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APPLICATION OF METHODOLOGY FOR THE REAL-TIME TORRENT FLOOD FORECASTING

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ABSTRACT

The characteristics of torrential floods necessitated the development of various methods for its reconstruction and genesis. Different types of cloud pattern and wind situation can cause, for similar cloud situation, different flood hydrograms. This is a key point for a design of the efficient flood forecasting emergency system applicable for the remote areas.
The paper presents the development of the methodology, which combines radar meteorology, torrential hydrology and new GIS technics to enable quick determination and assessment of the detected situation in order to provide a sufficient time for the flood defense system to be put in operation.

Key words: Hydrology, Torrent Flood Analysis, Meteorology

INTRODUCTION

Storms are caused by dynamic events in the atmosphere. The intrusion of cold air masses under the worm air most frequently causes an atmospheric instability and therefore a stormy weather. Other, much more intensive development of the convective cloudiness is related to by the passage of frontal zones with cold and unstable air masses, which characterizes

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developing of the congestive cloudiness within an instable air mass, and then so called "local development".
In summer months, the storm-bearers are (Cb) regardless to weather the development happened in the mass or on the front.
Macro and micro processes are very complex and their interaction in the atmosphere creates (Cb) clouds. Expressing the quantity, intensify and precipitation duration, as well as the encompassed area presents the higher order problem. But due to combining of different parameters and the data correlation, a further development of computation method has been performed. Generally speaking, floods are caused by natural phenomena and sometimes by people. .[M. Savic, N. Kovacevic, R. Bratic. R. Radovic]
Floods are usually caused by rainfall or snowfall, or the combination of both. Certain natural conditions and a coincidence of several factors cause atmospheric disturbances and therefore conditions for the occurrence of rainstorms in other words, the conditions for the formation of heavy water-bearing clouds and their maximum discharge in a very short time. Large-scale floods (regional floods) are caused by rains of long duration or by the influence of very high snow layers on the high air temperature. Although these floods could seem similar by their extent and effect, they substantially differ since the flood caused by a sudden snow melting is formed over the whole area, while the flood caused by a strong rainstorm is generated only over the area affected by the rain.
In the contrast to the large plain rivers where the floods are generated and continue for days and weeks, torrential stream floods last a few hours, sometimes even shorter. Torrential water waves mostly occur on small tributaries of a larger river i.e. at its sub catchments. How a flood wave will be formed and what damage will be made along the main stream, depends on how many of its tributaries have been affected by a heavy intensity rainfall, as well as on the possibility of flood waves coincidence along the main stream.
The consequences of torrential floods, different from plain rivers flooding, always have catastrophic extent regardless the real range of the flood, since torrential floods every time always followed by devastating effects on human and natural goods.

Fig.1. Comparative snapshots of the Kaluđerica (Belgrade suburb) from 1953 and 2001.year.

Many defenses against torrent flooding were constructed 40 years ago, incorporating components appropriate to the conditions prevailing in the catchment’s area at the time. It is seldom that changes of such conditions are so drastic that the efficiency of defenses is reduced by several orders of magnitude. The rate of urbanization, both legal and illegal, has

been greater than the rate of construction of defense systems. Comparative photographs show the same detail of the Kaluđerica (Belgrade suburb) from 1953 and 2001.year.
Over the period of thirty years a rural community became a chaotic non-urbanized suburb. This suburb is not an exception, but the rule. Runoff of heavy rainfall is several times greater than in the case of arable land. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]
Defense of traffic corridors against torrent flooding was initiated more than a century ago. Corridor 10 experienced numerous torrent floods that disrupted traffic for even longer than one month on the aggregate per year. There are well-known and less-known Torrent Rivers and streams in Corridor 10. The Korbevac is one of Well-knows Rivers. It regularly damaged a railroad line since it was constructed, until the 1950's when it was partially regulated.
In 1963 it damaged the railroad several days before the disastrous earthquake in Skopje and hindered delivery of aid to casualties. In 1975 it again destroyed a bridge at the very time it was being crossed by a train. Five lives were lost and 17 people were injured.

Fig.2. Torrent flood destruction of Railway Bridge on Korbevac river- 1975
The less-known torrent streams are those that appear tame, but can be very dangerous. The tame Ripe stream (catchment's area $A=0.7km^2$), with the oldest experimental station for erosion and torrent investigations, damaged a railroad line several times before it was fully regulated. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]
The Kokorin stream near Mladenovac destroyed a bridge on the Belgrade-Skopje railroad line during World War II (the winter of 1942/43). During the cold winter Corridor 7 (navigation route along the Danube) was frozen and transports had to diverted to the railways. The two weeks required to repair the damaged bridge disrupted delivery of war materiel to the German army at Stalingrad and indirectly shortened the battle. We hope that wars are behind us and that traffic corridors will only be used for transportation of passengers and goods.
Torrential flood protecting systems on small streams consist of structures (torrent barriers river channel engineering works, canals) sized to discharge the flood water of the given return period, most often the maximum discharge of hundred years return period.
The maximum discharge of any return period could be calculated using the statistic computations of the measured discharge or by using the parameter methods. Statistical methods are reliable only for the rivers with a large fund of observation. Parameter methods

are used for the flows with no monitoring or when the fund of the observation data is insufficient, and some water construction is envisaged.

That was the reason for developing numerous parameter methods for floodwater computations in case of insufficient quantity measured and observed.

The mentioned methods have been developed for more than hundred years, and they give the results called " 100-year flood" which more or less gives the order of magnitude of floodwater discharge with a return period of 1% obtained statistically. The approach to the problem when using the parameter methods is classical, i.e. used are the average values of precipitation for a catchment's area or a region and many other assumptions. Such approach includes many mistakes if it is used for calculating the genesis of torrential flood waves of natural characteristics. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]

A torrential flood occurs after a heavy rain originating from stormy cloud masses and usually covers an area smaller than the area of the observed catchment's basin, i.e. a part of the catchment's area does not take part in the flood wave genesis.

THE TORRENT DEFENCE ACTION PLAN

The methodology of torrent flood defence requires estimation of possible discharges and the time of flood wave onset for a potentially endangered region. In addition, the warning procedure has been shortened and direct communication was established between the radar center of the weather service and the flood defense headquarters of the endangered region.

Bodies of self-governance were given a special role in this regard. Municipalities are required to prepare Torrent flood defence of rivers and streams external to the regular flood defence system. In order to synthesize and standardize program quality, in 1998.year, the Ministry prescribed methodology to be applied in the preparation of the said program. The methodology were developed by the Institute for the Development of Water Resources “Jaroslav Černi”. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]

It is intended to compile necessary inputs for the preparation of these programs on the basis of current catcment status reports. Today, territory of Serbia and Montenegro has medium coverage with aplicated Action plans for torrent flood defence. Elevation of the covered territory is between 80-2800 m, and represents full range of torrent diverse, from high mountain torrents up to downstream torrents. Fig. 3. Show covered territory.

TORRENTIAL FLOOD COMPUTATION METHOD

Many methodologies and formulas have been developed throughout the world for computing the properties of torrential floods and their return periods.

During several decades of activity on the applied hydrologic and erosion control research work for small catchment's areas, a number of methods have been developed within the Department for catchment's area management of "Jaroslav. Černi" Institute for Development of Water Resources. This database served for the development of the Method of Flood Wave Genesis Simulation in Real Time. The method enables preliminary computation of the maximum discharge for assumed situations of cloud masses (shower) movements over the drainage area.

The performed analyses have proven certain properties of shower rains, which have enabled a more precise explanation of phenomena occurring as a consequence of heavy rains (torrential floods). The clouds that produce heavy shower-rains are cumulonimbuses. The very fact already determines the shower-rains properties. It practically means that the watershed area affected by a heavy shower could not be larger than the cumulonimbus, but only smaller or of the same size. An average cumulonimbus diameter is never more than 15 km, which means that rain gauging stations should be placed at a shorter distance in order to register local showers. Shower, however, is not of the same intensity over the whole area of the cloud. It is greatest in the core, which usually has the diameter of 4-5 km.

The distance between rain gauging stations, of our precipitation-pluviometer network, is usually too big this is why the existing data on the registered torrential precipitation are not reliable for the analysis of the torrential floods they have caused.

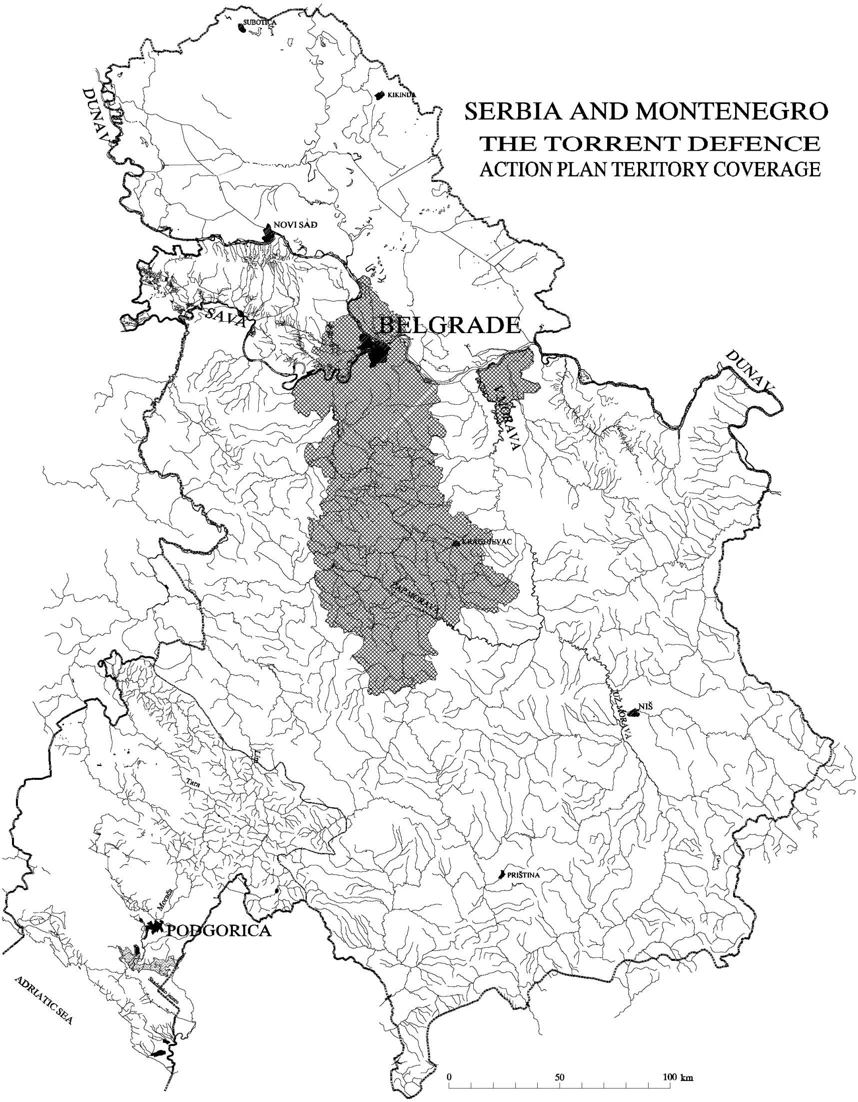

Fig.3. The torrent defence Action Plan coverrage in Serbia and Montenegro

Proposed for the assumed flood wave reconstruction is the modified Unit Hydrograph Method developed in the Jaroslav Cerni Institute for the Development of Water Resources.

The modified method lag time does not represent the catchment's constant as it is in the classical SCS method, but the rain duration function, i.e. the catchment's is not considered a linear and stationary system, and considered also are the precipitation intensity regime as well as the precipitation width within the watershed. [S. Jovanovic, M. Brajkovic]

The formula for maximum discharge and a triangle wave calculation is as follows:

$$Q\max = \frac{0.56 \times F \times Pe}{(K+1) \times \left[t_0 + (a+0.5) \times tk\right]} \quad (1)$$

Qmax - maximum water discharge (m^3/s)

F - catchment's area

Pe - effective precipitation

t_0 - instant hydrograph increase time is calculated using the formula from [S. Jovanovic, M. Brajkovic]

a - catchment's area shape and size parameter is determined

Using the nomograph a=f (F) [S. Jovanovic, M. Brajkovic]

tk - rain duration time

K - relation between the retardation time and catchment's area concentration

Natural flood wave is computed using the formula:

$$Qt = 10^{-\Theta} \times Q_{\max}$$

$Qt=10^{(-A\theta)}Qmax$ (2)

Qt-discharge in computation period of time (t)

Qmax-maximum hydrograph ordinate

A-parameter functioning as relation between retardation time (Tr) and wave concentration (Tp). This parameter is determined using the following function:

A=f(Tr/Tp) (3)

θ-parameter of relation between time t and Tp (θ=f(t/Tp=τ)

Model shape used for computation of total rain for each discrete time interval.[M. Brajkovic]:

$Pt=i_0t^{\alpha}$ where: (4)

Pt-rain height of any duration time

i_0-characteristic unit intensity

t- rain height calculation time (t>0)

α- regional parameter (0<α<1)

The parameter α depends on regional climatic properties and is defined by a statistical computation of the recorded precipitation.

The effective precipitation (Pe) is determined using gross precipitation and the following form:

$$P_e = \frac{(P_u - 0.2d)^2}{(P_u + 0.8d)} \quad \text{Where: (5)}$$

Pe-effective precipitation layer

Pu-gross (total) precipitation

d-soil moisture deficiency (runoff preconditions)

It is possible to demonstrate the principles of new torrent flood defense method by the example of a torrent flood of River Vlasina on 26 June 1988. The surface area of the Vlasina catchments is about 1000 km², with a pronounced mountainous relief. The entire region is erosion regulated and the population had already forgotten regular torrent flooding of not so long ago. On 26 June 1988 one third of the catchments was subjected to a heavy storm and rainfall of disastrous proportions. One third of the catchment's received over only a few hours one third of the mean annual overall precipitation. Devastation was very extensive and all encompassing. [Z. Gavrilovic, Z. Matovic]

Among destroyed or heavily damaged were:

- The dam at Vlasotince;
- Bus station and trade-and-craft center in Vlasotince;
- 80 km of regional roadways;
- 32 bridges;
- 252 housing projects;
- 524 ha of arable fields in the valleys;
- 108 ha of orchards.

Flooded and damaged were:

- 578 ha of valleys;
- 3231 houses and other buildings;
- Water supply facilities servicing Niš and Vlasotince.

Luckily, this general disaster resulted in the loss of only three human lives. Calculated damage cost is nearby one billion dollars.

An analysis of the overall scenario has shown that existing defenses were able to withstand flooding in places where the intensity had twice the design magnitude, and disaster occurred where the intensity was three times the design magnitude.

It is a fact that the likelihood of such heavy flooding is close to the computed occurrence once in a thousand years, but it did show it was not impossible. Since then and up to the present day numerous similar torrent floods have occurred all over Europe and the world.

The flood identified deficiencies of the torrent flood control system, where torrent floods exceeded the defense capability or such capability was entirely lacking.

The radar center of the weather service monitored the entire occurrence by the minute and was able to reliably forecast the sequence of events for the coming hours as well as the amount of precipitation.

The rate of data availability was simply slowed down by the archaic flood defense system, which in the case of large rivers provides for raising defenses one day after heavy rainfall.

The methodology of torrent flood defense requires estimation of possible discharges and the time of flood wave onset for a potentially endangered region.

In addition, the warning procedure has been shortened and direct communication was established between the radar center of the weather service and the flood defense headquarters of the endangered region.

It is intended to compile necessary inputs for the preparation of these programs on the basis of current catchment's status reports.

TORRENTIAL FLOOD WAVE FORECAST POSSIBILITY

It is possible, using the proposed method, to prepare and compute all the parameters which determine a flood wave character for the assumed meteorological situations causing torrential floods, and according to the obtained data, determine the unprotected points which could be affected by torrential waters, as well as to quite precisely define the time of maximum water discharge at the studied points.

The radar method is very useful in identifying the cloudiness producing heavy showers and abundant long-term precipitation, which could cause torrents and floods. Then, the Observer in a radar centre can see the exact geographic position of water-bearing cloud, define its velocity and direction, forecast and measure the precipitation intensity and the quantity of rain, as well as the time of the cloud discharge onto the observed catchment. The data, which the observer in the radar centre could not obtain, are the height and the intensity of the rain, which could cause a flood, and at which place; it gives only general regional warnings. The main problem is how to find precise empirical dependencies between these data and the pluviometer network data. As the time from the rain start to the occurrence of the maximum discharge could be foreseen, as well as its value, by using the described methodology for the calculation of the flood wave shape computation, while the observer at the radar centre forecasts the starting time of cloud discharge on the observed watershed. This way, the time from the identification of dangerous clouds to the occurrence of maximum discharge, is longer and enables the evacuation of the population and avoids great material damage and human losses. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]

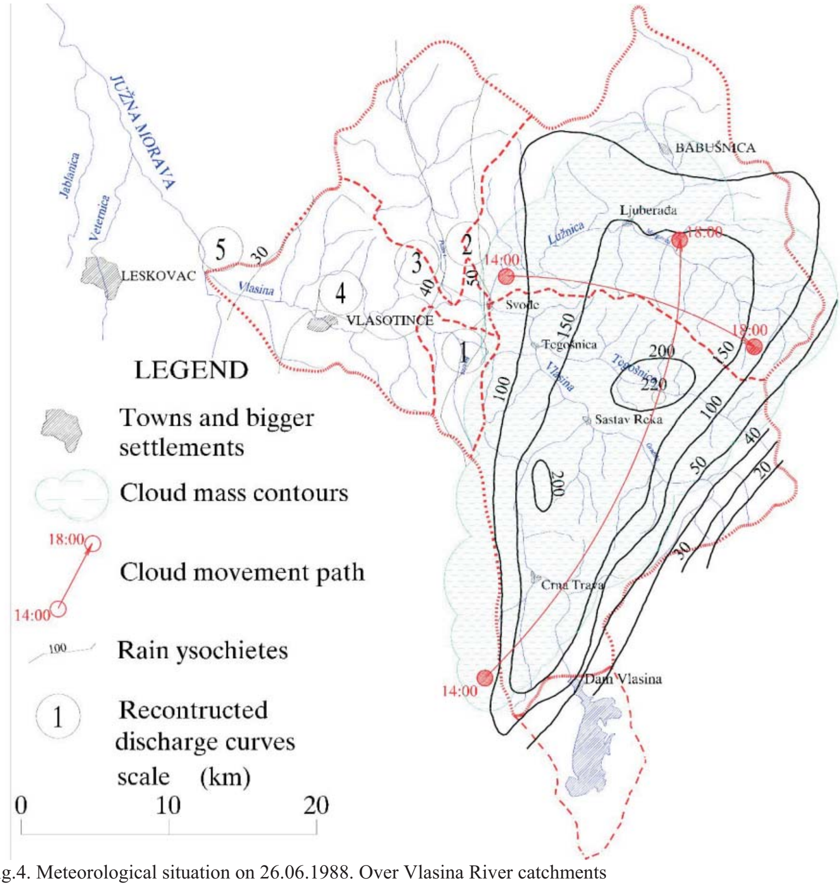

fig.4. Meteorological situation on 26.06.1988. Over Vlasina River catchments

Fig. No.4 presents possibilities of a meteo radar use for following cloud masses which produce heavy showers on the example of the situation above the Vlasina river catchment, dated on 26 June,1988., when the Vlasina river caused a great damage and death of one person who was trying to save his cattle from the flood. [Z. Gavrilovic, Z. Matovic]

Fig.5 shows a reconstructed torrential flood wave on the characteristic profiles of the Vlasina river mainstream. The Table presents the times after which appeared the maximum discharges of the river water in relation to the forecasted rain.

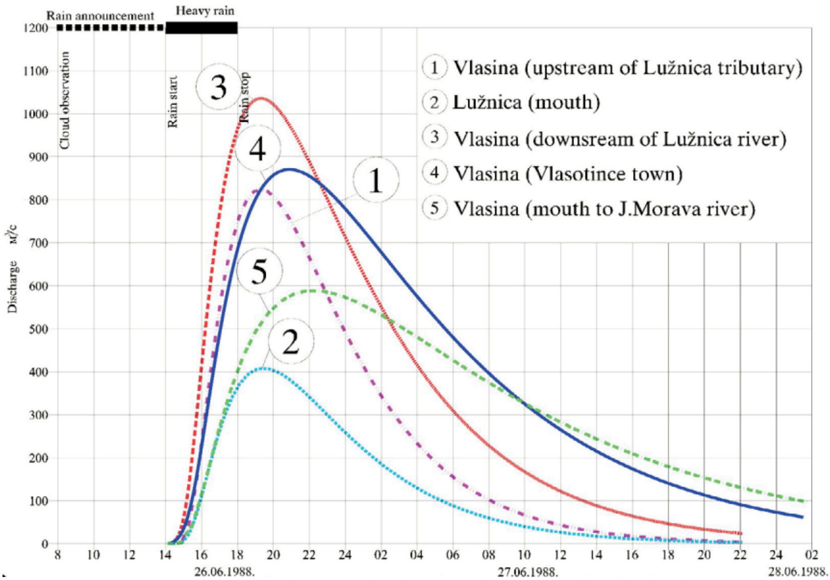

Fig.5. Clouds, rain start and food waves discharge and duration

Characteristic profiles	Time (t) (hours)			
	Rain Anouncement time	Rain Starting Time	Flood wave peak passage time	Posible intervention time
1.Vlasina	8^{00}	14^{00}	19^{00}	11^{00}
2.Luznica	8^{00}	14^{00}	20^{00}	12^{00}
3.Vlasina	8^{00}	14^{00}	19^{30}	11^{30}
4.Vlasina	8^{00}	14^{00}	21^{00}	13^{00}
5.Vlasina	8^{00}	14^{00}	22^{30}	14^{30}

ROLE OF METEOROLOGICAL SERVICE

A timely and successful torrent flood control on small streams calls for a close cooperation between meteorological alarm service and organization of population within the flood control system. However, a completely successful flood control includes reliable models for computing the flood and its genesis along the rivers. .[M. Savic, N. Kovacevic, R. Bratic. R. Radovic]

Since floods, as bad weather events, cause lots of damage everywhere, a special attention is paid to the monitoring of present, and forecasting of future weather conditions, i.e. dangerous meteorological phenomena, above an area, in order to announce a possible flood on rivers. It is especially important to properly forecast the kind of precipitation, its intensity, direction and transferring velocity of the precipitation zone, the precipitation start and termination, as well as an extremely thick snow cover and high temperatures which would condition a rapid melting of large quantities of snow, which may generate the flood wave. Beside a successful announcement of frontal cloudiness zone rains (4 hours in advance), a forecast for abundant shower rains could be also given for the same period of time (by combining the sounding, thermic, dynamic, orographic and general climatic properties, as well as a series of statistic methods as well as analogy (ones)). This is important since in this country such type of cloudiness most often causes the formation of flood waves. Using the RADAR method combined with other methods, gives good results in announcing torrential floods.

DEVELOPED METHOD FOR TORRENT FLOOD FORECASTING DEFENCE

Organization and implementation of flood control of rivers and streams external to the system of routine flood control is organized and implemented by torrent flood control headquarters. The headquarters need to include:

- A manager and deputies;
- Persons in charge of various sectors;
- Organized methods of communication with responsible services, managers, persons in charge, companies and all other persons and bodies involved in operational defense;
- A prepared defense program for each sector.

In order to implement torrent flood control, in addition to discharge, familiarization is necessary with the following typical weather features:

- Warning of impending heavy rainfall that threatens the municipal territory or torrent river catchments gravitating to the municipality (6-8 hours prior to actual rainfall);
- Time of commencement of rainfall in a certain catchment's area;
- Time of increase of discharge for every defined profile;
- Time of attenuation.

The headquarters are is in direct communication with the radar control center of the Hydro-meteorological Institute of Serbia and arrangements are made for timely warning of heavy rainfall. The following information is provided to the radar control center:

- Names of managers and means of communication (ordinary telephones, mobile phones, radio stations, etc.), competent to issue warnings and perform other important activities for ongoing coordination with the radar control center.
- A program that defines limits of intensity and amounts of precipitation hazardous to the entire municipality or individual defense sectors.

Headquarters are in communication with those of neighboring municipalities in order to coordinate defense efforts initiated when: The expected extent of flooding exceeds the defense potential of available manpower and defenses; In the case of floods that include several municipalities, headquarter coordination is at the district or state level.

The plan defines all relevant aspects ranging from methods of organization, management, and warning to details of participation and distribution of manpower and defenses required to complete the task. The Action Plan is released in the Official Herald of the municipality. [Z. Gavrilovic, M. Stefanovic, and M.Brajkovic]

AN EXAMPLE FROM DEFENCE ACTION PLAN

The Torrent flood defence Action Plan are proclaimed on the basis of provisions of the Law on water resources of the Republic of Serbia and an torrent status report of a municipal territory have been identified by applying the prescribed methodology. Such is an example of municipality Pozarevac, which comprises approximately 75% plains in the valleys of the River Great Morava, the River Danube and the River Mlava. The rest is rolling terrain with a maximal dieseling of 150m. There are erosion areas and many small torrents on this territory. They are identified and notably marked which is shown in Figure 6. Regardless of the fact those torrential flows are of proportionally small tracts and lengths, torrential floods are common occurrences. The one from July of 1999 had disastrous effect. Prepared data for Action torrent defence Plan has very simple form. Meteorogical Radar observation needs only data for calculated dangerous rainstorm intensity and high of the precipitations.

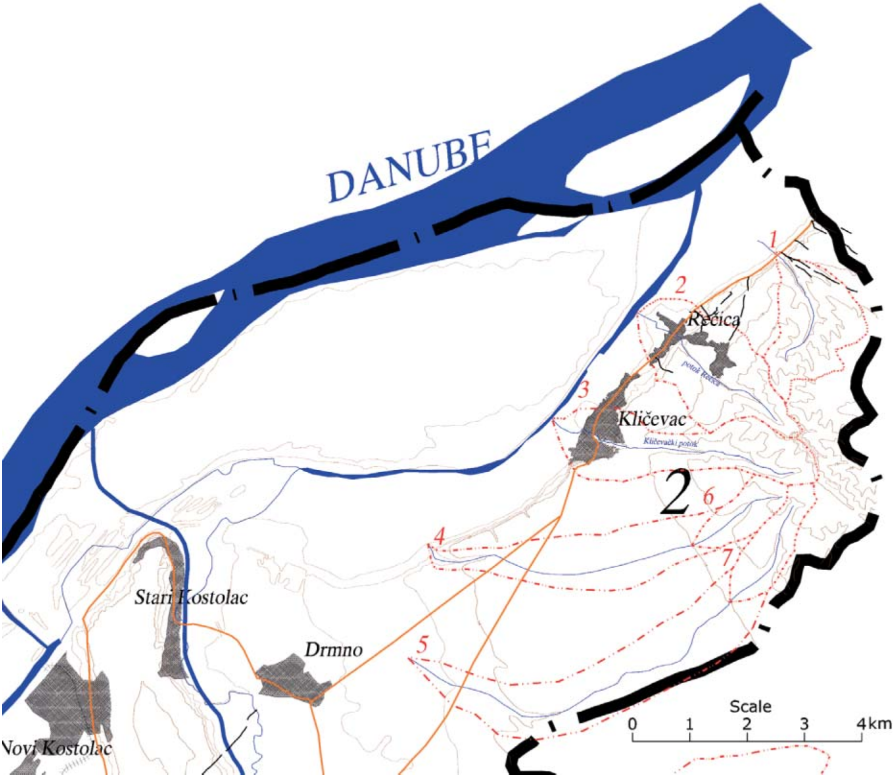

Fig 6. Erosion zone and torrent area Recica-Klicevac in Municipality Pozarevac

The headquarters need to know predicted discharge at the interesting points. Table shows usualy shape of those data precalculated for the torrents from fig 6.

Characteristic calculated data for Torrent Defence Action Plan						
No	Torrent name	Catchment area	The rainstorm intesity and high			
			I_0=37.2 mm/hour		I_0=70.6 mm/hour	
		km^2	tk	Qmax	tk	Qmax
1	No name torrent 1	2.70	1.4	2.32	0.86	10.7
2	Torrent Recica	3.72	1.41	3.14	0.81	14.9
3	Torrent Klicevacki potok	3.93	1.8	2.8	1.1	12.9
4	No name torrent 4	4.63	2.3	2.58	1.51	11.4
5	No name torrent 5	7.12	2.81	3.42	1.81	15.2

THE TRAINING TORRENT FLOOD DEFENCE SYSTEM

The fight against erosion and torrent flooding needs to be taken seriously since it is a war in the true sense of the word. Although some damage is hidden and other clearly visible, the magnitude is far greater than that of destruction in combat.

The task of the training center is to train people involved in the system of torrent flood defence. There are about 160 endangered municipalities in Serbia, and each command structure of flood control and erosion control includes at least five people. These 900 to 1000 people need to be trained in the use of modern computer systems to manage flood defense and implementation of erosion control measures.

The Jaroslav Černi Institute is the only institution that can provide the level of expertise and overall logistics for such a training center. At least 100 attendees per year need to complete the course, to replace persons that have left in the meantime.

CONCLUSION

The applied methodology for computing precipitation, floodwaters and flood waves reconstruction has given the results which, using an actual example; prove that it is reliable for the use in the scarce data situations. An earlier theoretical assumption that precipitation schedule and cloud movement direction, could condition, for the same rain, several different maximum discharge values. A correct approach to the torrential flood phenomenon combined with a correct Unit Synthetic Hydrograph application, and helped by computations of flood routing and transformation along the main stream, floodwater discharges could be computed for the watersheds of much bigger area than the one affected by the water bearing cloud. This method is being practically applied for computing the design floodwaters for watersheds with the area of over two thousand square meters.

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