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THE MOST IMPORTANT HIGH FLOODS IN VASLUI RIVER BASIN - CAUSES AND CONSEQUENCES

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Abstract: The frequency of flooding phenomena in Romania has significantly increased and the extreme catastrophic events became more frequent. Most of the rivers in the Eastern part of Romania are influenced by the excessive continental climate. That is why torrential rains are frequent and the possibility of high floods occurrence is extremely high. The Vaslui river is not an exception, and this is the reason why a series of measures to prevent floods have been taken in this river basin. The most efficient constructions for diminishing high floods consisted in damming the main water courses on certain sectors, building up of an accumulation in Solesti and slope forestation. The measures have as a main purpose the diminution of the negative impact on the town of Vaslui. The maximum flows in the Vaslui river basin can be recorded in any season, but most frequently they register during spring, sometimes at the end of winter, when snow melting is accompanied by high amounts of rain.

Keywords: high floods, maximum flow, reference flow, water volume, barrage**.**

1. INTRODUCTION

For the last few years, catastrophic floods have occurred in Romania every two years. The importance of the main high floods on the Vaslui river is pointed out, and their consequences, as well as the measures necessary to reduce the effects.

The main characteristic of the rivers in the Eastern part of Romania is the uneven flow, with extremely high flows during high waters. As a result of the fact that the Vaslui river has often over flown its banks, measures of regularization of the river course and barrage construction in order to diminish the high floods have been taken. From this point of view the Vaslui river basin is insured and the frequency or intensity of the floods has diminished significantly. Nevertheless, the phenomena with hydrologic risk start to have a special importance for the small river basins, tributaries to the main course.

The intrinsic connections between the amount of precipitation (especially those with torrential character), and the occurrence of the flood phenomena are pointed out. Therefore, the climatic data stored at the Moldova Meteorological Center in Iasi have been correlated with the hydrological data obtained from the Prut Water Headquarters in Iasi.

The facts revealed by the data processing are compared and corroborated with the data existent in the literature in the field, especially in the literature referring to the Moldavian Plateau

2. REGIONAL SETTING

Vaslui River represents one of the most important hydrographic elements of Vaslui County. The Vaslui river has its source under the Repedea – Paun plateau, at 340 m altitude, and the river flows into the Barlad river, at 80 m altitude. As a left tributary to the Barlad river, the Vaslui river is situated in the Eastern part of Romania. The area of the hydrographical basin represents 9.58 % of the Barlad river basin, which is the greatest river basin and the longest river in the Siret river basin (Fig. 1).

From a morphologic point of view, the Vaslui river basin is situated in the central-eastern part of the Moldavian Plateau, more precisely in the central - eastern part of the Central Moldavian Plateau. It is limited by the Rebricea and Telejna river basins to the west, by the Crasna river basin to the east, and by the Bahlui and Jijia river basins to the north

(Amariucai et al., 2004, Atlas of Water Cadastral Survey in Romania, 1992, Bacauanu et al., 1980, Panaitescu, 2007, Ungureanu, 1993).

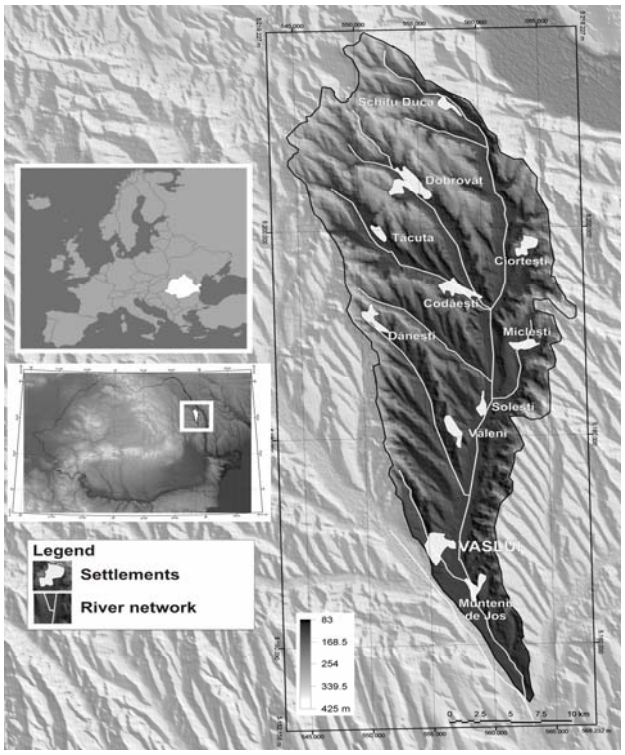

Figure 1 Geographical location and mathematic coordinates of the Vaslui river basin (Romania)

Table 1 Characteristics of the water courses and river basins

Water course	Data on the water course						Data on the river basin			
	Confluence position		Length (km)	Altitude (m)		Average slope (‰)	Sinuosity coefficient	Area (km^2)	Average altitude (m)	Forest cover area (ha)
				Upstream	Downstrea					
Vaslui	L		81	340	80	3	1.28	692	233	14,122
Carbunaria		r	7	340	196	21	1.15	15	289	1,187
Tabara (Valcele)		r	10	380	178	20	1.16	23	276	1,222
Pocreaca		r	9	360	152	23	1.18	15	273	93
Coropceni	L		6	380	150	38	1.10	10		95
Ciortesti	L		7	270	135	19	1.52	22	258	266
Dobrovat		r	27	330	122	8	1.16	185	248	6,412
Lunca		r	16	335	118	14	1,12	45	246	232
Rac (Iaz)	L		14	380	111	19	1.42	30	244	346
Glod		r	7	330	109	32	1.03	10	243	
Feresti		r	14	330	99	17	1.44	69	217	460
Munteni		r	6	155	98	10	1.05	19	235	237
Delea		r	14	222	92	9	1.18	19		160

l-left; r-right

It has a length of 81.0 km and a basin area of 692 km^2 (Atlas of Water Cadastral Survey in Romania, 1992). The total length of the water courses in Vaslui county, except the Prut river, is appreciated to be 1 960 km, with a density of 0.37 km/km^2, unevenly distributed.

The hydrographical network density is about 0.32 km/km^2, superior to the country average (0.33 km/km^2). The combined water courses have a length of 218 km. The Vaslui river course is subsequent, and the reception basin is asymmetrical to the right (73% of the total area), a characteristic which is also met in the case of other Barlad tributaries such as Crasna. The asymmetry is caused by the decrease of altitude of the Barladului Plateau towards the Prut river basin. In the superior basin the slopes are 10‰, and in the inferior course they decrease to average values of 3‰ (Panaitescu, 2007).

The water share is not proportional to the area of the basin, as it is a typical silvosteppe river, with very reduced flow and a low discharge.

3. MATERIALS AND METHODS

The methodology related to the maximum runoff is closely related to the issues that will be further outlined (Romanescu & Lassere, 2006). In the present study the hydrology specific methods have been used, especially those referring mainly to high floods and high waters. From this point of view, the following parameters have been analysed:

- maximum flow (Qmax, m^3/s);
- reference flow (Qb, m^3/s) – the flow where the high flood starts and ends;
- increase time (Tc, hours or days) – represents the time period in which the flows increase from the value of the reference flow to the maximum flow;
- decrease time (Td, hours or days) – represents the period of time in which the flow decreases from the maximum value to the value of the reference flow (always Td > Tc); total time (Tt, hours or days) – represents the duration of the high flood, Tt = Tc + Td;
- water volume (W, m^3), flown in an hour, a day, a season or a year – results from the multiplication between the average water flow in the specific time and the duration of the period. The total volume of the high flood (Wt) can be calculated, as well as the volume during high flood increase (Wc) and volume during high flood decrease (Wd). These are calculated using the following formula: W = Qmed x T, (Sorocovschi, Buta, 1994), in which: Qmed – average flow (m^3/s);T – time (seconds);
- flown layer (h, mm) – represents the thickness of the water layer obtained if the high flood volume is evenly distributed over the whole surface of the

river basin generating it. This is calculated using the following formula: h = W / (1000 x F), in which: W – high flood volume (m^3); F – river basin area (km^2) upstream the section in which the measurements have been taken (Minea & Romanescu, 2007);

- shape coefficient of the high flood (y) – represents the numerical characteristic of the high flood shape and it always has a value under 1. This is calculating using the following formula: y = (h x F) / [3,6 x Tt x (Qmax - Qb)], in which: Tt – total time (ore) (Smith & Ward, 1998).

The maximum flow, the increase time, the total time and the high flood volume are the main elements defining the high flood hydrograph and represent the basis for its calculation and construction.

4. RESULTS AND DISCUSSIONS

Due to its flooding potential, Vaslui River has been strongly regulated with hydrotechnical works with the purpose of diminishing the catastrophic events (Panaitescu, 2007).

The maximum flow is extremely complex, being influenced by a multitude of factors: the river basin shape and size, lithology, vegetation cover degree, slope inclination and river bed, flood plain width and configuration, presence of lakes etc. (Romanescu, 2003a,b,c).

Maximum flows represent one of the main problems of practical hydrology (Romanescu, 2006a,b). The knowledge of the values is necessary to the design, execution and exploitation of the hydro technical constructions, to the choice of the position of the bridges, to the correction of the river beds and the damming of the water courses, in order to protect the fields against floods etc. (Badaluta-Minda & Cretu, 2010, Blynth & Biggin, 1993, Gabitsinashvili et al., 2007, Mihnea et al., 2008, Muresan, 2009, Radoane et al., 2010, Romanescu, 2009) (Table 2).

The maximum values can be produced in any season, but most frequently they are recorded in spring, sometimes at the end of winter. when the snow melting is associated with high amounts of rain.

Table 2 The date when the historical maximum flows were recorded at the hydrometric stations in the Vaslui river basin

River	Hydrometric station	Qmax (m^3/s)	Date
Vaslui	Satu Nou	217	25.VIII.1970
	Codaesti	222	19.VI.1985
	Solesti	13,2	9.VII.1985
Dobrovat	Codaeati	47,1	27.V.1991

Analyzing the causes of the highest annual maximum flows, lead us to the conclusion that rainfall has a main role in producing them, either alone or accompanied by snow melting. Consequently, when calculating the maximum flows, the starting point is represented by the analysis of the annual maximum flows (Fig. 2).

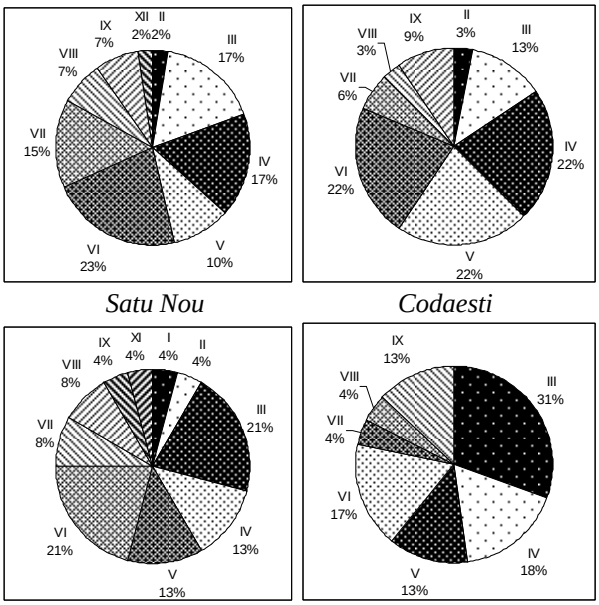

Figure 2. Percentage of the months in which annual maximum flows were recorded

The annual maxim values on the Vaslui river are recorded in Satu Nou in the months of June, March and April; in Codaesti in the months of April, May and June; in Solesti in March, June, April and May. On the Dobrovat river, at the hydrometric station in Codaeati, they are recorded in March, April and June.

High waters represent a phase of the river flow caused by snow melting, snow melting and rainfall, or only rainfall. They are characterized by a long duration of the consistent flow, relatively high peak flows and great or very great flown volumes or layers. They are usually recorded during spring, in spring – beginning of summer and sometimes during autumn. The high floods represent the sudden increase of the flow of a water course generated by torrential rains, by the sudden snow melting or by the association of the two. The artificial high floods are caused by the forced discharge of an accumulation, by manoeuvres or by the daily procedures at the micro-hydroelectric power stations.

In the analysis of the main high floods in the Vaslui river basin, for each hydrometric station, 5 high floods (the greatest) will be included. In this case, the data from Solesti will be only partly treated

as this hydrometric station is located very close to the downstream barrage - Solesti. Consequently, the flows recorded here are not relevant, as they are artificially controlled.

In the profile of Satu Nou hydrometric station the maximum flow is 217 m^3/s, recorded in 1970 (Table 3). A special situation occurs here: the 5 greatest high floods were registered in consecutive months, in different years, in the interval April – August. The lowest maximum flow was 105 m^3/s. This hydrometric station was set up on 1 September 1961, but measurements of liquid flows were performed only starting with 1968. Until then, only level measurements were done.

At the hydrometric station in Codaesti, on the Vaslui river, the maximum flow was 222 m^3/s, recorded in 1985 (Fig. 3). The maximum flows were recorded in the interval April – June and September. A characteristic is represented by the fact that in the month of May two of the maximum flows were recorded: 115 m^3/s in 1991 and 79.1 m^3/s in 2005, the latter one being the lowest maximum flow of the five.

The recording of maximum flows in different years at the hydrometric stations in Satu Nou and Codaesti (on the Vaslui river), in 1970 and 1985 respectively, is explained by the different time when these hydrometric stations were set up (1968 and 1977). This aspect is emphasized by the months and by the years in which, in these two sections, multiannual monthly maximum flows were recorded in the same month and year, except the months of July, August and December. Considering this aspect, the Vaslui river had probably a higher flow in 1970, than in 1985 (when the historic maximum was recorded) in Codaesti.

In Solesti, the maximum flow of 9.96 m^3/s in the month of June is not the annual maximum in 1985, but it is the multiannual maximum flow of the month of June. In 1985, in Solesti, two of the highest multiannual monthly flows were recorded: 9.96 m^3/s and 13.2 m^3/s. The flow of 8.30 m^3/s in 1991 is the lowest of the 5 multiannual maximum flows.

Even if the section in which measurements are taken is situated downstream the accumulation, some multiannual monthly maximum flows are in accordance with those recorded at the hydrometric stations upstream This is caused by the manoeuvre from the accumulation. In this section the multiannual monthly maximum flows occurred in three periods: March, the interval June-August and in November.

Along the Dobrovat river, the main right tributary of the Vaslui river, there is only one hydrometric station, in Codaesti. This was built after the Solesti barrage was constructed.

At this hydrometric station, the multiannual monthly maximum flows were recorded in the months of May, June and September. The multiannual maximum value was 47.1 m^3/s, recorded in 1991, in May. In this month, in 2005, another annual maximum flow was recorded, with the value of 35.0 m^3/s. In September, two of the highest multiannual flows were recorded: 31.4 m^3/s in 1989 and 39.5 m^3/s in 1996. The lowest flow of the 5 multiannual maximum flows was 30.8 m^3/s in 2001.

The maximum flows recorded depend on the precipitation with torrential character. (Fig. 4). It is not compulsory that a high annual amount of precipitation lead to a significant annual maximum flow, but to a significant average annual flow.

In Satu Nou, on the Vaslui river, the multiannual variation of the maximum flows (Fig. 5), indicates the fact that the interval 1997 – 2008, the maximum flows had values under 37.5 m^3/s. This is the period with the most reduced flows, even if the lowest maximum flow was 1.76 m^3/s, in 1987. This period starts in 1992, with 16.1 m^3/s, and the flow with the value of 68.8 m^3/s, in 1996, interrupts it. This is a period which raises a lot of questions, considering that it is a recent one, and the flow trend is decreasing. On the other hand, this evolution emphasizes the torrential character of the river and the continental character of the climate. Year 2007 was also important, characterized by meteorological drought, with impact on the river flows in 2008. The percentage of years with maximum flows under 50.0 m^3/s is of 73.2%.

Considering the fact that 2009 was a droughty year, the period started in 1997 is continued, the decreasing tendency is maintained, with influences on the surface flow in the years to follow, according to the precipitation regime, of course.

In the multiannual variation of the flows at the hydrometric station in Codaesti (Fig. 6), located on the Vaslui river as well, the trend is decreasing, but not so significant as upstream, in Satu Nou. Anyway, it is normal to find such a tendency in Codaesti as well, while it is manifested upstream, but in this case, the period 1997–2008 does not have the same evolution. At this station, the flows exceeding 50.0 m^3/s are: 68.4 m^3/s in 1999; 65.0 m^3/s in 2001; 79.1 m^3/s in 2005.

Although the area of the of the hydrographical basin (up to the hydrometric station), is much greater (362 km^2) that upstream (105 km^2), in 68.8% of the situations, the annual maximum flows do not exceed 50.0 m^3/s. At the hydrometric station in Codaesti, on the Dobrovat river (Fig. 7), the multiannual maximum flow is 47.1 m^3/s, which means that the multiannual variation of the flows runs under this value. It is normal that the flows are lower than those recorded at the hydrometric stations on the Vaslui river, considering the fact that the river basin is smaller (184 km^2).

Table 3. Multiannual monthly maximum flows and multiannual maximum flow at the hydrometric stations on the Vaslui river: Satu Nou (1968-2008), Codaesti (1977-2008), Solesti (1985-2008) and on the Dobrovat river at Codaesti (1986-2008)

River	Hydrometric station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Q max
Vaslui	Satu Nou	13.5	13.2	37.5	108	122	174	105	217	68.8	9.41	19.7	13.1	217
	year	1977	2005	1999	1979	1991	1985	1971	1970	1996	1998	1996	1971	1970
	Codaesti	19.0	35.4	68.4	133	115	222	41.3	19.2	106	16.2	28.6	22.2	222
	year	1977	2005	1999	1979	1991	1985	1985	1977	1996	1998	1996	1981	1985
	Solesti	3.07	4.69	9.09	7.35	7.48	9.96	13.2	8.30	3.96	0.354	9.95	8.27	13.2
	year	1997	1997	1999	1998	2005	1985	1985	1991	1988	1985	1996	1996	1985
Dobrovat	Codaesti	2.99	13.0	28.9	15.4	47.1	30.8	11.1	14.3	39.5	5.98	13.8	6.48	47.1
	year	1998	2005	1999	1988	1991	2001	1991	1988	1996	1996	1996	1996	1991

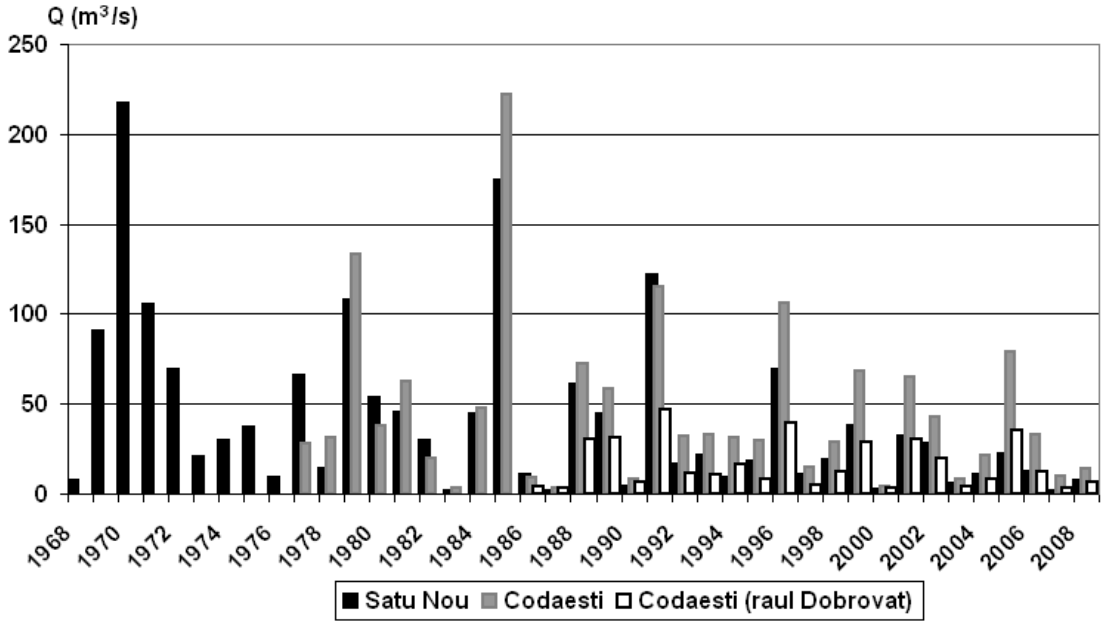

Figure 3. Hydrograph of the annual maximum flows at the following hydrographical stations Satu Nou, Codaesti (on the Vaslui river) and Codaesti (on the Dobrovat river)

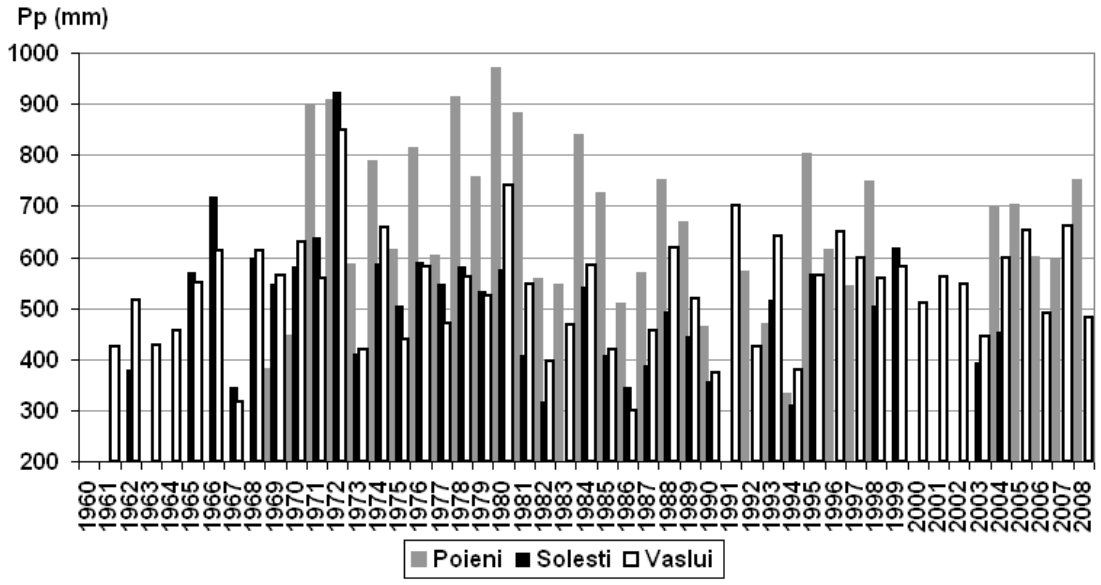

Figure 4. Annual amounts of precipitation at the pluviometric stations in the Vaslui river basin

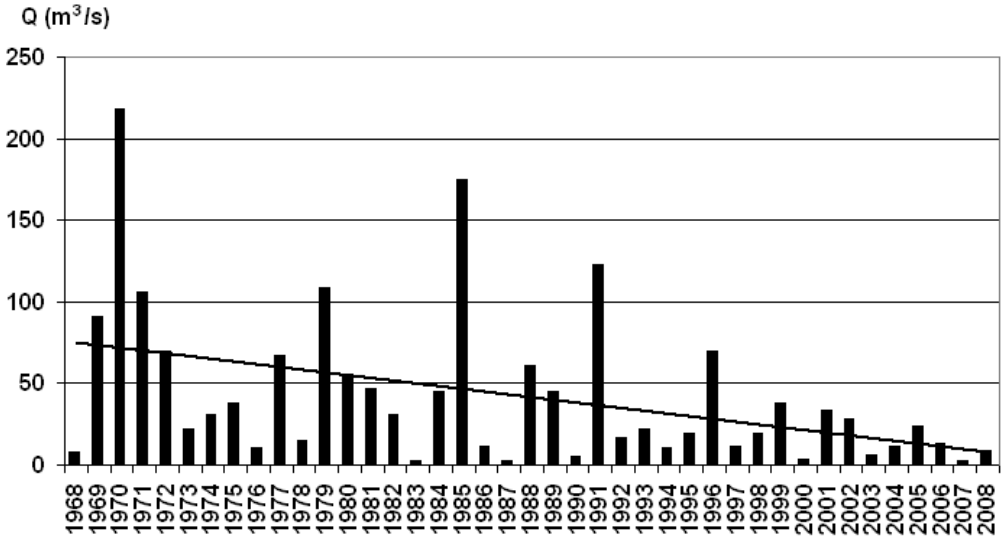

Figure 5. Multiannual variation of the maximum flows and their trend at the hydrometric station in Satu Nou (Vaslui river), in the period 1968 – 2008

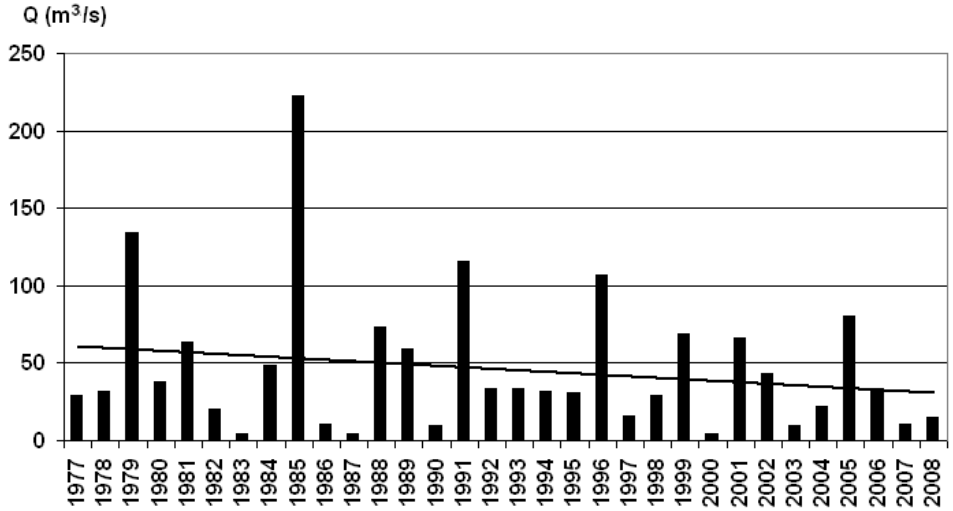

Figure 6. Multiannual variation of the maximum flows and their trend at the hydrometric station in Codaesti (Vaslui river), in the period 1977 – 2008

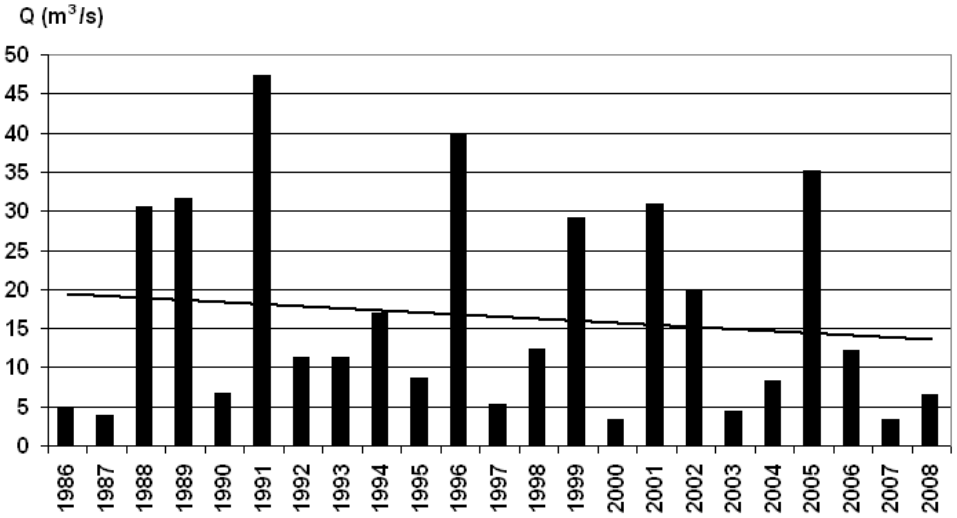

Figure 7 Multiannual variation of the maximum flows and their trend at the hydrometric station in Codaesti (Dobrovat river), in the period 1986 – 2008.

For this hydrometric station, in the multiannual variation of the maximum flows, three periods with flows under 20.0 m^3/s are noticed: 1992 – 1995; 2002 – 2004; 2006 – 2008 (and they represent 69.6% of the annual maximum flows).

The first period, 1992 – 1995, is important, with reduced flows, and this is characteristic to the other two hydrometric stations too. It is a well defined period, with constant flows on the Dobrovat river, between 8.42 – 16.7 m^3/s. In the second period the flows have values between 4.30 – 19.6 m^3/s, and in the third, between 3.26 – 12.0 m^3/s. These emphasize the manifestation of the periods in the other hydrometric stations, with reduced maximum flows as well, as compared to the whole evolution period. The evolution trend of the maximum flows in this case is decreasing as well.

Due to the fact that data of the high flood in 1971 at Satu Nou is not found in the Water Management System of Vaslui, the high floods recorded in 1969 was analysed, as this was the second greatest in terms of flows (Table 4, Fig. 8).

Table 4 Values of the flows depending on the main high floods at the hydrometric station in Satu Nou (Vaslui river)

Year	Month	Q_{max} (m^3/s)	Q_{med} year (m^3/s)	Q_{med} /month (m^3/s)	Q_{med} multiannual /month (m^3/s)	Q_{med} multiannual (m^3/s)
1969	VII	90.4	0.359	1.90	0.242	0.278
1970	VIII	217	0.721	2.12	0.146	
1971	VII	105	0.418	1.55	0.242	
1979	IV	108	0.520	3.24	0.561	
1985	VI	174	0.554	4.29	0.417	
1991	V	122	0.547	2.57	0.329	

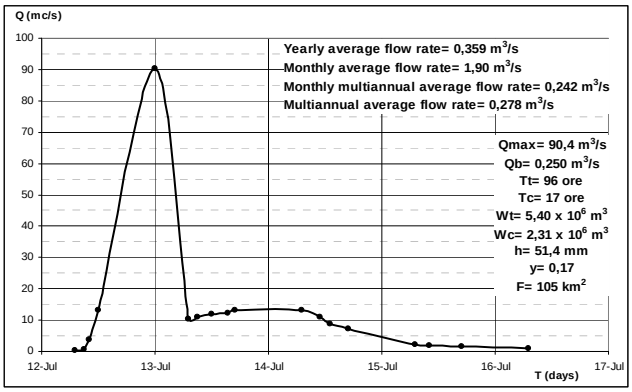

Figure 8. Hydrograph of the high flood on 12 – 16.VII.1969, on the Vaslui river, at the hydrometric station in Satu Nou and the main characteristics

The high flood recorded in 1969 in Satu Nou was caused by the combination of the precipitation periods in the month of June, when they registered the monthly maximum of that year (125.4 mm) and 86.3 mm in July, in Poeni.

The flow of 90.4 m^3/s was reached on 12.VII.1969. The high flood started the same day, with a reference flow of 0.250 m^3/s, under the conditions of a saturated soil, as a consequence of the previous precipitation. This high flood had a unique character as the maximum flow is preceded, on 11.VII.1969, by an amount of precipitation of only 4.4 mm, before which 8 days without precipitation were recorded. But the effect of the precipitation fallen in July is manifested later, and to this, the precipitation on 12.VII.1969, of 20.0 mm, are added, and therefore the maximum flow is recorded. Starting with 13.VII.1969 the flows are continuously decreasing, but due to the precipitation recorded on 13 – 14.VII.1969 (20.0 mm in each day), the high flood flows register a slight increase and the hydrograph of the high flood got a different shape, with a prolongation until 16.VII.1969.

For the interpretation of the high flood in 1970, only the data for the months of August and September are missing from the data provided by C.M.R. (in the month of August the historic maximum flow was recorded). This fact is not a coincidence, the lack of data is probably a proof of the fact that measurement conditions or instruments were deteriorated in that period, as these two months are the only in which precipitation data are missing.

In Poieni, for the year 1970, only the precipitation amount of 443.6 mm is represented on the graph, and this does not include the monthly amounts of August and September. The high flood in 1970 recorded the historic maximum flow in Satu Nou hydrometric station, with the value of 217 m^3/s, on 25.VIII.1970, with a start value of 0.039 m^3/s in the same day (Fig. 9).

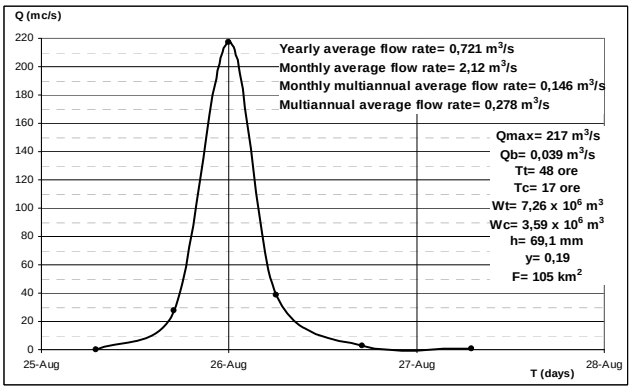

Figure 9. Hydrograph of the high flood on 25 – 27.VIII.1970, on the Vaslui river, at the hydrometric station in Satu Nou and the main characteristics

The maximum flow in 1971 (105 m^3/s), is due to the high amounts of precipitation recorded in

Poieni in the month of July (210.9 mm). The maximum amount on 24 hours had the value of 105.0 mm on 2.VII.1971, when the maximum flow was also recorded. This amount was supported by the previous ones, in the interval 12.VI. – 1.VII.1971 (114.5 mm). In the period 3 – 4.VII.1971 other 25.5 mm were recorded, supporting the flow.

The high flood in 1979 has a reference flow of 2.37 m^3/s on 8.IV.1979, due to the combination of several precipitation amounts in Poeni: 53.0 mm (3 – 5.IV.1979) and 30.2 mm (7 – 8.IV.1979) (Fig. 10). Under the circumstances of such precipitation and flows, on 9.IV.1979 other 80.1 mm were recorded, followed by a flow of 108 m^3/s, the high flood ending on 11.IV.1979.

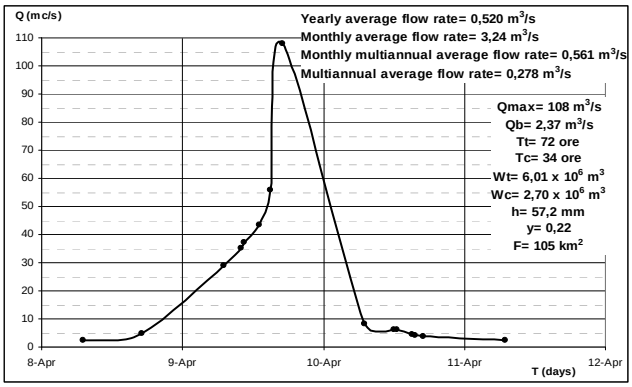

Figure 10. Hydrograph of the high flood on 8 – 11.IV.1979, on the Vaslui river, at the hydrometric station in Satu Nou and the main characteristics

In 1985, at the hydrometric station in Satu Nou, the high flood with the second greatest multiannual maximum flow was recorded (Fig. 11). This has a sudden increase, from 1.42 m^3/s on 18.VI.1985, a day in which the amount of precipitation in Poeni was 80.1 mm, to 125.0 mm in 19.VI.1985, when the maximum flow of 174 m^3/s was also recorded (Moldova Meteorological Center, Iasi, 2009).

The last high flood of the 5 ones, but not the one with the lowest flow, was recorded in 1991, a year for which there is no precipitation data for Poeni at the Moldova Meteorologic Center of Iasi. That is why we used only the precipitation measured in Solesti pluviometric station, situated downstream.

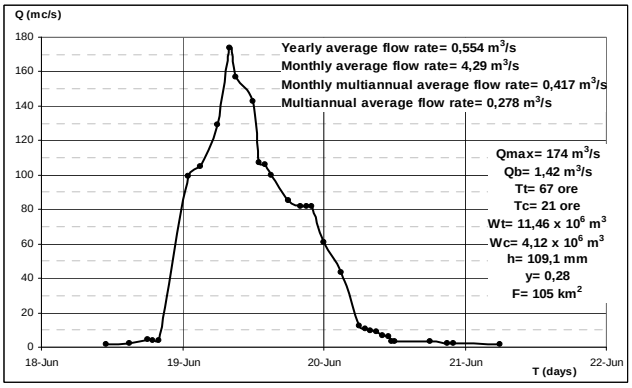

Figure 11. Hydrograph of the high flood on 18 – 21.VI.1985, on the Vaslui river, at the hydrometric station in Satu Nou and the main characteristics

In the beginning, the high flood in 1991 has a flow of 1.76 m^3/s on 26.V.1991. On 27.V.1991, the amount of precipitation is 127.5 mm, causing a maximum flow of 122 m^3/s (Table 5, Fig. 12).

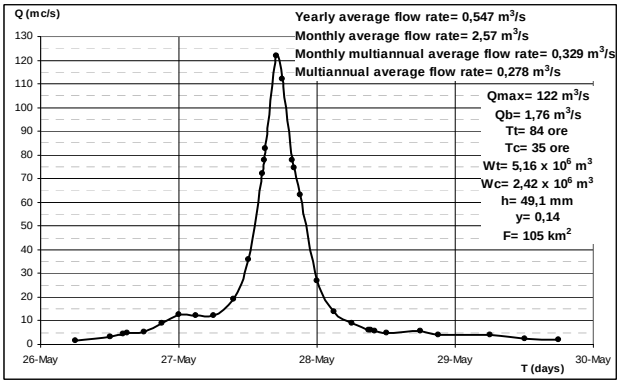

Figure 12. Hydrograph of the high flood on 26 – 29.V.1991, on the Vaslui river, at the hydrometric station in Satu Nou and the main characteristics

Of the 5 high floods, those recorded in 1970 and 1985 can be distinguished. The high flows were recorded in a very short time. In 1970, the flow increased from 27.8 m^3/s to 217 m^3/s in only 7 hours, and in 1985, from 4.19 m^3/s to 99.5 m^3/s in only 4 hours.

Table 5 Characteristic parameters of the high floods at the hydrometric station in Satu Nou

Year	Qmax (m^3/s)	Qb (m^3/s)	Tt (ore)	Tc (ore)	Wt (mil. m^3)	Wc (mil. m^3)	h (mm)	y	F (km^2)
1969	90,4	0,250	96	17	5,40	2,31	51,4	0,17	105
1970	217	0,039	48	17	7,26	3,59	69,1	0,19	
1979	108	2,37	72	34	6,01	2,70	57,2	0,22	
1985	174	1,42	67	21	11,46	4,12	109,1	0,28	
1991	122	1,76	84	35	5,16	2,42	49,1	0,14	

What draws our attention is also the total volume of the high flood in 1985, of 11.46 mil. m^3 and the volume of high flood increase of 4.12 mil. m^3. These volumes exceed the values of 1970 high flood, when the multiannual maximum flow was recorded. The flown layer is also significant, exceeding 109 mm, and also the high flood shape coefficient (0,28), as compared to the value of the flown layer and of the shape coefficient of the other high floods, with values between 49 – 70 mm, 0.14 – 0.22 respectively. This fact is due to the sudden increase and decrease of the levels, and of the high flood flow implicitly.

The high flood in 1979 is the direct consequence of the precipitation amount of 23.7 mm in the period 3 – 4.IV.1979, 17.3 mm in the interval 7 – 8 .IV.1979 and 20.5 mm on 9.IV.1979, the date when the maximum flow of 133 m^3/s was recorded. The reference flow of the high flood is 4.08 m^3/s, on 8.IV.1979, the high floods being over on 14.IV.1979 (Fig. 13).

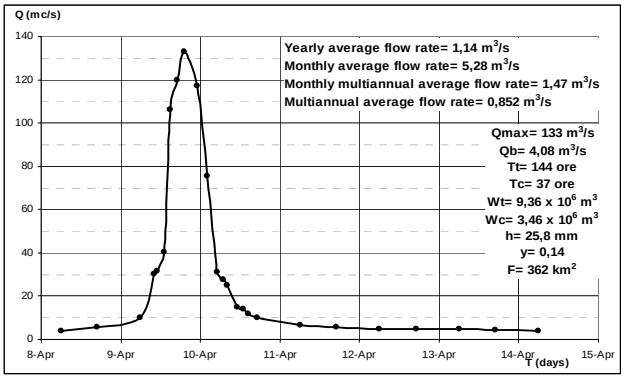

Figure 13 Hydrograph of the high flood on 8 – 14.IV.1979, on the Vaslui river, at the hydrometric station in Codaesti and the main characteristics

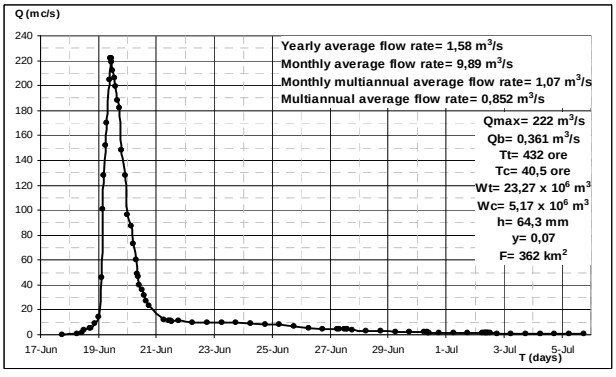

Figure 14 Hydrograph of the high flood on 17.VI – 5.VII.1985, on the Vaslui river, at the hydrometric station in Codaesti and the main characteristics

The high flood in 1985 has a similar character to the previous one. The high flows, the high amounts of precipitation recorded in the upper basin and the area of the river basin, caused the recording of the maximum flow at the same date with the one in Satu Nou. The amounts of precipitation are important, 27.7 mm on 8 – 9.VI.1985, and 43,3 mm on 18.VI.1085 and 31,3 mm in the day when the multiannual maximum flow was recorded, 222 m^3/s, as they induced a very low decrease rate to the high flood. Its start, on 17.VI.1985, had a reference flow of 0.361 m^3/s and the end was recorded on 5.VII.1985 (Fig. 14).

The high flood in 1991 has a special character, with a maximum flow of 115 m^3/s, recorded on the same date with the maximum flow in Satu Nou hydrometric station, on 27.V.1991, higher than the value recorded in Codaesti (Fig. 15). As in the case of the other high floods, the high flows are caused by the significant values of the flows and precipitation in the upper river basin. At the pluviometric station in Solesti, the amount of precipitation cumulated for the month of May, until the date when the maxim was registered, is 127.5 mm. Due to its distribution in time, it did not cause significant flows from a quantitative point of view.

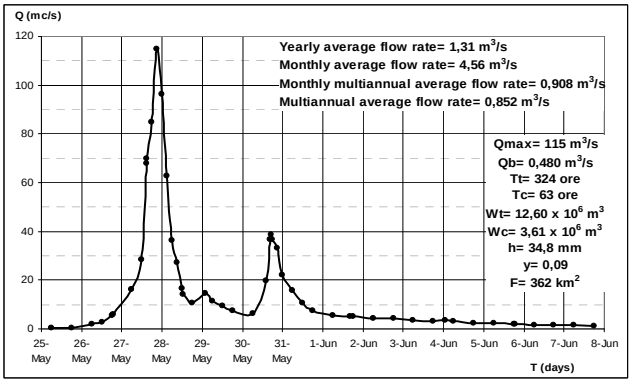

Figure 15. Hydrograph of the high flood on 25.V – 7.VI.1991, on the Vaslui river, at the hydrometric station in Codaesti and the main characteristics

This high flood is of a composed type, and it manifests in the period 25.V. – 7.VI.1991, with a reference flow of 0.480 m^3/s. The second important peak of the flow has a value of 38.6 m^3/s, on 30.V.1991, its beginning occurring the same day.

The high flood in 1996 occurred in the period 22.IX. – 5.X.1996. The value of the reference flow was 0.592 m^3/s, reaching the maximum flow of 106 m^3/s on 24.IX.1996 (Fig. 16). It has a normal increase time, but the decrease is very slow, similar to the high flood in 1985. There are no precipitation data for this high flood either.

A high flood of a composed type, but with another manifestation way, is the high flood in 2005. It presents three peaks with flows of 79.1 m^3/s, 28.8 m^3/s and 14.9 m^3/s. The high flood manifested in the interval 7 – 19.V.2005, starting with 0.876 m^3/s, and

reaching a maximum flow of 79.1 m^3/s on 8.V.2005 (Fig. 17).

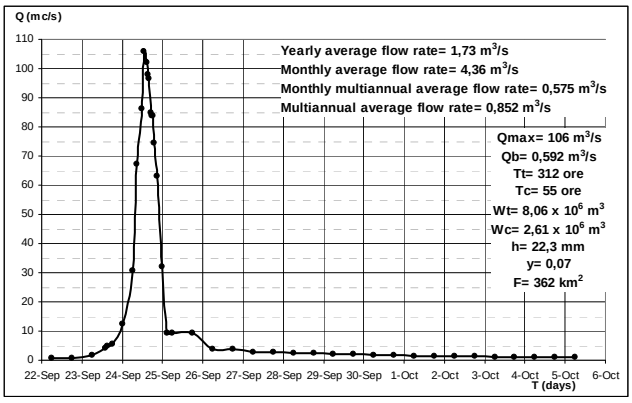

Figure 16 Hydrograph of the high flood on 22.IX – 3.X.1996, on the Vaslui river, at the hydrometric station in Codaesti and the main characteristics

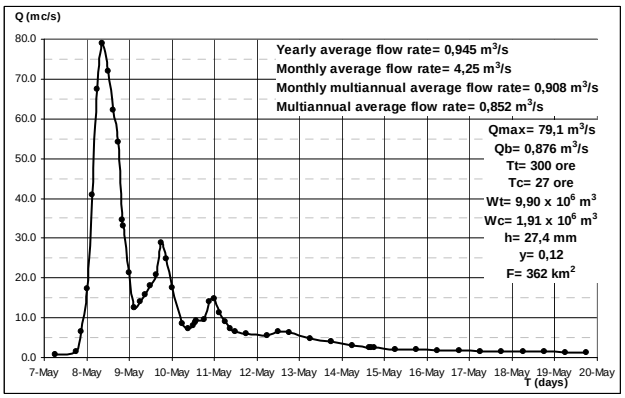

Figure 17. Hydrograph of the high flood on 7 – 19.V.2005, on the Vaslui river, at the hydrometric station in Codaesti and the main characteristics

The high flood in 1979 and 2005 are characterized by higher shape coefficient than other high floods (0.14 and 0.12 respectively), due to the fast increase of the flows, with significant values in a short period of time, and with a decrease which happens also fast.

As compared to the multiannual maximum flows recorded at the other hydrometric stations, reaching 217 m^3/s in Satu Nou, 222 m^3/s in Codaesti, both situated on the Vaslui river, in Codaesti, on the Dobrovat river, the 5 multiannual flows included in the present analysis are much lower. The multiannual maximum flow is 47.1 m^3/s, representing 21.7% of the multiannual maximum flow recorded in Satu Nou and 21.2% of the multiannual maximum flow in Codaesti. In the case of the Dobrovat river basin, due to the high vegetation cover degree and to its large area, the measured flows of the river are much lower. As compared to the high floods analysed before, on the Dobrovat river, 3 of the 5 maximum flows are of a composed type.

The high flood in 1989 has a unique evolution, due to the precipitation that are detected rapidly in the measured flows of the river (Fig. 18). It has a significant reference flow, of 0.664 m^3/s on 5.IX.1989, due to the precipitations on 30.VIII – 4.IX.1989, measured in Solesti pluviometric station, of 30.8 mm, a flow which was followed by a small increase in the same day, under the circumstances of another amount of precipitation, of 31.8 mm, followed by 4 days of rain, of 20.7 mm, 24.9 mm, 14.7 mm and 28.3 mm on 9.IX.1989. On 8.IX.1989 the maximum flow is recorded, with the value of 31.4 m^3/s. Before this, on 7.IX., two important peaks were recorded, of 29.1 m^3/s and 28.9 m^3/s, with a lower flow of 23.5 m^3/s between the two peaks (Moldova Meteorological Center, Iasi, 2009).

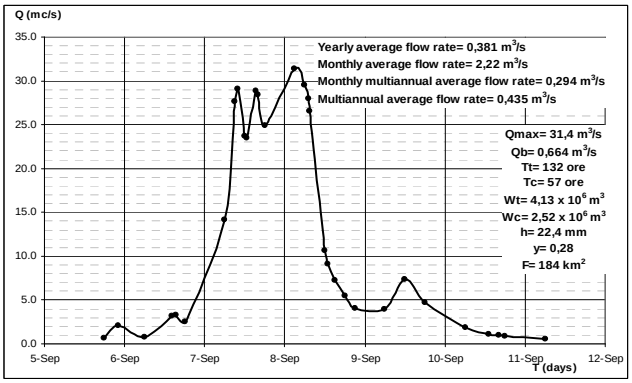

Figure 18. Hydrograph of the high flood on 5 – 11.IX.1989, on the Dobrovat river, at the hydrometric station in Codaesti and the main characteristics

Due to the distribution over a longer period of time of the precipitation, after the maximum flow was recorded, another increase of the flow was registered, but not so significant (7.40 m^3/s), the high flood ending on 11.IX.1989.

In 1991 the multiannual maximum flow was registered, with a value of 47.1 m^3/s, on 28.V.1991, when the maximum flows at the other two hydrometric stations were recorded on 27.V.1991. The reference flow of the high flood has the value of 0.300 m^3/s on 26.V.1991, and its end is recorded on 8.VI.1991 (Fig. 19).

After the maximum flow on 31.V.1991 another peak of the flow was recorded, with the value of 18.2 m^3/s, starting from a value of 3.20 m^3/s on 29.V.1991, under the circumstances of precipitations recorded at the pluviometric station in Solesti, mentioned in the case of the other high floods in 1991.

The high flood in 1996 is a simple one. It occurred in the interval 22 – 30.IX,1996, it has a reference flow of 0.540 m^3/s and a maximum flow of 39,5 m^3/s on 24.IX.1996 (Fig. 20). It has a slow increasing time and a much slower decrease.

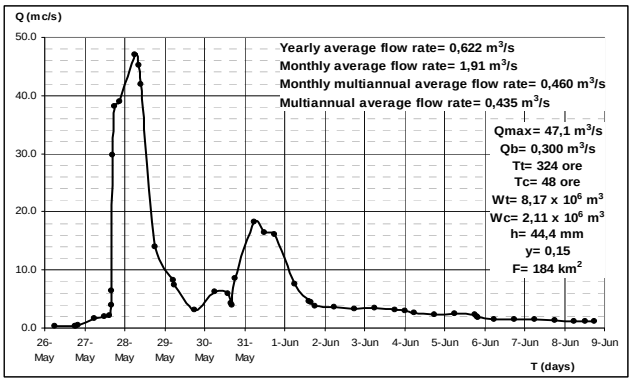

Figure 19. Hydrograph of the high flood on 26.V – 8.VI.1991, on the Dobrovat river, at the hydrometric station in Codaesti and the main characteristics

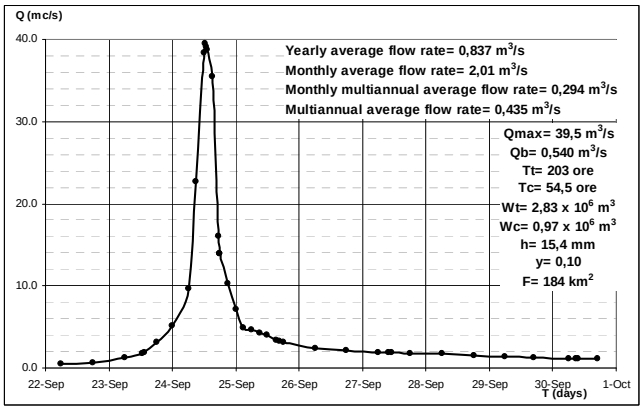

Figure 20. Hydrograph of the high flood on 22 – 30.IX.1996, on the Dobrovat river, at the hydrometric station in Codaesti and the main characteristics

There are no data for the precipitation accompanying this high flood, same as in the case of the high flood recorded in the same month, in the same year, on the Vaslui river, at the hydrometric station in Codaesti. The high flood in 2001 is of simple type, but with a lower maximum flow, of 30.8 m^3/s on 5.VI.2001 (Fig. 21). The high flood manifested in the interval 4 – 14.VI.2001, with a very slow decrease, as compared to the increase, which was sudden, with a reference flow of 0.099 m^3/s. The peak of the high flood was recorded on the basis of the significant precipitation, measured at the pluviometric station in Solesti, on 5.VI.2001, with a value of 44.7 mm, to which, the precipitation of the previous day were added, that is 21.5 mm.

The high flood in 2005 is a composed one (Fig. 22). It occurred in the period 6 – 24.V.2005, with a maximum flow of 35.0 m^3/s, recorded on 8.V.2005. The high flood has a significant reference flow, of 0.576 m^3/s. The peak has a flow of 13,4 m^3/s on 7.V.2005. The maximum flow is followed by three other peaks, the first with a value of 10.7 m^3/s on 9.V., and the next ones, of 5.25 m^3/s and 5.93 m^3/s respectively, both recorded on 10.V.2005.

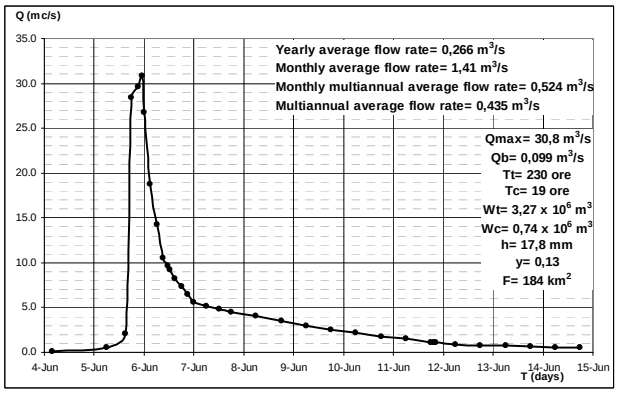

Figure 21. Hydrograph of the high flood on 4 – 14.VI.2001, on the Dobrovat river, at the hydrometric station in Codaesti and the main characteristics

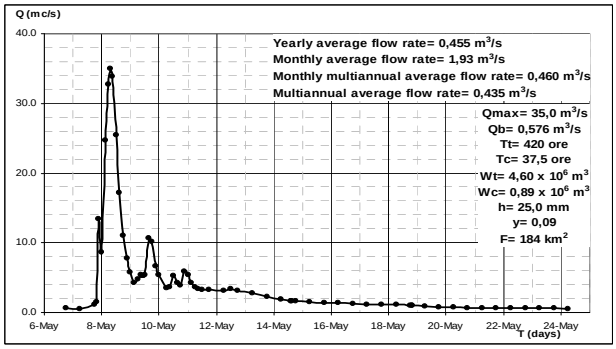

Figure 22. Hydrograph of the high flood on 6 – 24.V.2005, on the Dobrovat river, at the hydrometric station in Codaesti station and the main characteristics

The high flood in 1989, even if it does not have a very high flow, it has a high volume while increasing. It also has the highest shape coefficient (0.28). The high flood of composed type lead to the obtaining of high total volumes while increasing and high shape coefficients. The value of the observation levels (CA), the flood levels (CI) and the danger levels (CP) can undertake changes in time, especially depending on the evolution of the transversal profile in the sector of the hydrometric station or on the hydro technical works built along the river course. In the case when these levels are exceeded, a program for reading the levels at short intervals is run, in order to take measures in due time, for stopping the recording of any type of damage (Table 6).

Table 6. The observation, flood and danger levels at the hydrometric stations in the Vaslui river basin

River	Hydrometric station	C.A. (cm)	C.I. (cm)	C.P. (cm)
Vaslui	Satu Nou	400	580	650
	Codaesti	400	500	650
Dobrovat	Codaesti	400	500	600

Considering the present levels (observation, flood and danger levels), the levels recorded at the

hydrometric station in Satu Nou, for the highest multiannual flows, exceed the observation, flood and danger level. In 1985 the levels exceed the observation level with 497 cm and in 1991 with 472 cm. In 1969 the levels exceed the flood level with 639 cm. In 1970 and 1979 they exceed the dangerous level with 760 cm, and 389 cm respectively, when the historic maximum level of 760 cm was recorded (Table 7).

At the hydrometric station in Codaesti, on the Vaslui river, the levels of the high floods with the most significant multiannual flows exceeded the present flood level, with a maximum value of 612 cm in 1985.

On the Dobrovat river, at the hydrometric station in Codaesti, the levels of the most important high floods exceeded the observation and the flood level. In 1989 the emergency level was exceeded with 450 cm, in 2001 with 463 cm, and in 2005 with 477 cm. In 1991 the level of the high flood was 534 cm higher than the flood level, and in 1993, with 513 cm (Table 7).

In order to design and realize the hydro technical constructions and for an efficient management of water resources in a river basin, the calculation of the maximum flows with certain exceeding probabilities (Qmax) is necessary (Table 8). Therefore, in the Vaslui river basin the maximum flows with different probabilities (0,01%, 0,1%, 1%, 5% and 10%) were determined, using the insurance curves of Pearson III type, as well as the specific maximum flows (qmax): qmax = (Qmax / F) x 1000.

In Satu Nou the maximum flows produced during the 5 high floods, exceeded, in 1970, the probability of 1%, in 1985 the probability of 5%, and in 1979 and 1991 the probability of 10%. At the hydrometric station in Codaesti on the Vaslui river, the highest high floods exceeded the probability of 1% in 1985, and the probability of 10% in 1979 and 1991.

In the case of the flows recorded on the main tributary, the Dobrovat river, the flows of the high floods exceeded the probability of 5% in 1991 and the probability of 10% in 1996 and 2005. Analysing the multiannual maximum flows it is noticed that the probability of 1% was exceeded at the hydrometric stations on the Vaslui river, and on the Dobrovat river, only the probability of 5%.

For practical reasons, in order to design the hydro technical objectives, the maximum volume with exceeding probabilities were determined. For the probability of 1%, these are included between 1.85 – 6.02 mil m^3 (Table 9).

Table 7. The levels recoded at the high floods with the highest flows at the hydrometric stations in the Vaslui river basin

River	Hydrometric station	Hmax (cm)					Historic Hmax (cm)
Vaslui	Satu Nou	**639**	**760**	389	**497**	**472**	**760**
	Year	1969	1970	1979	1985	1991	1970
	Codaesti	**554**	**612**	**540**	**533**	**512**	**612**
	Year	1979	1985	1991	1996	2005	1985
Dobrovat	Codaesti	**450**	**534**	**513**	**463**	**477**	**534**
	Year	1989	1991	1996	2001	2005	1991

Table 8. Annual maximum flows (m^3/s) and specific maximum flows ($l/s/km^2$) with different calculated probabilities at the hydrometric stations in the Vaslui river basin

River	Hydro-metric station	Qmax (m^3/s) for the probabilities					qmax (l/skm^2) for the probabilities				
		0,01%	0,1%	1%	5%	10%	0,01 %	0,1%	1%	5%	10%
Vaslui	Satu Nou	343	268	189	131	104	3267	2552	1800	1248	990
	Codaesti	341	268	191	134	108	942	740	528	370	298
Dobrovat	Codaesti	102	80,9	58,6	42,0	34,4	554	440	318	228	187

Table 10. Maximum volumes (mil. m^3) and maximum water layers equivalent to the maximum volumes (mm) with different exceeding probabilities determined for the main hydrometric stations in the Vaslui river basin

River	Hydrometric station	Wmax (mil. m^3) for the probabilities					Hmax (mm) for the probabilities				
		0,01%	0,1%	1%	5%	10%	0,01%	0,1%	1%	5%	10%
Vaslui	Satu Nou	10,82	8,45	5,96	4,13	3,28	1030	805	568	393	312
	Codaesti	10,75	8,45	6,02	4,23	3,41	297	233	166	117	94
Dobrovat	Codaesti	3,22	2,55	1,85	1,32	1,08	175	138	100	72	59

Table 9 Statistics of the maximum monthly flows in the Vaslui river basin

Hydrometric / Station	Satu Nou / Vaslui	Codaesti / Vaslui	Codaesti/ Dobrovat
Maximum flow (maximum value)	217	222	47,1
Year	1970	1985	1991
Maximum flow (minimum flow)	1,76	3,28	3,19
Year	1987	1983	2000
Maximum flow (average value)	41,3	46,0	16,5
Cv	1,14	1,00	0,81
Cs	2,29	2,00	1,62
Cs/Cv	2,00	2,00	2,00
Σ	0,35	0,31	0,45

Cv – variation coefficient of the data series with annual maximum flows; Cs – asymmetry coefficient of the data series with annual maximum flows; Σ – square average deviation.

By reporting the maximum water volume corresponding to each exceeding probability, to the drained basin area, a maximum water layer is obtained, equivalent to the volumes (Table 10).

In the hydrological practice, the knowledge of the elements characteristic to the high flood waves, presents a special importance (Ceobanu & Grozavu, 2009, Diaconu, 1988, Diaconu & Serban, 1994, Ferenczi & Balog, 2010, Hobai, 2009, Pisota & Buta, 1975, Portela & Delgado, 2009, Rosu & Cretu, 1998, Selerescu & Podani, 1993). These elements are determined by using the hydrographs of the single high floods, recorded at the hydrometric stations, and on the basis of the analysis of the most important high floods. Afterwards, the average characteristic elements of the high flood waves, which represent the basis of the type hydrographs of the single high floods with different probabilities, can be calculated (Fig. 23).

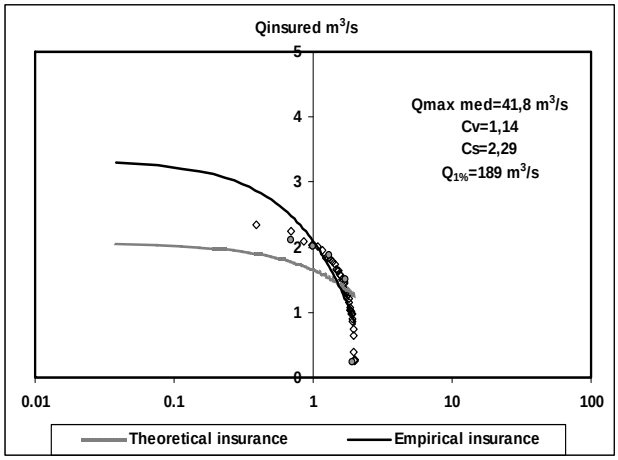

Figure 23. Curves of theoretic and empirical probability realized for the annual maximum flows at the hydrometric station in Satu Nou (Vaslui river)

5. CONCLUSIONS

Comparing to other hydrographic units in Romania, Vaslui River has undergone major transformations with the purpose of reducing its flooding characteristics.

All the river basins in the Moldavian Plateau undertake climatic conditions favourable to the genesis of torrential rains. In this case, the hydrological risks are very frequent and the material damage or human toll can reach immeasurable values.

The detailed analysis of the hydrographs of the maximum flows on the Vaslui river and its tributary, Dobrovat, emphasizes the fact that most of the works that have been accomplished on the water courses are efficient. The exception belongs to the sector upstream of Solesti barrage.

Besides of the precipitations with torrential character and the shape of the upper river basin, another decisive factor in producing floods in represented by deforestation. The barren slopes became more and more in number after 1990, when the agricultural land was given to the small land owners.

The basic characteristic of the high flood waves on the Vaslui river is represented by the existence of a clear modulation, very often vertical, in a relatively short time. The sharp waves are similar to those produced in the urban areas. This particular thing is caused by the existence of the barren slopes.

The barrage in Solesti, with a multiple purpose, has a very important role in diminishing floods (Romanescu et al., 2005, Romanescu et al., 2008). From this point of view the town of Vaslui is well protected against floods, and the hydrologic risk is no longer existent.

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