1.1.1.1 A. Main Results from the Hydrogeological Studies in the Krumovgrad Gold Mining Area

1. Multiannual fluctuations and a representative period

The multiannual fluctuations of the river outflow in the regions are presented in **Table 1** which presents the main annual characteristics of the outflow as m3/sec for Krumovitsa River, at Hydrometeorological Station 61550 Qmin,year. (absolute momentary minimum), Qsr,year. (average annual water quantity), Qmax,year. (absolute maximum flow), Qmin,average monthly (average monthly minimum). **Figure 1** presents the changes of annual values of flow and precipitation in Krumovitsa River.

Table 1 and **Figure 1** present the large fluctuations of the river flow and precipitation. So, the absolute minimum levels have been measured as 0.001 m^3/s to 0.580 m^3/s, and the average monthly minimum levels as 0.003 to 1.08 m^3/s. The maximum levels vary between 49.8 m^3/s and 1380 m^3/s, and the average levels are between 2.63 and 15.1 m^3/s. **Figure 1** presents the changes of annual values of flow in Krumovitsa River and precipitation in the town of Krumovgrad.

Table 1 and **Figure 1** show that the first half of the 56-year period is far more humid than the second. The first half of the period is characterised by the rhythmical alternation of high and low levels, in small intervals of 2.5 years, on average. The second half of the period is characterised by many lower and not very high values, with a rhythm of alternation of 5 years on average.

The total reduction of flow and increasing of the rhythm intervals are extremely unfavourable for any water use because of the prolonged deficiency of water caused by them.

2. Main hydrographic characteristics of the analogous representative site (Krumovitsa River at the Hydrometeorologicla Station)

Table 2 presents the average value estimates.

$\tilde{Q} = (1/n).\Sigma Q_i$, $i=1 \div n$, standard deviations $\sigma_Q = \sqrt{\Sigma(Q_i - \tilde{Q})^2 / (n-1)}$, $i = 1 \div n$ and the variation ratios C_v for the last 30-year period, for the preceding period of 1948-1973 (n = 26 years) and for the entire 56-year period of 1948-2003.

Table 1

Hydrometeorological Station No. – Krumovitsa River at Krumovgrad

Main flow characteristics by year

Year	$Qmin^{year}$	Qsp^{year}	$Qmax^{year}$	$Qmin,sp^{month}$
1948	0,021	5,59	49,8	0,063
1949	0,001	3,58	216	0,003
1950	0,018	6,79	1231	0,030
1951	0,050	5,42	729	0,220
1952	0,070	9,90	398	0,130
1953	0,580	8,93	251	1,080

1954	0,020	13,00	359	0,130
1955	0,200	14,30	874	0,640
1956	0,060	9,39	800	0,190
1957	0,050	7,14	210	0,092
1958	0,100	8,34	352	0,280
1959	0,050	4,12	370	0,140
1960	0,260	9,60	865	0,450
1961	0,070	6,03	157	0,210
1962	0,040	12,10	360	0,260
1963	0,067	13,20	634	0,130
1964	0,080	4,39	408	0,150
1965	0,070	9,30	670	0,094
1966	0,060	12,40	685	0,650
1967	0,200	5,65	259	0,420
1968	0,020	6,19	435	0,140
1969	0,022	15,10	1380	0,062
1970	0,070	10,10	434	0,120
1971	0,350	10,80	845	0,780
1972	0,110	6,03	372	1,110
1973	0,075	7,50	336	0,190
1974	0,060	4,85	408	0,330
1975	0,300	5,97	270	0,650
1976	0,160	5,38	379	0,290
1977	0,120	6,64	593	0,160
1978	0,030	7,12	365	0,057
1979	0,110	11,50	665	0,200
1980	0,240	11,20	602	0,350
1981	0,060	10,20	989	0,170
1982	0,110	6,94	444	0,170
1983	0,200	6,52	512	0,580
1984	0,070	8,00	740	0,150
1985	0,040	3,59	593	0,040
1986	0,039	5,03	265	0,064
1987	0,025	5,49	597	0,051
1988	0,075	6,23	534	0,076
1989	0,129	3,40	238	0,190
1990	0,090	4,96	572	0,120
1991	0,100	3,48	502	0,120
1992	0,109	2,83	344	0,120
1993	0,050	2,84	136	0,100
1994	0,079	3,23	273	0,085
1995	0,004	5,97	367	0,140
1996	0,014	7,74	500	0,048
1997	0,028	8,38	437	0,032
1998	0,109	11,95	492	0,145
1999	0,080	6,83	237	0,140
2000	0,020	3,80	334	0,081
2001	0,070	2,63	270	0,092
2002	0,060	6,19	594	0,210
2003	0,080	7,57	672	0,118

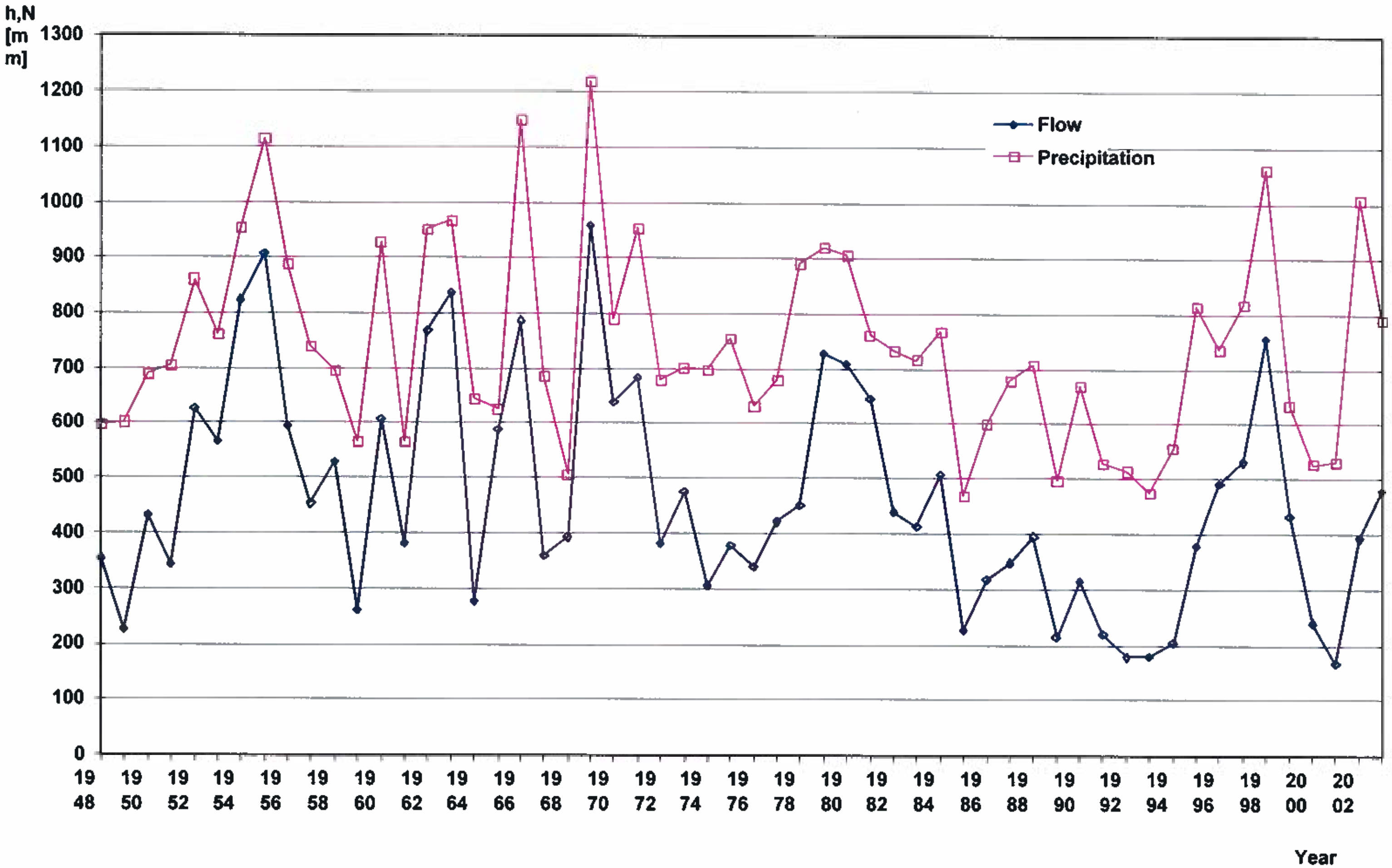

Fig 1 Typical hydrographs of Krumovitsa River flows in the layer [mm] and of the annual precipitation sums in the town of Krumovgrad [mm]

Table 2

Main statistics of the annual average quantities of water in Krumovitsa River (Hydrometeorological Station)

No.	Period,	Period length n, years	$\tilde{Q}$ m3/s	σQ m3/s	Cv -
1	1974 – 2003	30	6.215	2.590	0.417
2	1948 – 1973	26	8.650	3.283	0.380
3	1948 – 2003	56	7.345	3.152	0.429

Significant differences exist in the assessment of standard statistical parameters for these periods: low $\tilde{Q}$ and high C_v for the period 1974-2003, and high $\tilde{Q}$ and lower C_v for the period 1948-1973.

The empirical curves straightened through analytical approximation of non-exceedance of the flow P(Q<Qp) for three periods are presented in **Table 3.**

Table 3

1.1.1.1.1.1.1 Typical quintals Qp of the annual flow for different periods

No.	Period, Type of year	length N, years	Q_p, m^3/s for $P(Q<Q_p)$, %							
			1	5	25	50	75	95	99	Q_{sr}
1	1974-2003, calendar	30	1.901	2.678	4.259	5.781	7.739	11.498	14.925	6.215
2	1974-2003, hydrological	30	1.414	2.246	4.049	5.808	8.011	11.875	14.907	6.233
3	1961-2003, calendar	43	2.025	2.908	4.743	6.540	8.884	13.453	17.672	7.099
4	1948-2003, calendar	56	2.097	3.037	4.969	6.825	9.191	13.624	17.522	7.345

The changes of water balance elements in Krumovitsa River for the representative 30-year period are shown in **Table 4.**

Table 4

Changing elements of water balance in Krumovitsa River (Hydrometeorological Station) in various non-exceedance situations $P\ (x < x_p)$

No.	Water balance element	$P\ (x < x_p)$ %									
		0.1	1	5	30	50	70	95	99	99.9	99.99
1	Outflow layer $\tilde{h}_p$, mm	81	120	170	289	366	460	729	946	1246	1542
2	Precipitation layer $\tilde{P}_p$, mm	359	430	505	655	740	835	1081	1264	1505	1738
3	Evaporation $\tilde{E}$, mm	278	310	335	366	374	375	352	318	259	196
4	Outflow ratio $\alpha = \tilde{h}_p / \tilde{P}_p$	0.225	0.279	0.337	0.441	0.495	0.551	0.674	0.748	0.828	0.887

The minimum monthly average water quantities of 95% exceedance of the flow P(Q (Qp)% have been determined for Krumovitsa River also by way of analytical approximation, but for a 56-year period, and the results are presented in **Table 5.**

Table 5

Regulated quintals $Q_{m,95\%}$ ($K_{m,95\%} = Q_{m,95\%} / \bar{\bar{Q}}_{year}$) for average monthly minimums for various periods

No.	Period, Type of year	length N, years	with a minimum error		Boundaries			
			$Q_{m,95\%}$ m^3/s	$K_{m,95\%}$ $. 10^{-3}$	$Q_{m,95\%}^{min}$	$K_{m,95\%}^{min}$	$Q_{m,95\%}^{max}$	$K_{m,95\%}^{max}$
1	1974-2003, calendar	30	0.040	6.44	0.037	5.95	0.040	6.44
2	1974-2003, hydrological	30	0.040	6.42	0.037	5.94	0.040	6.42
3	1961-2003, calendar	43	0.045	6.34	0.039	5.49	0.045	6.34
4	1948-2003, calendar	56	0.030	4.08	0.022	3.00	0.030	4.08

The maximum water quantities Qm for Krumovitsa River have also been defined through analytical approximation for a period of 56 years and the results are presented in **Table 6.**

Table 6

Main flow characteristics of maximum flows in Krumovitsa River

Characteristics	**P in %**			
	0.01	**0.1**	**1**	**5**
Maximum water quantities Qp, m^3/s	3551	2484	1609	1092
Maximum flow module M_p, $m^3/s/km^2$	7.14	4.99	3.23	2.19
Arrival time τ, min	334	377	435	497
Precipitation layer $H_{p,\tau}$, mm	149	120	94.4	72.2

The calendar distribution of the flow by months in percentage of the annual flow is presented in **Table 7.**

Table 7

Percentage distribution of flow by months

Type of year	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**year**
Average, determined using averaged monthly values	2.56	27.15	25.60	13.25	7.24	4.96	0.38	0.10	0.10	0.10	5.30	13.26	100
Very dry 95% (2001)	32.36	17.47	8.14	23.13	6.32	0.88	0.31	0.29	2.80	0.35	0.57	7.38	100

3. Main hydrological characteristics of selected water bodies

The water bodies used for water supply or as flotation-waste disposal sites have the following parameters of flow and water balance (**Table 8**).

Table 8

Annual average flows and water-balance items of water bodies

No.	Water body (river, point	$\bar{M}_{\bar{Q}}$ $\ell.s^{-1}.km^{-2}$	$\bar{h}$ mm	$\bar{P}$ mm	$\bar{E}$ mm	$\alpha=\bar{h}/\bar{P}$ -	$\bar{Q}$ m^3/s	$\bar{W}$ 10^6m^3
1	Krumovitsa – Hydrometeorological Station	12.5	394	757	363	0.520	6.22	196.2
2	Krumovitsa upstream of Krumovgrad	13.7	432	779	347	0.555	4.78	150.7
3	Krumovitsa downstream of Virovitsa River	12.8	404	762	358	0.530	3.72	117.3
4	Krumovitsa upstream of Virovitsa River	12.3	389	755	367	0.514	2.06	65.0
5	Virovitsa River at the estuary	13.4	423	773	350	0.547	1.66	52.3
6	Kaldzhikdere at the estuary	9.09	287	699	412	0.411	0.0504	1.589
7	Vetritsa at the estuary	9.73	307	710	403	0.432	1.182	37.3
8	Kaldzhikdere – alternative tailings pond 1A	9.51	300	706	406	0.425	0.0379	1.195
9	Gorge – alternative tailings pond 2A	11.5	363	740	377	0.491	0.0404	1.274
10	Gorge – alternative tailings pond 2B	10.7	337	726	389	0.464	0.0246	0.776
11	Gorge – alternative tailings pond 2C	8.82	278	694	416	0.401	0.0168	0.530

The average monthly minimum water quantities of 95% - Q_{95}%month [ℓ/s] are presented in **Table 9.**

Table 9

Minimum 95% secured average monthly maximum values $\bar{Q}_{95\%,month.}$ in ℓ/s

No. of sites according to table 3.3.1.8										
1	2	3	4	5	6	7	8	9	10	11
40	31	24	13	11	0.32	7.6	0.24	0.26	0.0	0.11

The maximum water quantities Qp [m^3/s] for Krumovitsa river and its large tributaries, with exceedance probabilities of P<5% are presented in **Table 10.**

Table 10

Maximum water quantities Qp [m^3/s] of Krumovitsa River and of its large tributaries with low probability of exceedance $P(Q \geq Qp)$

No.	River at point	Q_p, m^3/s for $P(Q_M \geq Q_p)$, %			
		0.01	0.1	1	5
1	Krumovitsa River, at the Hydrometeorological Station	2954	2161	1473	1042
2	Krumovitsa upstream of Krumovgrad Below the estuary of Ikaschdere River	2694	1981	1224	835
3	Krumovitsa downstream of the estuary of Virovitsa River	2480	1709	1102	680
4	Krumovitsa upstream of the estuary of Virovitsa River	2180	1531	978	653
5	Virovitsa River at the estuary	797	578	370	247
6	Vetritsa at the estuary	1879	986	620	405

The maximum water quantities Qp and volumes of high water Wp and the duration T for alternative tailings ponds (or water reservoir) are presented in **Table 11.**

Table 11

Maximum water quantities Q_p, m^3/s, modules q_p [?.s-^{1}.km-^{2}], volume of high water W_p [$10^3.m^3$] and duration T_P [min] in triangular approximation of shape

No.	River at point	Characteristics	$P(Q_M \geq Q_p)$, %			
			0.01	0.1	1	5
1.	Kaldzhik water reservoir, alternative tailings pond 1A (downstream of Ada tepe) $A = 3.99\ km^2$, $H_6 = 356$	Q_p, m^3/s	55.1	34.8	19.1	8.5
		q_p, $m^3.s^{-1}.km^{-2}$	13.8	8.72	4.79	2.13
		W_p, $10^3.m^3$	1169	862	579	336
		T_p, min	707	826	1010	1318
2.	Gorge near Kaklitsa village, alternative tailings pond 2A $A = 3.51\ km^2$, $H_6 = 447$	Q_p, m^3/s	68.9	46.3	24.5	11.0
		q_p, $m^3.s^{-1}.km^{-2}$	19.6	13.2	6.98	3.13
		W_p, $10^3.m^3$	1053	804	519	302
		T_p, min	509	579	706	915
3.	Gorge near Sarnak village, alternative tailings pond 2B $A = 2.30\ km^2$, $H_6 = 409$	Q_p, m^3/s	34.6	23.2	11.7	5.67
		q_p, $m^3.s^{-1}.km^{-2}$	15.0	10.1	5.09	2.47
		W_p, $10^3.m^3$	683	522	340	199
		T_p, min	658	747	969	1170
4.	Gorge near Kapel village, alternative tailings pond 2C $A = 1.91\ km^2$, $H_6 = 32.5$	Q_p, m^3/s	36.8	25.8	14.0	6.50
		q_p, $m^3.s^{-1}.km^{-2}$	19.3	13.5	7.33	3.40
		W_p, $10^3.m^3$	556	426	279	162
		T_p, min	504	550	664	831

The main characteristics of precipitation, the average annual value $\tilde{P}$, average daily maximum $\tilde{H}$ and the average daily maximum for different water levels are presented in **Table 12.**

Table 12

Main characteristics of precipitation in Krumovgrad

No.	Altitude, m	$\tilde{P}$ Mm/a	Daily maximum H_p, mm for $P(HM \geq H_p)$, %								
			$\tilde{H}$ mm	0.01	0.1	1	5	10	20	39	63
1	200	648	51.3	198	153	112	86.2	75.4	64.1	52.3	42.6
2	250	666	52.0	201	155	114	87.4	76.4	65.0	53.0	43.2

3	300	685	52.6	203	157	115	88.4	77.3	65.8	53.7	43.7
4	350	704	53.3	206	159	117	89.5	78.4	66.6	54.4	44.2
5	400	722	54.0	208	161	118	90.7	79.4	67.5	55.1	44.8
6	450	741	54.6	211	163	120	91.7	80.3	68.2	55.7	45.3
7	500	760	55.3	213	165	121	92.9	81.3	69.1	56.4	45.9

The quintals for water levels of 39% and 63% are those required for sewerage construction and are equal to pipe overflowing 1 time in 2 years (P = 39%) and 1 time per year (P = 63%).
The changes of water balance items concerning expressed as sums, or applied to water surface (lake or tailings pond) are shown in **Table 13.**

Table 13

Average annual evaporation $E_{calc.}$ [mm] for different altitudes

No.	Altitude H, m	$\bar{P}$ mm	$\bar{h}$ mm	$\bar{E} = \bar{P} - \bar{h}$ Mm	$E_{ез.} = 2.47 . \bar{E}$ Mm	$E_{ез.} / \bar{P}$
1	200	648	186	462	1141	1.76
2	300	685	260	425	1050	1.53
3	400	722	331	391	966	1.34
4	500	760	398	362	894	1.18
5	600	797	463	334	825	1.04

The percent distribution of precipitation from the water (tailings) surface is presented in **Table 14.**

Table 14

Monthly distribution of evaporation from water reservoirs and tailings ponds, in %

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Год.
$E_{lake,\ \%}$	2.63	4.14	5.77	7.63	9.22	11.37	16.11	17.49	12.15	7.07	4.01	2.41	100

B. Main Results from the Qualitative Characterisation of Surface Water in the town of Krumovgrad

There is virtually no information about the background condition of Krumovitsa River, except for the study expeditions in the fall of 2004. In this case we turn to the main tributary, Kesebir River, in the area of Kalebair. Several houses are scattered around the spring above this area, and we can consider it as a background condition. The distance between the Krumovgrad HMS and this point is 5-6 km and the difference between the results is, therefore, not significant (Table 1). All water parameters considered place the tributary Kesebir River as category I. All impacts in this area are natural. There are several meadows along the left, more level area, planted with tobacco, but they cannot have a substantial impact. This is a wild mountainous area. It can be said most definitely here, that this section of the Kesebir tributary does not contain any sources of anthropogenic pollution. During the trip there was no water in the Kaludzhak and Elbasan gorges.

Our attention will be drawn predominantly toward the main river – Krumovitsa – downstream of Krumovgrad, near HMS 61550, where sufficient information is available.

1. Pollution with mineral substances

The following indicators were considered: total mineralization (ions Σi), sulphates (SO4), chlorides (Cl), hydrocarbons (HCO3), calcium (Ca), magnesium (Mg), sodium (Na), potash (K). Most minerals and quantities of dissolved substances in the water were determined by the above mentioned main ions.

The natural water has its initial (starting) mineral composition. This composition changes in a longitudinal fashion in natural conditions, in most cases increasing along the flow. These (primary)characteristics are enhanced by all forms of anthropogenic activity.

Depending on the ratio of natural and anthropogenic impacts, and consistent with current national and international regulations, certain irregularity of the quality or certain surface water pollution is possible.

As a general rule, the mineral composition is affected by activities related to processing and extraction of inert materials, china and faience production, mining, metallurgy, tanning, etc. There are no such activities in Krumovgrad at present, which explains the sustainable mineral composition.

The period under consideration is divided in two conditional parts: 1988-1994 and 1995-2004. This is caused by the political and economic changes in Bulgaria and by the resulting possibilities for changing anthropogenic impacts.

The quality of dissolved substances – total mineralization (ions Σi) – of Krumovitsa River is not high, due to the above reasons: Σi = 344.21 mg/l – 373.39 mg/l. In fact, it fluctuated within equal limits in both periods under consideration (Table 2). It should not be forgotten that the characteristics under consideration is the total of 11 ions and that the variations and the differences can be considered insignificant. The water temperature does not affect the changes in mineral composition as can be seen from the results. Only the water quantity has direct effect on the mineral content (Figures 1 and 2.). The content of individual ions is rather low, even the measured maximum quantities, such as sulphates (SO_4) and chlorides (Cl), are two to three times less than the category I standard level of 200 mg/l (Table 3, Figure 3).

Conclusion:

The studies show that the mineral content in the water of Krumovitsa River in Krumovgrad is rather low, not affected by pollution, and for this parameter, the water is Category I.

2. Organic pollution

Organic matter in the river water is subject to influence by transformation processes of varying type and characteristics. This results in the occurrence of new substances, minerals, in most cases.

The lack of methods for direct determination of organic pollution makes difficult the study of its dynamics and formation. Usually indirect parameters are used for estimation of its behaviour. This group includes: dissolved oxygen (O_2), BOD5 and permanganate oxidation (Ok).

The oxygen content in the water of Krumovitsa river is high. Even the minimum values meet the levels for water Category I. No change in oxygen content has been observed for the two periods under consideration (Table 2., Figure 4).

The organic content, expressed through the parameters BOD_5 and Ok, is subject to very slight changes in time, with a slightly downward trend: from BOD_5 average = 3.19 mg/l to BOD_5 average = 2.85 mg/l. If the water in Krumovitsa River had been category II in the period 1988-1994, now it is between I and II (Table 3).

The multi-annual evolution of BOD5 is rather uniform, particularly in the second period (Figure 4).

Concerning the parameter permanganate oxidation (Ok), the category of the water in both periods is I (Table 2).

Some fluctuation in the annual distribution is caused by direct discharging into Krumovisa River of some household water. Since lack of water in the river is a frequent occurrence of significant duration, the household water can cause direct pollution of the river bed. The rapid increase in river flow during precipitation dilutes the household water quickly, and this explains the low measured concentrations.

Conclusion:

The oxygen regime of Krumovitsa River is very good. Organic pollution is insignificant and the water is category I for all three parameters. The pollution in no-flow conditions is definite, and is absent in flow-conditions due to the high dilution rates.

3. Nutrient pollution

The formation of nutrients in the water of Krumovitsa River is, on the one hand, the result of synthesis and decomoposition of organic matter, and, on the other, of direct andindirect introduction of faecal and non-industrial wastewater, and animal farm and agriculgural wastewater.

Another very dangerous source – intensive fertilization – has occurred during the recent 30 years. The intensive precipitation feeds the applied fertilizers into the open flows which