Dynamics of the Surface Water Circulation between a River and Fishponds in a Sub-Mountain Area

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Abstract: Assessment of river-fishpond surface water circulation is recognised as to be of critical importance in the Upper Vistula river catchment (southern Poland). The Vistula river is characterised by a high flow in spring, partly retained in numerous fishponds, and a low flow in autumn. Evaluation of the water circulation cycle is based on an equation of pond water balance. Water balance components include regulated inflow to the ponds and regulated outflow from the ponds, precipitation, and evaporation. Results have been obtained during four-year monitoring period. Waters circulation between the ponds and the river has been computed for the annual hydrological cycle and for three periods; November – April, May – September and October. The three periods differ in the absolute magnitudes of the water balance components and, in the relative magnitudes of the components. Deviation from the normal pluviometric conditions during the considered years has been evaluated by comparing the current results with results of a thirty -year precipitation monitoring.

Keywords: water balance; precipitation; evaporated water; water requirement

Introduction

Poland is classified in a small group of European countries threatened with water deficiency. The poor resources of waters, chiefly surface ones, place Poland on one of the farthest positions in Europe [Europe's Environment, 1995]. Moreover, surface waters are unevenly distributed, most of them lying in the northern part of the country. Neither the dam reservoirs accumulate sufficient amounts of waters. In this situation the accumulation of 500 – 600 x 10^6 m^3 water stored in fishponds plays a fairly significant role in water economy of the country. The greatest agglomerations of carp ponds are found in south - western part of Poland [Bukacinska et al., 1995] where already in Middle Ages a dense water net offered favourable conditions for pond farming. This initiated the traditional consumption of the carp for Christmas Eve supper. The current limited resources of water in this region are the result of the considerably lowered level of ground waters due to the development of mining industry in the 17^{th} century. The increasing water consumption resulting from an increasing population also plays a significant role. In sub-mountain regions, such as the River Vistula basin, rapid runoff of surface waters and the negative tendency of the most abundant precipitation shifting from summer to autumn months create difficulties in meeting the requirements of pond farming. The difficulties chiefly consist in an insufficient supply of water to ponds in May and June, i.e. in the important period of the fish culture when juvenile forms of the carp are reared.

The aim of the work was the quantification of water exchange between the ponds and the catchment lying in a sub-mountain region during the annual hydrological cycle and the estimation of the river capability to meet the requirements of the semi-intensive carp culture there. The purpose of the semi-intensive carp culture is the production of about 1 000 kg fish from 1 ha of the pond area. In the temperate climate a full carp culture cycle usually takes three years.

Characteristics of the ponds

The investigation was carried out in one of the complexes of carp ponds of the Institute of Ichthyobiology and Aquaculture of the Polish Academy of Sciences at Gołysz (southern Poland, = 49°51’N, =18°48’E). The area of the ponds reaches 370 ha, the volume of the above - ground basin 4 625 and of the underground one 422 x 10^3 m^3. The complex is composed of ponds with the surface of a few to several hectares. It lies in the upper catchment of the river Vistula and is fed from the right side part of the river (Figure 1). The bottom of ponds is in most cases composed of heavy and medium clays impervious to water.

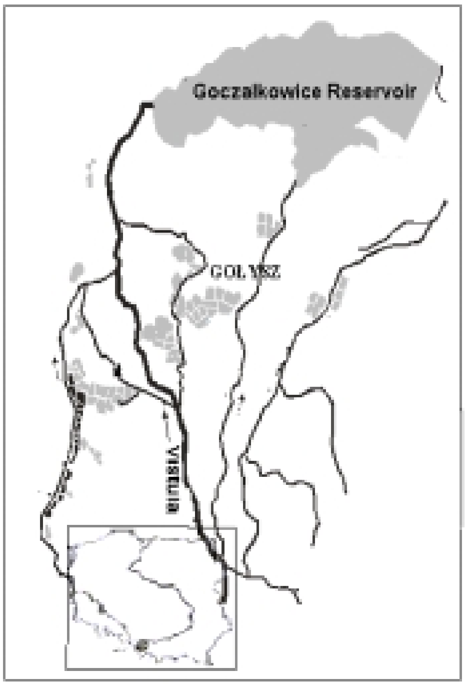


Figure 1. A sketch-map presenting ponds (lighter colours) of the Institute of Ichthyobiology and Aquaculture of Polish Academy of Sciences.

In the temperate climate the carp as a stenothermal organism is reproduced and reared only in the warm season of the year. Thus, the technology of carp culture is adapted to the annual thermal cycle, this determining the cycle of water exchange with the river (Figure 2).
About 80% of ponds is filled with river water from late autumn to spring and stocked with 2-year-old fish. From these ponds water is discharged to the river chiefly in October, when the 3-year-old consumption fish are caught. The remaining part of the ponds is filled with water on the turn of May and stocked with carp juveniles. After two years on the turn of March the fish are caught and the water is discharged to the river. The aim of the small inflow to ponds in the period May-September is maintaining a constant water level. From October to December small deep ponds – fish stores – are functioning. They are characterised by the intensive water flow and hence – in spite of covering only 1% of the pond area - they have a certain share in the water balance of the ponds.

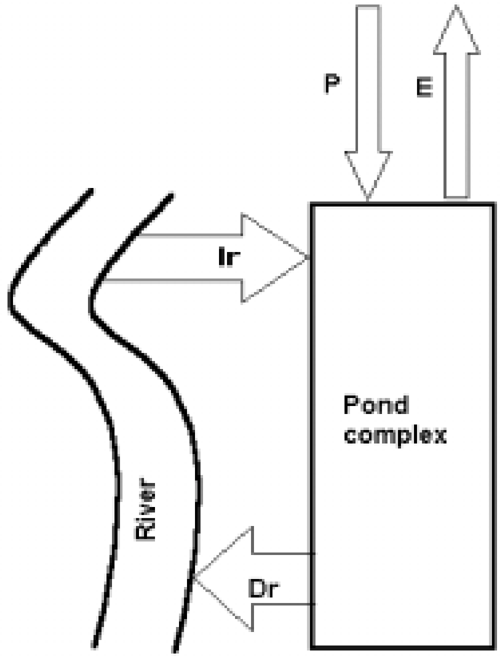


Figure 2. A scheme diagram of the water circulation between the pond complex and the river. Ir – regulated water inflow, Dr – regulated water discharge, P – precipitation, E – evaporated waters.

Methods

The evaluation of water exchange between the ponds and the river in the hydrological annual cycle was based on the calculation of components of the water balance equation

$$\Delta B = (Ir - Dr) + (P - E), \quad (1)$$

using one month time step. Ir is the regulated water inflow from the river to ponds, Dr – waters discharge from the ponds to the river, P - precipitation waters, E - waters lost in the process of evaporation from the pond water surface. The value of Ir consists of the volume of waters necessary to fill the aboveground and underground pond basins and to cover water losses due to the infiltration and evaporation if they are not covered by precipitation. The symbol ΔB denotes the change in the pond water storage. The level of water fed and outflow from the ponds was read every day from water-gauge recorders, the rate of water flow was measured with a hydrometric current meter at few-week intervals. The water volume Ir and Dr were calculated from the consumption curves. The volume of waters required for filling the underground basin of the ponds was calculated on the basis of measurements of the bottom humidity [Augustyn, 2001]. The precipitation and evaporated waters were monitored from May to September at the level of pond water surface using a standard evaporation station anchored in a pond of the investigated complex. In the remaining part of the year the precipitation was measured at a standard meteorological station at the height of 1 m, a correction for the difference in height being taken into consideration [Augustyn, 2001]. The evaporation losses from ponds partly or wholly drained during the cold season were calculated as terrain evaporation from the Konstantinov nomogram. The distance between the meteorological and evaporation stations is several hundred metres and they both belong to the Institute of Ichthyobiology and Aquaculture. The components of the water balance were monitored in 1995/1996 – 1998/1999; the sum and distribution of monthly precipitation were compared with results obtained in 1961 – 1990.

Results

The considered years can be classified as wet or very wet [Kaczorowska, 1962] since in all four years the annual totals of the precipitation exceeded the norm, considerably exceeding that norm in the first three years. That is the reason of a low differentiation between the water balance components in the particular years (Table 1). The 4-year-average showed the following values

$$\Delta B = (30.8 - 33.5) = (9.22 - 4.72) = 1.8 \quad (\text{x } 10^3 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}). \tag{2}$$

In spite of the pronounced precipitation sums in the considered years the regulated water exchange exceeded the direct exchange with the atmosphere by an order of magnitude. A similar regularity was maintained in all the months though the proportions between the components changed. The change in storage, ΔB, is for all four years lower than any of the fluxes Ir, Dr, P, and E.

Table 1. Components of water balance in carp ponds in four years investigated (x10^3 m^3 ha^{-1} $year^{-1}$).

Year Parameter	1996	1997	1998	1999
Ir	30.0	31.0	31.1	31.0
Dr	36.5	30.7	33.6	33.3
P	9.1	9.3	9.7	8.7
E	4.4	4.9	4.7	4.9
ΔB	-1.8	4.7	2.5	1.5

Knowledge on the annual water demand R is one of the most important issues in carp culture. R means sum of the total waters feeding ponds and of the difference between the precipitation and evaporation losses from the pond surface

$$R = Ir + (P - E). \tag{3}$$

Average results obtained during four years pointed at the following values required in the semi-intensive carp culture situated in the sub-mountain area

$$R = 30.8+4.5=35.3 \ (\text{x } 10^3 \text{m}^3 \text{ha}^{-1} \text{year}^{-1}). \tag{4}$$

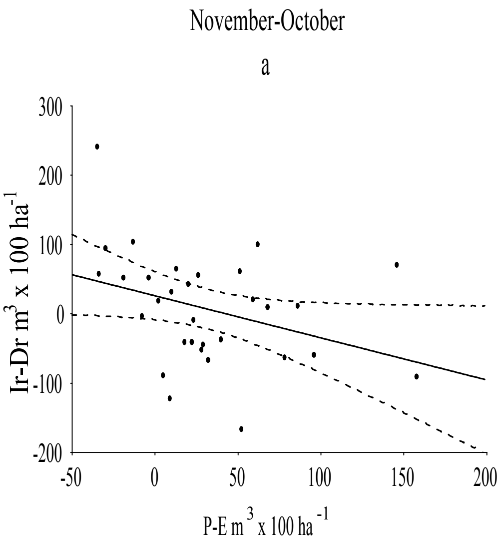
The above results have been proved as representative for water demand of ponds situated in catchment of the river Barycz (south – western Poland).

From the annual hydrological cycle (November – October) three periods were distinguished. They were determined by the method of carp culture in the temperate climate. These three periods differ by the magnitude of components of the water balance, by their relations, and the share in the volume of pond and river waters. Between November and April the regulated Ir inflow and the Dr outflow from the ponds played significant roles. These two values, especially Dr, decreased in the summer period of water stagnation in the ponds, when the role of the precipitation P and evaporation losses E increased. In October the high Dr value was due to fish catches in most ponds while the high Ir value resulted from the filling of fish-store ponds (Table 2). The absolute values of Ir, Dr, P, and E waters, like their participation in the total volume of pond waters Vp did not significantly change throughout the year. In October only the share of Ir and Dr increased, Dr even several times, while the shares of P and E decreased to a hundredth of percentage. The share of average monthly values of Ir and Dr in the river flow Sf varied about 1% while in October Dr increased the flow in the river by one quarter (Table 2).

Table 2. Average monthly values of components of the pond water balance Ir, Dr, P and E (m^3 ha^{-1} $month^{-1}$), absolute values of their relations to the pond volume Vp, and relations of Ir and Dr volumes to the river flow Sf.

	November October	November April	May September	October
Ir	2558	2329	2220	3400
Ir/Vp %	19	17	16	28
Ir/Sf %	0.4	1.0	0.6	9
Dr	-2791	-2700	-1180	-8700
Dr/Vp %	20	20	8.6	64
Dr/Sf %	0.6	1.1	0.5	24
P	767	393	1140	720
P/Vp %	6	3	8.4	<0.02
E	- 392	-179	-650	-220
E/Vp %	3	1.3	4.8	<0.01

Though in the pond water balance the meteorological water balance (P – E) is by one order of magnitude lower than difference between the regulated water exchange (Ir – Dr) it essentially affects (Ir – Dr) via the ground waters and the surface runoff. An attempt to evaluate the dependence of (Ir – Dr) on (P – E) showed the decrease of (Ir – Dr) with an increasing (P – E) both in the annual cycle and in the period of water stagnation in ponds (Figure 3a, 3b). From the regression equation between (Ir – Dr) and (P – E) the average monthly (P – E) value can be determined at which the average monthly (Ir – Dr) difference takes the negative sign, i.e. the Dr volume exceeds the Ir volume. For the hydrological year this (P – E) value was equal to 45 mm and in the stagnation period in ponds equal to 100 mm.



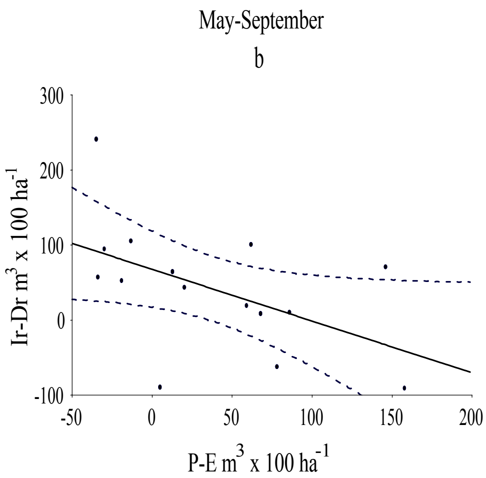


Figure 3. Scatterplot of monthly differences between the regulated water inflow and discharge from the ponds vs differences between precipitation and evaporation waters. Solid lines are regression curves; dotted - the 95% confidence limit

Discussion and summary

The regulated water exchange with the river plays a decisive role in the water balance of the ponds while the share of the direct water exchange with the atmosphere increases only in the warm season of the year. It may be supposed, however, that in normal pluviometric conditions this share is still smaller since the results were obtained with the annual average sum of precipitation about 10% higher than the norm and about 20% higher than the average sum in the stagnation period.

From the annual hydrological cycle (November – October) three periods were separated. They are determined by the method of carp culture in the temperate climate. These three periods differ in the absolute magnitudes of the water balance components, in their interrelations, and in the share in the total pond water volume and in the river flow. The intensive water intake from the river to fill the ponds occurs in the period November – April and that of summer water stagnation from May to September. The main discharge of pond waters to the river occurs in October.

The positive role of ponds in regulating the river flow is based on the intensive intake of water in spring, thus in period of the highest flow in the river, the intake of small volumes of the water throughout the warm part of the year, and in a considerable water supply to the river in October, when the lowest flow occurs. This is shown by the low shares, almost not exceeding 1 %, of Dr and Ir to the river flow in all months except October when these shares distinctly increase. However, in this month water discharges from ponds to the river are almost twice those of the intake. It is obvious that the share of pond waters in the river flow increases in dry years. The obtained average water discharge from ponds might have exceeded over 230% of the lowest flow in the river Vistula recorded in October 1961 [Augustyn , 2001].

The evaluation of effect of the meteorological pond water balance on the regulated water exchange between the river and ponds suggested an inverse relationship between (Ir – Dr) and (P – E). With a given (P – E) value the volume of waters drained to the river exceeded that supplied. The significance of quantification of this dependence should be confirmed by the more numerous results.

The correctness of the results obtained in the upper Vistula catchment is also affirmed by the similar values of the annual water demand recorded in a carp farm situated in the river Barycz basin in western Poland [Drabinski, 1991]. It only requires the differences between the depth of ground waters and the precipitation sums are to be considered. The components of the water balance of ponds situated in different geographic and climatic conditions can differ from those considered in the paper. For example, in a warm climate with abundant precipitation the chief source of water for ponds is the rain and the source of losses is the evaporation [Nath and Bolte, 1998].

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