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Modification by the River Vaslui of the Hydrological Regime and Its Economic Implications (Romania)

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***Abstract*—**The influence of human activities produced by dams along the river beds is minor, but the location of accumulation of water directly influences the hydrological regime. The most important effect of the influence of damming on the way water flows decreases the frequency of floods. The water rate controls the water flow of the dams. These natural reservoirs become dysfunctional and, as a result, a new distribution of flow in the downstream sector, where maximum flow is, brings about, in this case, higher values. In addition to fishing, middle and lower courses of rivers located by accumulation also have a role in mitigating flood waves, thus providing flood protection. The Vaslui also ensures a good part of the needs of the town water supply. The most important lake is Solesti, close to the Vaslui River, opened in 1974. A hydrological regime of accumulation is related to an anthropogenic and natural drainage system. The design conditions and their manoeuvres drain or fill the water courses.

***Keywords*—**Hydraulic works, hydrological regime, average flow, repeat flow.

I. Introduction

THE human factor, through its actions, can change the flow through works through construction and especially of agro-technical and hydro plants. Through agro-technical work, man, without significant changes in physical conditions, can alter the geographical region within a short time, compared to the natural progression of these conditions. In general, the influence of these operations is very complicated. Whatever the measures, there is a clear reduction of the leak. Among the measures, effective agrotechnical leakage can be mentioned: autumn ploughing, spring sowing, ploughing along contours, keeping soil water through curtains of protection in woodland areas, etc.

Man, through various construction and hydro plants consumes large quantities of water from rivers, substantially influencing their regime during dry periods. Also, the construction of ponds or lakes contributes to mitigating the system flow at flood, but on the other hand, due to evaporation in the reservoirs, contributes to the loss of a large amount of annual average flow. The measures outlined above, and rational water management, can significantly influence the flow regime. The measures taken to produce a radically degradation of surface drainage basins in the lowland and hilly regions is intensifying. However, groundwater flow to rivers follows intense infiltration.

Romanian literature in the field of hydrological flow phenomena in the eastern part of Romania or over all the territory of Romania is well represented [1]-[20]. At the same time, it is important to mention that most of the data, of a general or particular (punctual) character, were extracted from the international hydrological literature. Here we mention the most important or the most recent authors: [21]-[28].

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II. Geographic Setting

The left tributary of the Barlad, Vaslui River is located in eastern Romania. The catchment area is 9.58% of the river that flows through Barlad. In terms of river basin area and length, Barlad is the largest in the Siret basin. The river flows below the plateau Repedea Vaslui - Paun, from an altitude of 340m and flows into the river Barlad, about 80m altitude (Fig. 1). The Vaslui basin lies, from the morphological point of view, in the central – eastern Moldavian Plateau, specifically in the central – east of the Central Moldavian Plateau. It is limited to the west Telejna and Rebricea river basins to the east at the Crasnei, and to the northern river basins Jijia and Bahlui.

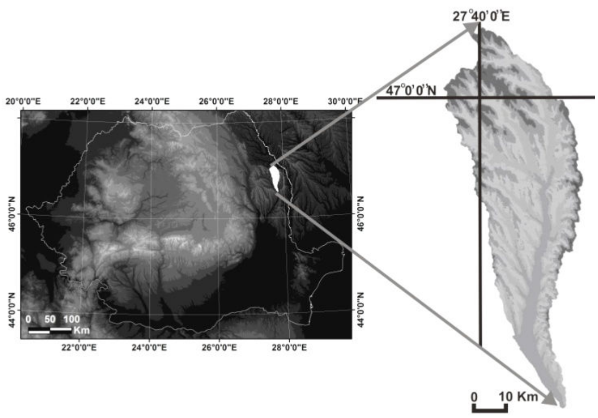

Fig. 1 The geographical position and mathematical coordinates of the Vaslui hydrographic basin

It has a length of 81.0km and a basin area of 692km^2 [29]. River network density is about 0.32km/km^2, above the national average (0.33km/km^2). Water courses give a total length of 218km (Table I). The subsequent river course of the Vaslui and catchment is asymmetric to the right (73% of total area), a feature seen in other tributaries of Barlad, and Crasna. Asymmetry in the Barlad Plateau is due to the lower altitude plateau of the Prut river basin (left). In the upper basin slopes are 10‰, and they fall to the lower average values of 3‰ [17].

Intake of water is not proportional to the surface of the basin, as it is a typical steppe river, with a very low leakage and a similar flow. The specific climate is excessively temperate continental, typical of Eastern Europe [2]. If groundwater flow had a reduced contribution from feed rivers, Vaslui River would be temporary in nature.

TABLE I
CHARACTERISTICS OF ALL WATERCOURSES AND HYDROGRAPHIC BASINS

Watercourse	Data from the watercourse					Data from the hydrographic basin			
	Position of confluence	Length (km)	Altitude (m) Upstream	Altitude (m) Downstream	The average slope (‰)	Surface sinuosity coefficient (km^2)	Surface (km^2)	Average altitude (m)	Forest area (ha)
Vaslui	s	81	340	80	3	1.28	692	233	14,122
Carbunaria	d	7	340	196	21	1.15	15	289	1,187
Tabara (Valcele)	d	10	380	178	20	1.16	23	276	1,222
Pocreaca	d	9	360	152	23	1.18	15	273	93
Coropceni	s	6	380	150	38	1.10	10		95
Ciortești	s	7	270	135	19	1.52	22	258	266
Dobrovat	d	27	330	122	8	1.16	185	248	6,412
Lunca	d	16	335	118	14	1.12	45	246	232
Rac (Iaz)	s	14	380	111	19	1.42	30	244	346
Glod	d	7	330	109	32	1.03	10	243	
Feresti	d	14	330	99	17	1.44	69	217	460
Munteni	d	6	155	98	10	1.05	19	235	237
Delea	d	14	222	92	9	1.18	19		160

s-left; d-right

III. METHODOLOGY

Statistical data were obtained from the Department of Water, Prut, Iasi, Moldavian Meteorological Centre, Iasi and Romanian Waters National Administration, Bucharest. These were processed in the Laboratory of Geo-Archeology of the Faculty of Geography and Geology, Iasi. Real satellite images were taken from the Remote Sensing and GIS Laboratory of the National Administration of Meteorology and Hydrology and partially processed or interpreted in the Remote Sensing and GIS Laboratory of the Faculty of Geography and Geology, University "AI. I. Cuza" of Iasi and the Geo-Archeology Laboratory. Most of the satellite images already processed were taken from the Romanian Space Agency (ROSA – Romanian Space Agency) or PNCD12 Project (http://sigur.rosa.ro) on the internet.

Observations and field measurements were taken between 2006, 2007, 2008, 2009 and 2010 from the major flood path of the river bed Dobrovat and Vaslui. Rates were monitored daily at three stations and topographic measurements were made upstream and downstream from it. All data analyzed were taken from four meteorological stations (Satu Nou, Codaesti and Solesti on Vaslui, and Codaesti on Dobrovat) and two rainfall stations (Codaesti and Solesti).

IV. RESULTS AND DISCUSSION

As for the Vaslui River, like many other rivers in the Moldavian Plateau, important works have had a hydraulic nature, for which reason the hydrological regime is strongly transformed. The same situation is present for the Bahlui, and Jijia, Miletin and Sitna rivers, etc. The economically most important river, the Vaslui, only serves one town in the county (Vaslui).

A. Influence of Anthropical Accumulations

In Vaslui basin lakes have accumulated in an oblong form, according to the direction of flow of the river where they are located. The main reservoirs are Solesti, located on the river Vaslui, and Delea, located on the river with the same name. Rainfall and emissions from the lake provide general and lasting sources of water, while other sources are local, limited in time, influenced by storage and the disposal capacity of the aquifer layer. Loss of lake water leakage occurs through emissions: evicted, bottom discharge, overflow of waters, uses (water supply pipe of the city of Vaslui, irrigation systems, through evaporation and seepage), etc.

Barlad Plateau, given the nature of physical characteristics - specific geographic conditions does not favor the formation of natural lakes. The only category of natural lakes, meandering lakes have been abandoned. Rivers that accompanied it were formed, with depths of up to 2.0 m. Later ameliorative water works have been mostly drained, with the land restored to agriculture [18].

Due to the flow regime, and rainfall regime with excessive weather favorable preconditions were created for the frequent occurrence of floods. In this context, the construction of storage tanks was required [11]. They were designed mainly for flood mitigation, but also for utilities: water supply, fisheries, irrigation, recreation, etc. The location of these accumulations was done taking into account the substrate lithology (which must be predominantly clay) to prevent any losses [13].

The hydrological regime of accumulation is related to the natural flow regime of river lakes that have been furnished by human means, and draining or filling manoeuvers required by the conditions of design (Table II). Accumulation at the Solesti complex was designed for operation while meeting the following requirements:

- city water supply Vaslui (population and industry) to ensure 97%;
- retaining a volume of water to irrigate an area of 1,500 ha;
- providing a water volume of 11.94 million m^3 NRL (118.00 mBS – meters Black Sea) for fish in natural conditions;
- flood mitigation: accumulation Solesti protects flooded Solesti localities, Valeni (residents of the floodplain), Moara Domneasca (residents of the floodplain), Satu Nou, Muntenii de Sus, Moara Grecilor and various social-economic objectives located downstream of the dam;
- controls a catchment area of 414 km^2;
- ensures minimum flow and permanent sanitation 0.010 m^3/s, providing 95%.

Sampling water: Vaslui city water supply is through a siphon located in a pit maneuvre near the tower. The diameter of the water supply pipeline, which crosses the dam through a concrete gallery, is 1000mm. The pipeline is located at elevation 113.00 mBS. Minimum operating level is 114.80 mBS. Transportation and maximum flow is 0.900m^3/s. Water intake diameter of 300 mm, with the axis located at elevation 112.95mBS, entering service by defusing the 1000 mm pipeline, has moved the maximum flow of 0.200 m^3/s. Power flows required for irrigation are carried out through a water outlet, a 700 mm diameter shaft at a rate of 112.32 mBS. Maximum flow is transported from 0.480 m^3/s.

TABLE II
PRINCIPAL CHARACTERISTICS OF RESERVOIRS IN THE VASLUI HYDROGRAPHIC BASIN

Lake	River	Surface for NRL (ha)	Volume NRL (mil. m^3)	Reduced volume (mil. m^3)	Total Volume (mil. m^3)	Length of crown (m)
Solesti	Vaslui	457	15.56	30.32	46.80	964
Delea	Delea	7	0.14	1.91	2.42	257
Total		464	15.71	32.23	49.22	

NRL=normal retention level

To highlight the anthropogenic influence on the hydrological regime of the river Vaslui, which is manifested by reducing the liquid flow, it will use data from measurement stations since 1985 - when the Solesti hydrometric station was founded, the Vaslui river, located downstream of the accumulation of the same name - to 2008 inclusive. The issues mentioned are highlighted by measurements at measurement stations upstream (Codaesti - Vaslui river, founded in 1977 and Codaesti - Dobrovat river, founded in 1986) and the Solesti downstream accumulation (all three established after release into the Solesti reservoir) and evaporimetric platforms: one located on Lake Solesti and the other on land, in the vicinity of the reservoir. Delea river measurement stations are not found in the annual hydrological studies to establish the hydrological station of the Vaslui Water Management System.

If the annual average is measured in parallel flow, annual average rates can again be seen in a graph that clearly expresses the differences between measured and reconstructed flows (Fig. 2). This is due to accumulation of a significant volume of water in the upstream lake and its redistribution over time, depending on socio - economic requirements. The annual average flows measured at the Solesti hydrometric station are much lower than those reconstructed. The fall in the spread from 0.001 to 0.954 m^3/s with an annual average 0.242 m^3/s in the period analyzed (1985-2008). It represents 28.8% of the multiannual average flow reconstituted. Only in 1985, 1997, 1999 and 2005 did rates exceed 0.500 m^3/s.

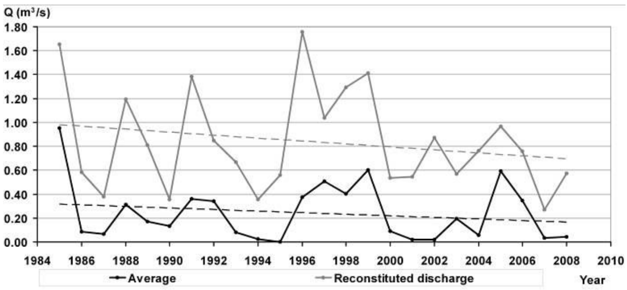

Fig. 2 Variation of the multi-annual average flow measured and reconstructed at Solesti hydrometric station and the river Vaslui

Annual average flows again, the same hydrometric station, have a spacing ranging from 0.269 to 1.76 m^3/s, with an annual average of 0.839 m^3/s, calculated for the same period. Many times the annual average rates again exceed 1.00 m^3/s: 1985, 1988, 1991 and from 1996 to 1999, representing 29.2% years. The Solesti hydrometric station, measuring a minimum annual average flow (0.001 m^3/s) was registered in 1995 and reconstituted at a minimum annual average in 2007 (in years of drought, the river flows in sections of the two measurement stations upstream were sometimes 0.001 m^3/s).

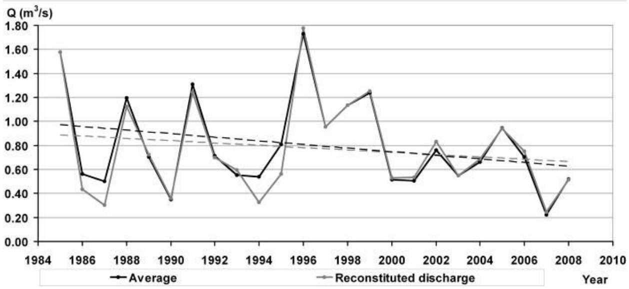

Fig. 3 Changes in the multi-annual average flow measured and reconstructed at Codaesti hydrometric station, river and tributaries of Vaslui

This parallel is significant only for Solesti hydrometric station because of its location downstream of the accumulation of the same name. In the other two measurement stations, the situation is different, in that the reconstructed annual flows are not always higher than the annual average measured (Figs. 3, 4). The difference is that the average flow rates, minimum and maximum annual average multiannual flows were measured, and gave similar values (Table III). The hydrometric station is on the Codaesti-Vaslui River. Annual average rates measured range from 0.223 to 1.73 m^3/s, and those reconstructed from 0.248 to 1.78 m^3/s. At the hydrometric station located on the river Dobrovat, annual average rates falling in the gap measured 0.120 to 0.852 m^3/s, and those reconstructed from 0.125 to 1.11 m^3/ s.

TABLE III
MEASURED AND RECONSTRUCTED AVERAGE ANNUAL FLOWS AT MEASUREMENT STATIONS CLOSE TO SOLESTI RESERVOIR (1985-2008)

River	Hydrometric station	Average multiannual mean measured (m^3/s)	Avrage multiannual mean reconstituted (m^3/s)
Vaslui	Codaesti	0.802	0.776
	Solesti	0.242	0.839
Dobrovat	Codsesti	0.382	0.422

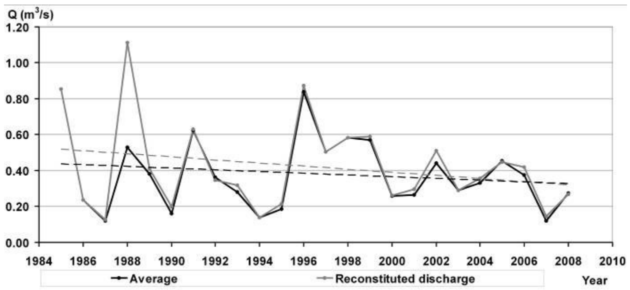

Fig. 4 Multi-annual variation of mean annual flow measured and reconstructed at Codaesti hydrometric station, river and Dobrovat tributary

Analyzing only the annual average flows measured, flow rates are important. Notes recorded on the river hydrometric station Codaesti-Vaslui (higher than those of other gauging stations) and flow accumulation downstream of the Dobrovat-Solesti river, or relatively close, most frequently the Dobrovat (Table IV). Reduced flows downstream due to the Solesti reservoir, retain a significant amount of water at times when flows carry large tributaries, while redistributing this volume, depending on design conditions.

Another point of view, equally important in the analysis of human influence on river hydrological regime of Vaslui, offers the annual maximum flows recorded at the same three hydrometric stations. Year 1985 highlights the human impact of accumulation and its importance. These issues are presented for registration in 1985. The maximum and minimum flow at Codaesti and Solesti hydrometric stations, is located in the Vaslui river: 222 m^3/s, respectively 13.2 m^3/s. However, these flows were recorded in different months of the accumulation and flood mitigation. A maximum flow of Codaesti was registered on 19.VI., and Solesti on 9.VII.

Annual maximum flow rates during 1985 - 2008 ranged from Codaesti hydrometric station (Vaslui River), between 3.52 to 222 m^3/s at Codaesti (Dobrovat river), between 3.19 to 47.1 m^3/s, to the Solesti between 0.003 to 13.2 m^3/s (Figs. 5-7). Annual minimum debit with tendency of growth, smaller than that registered at Codaesti hydrometric station on Vaslui River. Attention is drawn to the annual average measured flow reconstructed, and annual maximum flows for the period 1985 - 2008, because the same trend is decreasing (Figs. 8-14). Annual minimum flows trend to increase, other than those recorded at the hydrometric station on the Codaesti on Vaslui River.

TABLE IV
MULTI-LIQUID FLOW RATES AND SPECIFIC LIQUID FLOW IN THE RIVER VASLUI

Water course	Hydrometric station	Area of basin (km^2)	Q Multianual mean measured (m^3/s)	Q Multianual mean reconstituted (m^3/s)	q specific (l/s/km^2)	Period (years)
Vaslui	Satu Nou	105	0.286	0.286	2.7	1950-2005
Vaslui	Codaesti	362	0.869	0.862	2.4	1950-2005
Vaslui	Solesti	429	0.211	0.903	2.1	1985-2005
Dobrovat	Codaesti	184	0.454	0.455	2.5	1950-2005

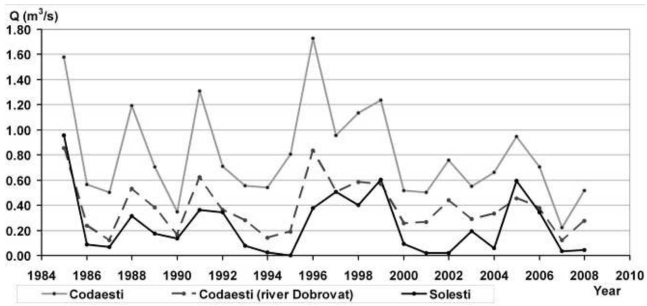

Fig. 5 Annual mean hydrographic flow measuring stations Codaesti, Solesti (located on the river Vaslui) and Codaesti (Dobrovat River)

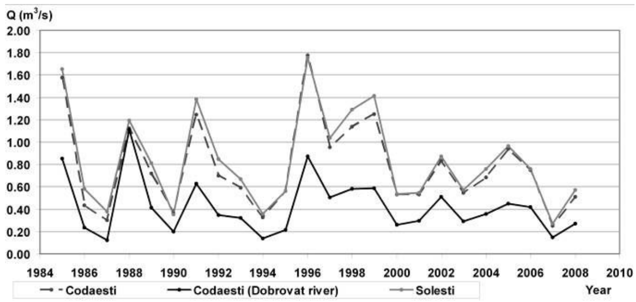

Fig. 6 Codaesti flow hydrographic measuring stations again, Solesti (located on the river Vaslui) and Codaesti (Dobrovat River)

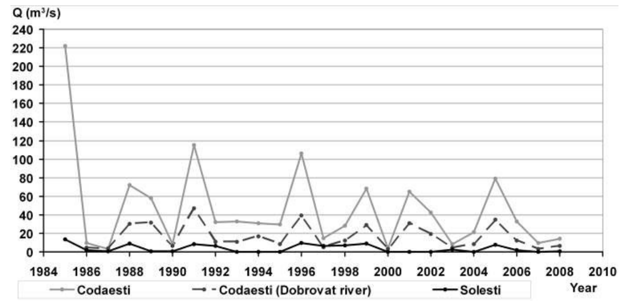

Fig. 7 Annual maximum hydographic debit at the hydrometric stations of Codaesti, Solesti (located on Vaslui River) and Codaesti (on Dobrovat River)

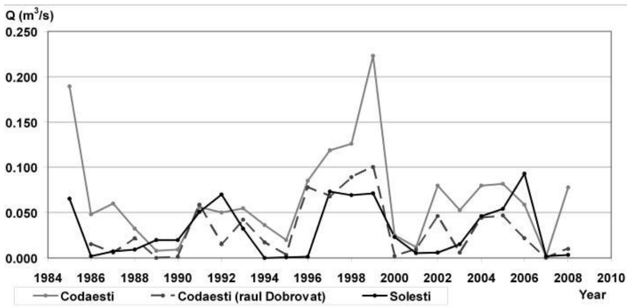

Fig. 8 Annual minimum hydographic debit at Codaesti, Solesti hydrometric stations (located on Vaslui River) and Codaesti (on Dobrovat River)

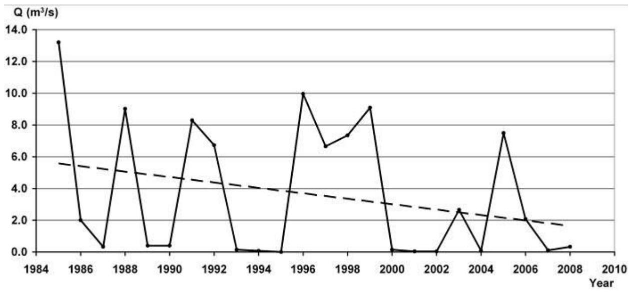

Fig. 9 Multianual variation of flow rates to annual maximum at Solesti hydrometric station, river Vaslui and tendency of these variations

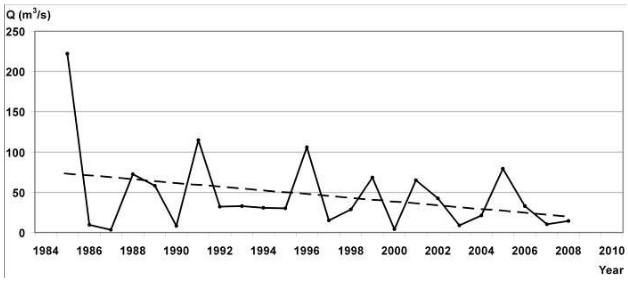

Fig. 10 Multiannual maximum annual flow rates at Codaesti hydrometric station, river Vaslui and tendency of these variations

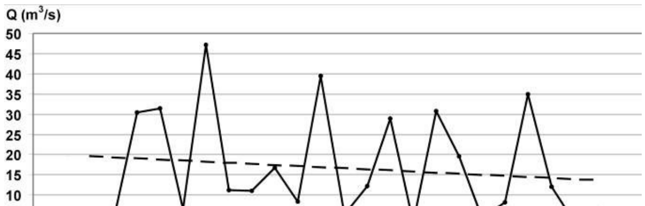

Fig. 11 Multianual variation and maximum annual flow rates at Codaesti hydrometric station, river Dobrovat and its tributaries

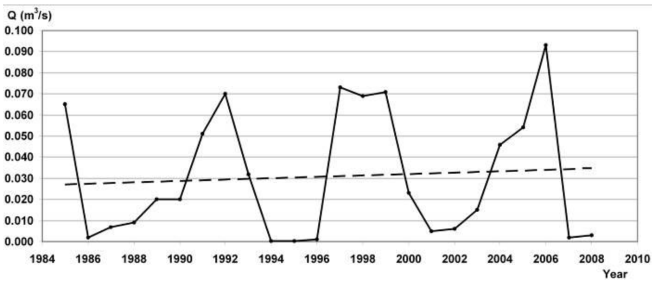

Fig. 12 Multiannual variation and minimal annual flow rates at Solesti hydrometric station Solesti, river Vaslui and its tributaries

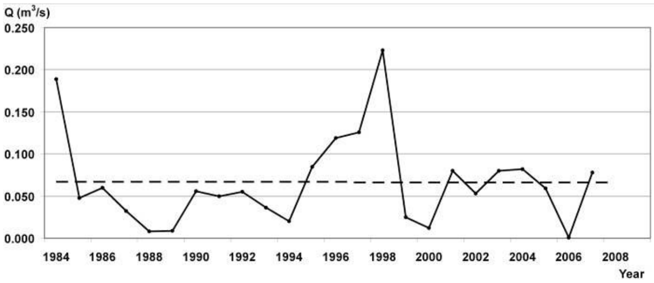

Fig. 13 Multianual variation of annual minimum flow rates at Codaesti hydrometric station, river Vaslui and tendency of these variations

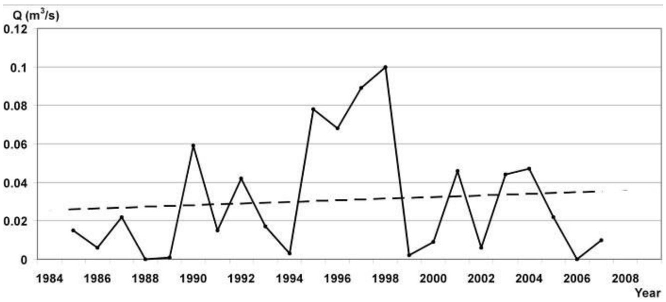

Fig. 14 Multianual variation of annual minimum at Codaesti hydrometric station, river Dobrovat and tendency of these variations

B. The influence of Damming on the Hydrological Regime

The most important effect of the influence of damming of the flow regime is to reduce flooding. Broad flood floodplains, before damming, act like natural storage basins, which have major flood mitigation. The water rate creates naturally constricting dams. These act as dormant natural reservoirs and therefore there is a new distribution of flow in the downstream sector. In this case the maximum flow has higher values and causes more flooding across the downstream embankment.

Reduction of the downstream flow, from what will be dammed, is calculated as:

$$Q_d = \frac{Q_a}{V - V_{at}}$$

where: Q - flow under natural flood calculation in section dammed downstream sector; V - volume calculation flood; V_{at} - the volume of flood water under natural computing, which is found in dike-like precincts [3], [30]. Also due to narrowing of the drain section, the flood waters rose to the adjacent upstream beyond those pre-damming. The length of this positive remuu, created at the upstream neighbor that dike will become, is:

$$D = \frac{2x}{Ja}$$

where: x - is the elevation in the level of what is dammed; Ja - slope of the drainage system of calculation of the upstream sector [3].

There is a new distribution of flows and speeds in the dam, and longitudinal slope of the body of water changes (Fig. 15). When the new distribution of the concentration of water flow is generally high, this makes underground aquifers that under certain conditions do not reach saturation. In periods of underground water flow below the support surface, this phenomenon occurs, but with low weight, because of hydraulic works. This development can be seen at piezometric levels measured by hydrogeological drilling, comparing the years before and after the execution of hydraulic works.

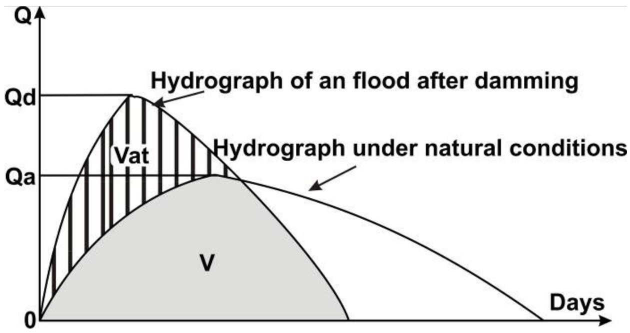

Fig. 15 Modification of a flood by damming (generalization)

Significant changes are observed in the riverbed processes. In some parts of the dammed area there is clogging of the riverbed reshaped intensely, which increases the danger of overcoming the flood embankments. In other areas, usually where the main riverbed route has given sinuosity and direction of flow at high water, the water differs from the average in the main river bed. Erosion of banks is particularly active in the immediate aftermath of the peak of the flood wave (Fig. 16).

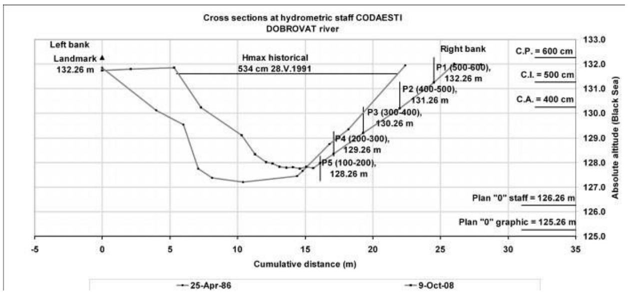

Fig. 16 Hydrometric transverse profile of the Codaesti (on Dobrovat River) after producing the historic peak of 28.V.1991

A few kilometers below dams behave like hydraulic controls and works in the riverbed at the bridge. Upstream damming occurs in the depositing. In the tributary sector, and in the damming downstream, deposits occur again. Dams tens of kilometers in length allow a leak to the calmer waters because the water longitudinal slope does not change too much, but experiences only an upwards transition which is relatively continuous. In small areas with slopes, greater turbidity and currents with all narrow riverbeds, give a speed increase, producing intense clogging on the main riverbed, especially in the dam - due to existing vegetation on the shore. This means that the necessity of warping dams cannot continue. The bed created after a long period of riverbed is reshaped by damming and has higher rates in embanked enclosures. Long dammed downstream sectors of the considerable increase in flow occur because the effect of the flood is more pronounced in a long breakwater.

One advantage of hydro-engineering works is to reduce the danger of draining dammed sectors. Compared to these effects of damming on the influence of river flow, it requires that the design of works to choose distance between the dam, the dam bank and routes as appropriate to reduce the shortfalls. Sometimes, there is a rational use of the site as polder compartments for flood mitigation, and higher rates of water storage ponds to be set up.

The influence of human activities on dams along the river beds is minor, but the location of accumulation directly influences the hydrological regime. Along watercourses in the Vaslui catchment embankment, works are executed, and the adjustment of the Vaslui and Delea riverbeds. Vaslui River is dammed by a length of 68.4km in the downstream reservoir Solesti - Barlad River confluence. The Vaslui River amounts to 35.22km in the same sector. Delea river is dammed by a distance of 3km and 4.80km adjusted over the bed, near the town of Vaslui, the Delea reservoir downstream. To show the anthropogenic influence on the hydrological regime of the damming of Vaslui, measurement stations should be established for many years before completion of these hydraulic works. If there are no measurement stations, the influence of anthropogenic impact cannot be demonstrated concretely.

C. At the Prut River Junction – Vaslui

Derivation Prut – Vaslui, there are works that transfer water from the River Prut to the River Vaslui, from one river basin to another, where it is required. For example, where the Vaslui River flows, there is a poor record when the Prut River shows significant increases in flows after a significant quantity of precipitation falling, or after works undertaken to build Stanca – Costesti [18]. The project was not completed. The route had to transit pipelines 1.00m^3/s in the Prut River (first pumping station, near the confluence of the Prut Jijia) – Osoi village east - north-eastern village Comarna (second pumping station) – River Vaslui (upstream of the village of Schitu Duca).

D. Anthropogenic Influences on Water Quality

Water is an environmental factor of particular importance to plant, animal and human life. Irrational use of water resources and their pollution by man, can give rise to adverse implications of the water supply to population and industrial centers, agricultural land or fish ponds. These are caused by:

- excessive use of chemical fertilizer, nitrogen and phosphorus and pesticides in agriculture, which led to the accumulation of agrochemical residues in soil;
- discharge from the densely populated towns, big polluters because of wastewater treatment plants, and primitive or obsolete because of their absence;
- the location of garbage platforms near the small beds.

E. The Main Sources of Pollution in the Vaslui Catchment Area

The area occupied by the catchment area under study is found mostly on the territory of Vaslui county, and the county of Iasi. The Vaslui city treatment plant is the main source of pollution, impacting negatively on the Barlad and Vaslui rivers, but is phreatic in this area. Vaslui city currently has a wastewater treatment plant and a sewage system that includes centralized sewers, pumping stations and main intermediate collectors. The sewage system was designed to run on any system and divider, comprising a network for municipal and industrial wastewater collection and another for collecting rainwater. However, in certain areas of the city, sewers, sewage and rainwater interpenetrate.

The treatment plant is located in the built-up area of the town of Vaslui, on the right bank of the river upstream from the confluence with the river Delea, has a capacity of 600 l/s. It currently discharges into the Vaslui river flows at a rate of about 170-180 l/s. The treatment plant was dimensioned and executed to achieve yields of 95% for suspended solids, and pointer to pointer BOD_5 90%, while the raw water has a maximum load of 220 mg/L suspended solids and 230 mg/l substance organically expressed BOD_5. The treatment plant cannot provide permanently covered quality indicators because of physical and moral wear, and frequent mechanical and electrical failures. This situation, coupled with the negative impact of direct discharges of untreated waste water, degrades the quality of river water and the ground water beneath the Vaslui.

Vaslui city discharges wastewater directly into the river Delea, through sewage collectors which have no continuity and are not connected to the sewage plant. Also in Delea River, a tributary of Vaslui, discharged untreated wastewater reaches the city of Vaslui, at Spatar Angheluta point, the Delea treatment plant, as well as storm evacuations. These waters become still in the Vaslui River, contributing to its degradation and hence the quality of phreatic water.

V. Conclusions

In rivers of the Moldavian Plateau, where flooding is frequent, some specific constructions (reservoirs and dams) were essential to mitigate or reduce flooding damage. The main construction of this kind is the Solesti reservoir on the river Vaslui. This has a complex character: it takes over surplus water, feeds in water, and provides facilities for fish farming.

The barrage in Solesti, with a multiple purpose, has a very important role in diminishing floods. From this point of view the town of Vaslui is well protected against floods, and the hydrologic risk is no longer existent. Effective dams along the main river arteries, especially on river Vaslui, change levels and processes in the downstream riverbed. In this case the management should be reviewed continuously.

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