TIMJANICKA RIVER FLOOD WAVE ANALYSIS AT NEGOTINO, DATED JULY 6TH 1995

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Abstract: On July 6th 1995, a high-intensity rain occurred in big part of the Republic of Macedonia, including the watershed of Negotinska (Timjanicka) River (F= 26 km^2), which then flooded the city of Negotino, the international highway and railway and the surrounding agricultural fields. On that day, intensity of the rain in Negotino was 175 mm in 165 minutes (1.06 mm./min). The estimate cost of damages was about 20 000 000 DEM.
Based on the traces of the flood flow and videotape material, the maximum discharge of the flood wave has been estimated and analyzed, and the method of SCS has been used to determine the return period of the observed discharge. It has been concluded that in Negotinska (Timjanicka) River, on the center of the city, the maximum discharge amounted to Qmax = 220,00 m^3/s, i.e. specific discharge amounted to 12,23 m^3/s/km^2.

The probability of occurrence of these rain and discharge, couldn’t be real estimated because they are many times higher than the results based on data from last 40 years.
Key words: *flood wave; maximum discharge; probability of occurrence; return period*

1. Background

On July 6th 1995, a high-intensity rain occurred in a big part of the Republic of Macedonia, including the watershed of Negotinska (Timjanicka) River (F= 26 km^2), which then flooded the city of Negotino, the international highway and railway and the surrounding agricultural areas. It happened to be a typical natural disaster.

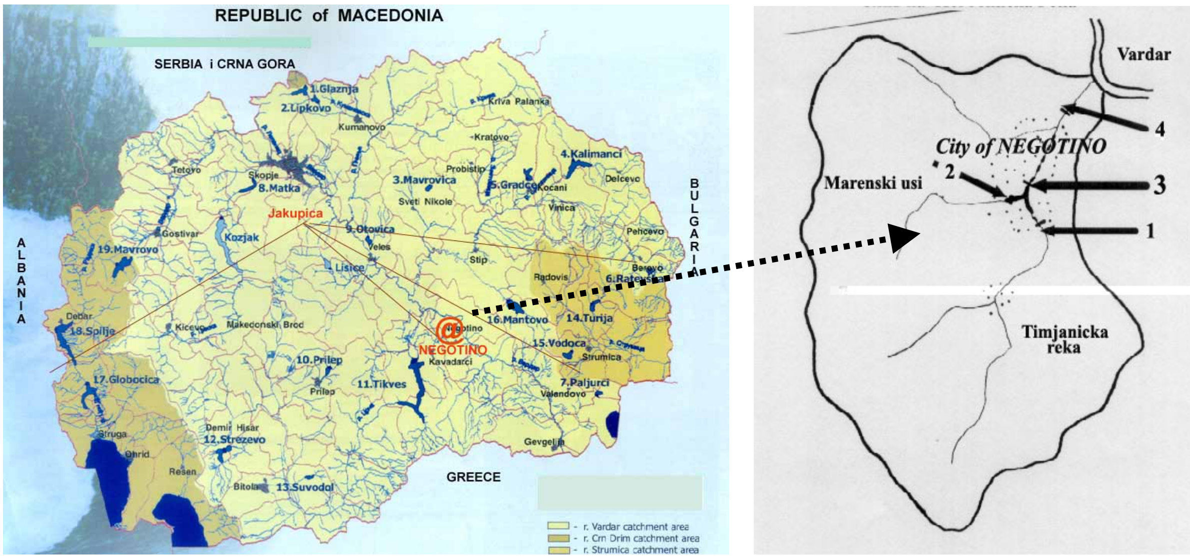

Figure 1.Study area - Timjanicka (Negotinska) River catchment

Timjanicka River catchment is located in central part of Macedonia (Figure 1)
Negotinska (Timjanicka) River is a right tributary to *Vardar,* the main Macedonian river. Its catchement area covers about 26 km^2. Two currents: Timjanicka river (the bigger and the more important one) and Marenski Usi, merge in the center of the town of Negotno and form Negotinska River.

Negotinska River was trained in 1992. The right branch (Timjanicka River) was also trained, thus an open channel and a tunnel were constructed as riverbed. From the entrance into the city, an open channel long 237 m exists, and then a tunnel long 470 m with rectangle form and dimensions 5.5 x 2.5 m follows on through the town most urban part. The other branch (Marenski usi) was trained in a similar way.

These two tunnels flow one-into-another under the very central part of the city. From this junction point starts an open representative trained cross section down the city. A minor and a major riverbed were constructed.

Dimensions of this channel (Figure 2) are:

minor bed : a = 1.5 m ; b = 3.5 m ; h = 1.0 m ; n = 1: 1

mayor bed : a = 9.5 m ; b = 10.5 m ; h = 2.35 m ; n = 5:1

This channel was designed and estimated as so, to accept water discharge $Q_{1\%}$ = 70 m^3/s, but due to cross section geometry, it has been re-estimated that at about Q = 168 m^3 relatively clean water could pass throw the channel counting up to the top point of the quay walls - embankments (source: Final design on Timjanicka River).

CROSS PROFILE OF THE RIVER BED

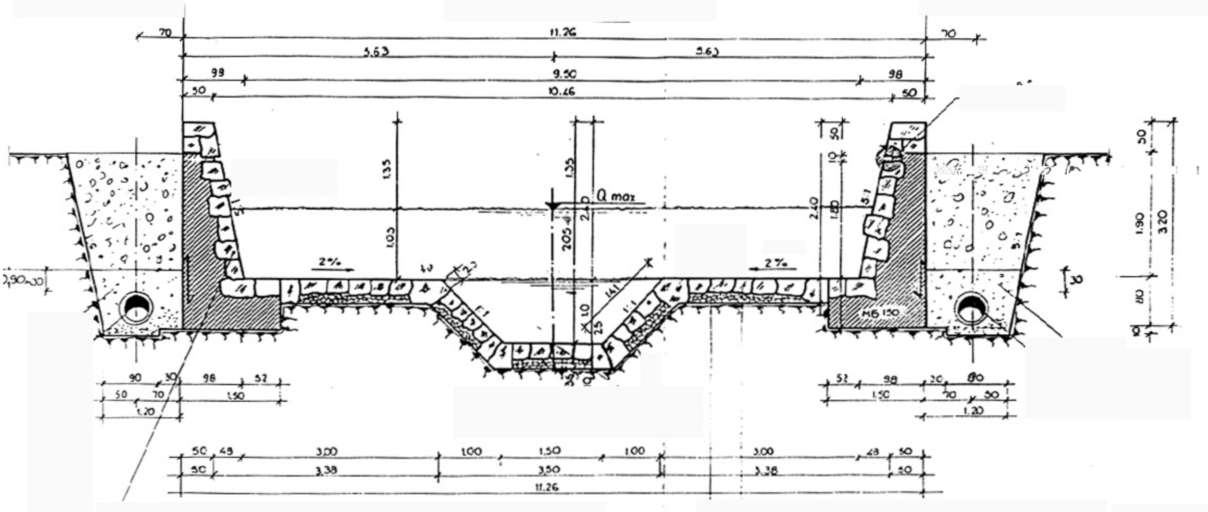

Figure 2. Cross profile of the river bed in the center of the Negotino

The chronology of this appearance from a meteorological point of view could be described as follows:

A jet stream passed cross over Macedonia on elevation of 10 km. On the territory of Republic of Macedonia a cyclone circulation was formed early in the morning. At about 2 PM, the center of depression appeared over the mountain region Karadica-Yakupica, with a depression axis directed as SW-NE. Daily temperature was around +35^o C.

At about 3^{30} PM, a gigantic cloudy system was formed over the mountain Yak pica with direction to the south. The critical time was 4 pm, and the critical region was Tikves valley. Top of the gigant cumulonimbus was on an elevation of 18 km. Due to radar observations, the cloudy system was of 60 km long and 30 km depth.

Due to all these conditions, the town of Negotino and its neighborhood were attacked by a catastrophically natural disaster.

On that very day, the rain intensity in Negotino was 175 mm in 165 minutes (1.06 mm./min). The curiosity to be more expressive, Tikves region is classified as one of the driest regions in Macedonia and Europe too. An average total annual rainfall for that region amounts less then 500 mm. The value of the total annual rainfalls in the driest 1948/49 was only 163 mm.

2. Study methods

The working method was adopted to specific problem decision i.e. flood wave reconstruction in conditions where no measuring exists. A lot of activities were carried out:

- collection and study of all previous projects, maps and other documentation about Negotino , Negotinska River, Tikves region and wider;
- field activities (area recognizing, river bed lay-out and longitudinal surveying, cross section surveying , land-use mapping , erosion mapping ….) ;
- detail analyze of physical-geographical conditions in the catchement area;
- maximum discharge estimations;
  hydraulic methods – (flow over weir ; uniform water flow in open channel)
  hydrological methods – (US SCS method ; Gavrilovic method, Concentration time method))
- defining up mind maximum discharge probability

All map measurings were carried out on topographic map in scale M = 1: 25 000, but for some measuring thematic geological and pedological maps (M=1:100 000) were used

Few sections were chosen for analyzes, but this paper concentrates on the results of the river section “Center of the town”, the one that could be seen on a videotape. The position of this section lays on Negotinska (Timjanicka) River, 16 m downstream the exit from the tunnel (Figure 1, section no. 3).

3. Results

3.1. Natural characteristics

Tikves region (where Timjanicka river catchment belongs) was a sea and lake covered land in the geological history, so the neogen sediments are the parential rocks. One of their major characteristics is the high permeability.

Climate is classified as *Modified Mediterranean.* The next table shows some meteorological characteristics gauged at meteorological station Demir Kapija (15 km from Negotino).

Table 1 - Some meteorological characteristics of the treated area

average annual temperature	^oC	13.0
average summer temperature	^oC	23.1
absolute extreme temperature (maximum)	^oC	44.3
absolute extreme temperature (minimum)	^oC	-19.5
average annual summer days (t>20^{o}C)	*days*	125
average annual tropical days (t>30^{o}C)	*days*	70
average total annual precipitation	*mm*	450
average total summer precipitation	*mm*	110
absolute minimum total annual precipitation	*mm*	163
drought index (by De Martone)		28.7
humidity deficit - annual *humidity deficit – summers*	*mm* *mm*	315 257
average annual drought periods	*nro*	9
the longest drought period	*days*	69
average annual drought days	*days*	141

The catchement area of this river belongs to hilly region (top point - the highest elevation is 419.00 mosl). Slopes are relatively gentle. The elevation of Timjanicka River mouth (in-flow) to river Vardar is 114 mosl.

Significant part of the catchment area (more then 80 %) is covered by agricultural land. Vineyards are being a major crop, but there are orchards and vegetables planted on some small plots. There is a narrow belt along the river covered with riparian forest (Salix spp , Populus spp. …) but this forest is not to much important to the runoff.

Some physical – topographical catchment characteristics are presented in the next table. All values are relevant for the treated profile (Center of the city).

Table 2 - Some hydrographic characteristics of the treated profile

	Parameter	*Sign*	*Measure unit*	*Values*
1	*catchment area*	*F*	km^2	17.80
2	*area (left side)*	*Fl*	km^2	9.20
3	*area (right side)*	*Fr*	km^2	8.60
4	*watershed perimeter*	*S*	km	17.60
5	*watershed length*	L	km	6.60
6	*catchement form coefficient*	A		0.52
7	*top point elevation*	*Kout*	masl	419.00
8	*profile elevation*	*Kin*	masl	140.00
9	*mean basin elevation*	*Nsr*	masl	260.00
10	*mean elevation difference*	*Dsr*	M	115.00
11	*mean catchment inclination*	*Isr*	%	11.80
12	*mean riverbed inclination*	*It*	%	5.74
13	*drainage pattern length*	□L	km	37.00
14	*drainage pattern built*	W	km^{-1}	2.08
15	*hydrographical class (by Gavrilovic)*	Hk		8.09 - C
16	*run-off potential (by Gavrilovic)*	Psl	$m.km.s^{-1}$	195.23
17	*Erosive energy coefficient*	Er	$m.km^{0,5}$	39.29
18	*geomorphologic erosive coefficient*	Mr	$m.km^{0,66}$	81.66

3.1.1. <u>Discussion about natural characteristics</u>

From this point of view, there aren't any preconditions for high values of rainfalls regarding the fact that this catchment is being a part of the driest region in Macedonia. All the other characteristics (slopes, parential rocks, soil types, elevation difference, runoff potential) do not give preconditions for high vallues of runoff, water and sediment discharge. But something very unusual happened on July 6th, '95.

3.2. Erosion and sediments

Processes of surface erosion are typical for this catchment. The intensity of erosion processes is rather low (due to classification by Gavrilovic). The interesting things could be an appearance of a big landslide in the catchment area, being a source of erosion sediments. This landslide occurred in 1992. In the next table erosion classes distribution and values of produced and transported annual sediments due to Gavrilovic methodology are presented, where:

Z – erosion coefficient by Gavrilovic (0.05 – 1.50). Rn – retention coefficient;
E – total annual produced sediments; W – specific annual production of sediments
G – total annual transported sediments; Gsp – specific annual transported sediments

Table 3 - Erosion and sediment transport by Gavrilovic method

	Distribution of Z (erosion coefficient by Gavrilovic) by categories				
Category	*I*	*II*	*III*	*IV*	*V*
km^2	0.6	1.7	1.8	7.3	6.2
Sediment estimation by Gavrilovic					

Z average	Rn	E	W	G	Gsp
		m^3/g	$m^3/g.km^2$	m^3/g	$m^3/g.km^2$
0.37	0.38	8248	305	3134	116

3.3. Maximum water discharge estimated by hydraulic methods

Basic parameters for maximum water discharge by hydraulic methods are geometric characteristics of the cross section: section dimensions (depth and width), section area, riverbed longitudinal slope. Detail geodetic survey was carried out in purpose to get exact dimensions of the section.

During the flood there was a flood flow in both the riverbed and out i.e. along the bed on the streets and pavements.

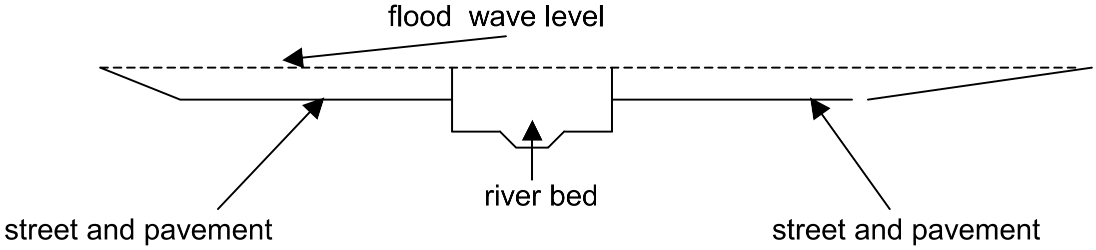

Figure 3. Cross section of the riverbed and out of the bed in the center of Negotino

Roughness coefficients are accepted due to field prospection and literature data of laboratory experiments.

Due to extreme rainfall intensity, extreme surface erosion intensity in the catchment and deep erosion in the riverbed, a lot of sediments into the torrential mass appeared. The torrential coefficient (K) was estimated after some detail analyzes.

On the base of all these estimations, maximum water discharge was determined by 2 hydraulic methods and 3 hydrological methods. Hydraulic methods were:

- Flow over wide edge weir (by Basin) - Q = □□□b$(2g)^{0,5}$ $Hp^{1,5}$
- Uniform flow in open river channel (by Cheesy) Q = A K C $(Rsr\ J)^{0.5}$

3.3.1. <u>Flow over wide edge weir</u>

Table 4 – Water discharge in the river bed

H	river bed depth	H = Kg-Kd	m	3.48
m	overflow coefficient	m = □□□		0.46
V	Clear water velocity	V = C $(Rsr\ J)^{0.5}$	m / s	7.00
Vsr	torrential water velocity	Vsr = K C $(Rsr\ J)^{0.5}$	m / s	5.60
Ho	depth of water flow over spillway	Ho = H + □$V^2/2g$	m	5.20
Hp	reduced depth of water flow	Hp = 0,8 Ho	m	4.20
b	reduced river width		m	10.00
Q_b	maximum water discharge	Q = □□□ b$(2g)^{0,5}$ $Hp^{1,5}$	m^3 / s	175.40

Table 5- Water discharge out of the river bed

H	river bed depth	H = Kg-Kd	m	0.80
m	overflow coefficient	m = □□□		0.40
V	clear water velocity	V = C $(Rsr\ J)^{0.5}$	m / s	2.70
Vsr	torrential water velocity	Vsr = K C $(Rsr\ J)^{0.5}$	m / s	2.70

Ho	depth of water flow over spillway	Ho = H + □V^2/2g	m	1.21
Hp	reduced depth of water flow	Hp = 0,8 Ho	m	0.95
b	reduced river width		m	13.00
Q_b	maximum water discharge	Q = □□□ b$(2g)^{0,5}$ $Hp^{1,5}$	m^3 / s	21.45

Total water discharge is estimated as $Q = Q_b + 2\ Q_o = 175.40 + 2 * 21.45 = 218.30\ m^3/s$

3.3.2. Uniform flow in open river channel

Table 6- Water discharge in the river bed

J -	relative current slope	measured		8.50
Asr -	cross section area	measured	m^2	28.00
Osr -	average wet perimeter	measured	m	15.80
Rsr -	average hydraulic radius	Rsr = Asr / Osr	m	1.77
K -	torrential coefficient (by Thierry)	K = □□		0.80
n -	roughness coefficient	from diagram		0.02
C -	velocity coefficient by Manning	C = 1/n $Rsr^{1/6}$		56.05
Vsr -	average flow velocity by Chezy	Vsr = K C $(Rsr\ J)^{0.5}$	m /s	5.52
Q_b -	maximum water discharge	Qmax = Asr Vsr	m^3/s	154.60

Table 7- Water discharge out of the river bed

J -	relative current slope	measured		8.50
Asr -	cross section area	measured	m^2	17.60
Osr -	average wet perimeter	measured	m	20.90
Rsr -	average hydraulic radius	Rsr = Asr / Osr	m	0.84
K -	torrential coefficient (by Thierry)	K = □□		0.80
n -	roughness coefficient	from diagram		0.03
C -	velocity coefficient by Manning	C = 1/n $Rsr^{1/6}$		32.19
Vsr -	average flow velocity by Chezy	Vsr = K C $(Rsr\ J)^{0.5}$	m /s	2.18
Q_0 -	maximum water discharge	Qmax = Asr Vsr	m^3/s	38.00

Total water discharge is estimated as: $Q = Q_b + 2\ Q_o = 154.60 + 2 * 38.00 = 230.40\ m^3/s$

3.4 Maximum water discharge estimated by hydrological methods

3.4.1. Method by Gavrilovic

$$Q = A\ S_1\ S_2\ W\ (2gDF)^{0.5}$$

Table 8- Water discharge estimated by Gavrilovic method

F	*catchment area*	measured	km^2	17.80
S	*Watershed perimeter*	measured	km	17.60
L	*watershed length*	measured	km	6.60
Hsr	*mean basin elevation*	measured	m	260.00
Hul	*mouth (profile) elevation*	measured	m	140.00
D	*elevation difference*	D = Hsr - Hul		120.00
g	*earth acceleration*	well known	m/sec^2	9.81
h	*extreme rainfalls intensity*		m	0.18
A	*catchment form coefficient*	A = 0.195 * S / L		0.52
S1	*permeability coeff by Gavrilovic*			0.83
S2	*land cover coeff. by Gavrilovic*			0.93
W	*catchment area retention*	W = h(5–22h – $0.3L^{0.5}$	m^2/km^2	1.82
2gDF	*energetic potential for runoff*		m.km/s	204.72

Q	*water discharge*	$Q = A\ S_1\ S_2\ W\ (2gDF)^{0.5}$	m^3/s	148.45

3.4.2. US SCS method

Table 9- Water discharge estimated by US SCS method

F	*catchment area*	measured	*km^2*	*17.80*
L	*watershed length*	measured	*km*	*6.70*
Lc	*Length to the catchment center*	measured	*km*	*3.20*
Jt	*relative slope*	measured	*%*	*3.50*
Jmax	*mean slope*	measured	*%*	*2.73*
K	*water concentration factor*	$K = L / Jt^{-0.5}$		*35813*
Tc	*concentration time*	$Tc = [0.868\ (L/J)]^{0.385}$	*hours*	*1.04*
Tk	*time of effective rainfalls*	$Tk = 2\ Tc^{0.5}$	*hours*	*2.04*
Tp	*rising time*	Tp = tp + Tk/2	*hours*	*2.53*
k	*hydrogram form coefficient*	k = Tp / Tk		*1.24*
Tr	*retardation time*	Tr = k Tp	*hours*	*3.14*
Tb	*time base of the hydrogram*	Tb = Tp + Tr	*hours*	*5.68*
CN	*curve number*	from table and measuring		*76.00*
d	*humidity deficit*	d = 25,4 ((1000 / CN) - 10)	*mm*	*80.21*
P	*precipitation intensity*	*from diagram*	*mm*	*175.00*
Pe	*effective precipitation intensity*	$Pe= (P - 0{,}2d)^2 /(P+0{,}8d)$	*mm*	*121.46*
Qmax	*water discharge*	Q = 0.56 F Pe / Tb	*m^3/sec*	*185.00*

3.4.3. Concentration time (CT) method

Table 10- Water discharge estimated by CT method

F	*catchment area*	measured	*km2*	17.80
dH	*elevation difference*	measured	*m*	270.00
L	*watershed length*	measured	*km*	6.70
Isr	*mean catchment slope*	Isr = dH /(10 L)	*%*	4.03
tk	*concentration time*	from diagram	*minutes*	124.07
i`	*precipitation intensity*	from diagram (Blinkov, Jagev)	*l /s.ha*	175.00
□	*runoff coefficient*	from diagram …		0.65
q	*specific runoff*	q = □ i / 10	*$m^3/s.km^2$*	11.38
Q	*water discharge*	Q = q F /10	*m^3/sec*	202.64

3.5. Maximum water discharge cross analyze

Table 11- Water discharge estimated by difference methods

Method	***Acronym***	***Q (m^3/sec)***	***% of difference (M-ACC)/ACC*100***
Flow over weir wide sill	*FW*	218.30	-0.77
Uniform flow in open river channel	*UF*	230.40	4.73
Method by Gavrilovic	*GAV*	148.45	-32.52
US SCS method	*SCS*	185.00	-15.91
Concentration time method	*CT*	202.64	-7.89
A C C E P T E D	*ACC*	220.00	

After a long and serious review of the results obtained by difference methods, it was accepted that the most real values of water discharge was **220 m^3/s**.

3.6. Return period of the accepted water discharge

Data of the meteorological station Demir Kapija (15 km from Negotino) were used in this purpose. Due to data from the period 1956-1988, annual extremes with duration of 150 minutes are between 9.1 and 41.2 mm.

Progression parameters are:

- data number – N = 33
- average values Xsr = 24.18 mm
- standard deviation □□8.09
- variation coefficient Cv = 33.48 %

Empirical rainfall probability distribution was approximated by Gumbel function. Results are presented in the table bellow.

Table 12- Extreme rainfalls with different return period (t = 150')

Appearance - %	*0.1*	*1*	*2*	*5*
Rainfalls - mm	70.11	53.47	48.43	41.72

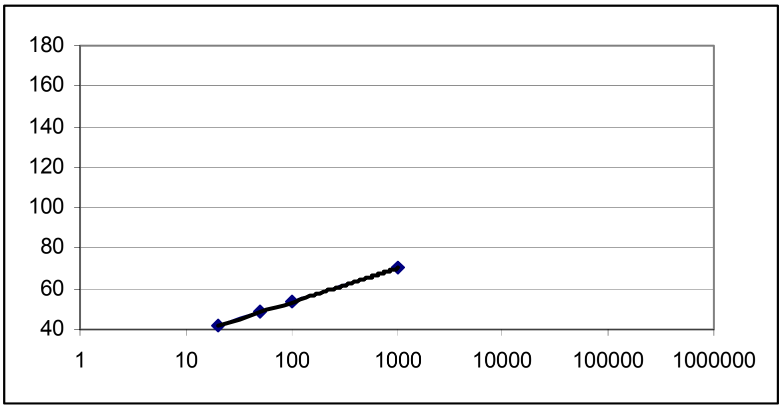

Figure 4. Extreme rainfalls with difference return period distribution

If this line could be extrapolated, results are enormous. On July 6th, 175 mm for 150 min were measured at the meteorological station. Due to mathematical analyzes, it is adequate to appearance 0.0000001 % or once in a 1 billion years. This is accepted as an unreal result.

Regarding the all above said, the return period of this water discharge couldn't be estimated in a realistic manner.

3. Summary

On July 6th, 1995, a high-intensity rain occurred in big part of the Republic of Macedonia, including the watershed of Negotinska River (F= 26 km^2), which then flooded the city of Negotino, the international highway and railway and the surrounding agricultural fields.

On that day, intensity of the rain in Negotino was 175 mm in 165 minutes (1.06 mm./min). The estimated costs of damages were about 10 000 000 EUR.

Based on the traces of the flood flow and videotape, the maximum discharge of the flood wave has been estimated and analyzed. Few methods were used for these analyzes.

It has been concluded that in Negotinska River, in the center of the town, the maximum discharge amounted to Qmax = 220,00 m^3/s, i.e. the specific discharge amounted to 12,23 m^3/s/km^2.

The probability of occurrence of the both rain and discharge, couldn't be realy estimated due to the fact that they are many times higher than the results based on data of the last 40 years.

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