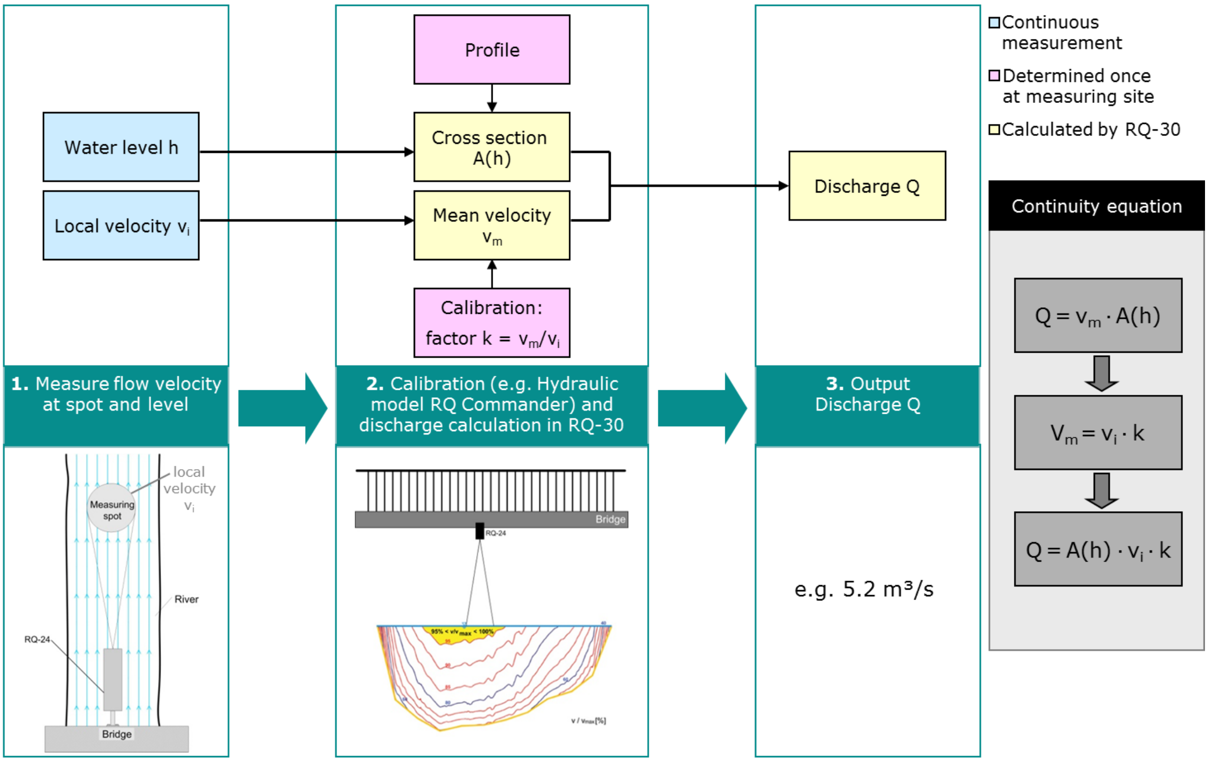


Figure 13 Discharge determination using RQ-30 sensor (Sommer, 2017)

Table 2 Technical data (Product information, © Sommer GmbH, 2017)

General	
Dimension in mm	338 x 333 x 154 mm 2 brackets for pipe Ø 34 - 48 mm
Total weight	5.4 kg
Protection class	IP 67
Power supply	6 ... 30 V
Consumption at 12 V	Standby appr. 1 mA active measurement about 140 mA
Operation temperature	- 35° ... 60° C
Storage temperature	- 40° ... 60° C
Protection	over voltage protection, reverse power protection, lightning protection

Level measurement	
Level range	• 0 ... 15 m - Standard version • 0 ... 35 m - Extended measuring range (optional)
Resolution	1 mm
Accuracy	+/- 2 mm
Radar frequency	26 GHz (K-Band)
Radar opening angle	10°

Velocity measurement	
Detectable measurement range	0.10 ... 15 m/s (depending on flow conditions)
Accuracy	+/- 0.01 m/s; +/- 1 % FS
Resolution	1 mm/s
Direction recognition	+/-
Measurement duration	5 ... 240 sec.
Measurement interval	8 sec. ... 5 h
Measurement frequency	24 GHz (K-Band)
Radar opening angle	12°
Distance to water surface	0.50 ... 35 m
Necessary minimum wave height	3 mm

Automatical vertical angle compensation	
Accuracy	+/- 1°
Resolution	+/- 0.1 °

Interface	
Analog Output (RQ-30 a)	4 x outputs 4 - 20 mA for level, velocity, discharge and AUX
Interface	Interface: 1x SDI-12 1x RS 485 or Modbus Transfer rate: 1.2 to 115.2 kBd Protocol: various ASCII-Protocols, Output: discharge, flow velocity, level, quality parameter

Finally, the instruments installation in the study area is presented in photos of Figure 14.

Figure 14 Procedure of stations' installation.

3 Geomorphological analysis & Unit Hydrograph determination for the Dragor river basin

3.1 Introduction

The last decades, Europe has suffered from major floods, causing deaths, displacement of people and large economic losses. Projections reveal an increase to the intensity and frequency of floods. Most of the observed upward trend in flood damage can be attributed to socio – economic factors, such as increases in population, wealth and urbanization in flood – prone areas and to land use changes, such as deforestation and loss of wetlands and natural floodplain storage.

Floods are natural phenomena which cannot be prevented but through the right measures we can reduce their likelihood and limit their impacts. In addition to economic and social damage, floods can have severe environmental consequences, for example when industrial installations are inundated or wetland areas destroyed. The coming decades are likely to see higher flood risk and greater economic damage.

Natural phenomena are very difficult to be accurately simulated, as our knowledge of the physical laws that govern these phenomena is not complete and the available data on the current situation are inadequate. Therefore, the models that are created for these processes are *conceptual* and their accuracy depends on the values of the parameters.

Hydrological models are important for a wide range of applications, including water resources planning, development and management, flood prediction and design, and coupled systems modelling including, for example, water quality, hydro – ecology and climate. However, due to resource constraints and the limited range of available measurement techniques, there are limitations to the availability of spatial – temporal data (Pechlivanidis et al., 2011).

The Unit hydrograph (UH) concept was first proposed by Sherman (1932), on the basis of principle of superposition, and since then, UH has been used as an important technique for lumbed rainfall - runoff data. Clark (1945) was the first to introduce the idea of Instantaneous Unit Hydropraph (Clark's IUH) by combing the time – area diagram of the catchment with linear reservoir at catchment outlet. Nash (1959) proposed a conceptual model having a cascade of linear reservoirs and introduced the gamma distribution as unit hydrograph equation. The geomorphological instantaneous unit hydrograph (GIUH) was introduced by Rodriguez-Iturbe and Valdez (1979), who used the geomorphological catchment characteristics to interpret the instantaneous unit hydropraph as a time – travel distribution; controlled by hillslope (Horton's geomorphologic law) and channel network response (Strahler's ordering scheme).

This chapter presents an integrated approach regarding geomorphological and hydrological analysis performed on Dragor River Basin, in the context of flood risk assessment and management. The area is a case of an *ungauged watershed*, thus, physically-based approaches are adopted and freely-available datasets incorporated in this analysis, as discussed in detail in the following paragraphs. The chapter includes the description of the main characteristics of both the study area and the datasets that are utilized. Further, the methodological scheme, which is developed in the frame of this research project, is presented and indicative results are illustrated. More specifically, after performing an integrated geomorphological analysis, a GIS – based rainfall – runoff model was developed and implemented by using the *method of isochrones* that is suitable for ungauged basins, as indicated in many similar studies (e.g., Anastasiadis et al., 2013). This approach that is based on the theory of Clark's synthetic unit hydrograph technique, is used to estimate runoff response in the catchment up to Bitola city, located in the southwestern part of North Macedonia. The GIS-based hydrologic approach results in the time – area diagram of the catchment by using information regarding the Digital Terrain/Elevation Model (DTM/DEM), soil type and land use distribution, e.g., the dataset CLC2018 (Büttner et al., 2017). Finally, land use and soil properties are further used to relate the rainfall volume to catchment response using the curve number (CN) method (SCS, 1986).

3.2 Methodological framework

3.2.1 Basic concept

Geomorphological - Hydrological analysis on Dragor river basin is performed according to the steps described in Figure 15.

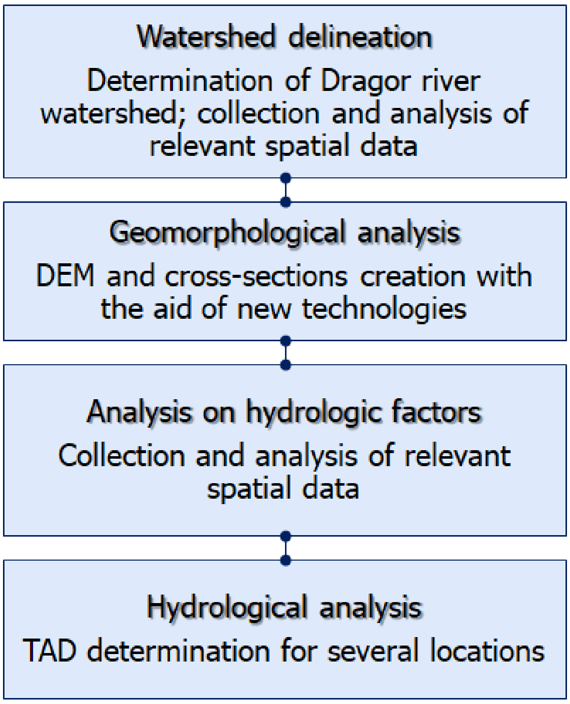


Figure 15 Main steps of the Geomorphological - Hydrological analysis

In the first stage, the geomorphological analysis of the area was carried out in a Geographical Information Systems (GIS) environment. Several datasets were used for the analysis, such as the digital elevation model (DEM) as shown in Figure 16, the land use distribution based on CLC (2018), as well as, other physiographic characteristics of the study area (soil types, etc.) that are provided by the partner National Park Pelister through available historic reports for the study area.

The second stage of the work includes the hydrological analysis. The aim of the analysis is to determine a representative unit hydrograph (UH) for the study area, which will be then used to simulate specific rainfall-runoff events from a hydrological perspective. As natural phenomena are very difficult to be accurately simulated, as our knowledge of the physical laws that govern these phenomena is not complete and the available data on the current situation are inadequate, the models that are created for these processes are *conceptual* and their accuracy depends on the values of the parameters introduced. This approach develops distributed conceptual models in G.I.S. environment using the

ArcGIS software. The first model simulates the hydrological phenomena that take place during rainfall - runoff and calculates the required time for each section of the basin to be fully drained. The model can calculate the curves representing equal timing conditions for the runoff of each region, given the DEM and CLC, and produces the corresponding runoff hydrograph resulting from the synthetic unit hydrograph of the basin. The main objective of the model is to estimate the peak of the flood discharge and the corresponding time.

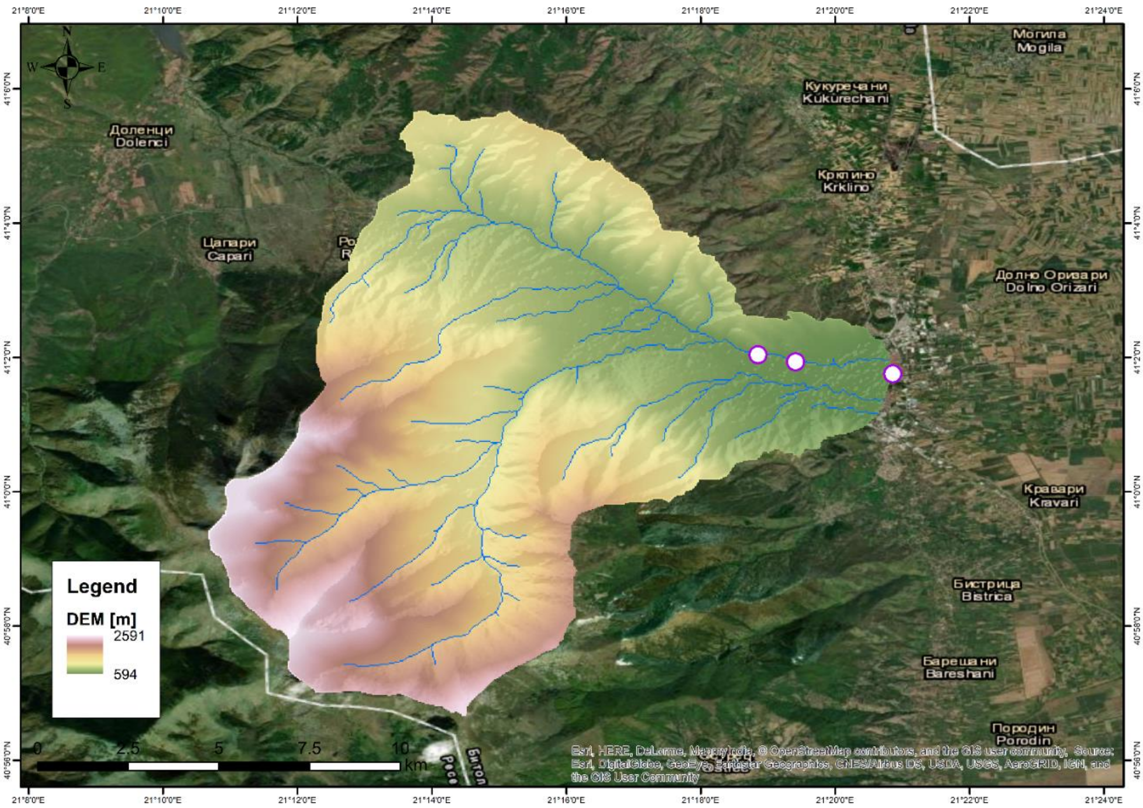


Figure 16 The Digital Elevation Model for the study area and the three locations selected for the analysis

The second model provides estimates of the discharge at the outlet of the basin (three locations as shown in Fig.2), taking as input the (measured/synthetic) values of rainfall in specified measuring stations or a surface distribution of a given rainfall. The purpose of this model is the creation of the flood hydrographs for a basin with different conditions of rainfall (intensity, duration and spatial distribution) and it is part of future work.

3.2.2 The Time – area diagram

The time – area histogram represents the area of the catchment contributing to the flow at the outlet at any given time after the application of a unit of effective rainfall. Having calculated all the parameters required in order to apply Clark's methodology, the runoff response is estimated using the UH theory (part of future work). The percentage of the total volume contributing to runoff at the outlet of the basin in each time interval is being calculated from the time – area histograms of the basin. The estimated volumes are converted to discharge for the corresponding time intervals, resulting to the estimated Instant Unit Hydropraph (IUH).

Figure 17 presents the main steps performed in a GIS environment for the TAD method implementation. As shown, DEM-derived datasets as well as data regarding land cover distribution are required and Map Algebra is applied in order to calculate water velocity for each cell of the basin. The final step of the method is the reclassification of the runoff time dataset into classes of hours.

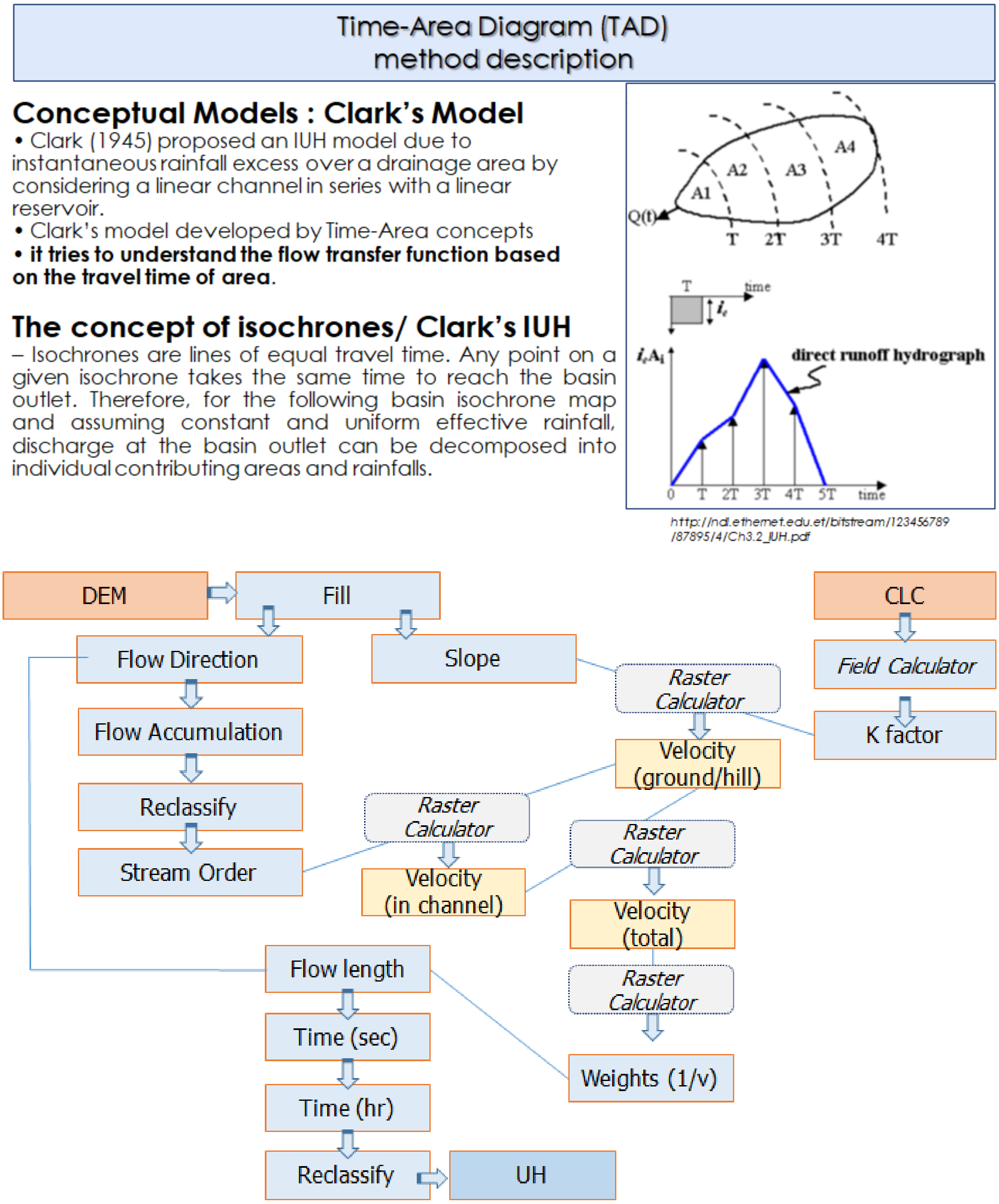


Figure 17 TAD method description (upper panel) ad GIS-based TAD method flowchart (lower panel)

The principle of Routing time–area curve of basins that underlies this method is the division of a catchment into a series of subareas, each contributing inflow into drainage channels (which have storage) due to a flash storm. These sub-areas are called isochrones such that the rain falling in any sub-area has the same time of travel to the outflow point. Clark (1945) used time–area diagrams (TADs) for the calculation of IUH. Two parameters other than TADs are necessary for this method: the time of concentration for the basin tc and K a storage coefficient. Clark's method is as follows. Any ordinate following O2, the first O1, is given by the relationship:

$O_2 = C'I + C_2O_1$,

where

$C' = t/(K + 0.5t)$,

$C_2 = 1 - C'$, $O_1 = Q_1$

where

t is the Δtc between successive isochrones

K is storage coefficient

I is the inflow to the isochrone sub-area.

3.3 Study area and Datasets

The Dragor (Macedonian: Драгор) is a small river situated in the south of North Macedonia (41.0471°N 21.4365°E). It flows mainly through the city of Bitola (Fig.4). Its spring is located near Sapunčica[1], on the Baba Mountain. The Dragor is a right tributary of the Crna river. More particularly, the Dragor river is formed of several small rivers, from the Dihovski Dragor (with length of 12 km, whose original part is made up of several watercourses that spring from the slopes of Pelister: Sapunčica, Lak stream, Crvena reka and Klisurica) and Bratinodolski Dragor or Boroica. The total length of the river Dragor is 25,123 km with basin of 188 km^2 and the mean drop of 17,0 ‰. The amount of water in the river depends exclusively on the precipitation and ground waters of Baba mountain. The average flow of the river Dragor through the city is relatively low and it is observed from November to June around 2 – 3 m^3/ sec.

[1] Information provided after personal communication with the Pelister Info Center personnel.

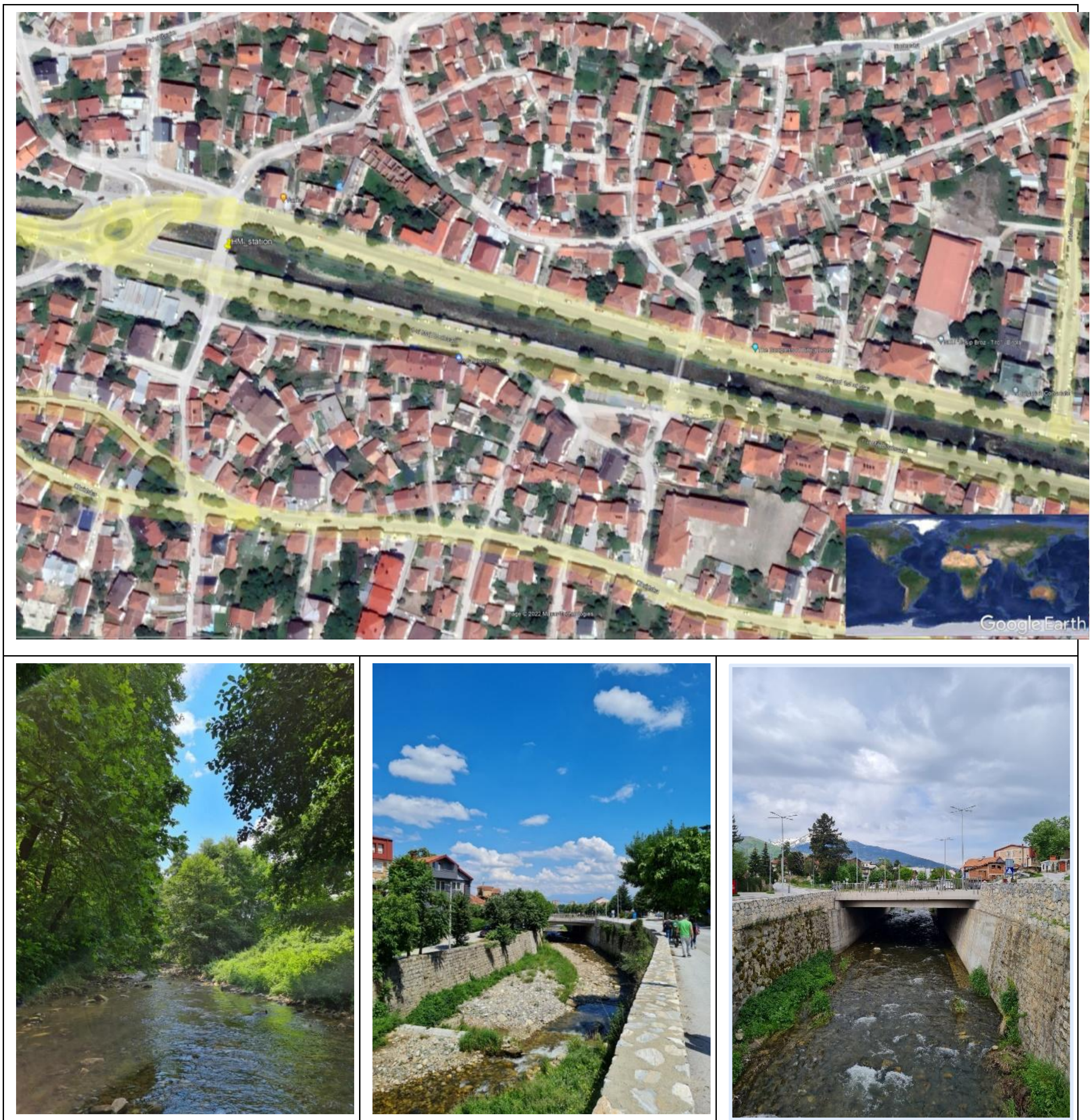


Figure 18 Dragon riven in Bitola city

A freely available Digital Terrain Model (DTM or DEM) is used to identify the areas that contribute to the catchment of interest (Figure 5). Land use data were downloaded from the Corine Land Cover 2018 database (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018) (Figure 19). The hydrological soil groups were redefined and digitized based on soil type and permeability forming a geo – database to support the proposed methodology.

Regarding land cover type distribution, the area is mainly agricultural and also forest areas prevail in the highlands, in the western and northern parts (Figures 21 - 22).

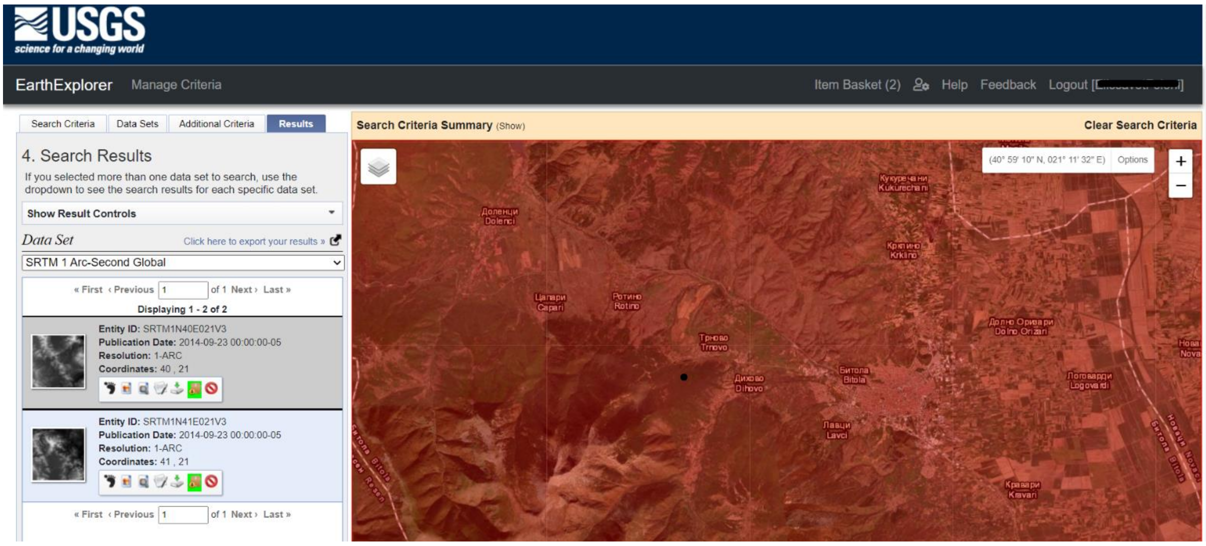


Figure 19 Selection of DEM datasets in EarthExplorer

The western, northern and southern parts are characterized by steep slopes and rocky areas with medium and high elevation. The eastern part of the catchment has smooth slopes with low elevation. This part of the catchment belongs to the municipality of Bitola. The drainage network is rich, as a result of the great amount of precipitation and the type of the shape of the catchment is *dendritic*, which means a tree-like pattern with tributaries converging on the main river channel that crosses Bitola city. The mountainous area is dominated by homogenous rocks.

Flash floods can be more frequent when high intensity rainfall occurs the period when snow fall at higher elevation. The catchment has an average altitude of 1272m (altitude varies between 594 & 2591 m) (Figure 20).

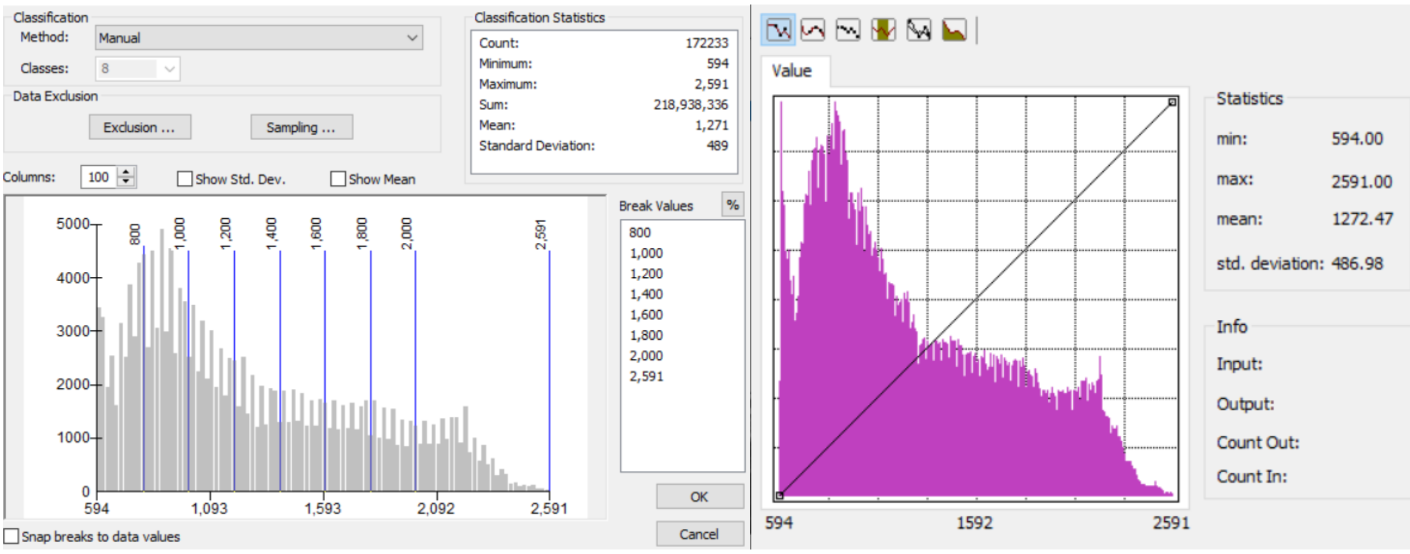


Figure 20 DEM statistics

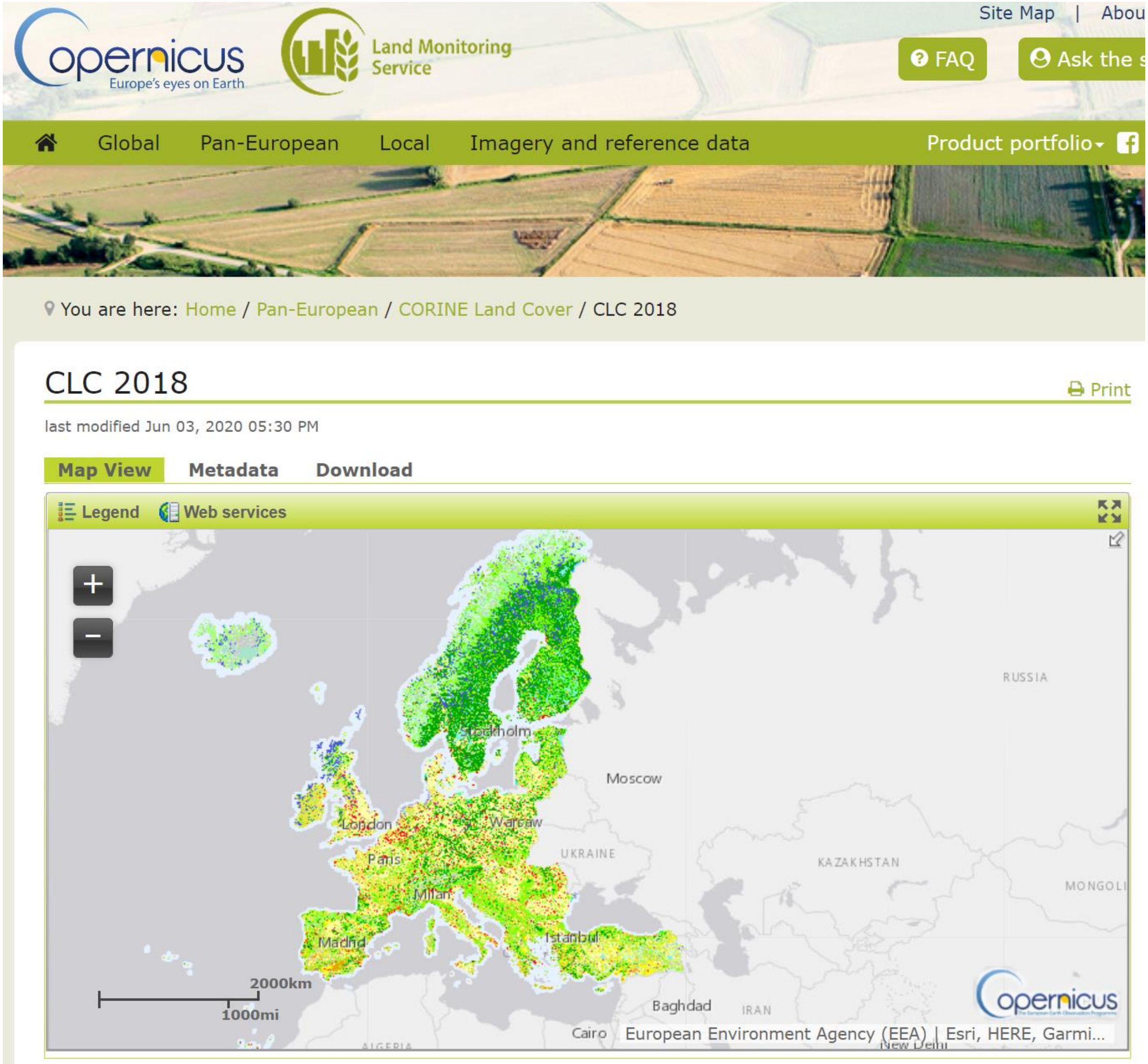
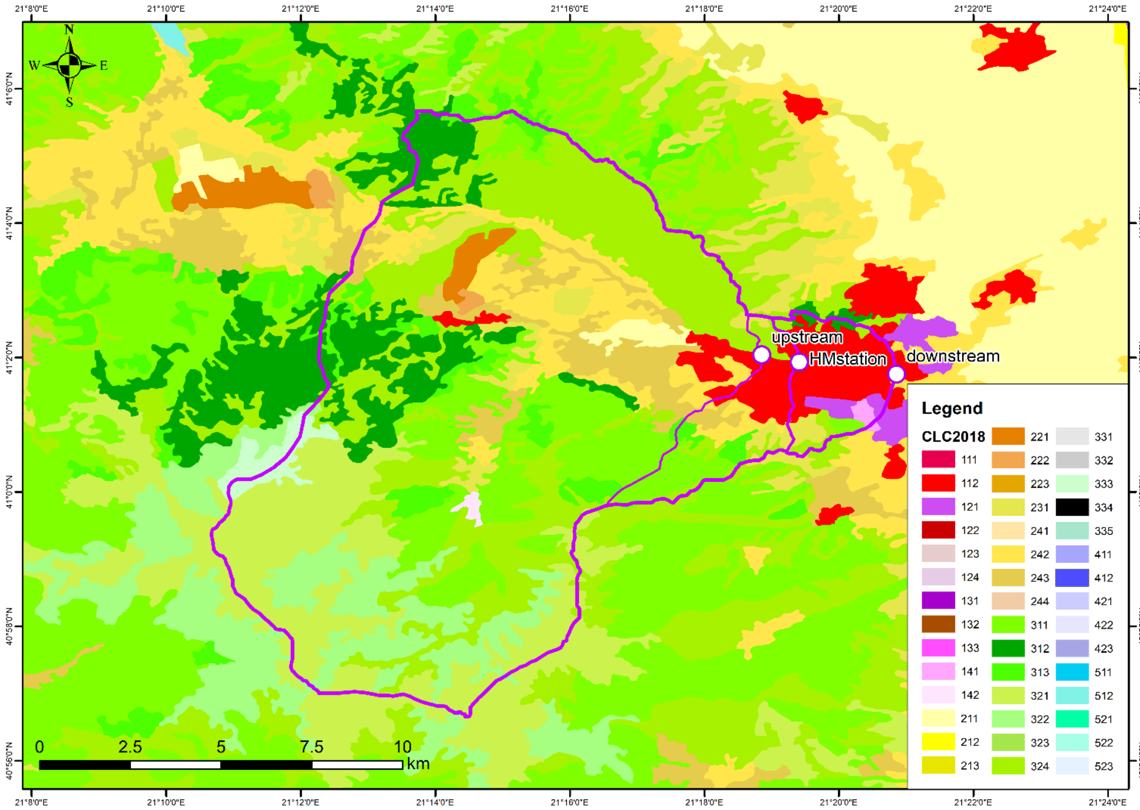


Figure 21 Selection of CLC datasets in Copernicus


21°8'0"E
21°10'0"E
21°12'0"E
21°14'0"E
21°16'0"E
21°18'0"E
21°20'0"E
21°22'0"E
21°24'0"E
41°6'0"N
41°4'0"N
41°2'0"N
41°0'0"N
40°58'0"N
40°56'0"N
N
W
E
S
upstream
HMstation
downstream
Legend
CLC2018
111
112
121
122
123
124
131
132
133
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142
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311
312
313
321
322
323
324
331
332
333
334
335
411
412
421
422
423
511
512
521
522
523
0
2.5
5
7.5
10
km


Corine land cover classes
1. Artificial surfaces
1.1 Urban fabric
1.1.1. Continuous urban fabric
1.1.2. Discontinuous urban fabric
1.2 Industrial, commercial and transport units
1.2.1. Industrial or commercial units
1.2.2. Road and rail networks and associated land
1.2.3. Port areas
1.2.4. Airports
1.3 Mine, dump and construction sites
1.3.1. Mineral extraction sites
1.3.2. Dump sites
1.3.3. Construction sites
1.4 Artificial, non-agricultural vegetated areas
1.4.1. Green urban areas
1.4.2. Sport and leisure facilities
2. Agricultural areas
2.1 Arable land
2.1.1. Non-irrigated arable land
2.1.2. Permanently irrigated land
2.1.3. Rice fields
2.2 Permanent crops
2.2.1. Vineyards
2.2.2. Fruit trees and berry plantations
2.2.3. Olive groves
2.3 Pastures
2.3.1. Pastures
2.4 Heterogeneous agricultural areas
2.4.1. Annual crops associated with permanent crops
2.4.2. Complex cultivation patterns
2.4.3. Land principally occupied by agriculture
2.4.4. Agro-forestry areas
3. Forest and seminatural areas
3.1 Forests
3.1.1. Broad-leaved forest
3.1.2. Coniferous forest
3.1.3. Mixed forest
3.2 Shrub and/or herbaceous vegetation associations
3.2.1. Natural grassland
3.2.2. Moors and heathland
3.2.3. Sclerophyllous vegetation
3.2.4. Transitional woodland shrub
3.3 Open spaces with little or no vegetation
3.3.1. Beaches, dunes, and sand plains
3.3.2. Bare rock
3.3.3. Sparsely vegetated areas
3.3.4. Burnt areas
3.3.5. Glaciers and perpetual snow
4. Wetlands
4.1 Inland wetlands
4.1.1. Inland marshes
4.1.2. Peat bogs
4.2 Coastal wetlands
4.2.1. Salt marshes
4.2.2. Salines
4.2.3. Intertidal flats
5. Water bodies
5.1 Inland waters
5.1.1. Water courses
5.1.2. Water bodies
5.2 Marine waters
5.2.1. Coastal lagoons
5.2.2. Estuaries
5.2.3. Sea and ocean

Figure 22 Land Cover

3.4 Analysis in GIS for the UHs' determination

The calculation of the UH was made for three locations across Dragor river, as shown in Figure 23. The selection of these areas is a combination of both the requirements of the following steps (i.e., upstream-downstream input hydrograph to perform the hydraulic simulation) and the fact that in one location a hydrometric (HM) station is installed in the frame of the project, thus, the location is used as a reference ones. In the same figure, one can see the area of each subbasin of Dragor river basin.

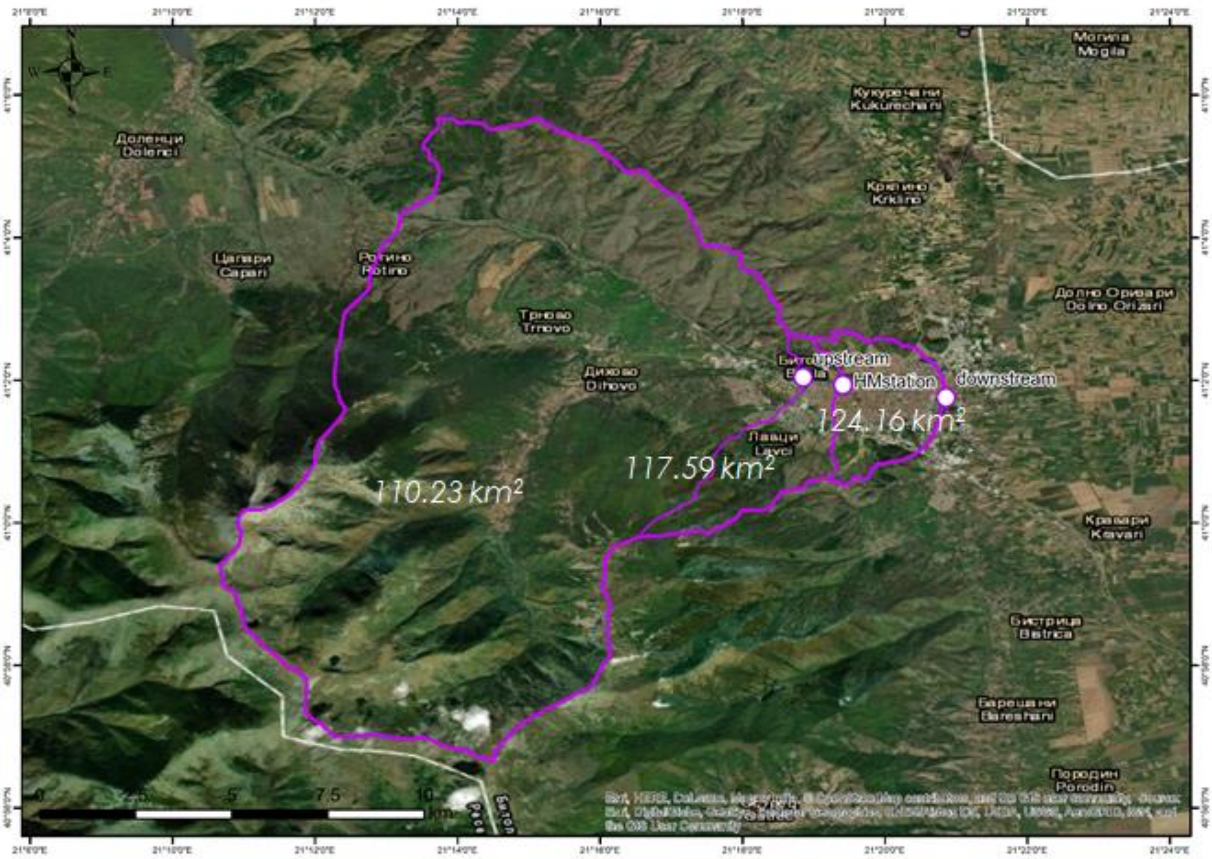
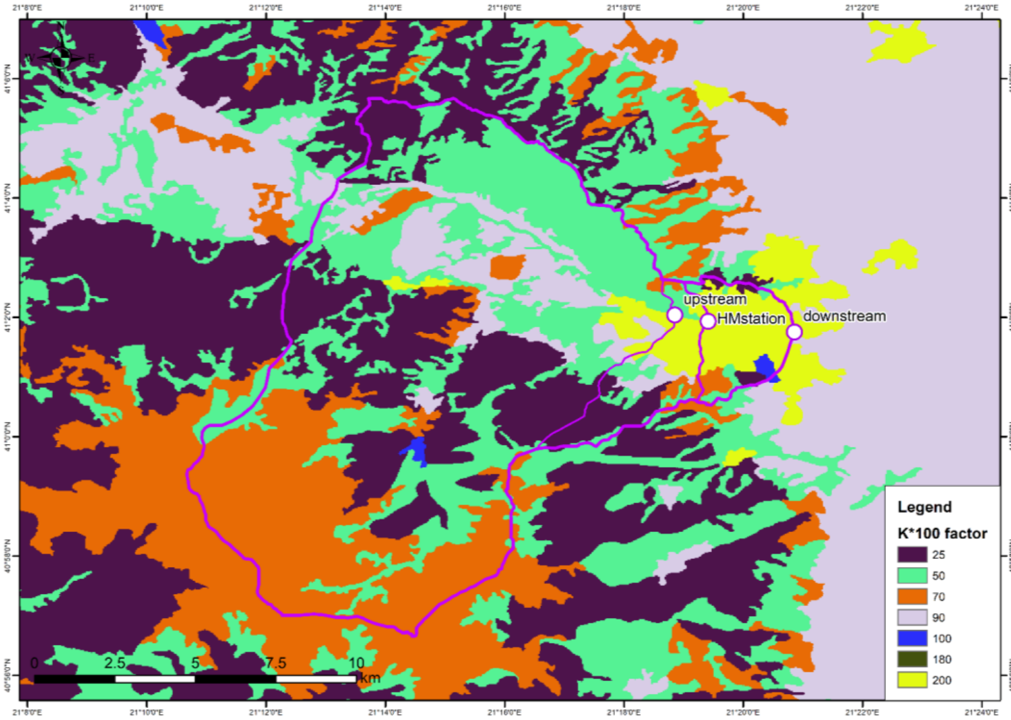


Figure 23 Subbasins of the analysis

To implement the methodology presented in Figure 3, the K*100-factor that is related to the roughness coefficient was initially determined. The values presented in the map of Figure 24 are attributed to each land cover type, according to the table on the right.

Then, using the K*100-factor and the slope (%) dataset (Figure 25), the Map Algebra is performed to finally calculate the runoff time for each cell of each subbasin.

The final GIS output is the runoff times, shown in Figure 26 as classified information that is then analysed to calculate the UHs. This dataset resulted in the time-area diagrams presented in Figure 27.



CLC code	Manning_n	K100
111	0.013	200
112	0.013	200
121	0.013	200
122	0.013	200
123	0.013	200
124	0.013	200
131	0.013	100
132	0.013	180
133	0.013	200
141	0.025	100
142	0.025	100
211	0.03	90
212	0.03	90
213	0.03	70
221	0.08	90
222	0.08	90
223	0.08	90
231	0.035	70
241	0.04	90
242	0.04	90
243	0.05	50
244	0.06	50
311	0.1	25
312	0.1	25
313	0.1	25
321	0.04	70
322	0.05	70
323	0.05	25
324	0.06	50
331	0.025	100
332	0.035	100
333	0.027	50
334	0.025	50
335	0.01	50
411	0.04	100
412	0.04	100
421	0.04	100
422	0.04	100
423	0.04	80
511	0.05	100
512	0.05	100
521	0.07	100
522	0.07	100
523	0.07	100

Figure 24 Map of K*100 factor

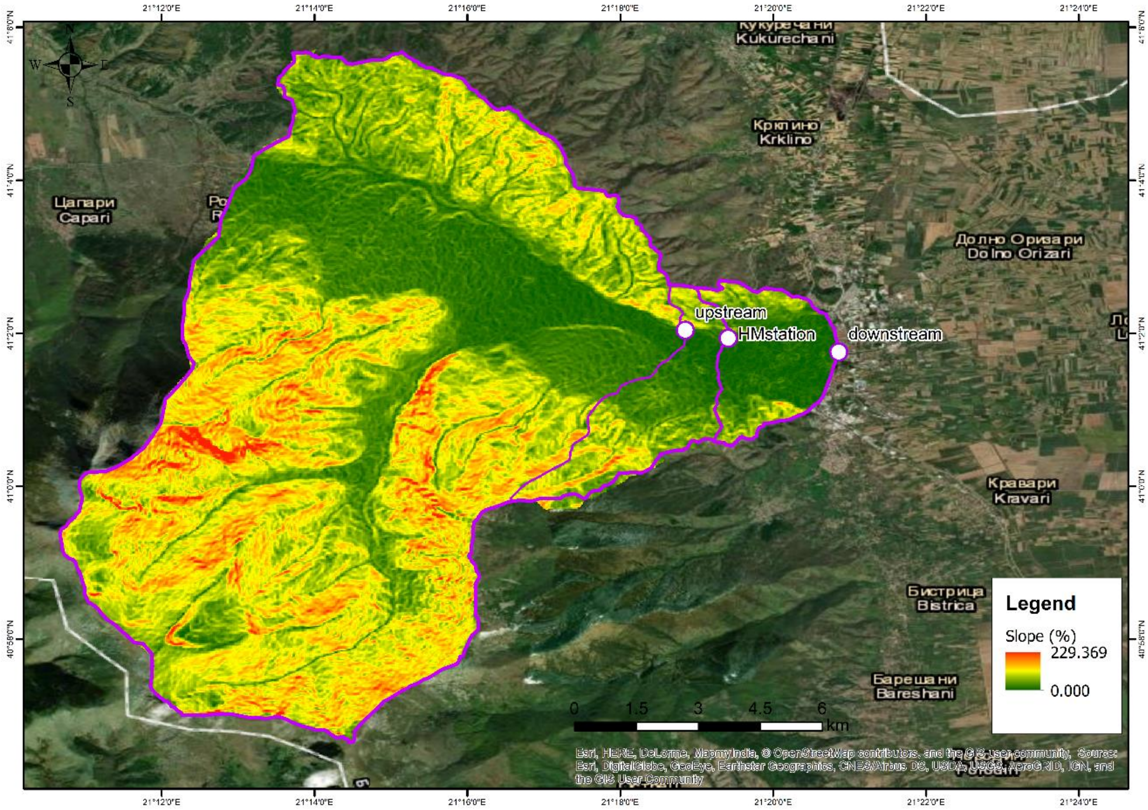


Figure 25 Map of Slopes (%)

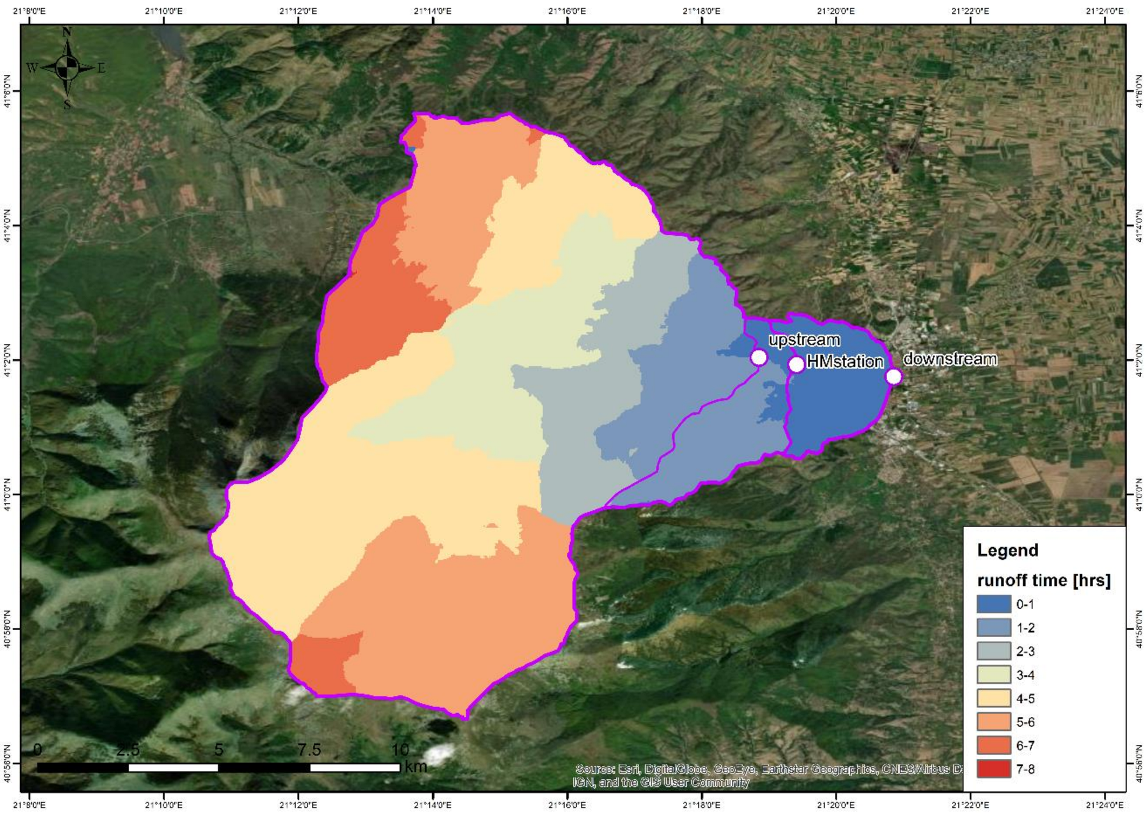


Figure 26 Map of runoff time in hrs (distributed information)

The TADs of Figure 27 depict the hydrologic response of each subbasin, which was estimated with the aid of GIS techniques after taking into consideration the physical (geomorphological, hydrological) characteristics of the study area. Table 1 includes the necessary calculations for the transformation of the number of cells per class of runoff time into discharge. The UHs are presented in Figure 28.

Table 3 Calculation of UH per subbasin based on the TADs

upstream

class	Time [hrs]	Cells Count	Q (cbm/s)
0	0	0	0.00
1	1	13610	27.25
2	2	11133	22.29
3	3	17682	35.41
4	4	45174	90.46
5	5	39729	79.55
6	6	23452	46.96
7	7	2137	4.28
8	8	0	0.00
		152917	306.2014

$Area\,[m^2] = \sum Q * 3600$ 1102325

HMstation

class	Time [hrs]	Cells Count	Q (cbm/s)
0		0	0.00
1	1	16102	32.24
2	2	13463	26.96
3	3	16414	32.87
4	4	30809	61.70
5	5	45781	91.68
6	6	35975	72.04
7	7	4572	9.16
8	8	0	0.00
		163116	326.6436

$Area\,[m^2] = \sum Q * 3600$ 1175917

downstream

class	Time [hrs]	Cells Count	Q (cbm/s)
0		0	0.00
1	1	11648	23.32
2	2	20590	41.23
3	3	16850	33.74
4	4	20908	41.87
5	5	47380	94.88
6	6	41430	82.96
7	7	13388	26.81
8	8	39	0.08
9	9	0	0.00
		172233	344.886

$Area\,[m^2] = \sum Q * 3600$ 1241590

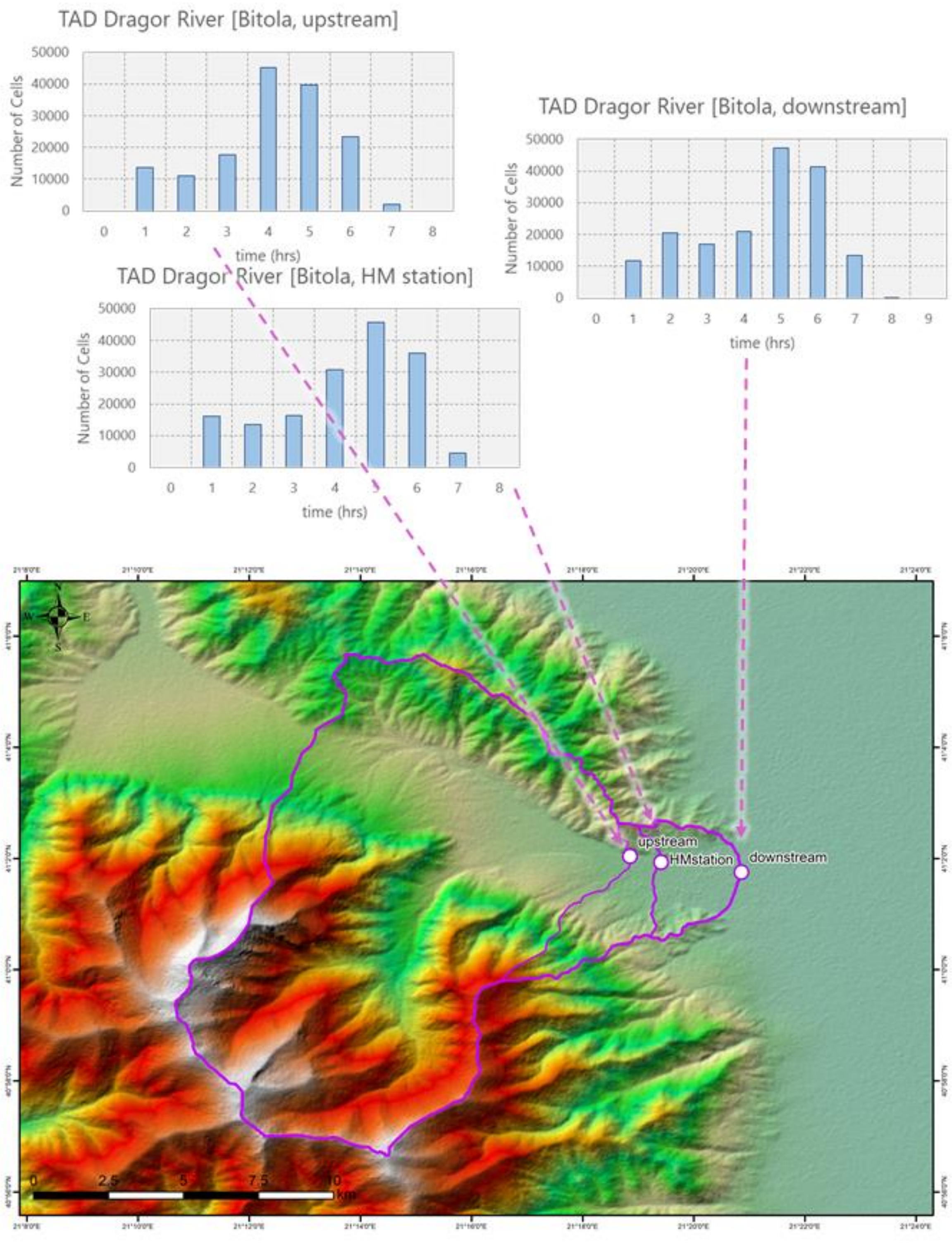
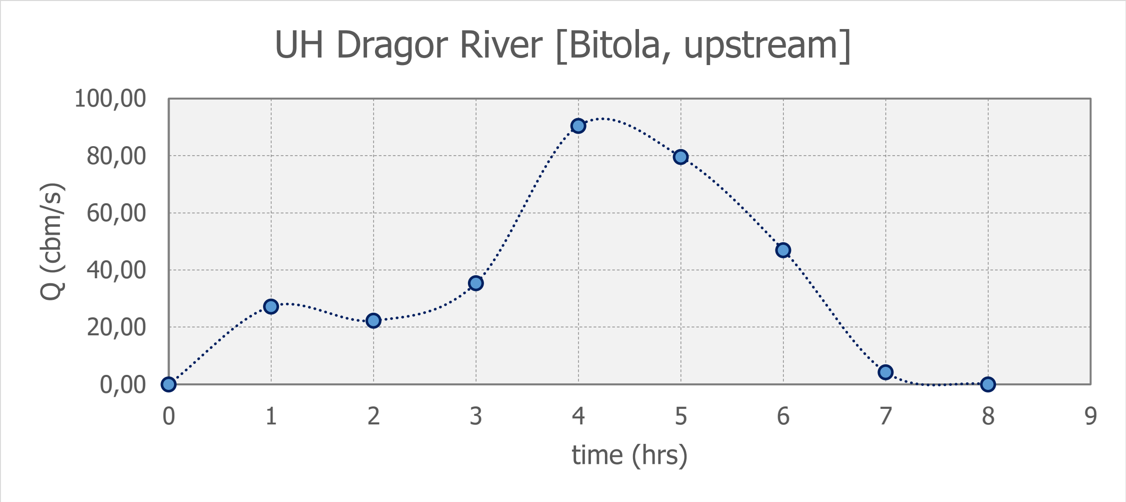
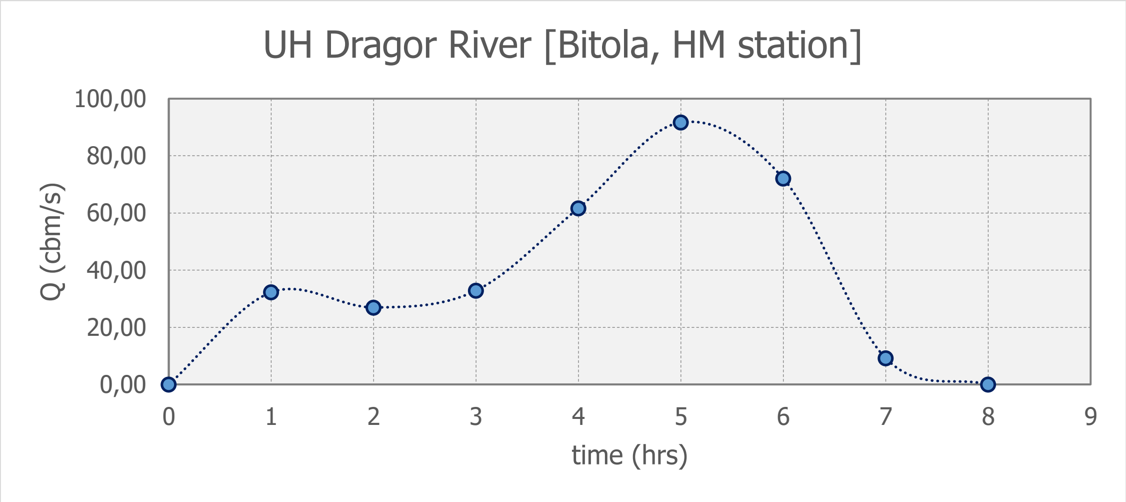


Figure 27 TADs for the three subbasins of Dragor river

(a)



(b)



(c)

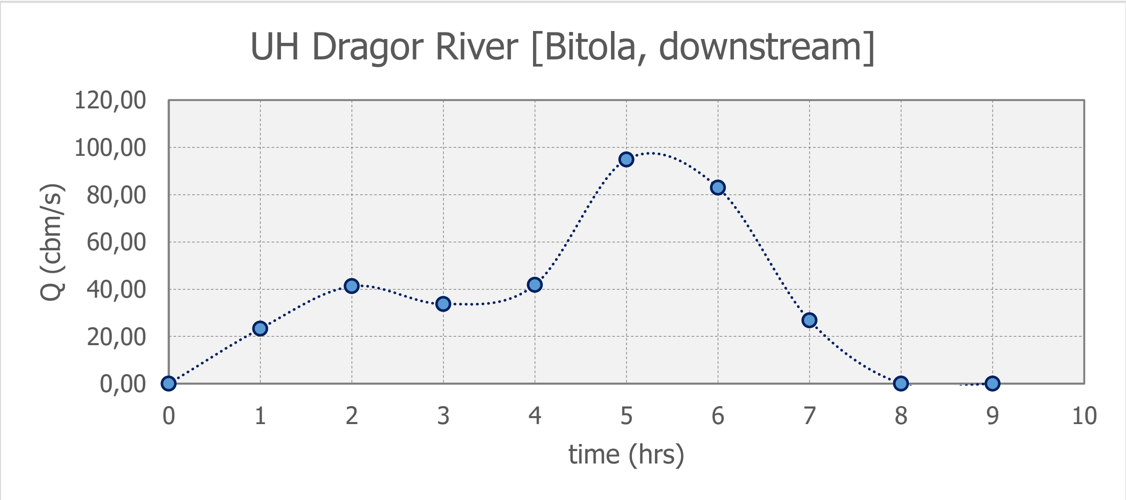


Figure 28 UH determination for each subbasin

4 Hydrological model development for the Dragor river basin

4.1 General description of the approach

Three simulation points are defined across the mainstream of Dragor river; upstream of Bitola city, in the location of the HM station location and downstream the city of Bitola. The basins delineation is done using the ArcGIS toolset "Hydrology" that provides a set of procedures, tools, and utilities for the preparation of GIS data that are required for the UH determination.

- The objective of subbasin determination is the estimation of flow hydrographs for the outlets using the hydrological model approach that is implemented in the frame of this project. The hydrological model is a physically based and conceptual semi-distributed model developed, useful to simulate rainfall-runoff processes for a wide range of geographic areas. The necessary components for running the hydrological model simulations are a basin-based UH model, a meteorological concept (design hyetograph), and data regarding the soil moisture conditions to estimate the hydrological losses. More specifically, the basin model encompasses the basin features, the selection of a loss method among various infiltration loss parameterizations (USACE 2005), and the selection of a transform method. Additionally, there is the option to include baseflow in the simulation, but no baseflow method is selected in this study due to the very low amount of baseflow discharged into the stream.
- Precipitation losses are computed using the Soil Conservation Service (SCS) curve number (CN) method, which calculates the effective precipitation through an empirically derived relationship between location, soil type, land use, antecedent moisture conditions, and runoff.
- For the current application, the CN distribution is determined for each subbasin based on the land uses and soil type of the subbasin. Then the mean value of CN is calculated for each subbasin and used to finally calculate the effective rain.
- Regarding the estimation of the temporal runoff distribution, the combination of the total runoff volume estimated by the curve number (CN, Figure 29) method with the UH is required.

→ *Hydrological losses and Effective rainfall calculation*

1

Sl No.	Landuse	Trestment/practice	Hudrologic condition	Hydrologic soil group A	B	C	D
1	Cultivated	Straight row	…..	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			Good	62	71	77	81
				67	75	81	83
		Bunded	Poor	59	69	769	79
			Good	95	95	5	95
		Paddy (rice)	…..				
2	Orchards	With under stony cover	…..	39	53	67	71
		Without under stony cover	……	41	55	69	73
3	Forest	Dense	….	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	67
4	Pasture	…….	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5	Wasted Land	……..	….	71	80	85	88
6	Hard Surface	…….	….	77	86	91	93

2 $S = 254\left(\frac{100}{CN} - 1\right)$

3 $h_e = \begin{cases} 0 & h \leq 0.2\,S \\ \frac{(h - 0.2\,S)^2}{h + 0.8\,S} & h > 0.2\,S \end{cases}$

Figure 29 CSC-CN concept implementation

The GIS-based TAD Unit Hydrograph, as presented in the previous chapter[2], is selected as the transform method for converting excess precipitation into direct surface runoff. The derived UHs are imported into the hydrological model.

- Another necessary input for discharge estimation at the outlets of the subbasins is the rainfall data. In this study, a design hyetograph is calculated by applying the alternative block method with the aid of the IDF (intensity-duration-frequency) curve for the Florina hydrometeorological station, which were determined in the frame of Floods Directive (2007/60/EC) implementation, using a return period of 100 years. While Table 4 includes the corresponding parameters for Florina station (Figure 30). The IFD formula is as follows:

$$i(d, T) = \frac{\lambda'(T^{\kappa} - \psi')}{(1 + d/\theta)^{\eta}}$$

Table 4 IDF parameters for Florina Station

Name	**X**	**Y**	**Z**	
Florina Station	280958	4517791	660	
κ	**λ΄**	**ψ΄**	**θ**	**η**

[2] The calculation of the UH is executed in the GIS environment by applying the time–area (TA) diagram method. The TAD histogram, which is the basic idea of the method, denotes the distribution of the partial watershed areas that contribute to runoff at the watershed outlet as a function of travel time (Roy and Thomas 2017). The determination of UH is executed by multiplying rainfall of unit depth by the cell dimensions (approx.. 25 m × 25 m) and by the number of cells that result for each time step (Theochari et al. 2021).

0.126	265.5	0.69	0.076	0.686

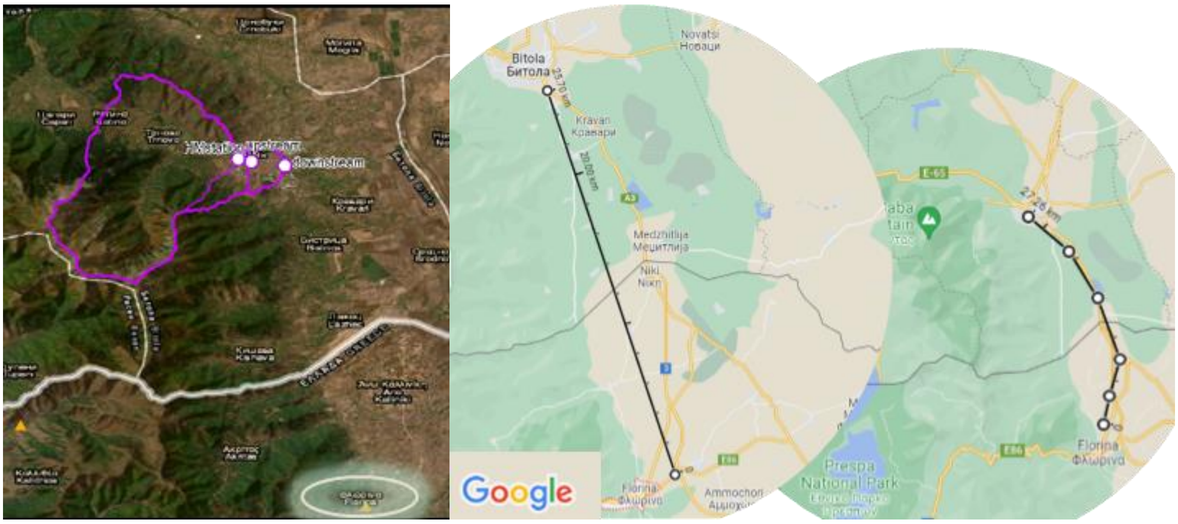


Figure 30 Distance between the study area and the Florina station

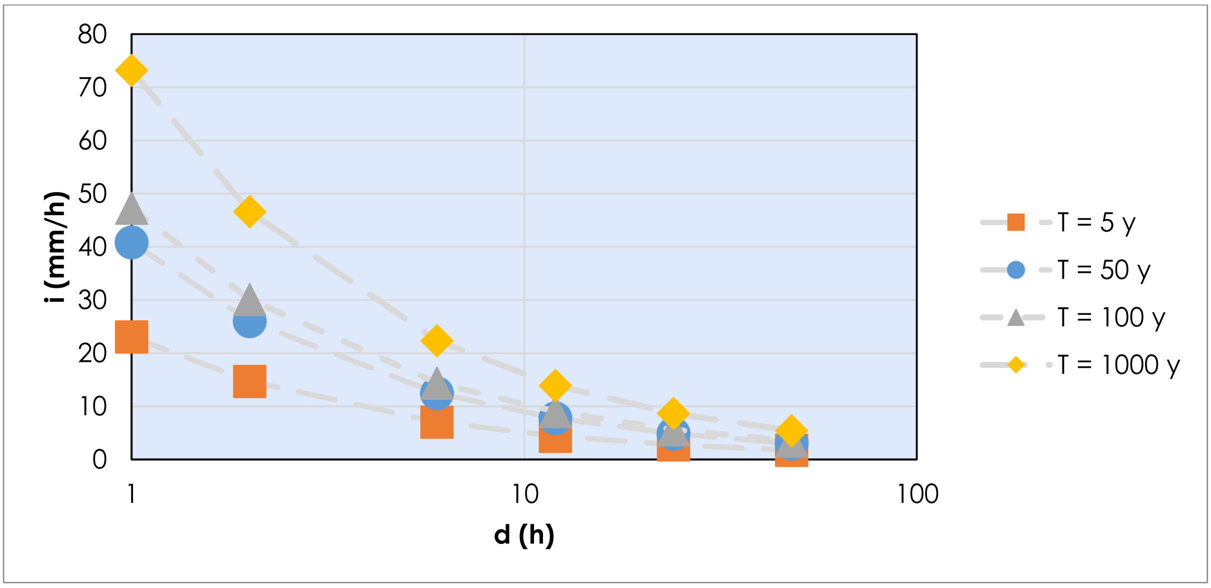


Figure 31 IDF estimation | (maximum) Intensity – Duration – Frequency curves

The results are used to create the meteorological model. Subsequently, the control specification model is created, where the time pattern for the simulation is defined. The time step for the simulation is used according to the time interval used in the alternative block method (Figures 32-33).

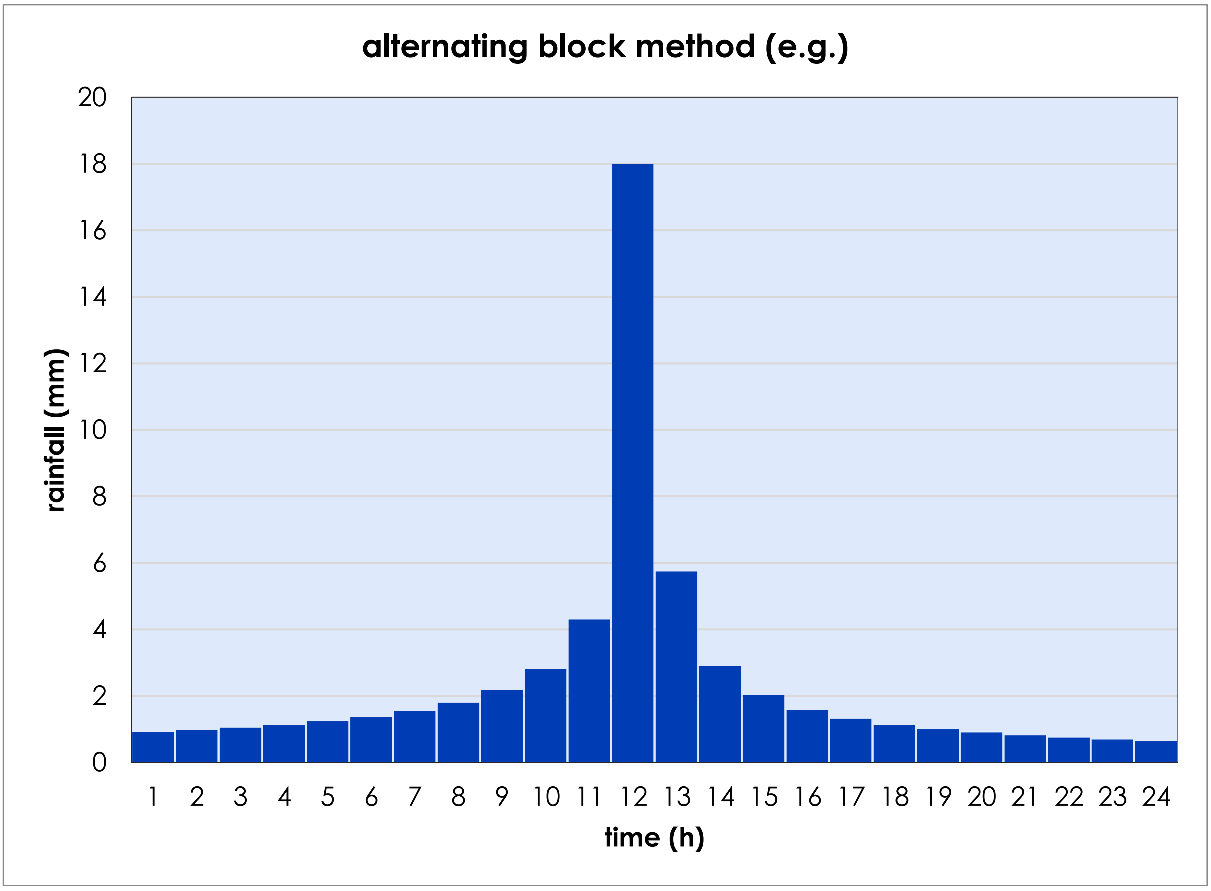


Figure 32Alternating block method example (Total rainfall for an 24-h event according to the EU Flood Directive practices) | Return periods(T=100 years)

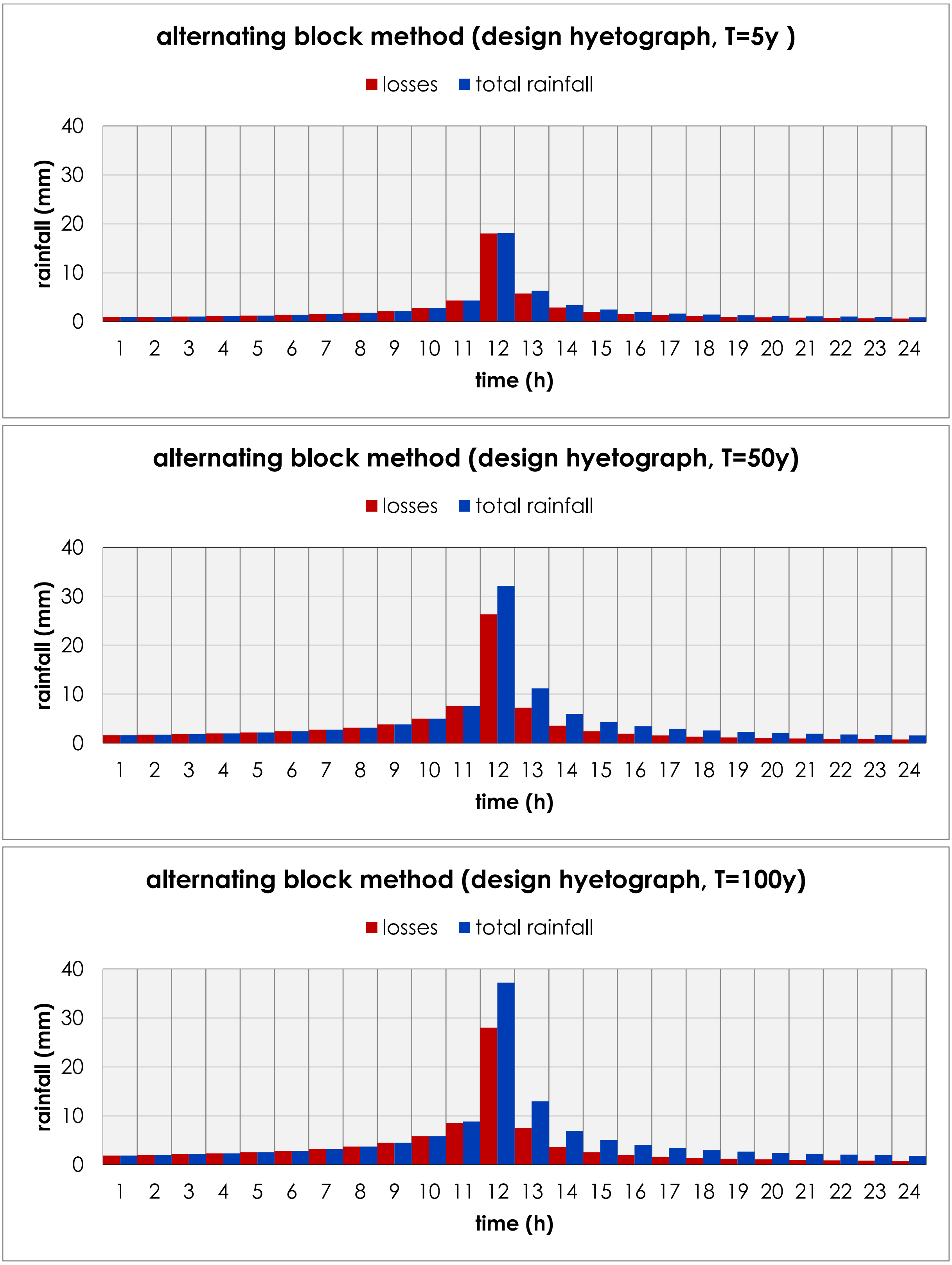


Figure 33 design storm examples for three return periods (total rainfall, losses)

Finally, each simulation run combines the aforementioned components with run options to calculate the flood hydrograph.

- The simulated hydropraph is calculated with multiplication of IUH with the rainfall at each time. This processing followed for the three catchments. It should be noted that, as this is a case of an ungauged basin, calibration and verification processes could not be performed, and this is the reason why the selected method for the UH determination is a GIS-based one.

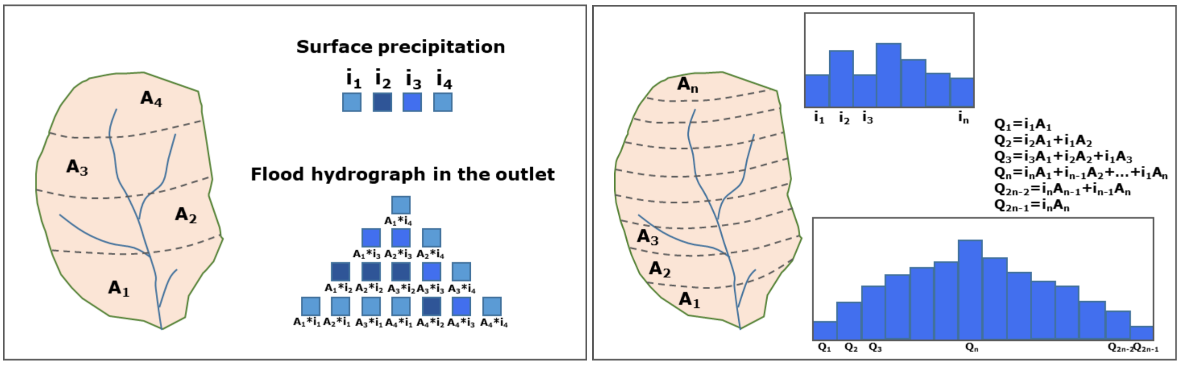


Figure 34 The hydrological approach scheme for flood hydrograph determination

4.2 Resulting flow hydrographs - Scenarios

Several flood hydrographs are determined after using the rainfall distribution from design hyetographs, the estimated losses based on the CN method and the UHs for each subbasin. Thee peak discharge values vary as a function of the basin's area and specific characteristics, and differences are obvious among the scenarios. Indicative results for the total basin area (downstream Bitola city) and for low hydrological loses, are shown in Figure 35.

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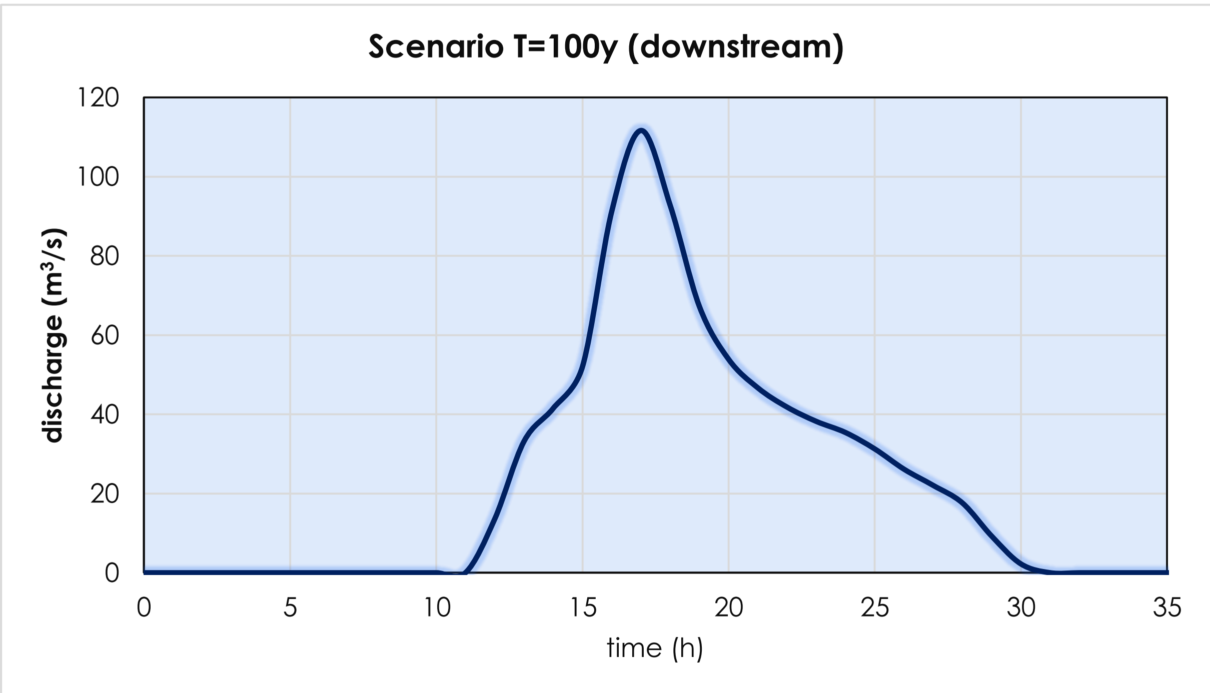


Figure 35 Flood hydrograph (e.g. scenario T=100y)

5 Hydraulic simulations in Bitola city

5.1 Description of the simulation scheme

The final step of the proposed methodology for the examination of flood-related consequences through the determination of the corresponding inundation map that is created using the HEC-RAS 2D 5.07 model.

- The HEC-RAS is an free software (but not open-source) that can perform 2D unsteady flow routing with two different equations: the 2D full Saint-Venant and 2D diffusion wave equations (Urzică et al. 2021).
- In the current process, we select the numerical solution to the Saint-Venant equations, which use an implicit finite difference approach through the computational box scheme (USACE, 2016). The 2D hydraulic simulation requires hydrological data (e.g., flood hydrographs) and an accurate volume of spatial data (e.g., DEM, Manning roughness coefficient).
- The flood hydrograph is used as an upper boundary condition.
- The Manning roughness coefficients are determined in correspondence to the land-cover type derived from the CLC (2018) according to the literature (e.g., Arcement and Schneider, 1989; Barnes, 1967). The default mesh consists of non-overlapping polygons limited to a maximum of eight sides (Pinos, 2019).
- The results of the simulation run indicate the flood extent using the maximum depth and maximum velocity.

Overall approach is summarised in Figure 36.

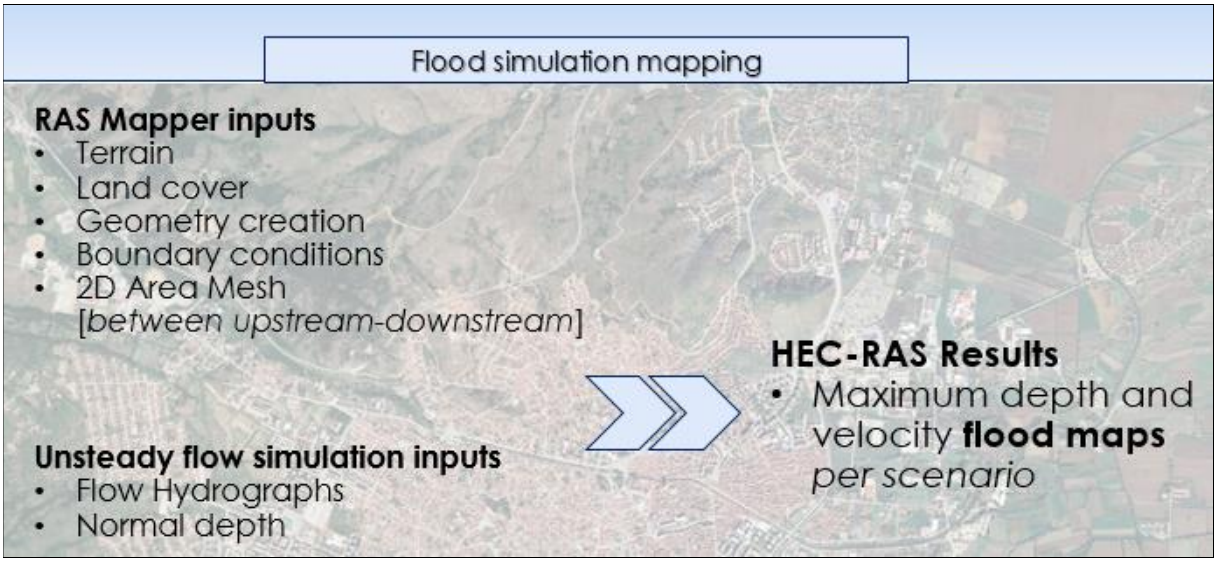
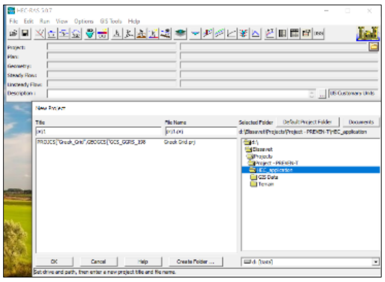


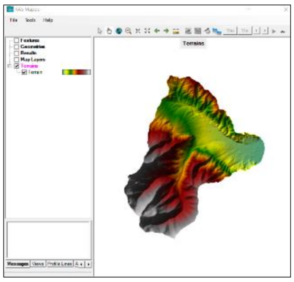
Figure 36 Hydraulic simulation outline

5.2 Indicative results

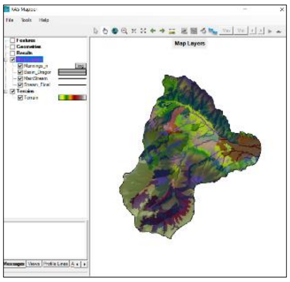
Based on the aforementioned procedure, each hydrological analysis' output may generate a specific inundation map. For the sake of brevity, the most common scenario of return period equal to 100 years is presented regarding flood risk map. This map corresponds to the inundation map (maximum depth) for a specific scenario, including the characteristics of areas and activities that are under potential risk. In general, flood hazard and risk maps are engineering maps, often used as regulatory maps for land use planning related to flood mitigation. The main steps in the frame of hydraulic simulation performance are shown in Figure 37.



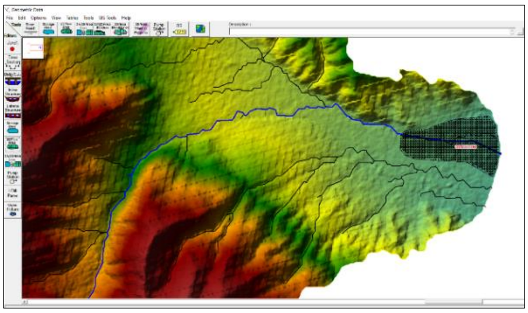
a. Project setup



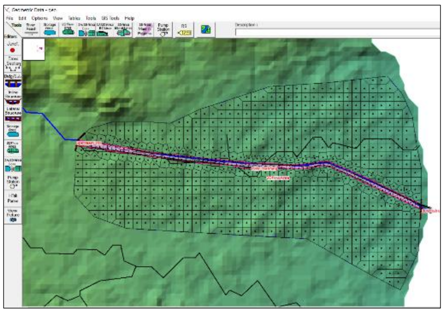
b. RAS Mapper environment | Terrain import



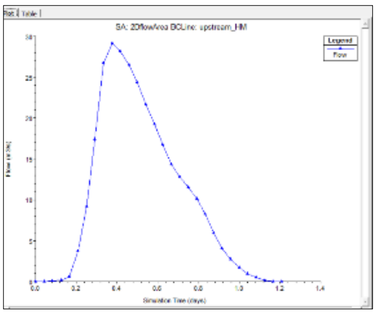
c. Manning coefficients and River geometry import



d. Geometry Data environment



e. Creation of the 2D Flow Area element cells



f. Upper boundary conditions: flow hydrograph

g. Inundation map (maximum depth) for a simulation Plan

Figure 37 Main steps regarding hydraulic simulation

Finally, the map in Figure 38 corresponds to the maximum water depth map for a flood scenario of T=100yrs.

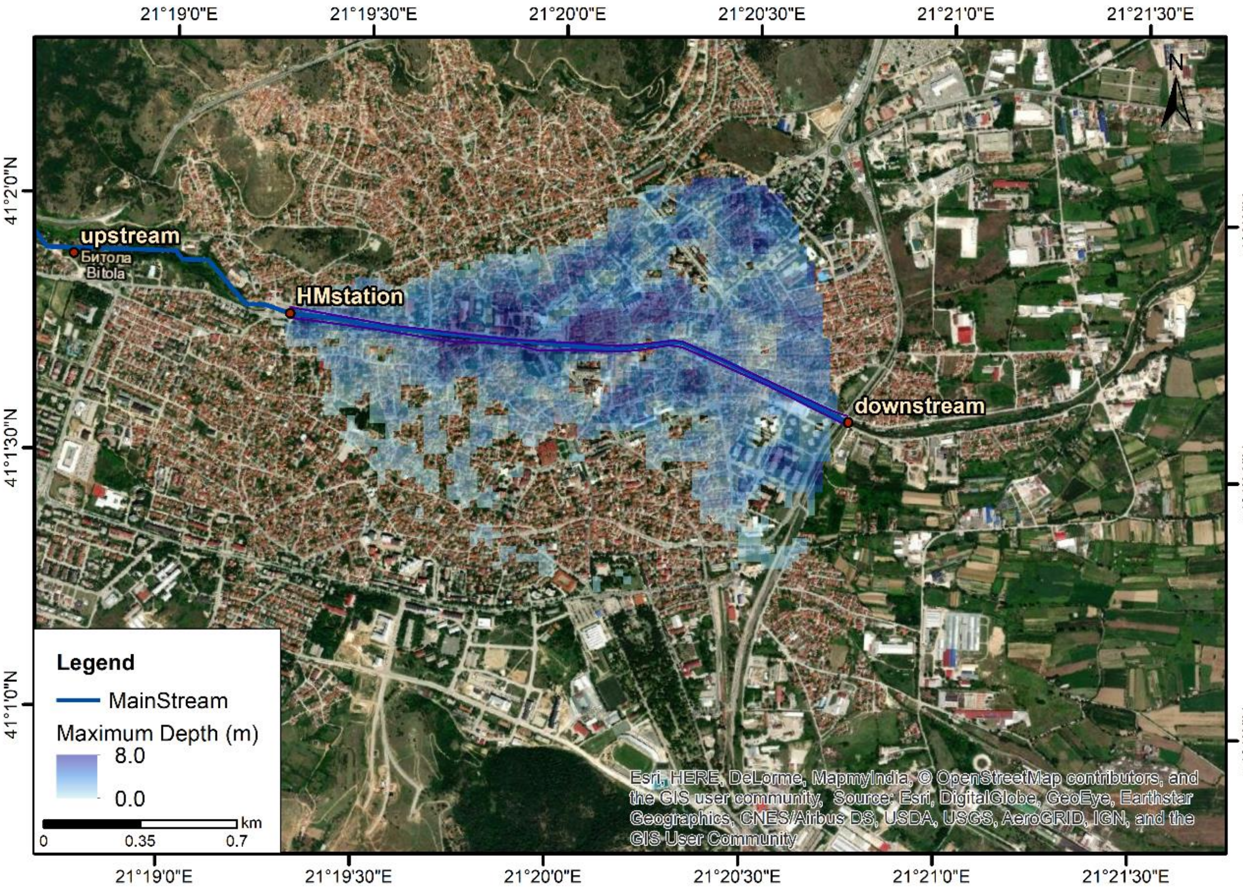


Figure 38 Inundation map (maximum depth, scenario: T=100yrs)

In this analysis, a holistic hydrological approach was presented, in terms of assessing flood risk. The methods applied produced appropriate maps with high spatial accuracy at the basin scale, which can contribute to the protection and preservation of the environment. Given the limited historic available hydrological dataset, the application of multi-criteria decision analysis for the determination of flood susceptible areas in a wider region could be a useful tool in the early stages of a study for assessing an area's vulnerability to natural hazards such as floods, debris flows and landslides. Additionally, the creation of flood risk maps, allows experts to focus on areas that belong to the very high risk class and to develop targeted risk prevention plans. In particular, the results indicate specific parts in the study area that water depth exceeds 0.5m.

Three simulation points across the mainstream were selected for hydrological analysis, however, research finally focused on the use of the HMstation location as upper boundary condition location, because the installed station and its location is the most useful from an operation perspective.

Finally, in the frame of future research, the investigation of more scenarios would contribute to the development of innovative early warning tools.

6 The AH (Atmospheric- Hydrological) local model scheme

6.1 Flood Early Warning Systems

Floods are among the most devastating natural disasters, causing loss of life, damage to infrastructure, and significant economic and environmental consequences. Rapid urbanization, climate change, and changing precipitation patterns have increased the vulnerability of many regions to floods. In response to these challenges, Flood Early Warning Systems (FEWS) have emerged as a crucial tool for mitigating the impacts of flooding and enhancing community resilience.

A Flood Early Warning System (FEWS) is a comprehensive framework designed to monitor, forecast, and disseminate timely information about impending floods. The primary goal of FEWS is to provide advance notice to communities, governments, and disaster management agencies, allowing them to take proactive measures to reduce the impact of floods. A typical FEWS includes several key components (Sene, 2008):

- Monitoring Infrastructure,
- Meteorological and Hydrological Data Collection and Analysis,
- Warning Generation,
- Communication and Dissemination,
- Response and Preparedness.

The implementation of Flood Early Warning Systems offers several significant benefits:

- Reduced Loss of Life: FEWS can provide crucial minutes, hours, or even days of advance warning, allowing people to evacuate safely and minimize casualties.
- Property Protection: Early warnings enable individuals and businesses to safeguard their property and assets, reducing economic losses.
- Enhanced Preparedness: Communities that receive regular FEWS alerts are more likely to have disaster preparedness plans in place, increasing their resilience to floods.
- Improved Resource Allocation: Governments and emergency responders can allocate resources more efficiently and deploy assistance where it is most needed.
- Environmental Benefits: FEWS can also help minimize environmental damage by providing time for measures like dam releases to control water levels.

While FEWS have proven effective, challenges remain, including the need for infrastructure investment, data sharing, and community engagement. In the future, the integration of remote sensing, artificial intelligence, and community-based monitoring can enhance FEWS capabilities further. Additionally, international cooperation and knowledge sharing are crucial for addressing transboundary flood risks.

In conclusion, Flood Early Warning Systems play a pivotal role in disaster risk reduction and climate resilience. By combining advanced monitoring technology with effective communication and preparedness measures, FEWS empower communities to respond proactively to flood threats, ultimately saving lives and reducing the impact of one of the world's most destructive natural disasters.

6.2 The proposed scheme for the study area

In the scheme of flood forecasting, the seamless integration of a Weather Research and Forecasting (WRF) model (See also WP 4.1) with a hydrological model (WP 4.2) has emerged as a powerful approach to enhance our capacity for flood prediction and management.

- The WRF model, renowned for its high-resolution weather simulations, provides a valuable input by delivering precise meteorological data, including rainfall patterns, temperature, humidity, and wind dynamics.
- This rich source of information serves as the foundation for hydrological models (Figure), enabling them to better capture the intricacies of rainfall-runoff processes. By assimilating real-time weather data from WRF, hydrological models can continuously update their forecasts, offering a more accurate and timely assessment of river discharge and flood potential.
- This integrated approach not only bolsters the reliability of flood predictions but also supports more effective early warning systems, empowering communities and authorities to take proactive measures in response to impending flood events.

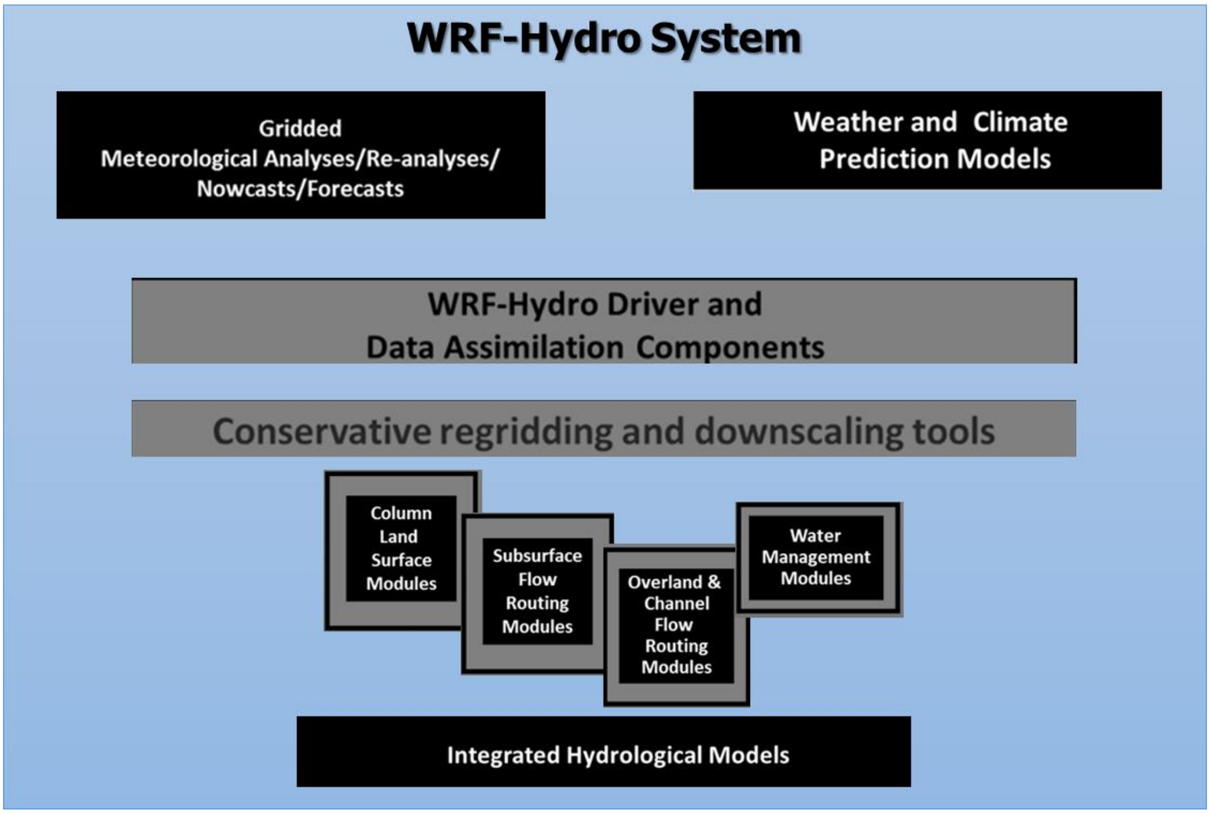


Figure 39 The WRF-Hydro System scheme

6.3 Actions required in the frame of developing an Evacuation Plan for Bitola city

Developing an effective evacuation plan in the event of flooding is crucial to ensuring the safety of individuals and communities. Here are some key actions and considerations that should be taken into account when developing such a plan:

Risk Assessment: Conduct a comprehensive flood risk assessment to identify areas vulnerable to flooding, taking into account historical flood data, floodplain maps, and climate projections.

Community Engagement: Involve the local community in the planning process. Understand their needs and preferences, and raise awareness about flood risks and the importance of evacuation plans.

Early Warning System: Establish or enhance a flood early warning system that can provide timely and accurate information about impending floods to residents and authorities.

Evacuation Routes: Identify and mark safe evacuation routes that lead to higher ground or designated evacuation centers. Ensure these routes are well-maintained and clearly signed.

Evacuation Centers: Designate and prepare evacuation centers that are equipped to accommodate evacuees with essentials like food, water, medical supplies, and shelter.

Transportation: Coordinate with local transportation authorities to ensure that sufficient vehicles and resources are available to assist with evacuations, especially for those who may have mobility challenges.

Communication Plan: Develop a communication plan that includes multiple methods of alerting residents, such as sirens, text messages, social media, and community leaders.

Emergency Contacts: Compile and distribute a list of emergency contacts, including local authorities, rescue services, medical facilities, and community leaders.

Special Needs Populations: Identify and address the needs of vulnerable populations, such as the elderly, disabled, and those with access and functional needs, in the evacuation plan.

Training and Drills: Conduct regular evacuation drills and training exercises to familiarize residents with the evacuation process and ensure that it runs smoothly during an actual flood event.

Communication During the Event: Maintain continuous communication with residents during a flood event to provide updates, reassurance, and instructions.

Emergency Supplies: Encourage residents to assemble emergency kits that include essential items like water, non-perishable food, clothing, flashlights, batteries, and important documents.

Pets and Livestock: Include provisions for the evacuation of pets and livestock, as they are an important part of many households.

Traffic Management: Plan for traffic management during evacuations to prevent congestion and ensure the smooth flow of traffic along evacuation routes.

Recovery Plan: Develop a post-flood recovery plan to assist residents in returning to their homes, assessing damage, and accessing necessary resources for rebuilding.

Public Education: Conduct public education campaigns to inform residents about the evacuation plan, flood risks, and the importance of preparedness.

Regular Updates: Periodically review and update the evacuation plan to incorporate new data, lessons learned from past events, and changes in the community.

Coordination with Authorities: Collaborate closely with local authorities, emergency responders, and neighboring communities to ensure a coordinated response in the event of a flood.

Overall, the effectiveness of an evacuation plan depends on thorough preparation, community engagement, and clear communication. Regularly testing and updating the plan will help ensure its success in safeguarding lives and property during flood events.

7 Conclusions

With the completion of the project entitled "Modern Tools for wildfires' and Floods' Risk punctual forecast and monitoring and innovative techniques for citizens' safeguard awareness and preparedness" [PREVEN-T], and more specifically regarding the WP 4.2 "Local hydrological model for basin's run - off and torrent's discharge estimation on Pelister's Park area", some useful results are provided regarding the implementation of the geomorphological analysis, local hydrological model and the lydraulic simulation, as well as, regarding station network installation.

- As this was an ungauged basin, a GIS-based approach was developed to finally perform a hydrological analysis and the following hydraulic simulation to produce the corresponding inundatin map, as a way to quantify the flood risk for Bitola city.
- The combined results from the WP 4.1 model and WP 4.2 model could be used for the implementation of an AH (Atmospheric Hydrological) model, which will be able to inform both the authorities and local population of Bitola (around 24h prior to an event of high risk), for any forthcoming threat by presenting precise estimations.
- The methods applied produced appropriate maps with high spatial accuracy at the basin scale, which can contribute to the protection and preservation of the environment.
- Given the limited historic available hydrological dataset, the application of multi-criteria decision analysis for the determination of flood susceptible areas in a wider region could be a useful tool in the early stages of a study for assessing an area's vulnerability to natural hazards such as floods, debris flows and landslides. Additionally, the creation of flood risk maps, allows experts to focus on areas that belong to the very high risk class and to develop targeted risk prevention plans. In particular, the results indicate specific parts in the study area that water depth exceeds 0.5m.
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- Finally, in the frame of future research, the investigation of more scenarios would contribute to the development of innovative early warning tools.

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