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THE INFLUENCE OF THE SMALL RESERVOIRS ON THE AMOUNT OF SUSPENDED SEDIMENT IN A STREAM AND THE SEDIMENT YIELD VALUE

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ABSTRACT

The presented paper is an edited version of Ph.D thesis of the same title and by the same author. The investigations were carried out in a small agricultural catchment area in the hydrological years 1998/1999-1999/2000. Four cross sections, above and below two small ponds of the total area of 0.8 ha, were subjected to daily bathometrical and hydrological measurements. For each hydrological year, the total suspended loads both supplied and carried out from the ponds were determined. The accumulation rate was analysed against the changeable water discharge and supplied sediment load. The changes in sediment yield values were analysed against the archive data from the years 1977/78-1993/94 in which no ponds were present in the area covered by the studies.

Key words: water erosion, sediment yield, fish ponds

INTRODUCTION

Surface of the Earth has been always affected by changes caused by water erosion. Landscape soil erosion alike the permanent deformation of agricultural space, seriously influences the quality of surface waters [2, 3, 4, 5, 14, 19]. Eroded soil is transported to watercourses and reservoirs. Suspended sediments lower the water quality. The total volume of reservoirs keeps shrinking, hydrotechnical systems are silted up, productivity of fisheries decreases [6, 7, 8, 16, 18].

Limiting the amount of soil material in streams can bring considerable economical effects and advantages [17]. Effective water pollution protection measures include erosion control in a catchment scale, proper agricultural techniques, afforestation and direct technical solutions applied to streams [1, 9, 10, 13].

The aim of the studies was to assess the impact of small ponds on the amounts of suspended sediments in the stream and to evaluate the role of reservoirs in surface water protection measures against the excessive sedimentation.

STUDY AREA

Erosion research was carried out in Trzebnica Hills area situated north of Wroclaw. The selected catchment area of Mielnica stream is located in the southern part of the hills. The total basin area amounts to 7.114 km^2. The catchment covers the villages of Bolescin, Gluchów Dolny and Gluchów Gorny, Radlow, Skotniki, Piersno and Krakowiany. The investigated catchment area of Mielnica stream is situated in the Low Silesia province, in the south-western Poland.

The Mielnica catchment lies between 169.4 m and 246.1 m above the sea level. The stream spring area is located at the altitude of 218.10 m. It is 3.7 km long and its mean width is 1.8 km. The mean slope of the catchment is 2.9 %. The catchment area is richly profiled and characterised by typical highland topographic features (Fig. 1). The modelling areas of the same slope were selected with help of topographic maps of a scale of 1:10 000 and digital elevation. The slope classes were used, according to Ziemnicki [20], in the following ranges: 0-3%, 3-6%, 6-10%, 10-20% and >20%. Such a classification is commonly used in water erosion risk assessment on the loess areas (Tab. 1). The weighed mean of a hill slope in the catchment, calculated on the slope map is 8%.

Fig. 1. Catchment relief

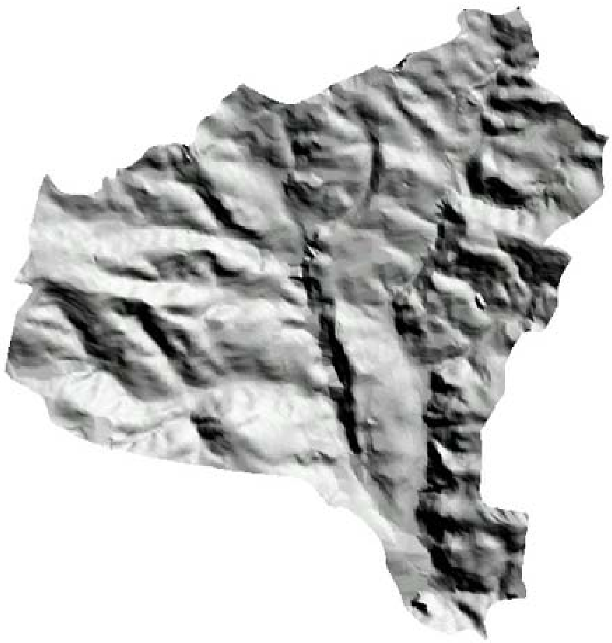

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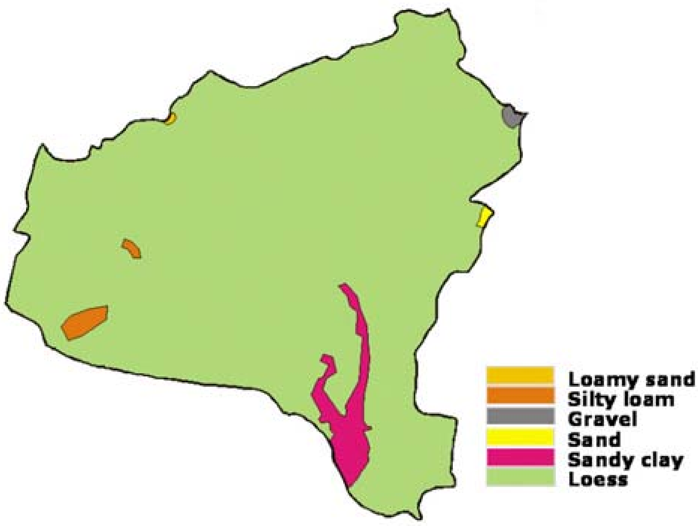
Table 1. Hill slopes in the catchment

Slopes	Area	
	km^2	%
0 - 3 %	2.398	33.69
3 - 6 %	3.007	42.27
6 - 10 %	1.303	18.32
10 - 20 %	0.399	5.62
> 20 %	0.007	0.10
Total	**7.114**	**100.0**

Descriptions of the Mielnica catchment soils were based on the soil agricultural maps and grain size analysis of soil samples. Regarding the textural classification, almost the whole area of the catchment is homogeneous and covered by the one textural soil group — loesses, as shown on the map of the soil textural groups of Mielnica catchment (Fig. 2). Such a large occurrence of the loess group means that the catchment is seriously threatened by erosion processes worsened still by intensive agricultural activities [11, 12, 21].

Fig. 2. Map of soil textural groups



During the investigations several local survey visits were performed to find out the pattern of land use distribution. The visits, supported with the data gathered from local authorities, resulted in a land use map presented in Fig. 3. Particular land use areas were calculated; the values are presented in Table 2.

Fig. 3. Land use map

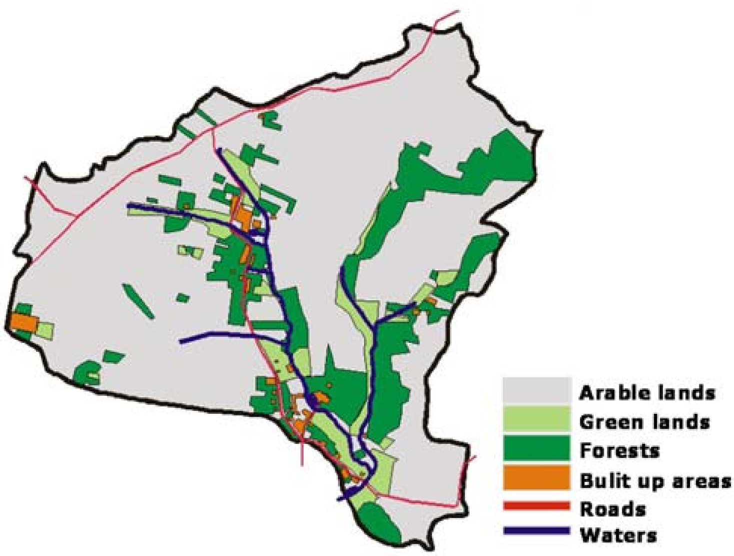


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Table 2. Land use structure

Land use		Area	
		km^2	%
Agriculture use	Arable lands	5.353	75.24
	Greenlands	0.455	6.40
	Total:	5.808	81.64
Forests		1.204	16.92
Waters		0.010	0.14
Bulit-up areas		0.092	1.30
Total:		**7.114**	**100**

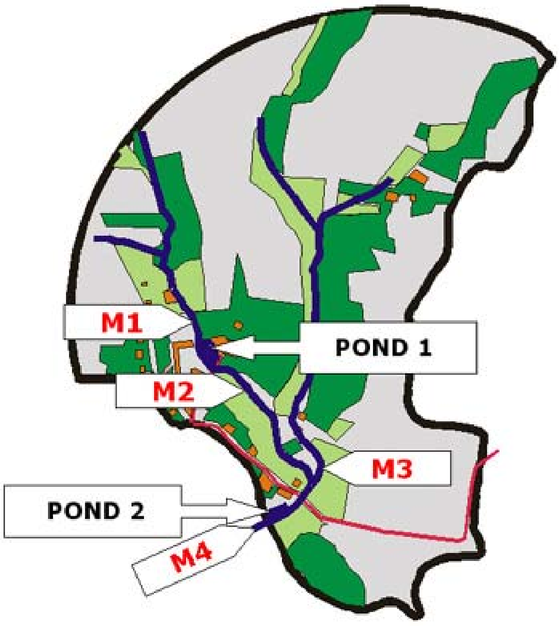
Two small reservoirs are located in the catchment area. The first one serves a decorative function in the Palace Park. In 1996 the reservoir underwent a complex conservation and in a consequence the pond total area reaches today 0.4 ha.

The second object, of the area of 0.33 ha, was built in 1997 in a private area and is located near the gauging cross-section, which closes the catchment. This reservoir is used for intensive fish farming.

To assess the impact of ponds on the amount of sediments in the surface water, four hydrological and bathometrical cross-sections were installed in the main watercourse and its tributary M1-M4 (Photo. 1). The location of gauging points allowed to control the water quality both on the inlets and outlets of the adequate reservoirs (Fig. 4).

Photo. 1. Hydrobathometrical cross-section

Fig. 4. Cross-sections locations



METHODS AND SCOPE OF THE RESEARCH

Direct measurements, survey investigations, laboratory analyses and indoor studies were undertaken for the studies performed in the hydrological years 1998/1999-1999/2000.

The work included:

- daily measurements of water levels at the catchment closing cross-section;
- periodical discharge measurements in Mielnica stream;
- daily bathometrical measurements in the cross-sections below and above the ponds;
- meteorological measurements, namely precipitation and air temperature.

The results of the research carried out over many years by the Institute of Environmental Development and Protection, whose valuable material was compiled and analysed for the first time, were also taken into account in the studies. However, the investigations did not cover all the chemical and physical processes and reactions taking place in the reservoirs, since the material is both rich and complex and therefore could constitute a separate study and research.

RESULTS OF THE RESEARCH

Meteorological conditions. Basing on the criteria used in the thesis, the investigated hydrological years 1998/99 and 1999/2000 were classified as dry with the total annual precipitation of 513.6 mm, and medium wet with 669.4 mm of precipitation, respectively. According to USLE criteria significant rainfalls are the ones higher than 12.7 mm. However, the survey visits to the research sites proved that sheet erosion occurred even after daily rains of 5-7 mm. The cause for it was low erosion resistance of the loess soils. In 1998/99 rainfalls of such intensity took place 31 times and 36 times in the following year. The hydrological year 1998/99 was classified as normal, according to the thermal classification. The year 1999/2000 was evaluated as a hot one. Advection snowmelts are especially important for proper assessment process of the erosion risk. In the hydrological year 1998/99 ten events of that nature were observed, while 11 in 1999/2000. At that time appeared surface runoffs and higher concentrations of sediments in the waters were detected.

Hydrological conditions. In the investigated period, the mean daily discharges in gauging cross-section ranges were as follows:

- M1 from 9.0 to 14.4 $dm^3 \cdot s^{-1}$
- M2 from 10.0 to 15.2 $dm^3 \cdot s^{-1}$
- M3 from 0.6 to 1.8 $dm^3 \cdot s^{-1}$
- M4 from 10.5 to 16.9 $dm^3 \cdot s^{-1}$.

The values quoted above refer to the following the mean monthly specific runoffs from the particular sub catchments:

- M1 from 2.65 to 4.24 $dm^3s^{-1}km^{-2}$
- M2 from 2.65 to 4.04 $dm^3s^{-1}km^{-2}$
- M3 from 0.18 to 0.64 $dm^3s^{-1}km^{-2}$
- M4 from 1.48 to 2.38 $dm^3s^{-1}km^{-2}$.

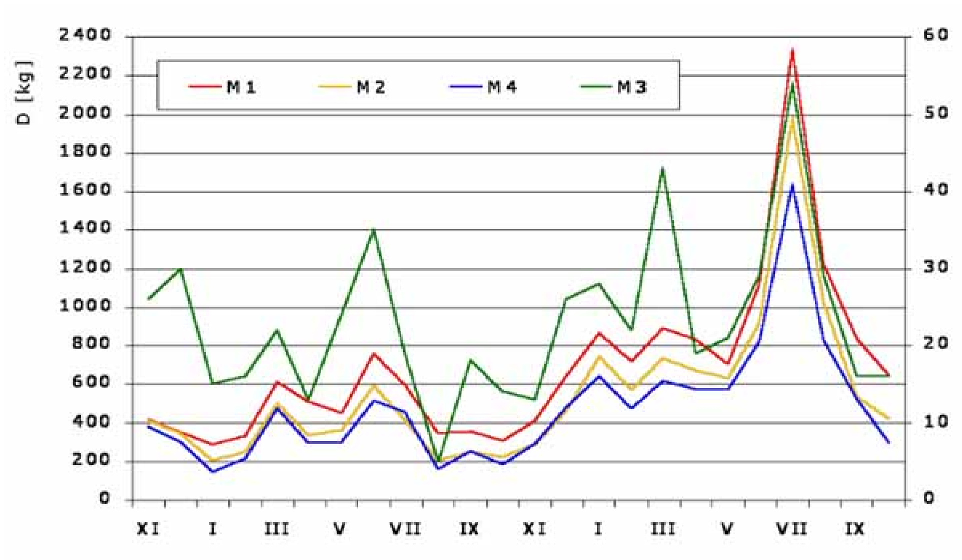
Suspended sediment concentration in the stream was determined with respect to standards and measurement methods. During the investigations (1998/99-1999/2000) the mean daily concentrations of suspended material in all cross-sections reached 0.0141 g dm^{-3}, 0.0152 g dm^{-3}, and 0.0125 g dm^{-3} for the year, the summer half year and the winter half year, respectively. The maximum determined value of concentration (18 VII 1999 — cross-section M1) reached 0.6377 g dm^{-3}, while the minimum one was equal to 0.0002 g dm^{-3}. The values observed in particular bathometrical sections showed the changes in the concentrations that took place while the water flew through the corresponding reservoirs. In Table 3 the mean monthly values of sediment concentrations for adequate cross-sections are shown. Generally in M2, located below pond 1, measured concentrations are lower than in M1. A similar situation appears below pond 2 in M4 for water quality changes.

Table 3. The mean sediment concentrations in flowing water

Lata	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI-IV	V-X	Rok
M1															
1998/99	0.0130	0.0132	0.0102	0.0110	0.0151	0.0172	0.0148	0.0263	0.0194	0.0135	0.0151	0.0123	0.0133	0.0169	0.0151
1999/00	0.0134	0.0198	0.0235	0.0214	0.0265	0.0336	0.0276	0.0361	0.0598	0.0316	0.0225	0.0167	0.0231	0.0324	0.0278
M2															
1998/99	0.0121	0.0121	0.0068	0.0078	0.0118	0.0109	0.0113	0.0163	0.0118	0.0064	0.0089	0.0078	0.0103	0.0104	0.0103
1999/00	0.0088	0.0131	0.0187	0.0159	0.0200	0.0245	0.0219	0.0277	0.0478	0.0249	0.0135	0.0103	0.0168	0.0244	0.0206
M3															
1998/99	0.0104	0.0106	0.0069	0.0065	0.0086	0.0063	0.0060	0.0093	0.0069	0.0027	0.0055	0.0046	0.0082	0.0058	0.0070
1999/00	0.0042	0.0061	0.0066	0.0061	0.0094	0.0068	0.0070	0.0096	0.0130	0.0087	0.0057	0.0056	0.0065	0.0083	0.0074
M4															
1998/99	0.0107	0.0097	0.0045	0.0062	0.0102	0.0087	0.0083	0.0127	0.0120	0.0048	0.0077	0.0058	0.0084	0.0085	0.0084
1999/00	0.0082	0.0121	0.0147	0.0119	0.0150	0.0192	0.0181	0.0228	0.0357	0.0187	0.0124	0.0068	0.0135	0.0191	0.0163

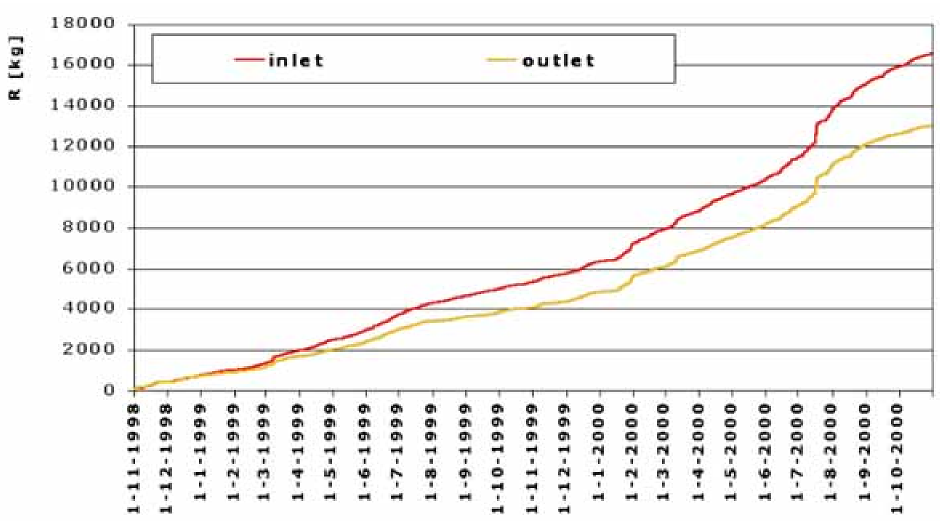
The mean daily concentration and the mean daily water discharge in the stream allowed to calculate daily soil material loads washed beyond cross-sections. During the two-year research program a total of 16 511 kg and 13 024 kg of sediments was carried out beyond M1 and M2, respectively.556 and 11421 kg were measured for cross sections M3 and M4, respectively (Fig.5). The balance of these quantities permits to assess the amounts of sediments accumulated in particular reservoirs.

Fig. 5. Suspended sediment loads (M3 is presented on additional Y axis)



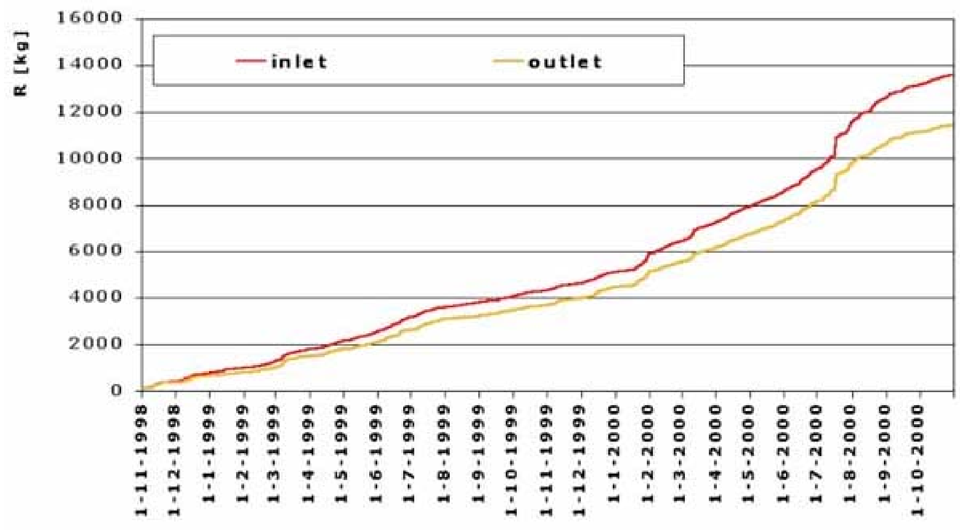
In pond 1, 1235 kg of sediments were deposited in the hydrological year 1998/99, which constituted about 23% of the total delivered sediment. The values of 457 kg and 779 kg, corresponding to 18% and 28%, were observed in the winter half year and the summer half year, respectively. The major part of sediments was accumulated in July, namely 183 kg. In the hydrological year 1999/00 in pond 1 about 20% of the total delivered sediments were accumulated. The total mass of deposits reached 2252 kg. The seasonal distribution amounted to 881 kg in the winter half year and 1371 kg and in the summer period. The highest accumulation was observed in July (356 kg), the lowest in May (78 kg). The highest percentage value was registered in October 35% (Fig. 6).

Fig. 6. Sediment balance in the Pond 1



A similar analysis of inlet and outlet cumulative curves was made for pond 2 (Fig. 7). In the first year of investigations the total mass of deposits reached 634 kg, which corresponds to 15%. In the winter half year 346 kg (16%) of sediments stayed in the reservoir, in the summer 288 kg (13%). The highest deposition of 111 kg was registered in June. The highest percentage accumulation of 35% was reached in January. In the hydrological year 1999/00 in pond 2, the total deposition of sediments was equal to 1525 kg, which constituted 16% of the delivered amount. Respectively, in the winter half year the value reached 542 kg (15%), and in the summer 983 kg (17%). The biggest accumulation of 398 kg was registered in July, the least of 11kg in November. The highest percentage deposition of 32% occurred in October.

Fig. 7. Sediment balance in the Pond 2



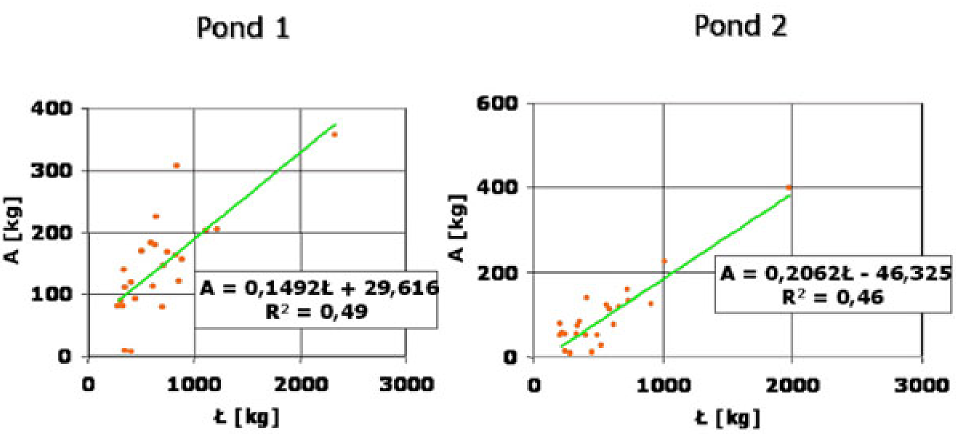
Generally, in pond 1, annually about 20% to 23% of the total delivered sediment were accumulated. For the second reservoir the values were distinctly lower and ranged from 15% to 16%. Such differences were most likely influenced by management of the ponds. Pond 2 is the place of intensive carp production, whose presence can cause bottom sediments to move. Removed deposits, affected by water flow, could be carried away from the reservoir. The water management of the pond has also a serious impact on the annual sediment mass balance.

The accumulation processes were also assessed during the high water periods from the 5–9 March 1999 and 14–18 July 2000 by means of analysing the hydrographs. Generally, it was noticed, that in high flows regime, the accumulation in the ponds did not exceeded 17-18%. Similarly, depositing of sediment during the low water periods was also analysed. The analysis of hydrographs revealed the presence of one distinct period from 3 till 17 September 1999. In general, it was noticed that for the low flows regimes accumulation in the reservoirs was significantly higher and reached 60%.

The results presented above suggest that amounts of deposits in the reservoirs are changeable and depend upon the inflow discharge and the total delivered sediment loads.

The significant correlation between the accumulated sediments and the inlet loads was found for the monthly values. The correlation coefficients were calculated both for the annual and the half hydrological year relations. In both ponds the amount of deposits depends on the total delivered sediment loads (see Fig. 8).

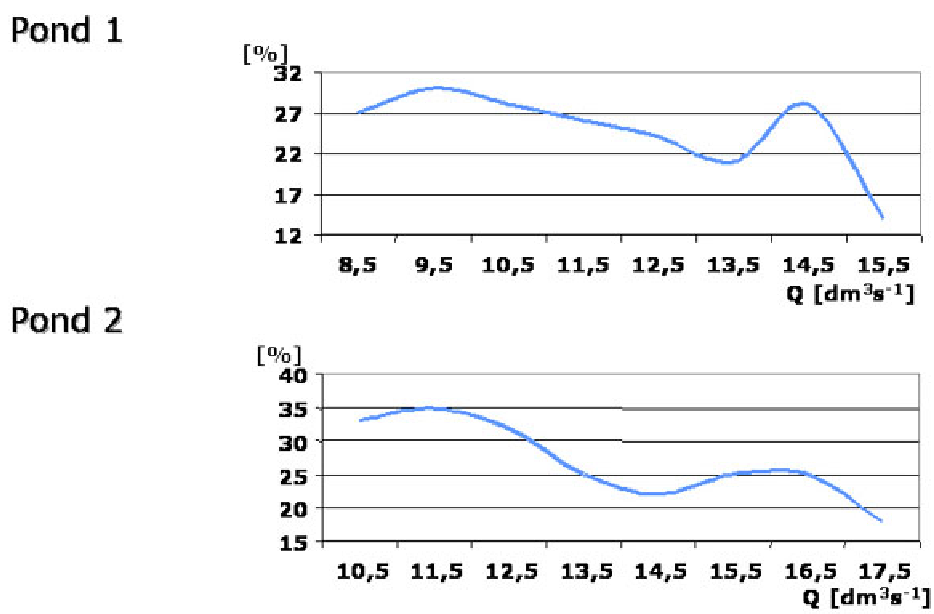
Fig. 8. Accumulation versus sediment loads



Obtained equations show that accumulation is directly proportional to the inlet sediment loads. However, the same assumptions fails for the 'accumulation – water discharge' relation.

The analysis of the relation between accumulation and the inflow rate was based on the average daily data from the two-year research period. For pond 1 the correlation coefficient of the analysed factors was estimated to 89%, while for pond 2 it was equal to 70%. The obtained curves (Fig. 9) revealed interesting characteristics. They remain very similar in shape and character independently of the pond in question. Generally, the highest accumulation takes place during the low discharges and the lowest accumulation during the highest discharges when the bottom sediments could be removed and washed out from the reservoirs. The PhD thesis covered also the analysis of preliminary sediment yield time series and probability calculations of extreme erosion occurrence.

Fig. 9. Accumulation versus inflow rate



Presented analysis covers two years of investigations. On the grounds of the gathered data the fishpond impact on the lower stream can be assessed, whereas the influence on sediment yield reduction, in the catchment scale aspect, escapes evaluation. To confirm the real and rational influence of the ponds on the amount of soil material carried out from the agricultural catchment, a comparison between the quantities from the periods prior to and following the construction of the ponds shall be made.

Comparative analyses incorporating the archive data from years 1977/78 to 1993/94 were made. The analyses were aimed at finding similar years, with regards to hydrometeorological conditions, and subsequently compare the respective denudation yields. Comparison of cumulative curves for selected factors focused on the similarity of shapes, allowed to choose the right periods. Factors like precipitation, air temperature and specific runoffs courses were considered. All evaluations were based on daily data. The first classification criterion was the precipitation. According to the presented classification, the year 1998/99 was classified as a dry one, whereas 1999/2000 as a medium wet. From the range of years 1977/78 -1993/94 similarity of the precipitation curves allowed to select the most suitable periods:

- to compare to year 1998/99 — years: 1988/89; 1989/90; 1990/91;
- to compare to year 1999/00 — years: 1985/86; 1987/88; 1992/93; 1993/94.

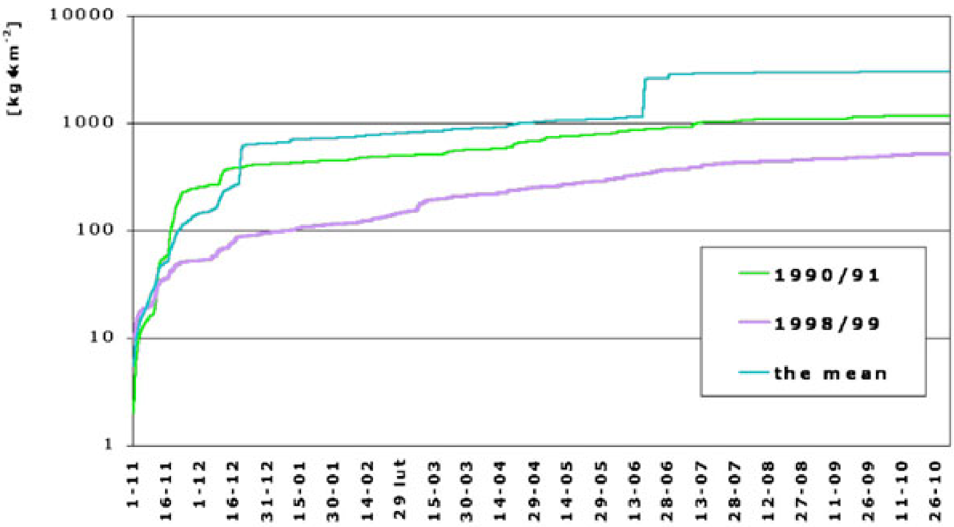
Considerations of the curves for 'amount of intense rainstorms' factor revealed the same comparable years.

Mean daily air temperature and mean daily specific runoff were the next analysed factors. Finally, for the selected years the cumulative curves of the daily sediment yields were plotted. The year 1998/99 was presented against the year 1990/91 and 1999/2000 against the year 1987/88. Additionally, the plots contain also the mean values curves. They represent all dry and wet years that occurred in 1977/78-1993/94. Presented charts show that the pond functioning has a serious impact on the amounts of soil mater carried out from the catchment.

Twice as much sediment used to be carried beyond the closing cross-section then today (Fig. 10) in a similar dry year before the ponds were built. The sediment yield calculated from the mean values of dry years is almost 6 times higher then today. Such large values are generated by two single intensive erosion events of 19 December

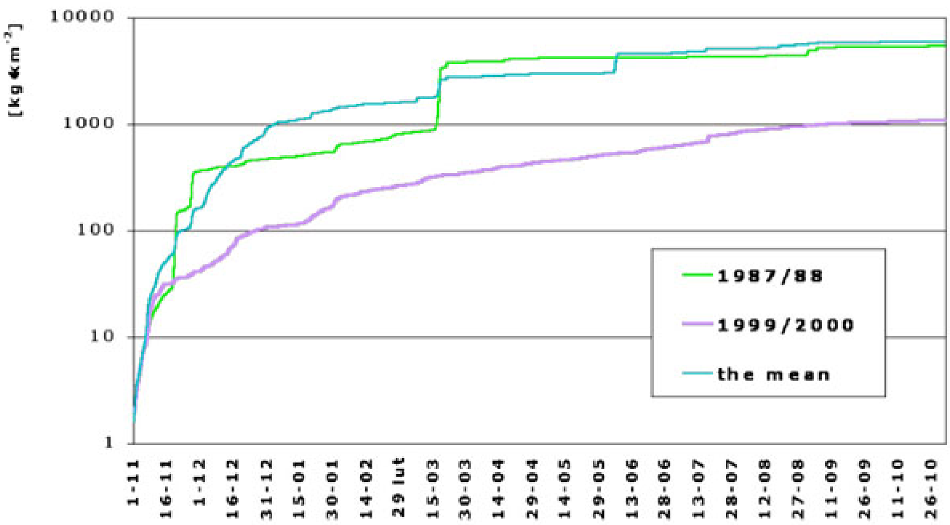
1988 and 17 June 1989. If we omit these special occurrences, a 'reduced mean' value can be obtained, which is 2.5 times higher than today's value, and similar to values from 1990/91.

Fig. 10. Denudation yield in similar dry years



The year 1999/2000 was shown against a similar wet year of 1987/88 (Fig.11). In comparable meteorological conditions the annual sediment yield was almost 5 times higher than today's value. It means that, in wet years, the amount of sediments was 5.5 times higher than the value observed nowadays, i.e. following the ponds construction.

Fig. 11. Denudation yield in similar mean wet and wet years



CONCLUSIONS

The research and analyses has led to the following conclusions:

1. The suspended sediment transport intensity depends upon the scale of the erosion processes in the catchment.
2. Opinions concerning the minimal rainfall as the factor generating the sheet water erosion should be revised. In the Mielnica catchment area erosion changes occurred after a rainfall of only 5-7 mm.
3. Suspended sediment concentration keeps diminishing as a result of water flow through the reservoirs.
4. The small reservoirs had a significant impact on the amount of sediments in the stream. In pond 1, the mean value of accumulation during the year could range from 20 to 23% of the total inlet mass of sediments; for pond 2 it ranged from 15 to 16%.

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5. The amount of accumulated soil materials in the ponds depends upon the water management of reservoirs and on current hydrometorological conditions.
6. Accumulation is directly proportional to the delivered sediment loads.
7. The intensity of pond silting depends upon the water inflow discharge. The relative percentage accumulation in the ponds is the highest for low flows regime.
8. The reservoirs play a protective role to the lower stream. In the period prior to the ponds construction the amounts of sediments transported by the waters were 2.5 times larger then today.

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