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# Water retention in ponds and the improvement of its quality during carp production

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**Abstract**

Ponds play various functions both productive and non-productive. It was demonstrated in the paper that ponds retain water and during heavy rainfalls they act as a flood control measure. Self-purification of water takes place along the pond. Statistically significant reduction of nitrate-N, phosphate-P and calcium concentrations was found in pond water. From 102±24 to as much as 360±53 kg nitrate-N per ha of fishpond is retained during fish growth. Phosphorus may not be retained in fishpond; if it is then the amounts of stored P are small (from 1 to 7 kg·ha$^{-1}$ on average). Slightly more potassium may remain in the pond. After the period of fish growth and draining the pond, only part of stored load of nutrients reaches the recipient water body. From 200 to 400 kg N-$NO_3$ and up to 2300 kg Ca per ha does not flow out of the pond. The outflow of ammonium-N, phosphorus and potassium may, however, increase or decrease.

**Key words:** *ammonia, calcium, magnesium, nitrate-nitrogen, phosphate-phosphorus, potassium, reduction of concentration, reduction of load*

## INTRODUCTION

Ponds serve various, both productive and non-productive functions. They play important role mainly in small and medium catchment basins [DRABIŃSKI 1991; DRABIŃSKI, WIENIAWSKI 1992] as retention reservoirs [KACA, LIPIŃSKI 2008; KUCZYŃSKI 2007]. By maintaining high ground water level and affecting microclimate, they become part of the programme of small retention [KOWALEWSKI 2008]. Usually highly eutrophic [BOROWIEC 1981], fishponds are the sanctuaries of waterfowl and refuges for many plant and animal organisms [BARSZCZEWSKI, BARSZCZEWSKA 2008] including small mammals, reptiles, amphibians, insects and other invertebrates [SZUMIEC 2003; KUCZYŃSKI 2007]. They also contribute to the self-purification of surface waters [BARSZCZEWSKI *et al.* 2008; KNOESCHE *et al.* 2000; LEWKOWICZ 1994; ZYGMUNT 2006]. Moreover, fishponds are an important landscape element and a place for rest and recreation.

## AIM AND SCOPE OF THE PAPER

Despite positive opinions expressed in the introduction, the role of fishponds in the control of water flow in a river and the transformation of riverine pollutants is questioned in some circles. A negative role of these small water bodies is often underlined. Therefore, the aim of this study is focussed on the retaining functions of carp fishponds. This notion is meant as an ability of fishponds to temporarily or permanently retain water and pollutants in the process of carp breeding. The scope of this paper is limited to the retention of water and inorganic compounds of nitrogen ($N\text{-}NO_3$, $N\text{-}NH_4$), phosphorus ($P\text{-}PO_4$), potassium (K), calcium (Ca) and magnesium (Mg) in low-productive carp fishponds. Particular attention was paid to the retention of nutrients ($N\text{-}NO_3$ and $P\text{-}PO_4$) that increase water eutrophication. Electrolytic conductivity as a measure of dissolved salts was also analysed.

The aim of this study was to collect additional data (apart from those in the literature) demonstrating the effect of fishpond on water flow and the quality of water discharged from the pond to recipient water body. Based on these data we attempt to answer the following questions:

1. What is the effect of water retention in a fishpond on water flow regime in the recipient?
2. Does the concentration of pollutants, mainly nitrate-nitrogen and phosphate-phosphorus, change along the fishpond from water inlet (inlet monk) to water outlet (outlet monk) from the fishpond during the period of carp growth?
3. What is the load of pollutants temporarily (during fish growth) retained (or lost by e.g. denitrification) in the pond?
4. If and to what degree do the fishponds decrease the load of substances discharged to the recipient?

It was *a priori* assumed (working hypothesis) that fishpond – due to its retention capability – significantly and positively affects water regime in the recipient and water quality there. An alternative hypothesis was that the fishpond does not affect both.

## STUDY OBJECT AND METHODS

A general study method was to test working hypothesis on the significance of the fishpond effect on water quality and flow regime in the recipient through falsifying the alternative hypothesis (in statistical analysis an alternative hypothesis is the null hypothesis) and then to check whether this effect is positive or negative based on commonly accepted criteria.

The paper is based on studies carried out in 2009 and 2010 in two ponds (no 7 and 9) of a pond complex Stawy Raszyńskie (nature reserve) stocked with c. 900 fishes per ha in a low-productive fish farming system. The ponds are drained, vegetation covers c. 6–7% of water table surface area. Liming at a rate of c. 500 $kg\cdot ha^{-1}$ is applied every year in both ponds to provide appropriate sanitary status. Due to the presence of nesting birds, vegetation is not cut in both ponds. To secure pond fertility, ponds are fertilised with manure in a dose of 2 to 3.5 $t\cdot ha^{-1}$. Carps are fed exclusively with cereal feed (triticale and wheat). Surface area of pond 7 is 4.13 ha and maximum volume – 41.9 thousand $m^3$, respective figures for pond 9 are: 6.69 ha and 80.6 thousand $m^3$.

Water from the ponds is drained to the Raszynka River. This is a small lowland river of a total length of 16.84 km and the surface area of its catchment basin is 72.42 $km^2$. At the outlet of water from fishponds, the catchment area is 46.45 $km^2$ and annual mean water flow is estimated at several dozen $dm^3\cdot s^{-1}$ there.

In order to answer the first question, water inflow to ($Q_{Do}$) and outflow ($Q_{Od}$) from each pond was measured and water stages were recorded weekly. Based on these measurements, water input ($V_{Do}$), water output ($V_{Od}$) and retention ($R$) were calculated in the beginning and at the end of the period of water balance. Water flows were measured with triangular free weirs installed on inlet and outlet monks. Water retention $R$ was determined from the storage curve based on the records from stage gauge installed near the outlet monk. Curves were elaborated for each pond with the use of the performed geodetic measurements.

Measured values are the basic elements of water balance in a pond. From these values, the deficit of rainfall and infiltration water $N$ was calculated for the whole period:

$$N = (ET + Str) - (P + Inf) = (V_{Do} - V_{Od}) - R_k - R_p \quad (1)$$

and the demand for water $Z$ in a pond:

$$Z = (V_{Do} - V_{Od}) = N + (R_k - R_p) \quad (2)$$

where:

- $ET$ – evaporation from water table and evapotranspiration of aquatic vegetation, $m^3$;
- $Str$ – water losses from the pond (seepage through dikes, constructions), $m^3$;
- $P$ – sum of rainfall on the pond surface, $m^3$;
- $Inf$ – infiltration of water to pond from adjacent area, $m^3$;
- $V_{Do}$, $V_{Od}$ – volume of measured water input to and output from the pond, respectively, $m^3$;
- $R_k$, $R_p$ – volume of retained water in the pond at the end ($k$) and in the beginning ($p$) of the balanceperiod, $m^3$.

In order to answer the other questions it was necessary to measure the concentrations of selected components in water. For this purpose, water samples were taken from the inlet (in pond just beneath the inlet monk) and outlet (in pond just above the outlet monk) every month during fish growth season. Such location of sampling points was determined by the need of water sampling even in the case when the pond was not fed with water or water was not drained. During the drainage of a pond, water was sampled three times at the outlet – in the beginning of drainage, in the time when 30% of pond volume was drained and at the end of drainage. In every case and sampling point water samples for chemical analyses were triplicated. Determined water constituents included: pH, nitrate-nitrogen, ammonium-nitrogen, phosphate-phosphorus, magnesium, calcium, potassium, and electrolytic conductivity. Chemical analyses were

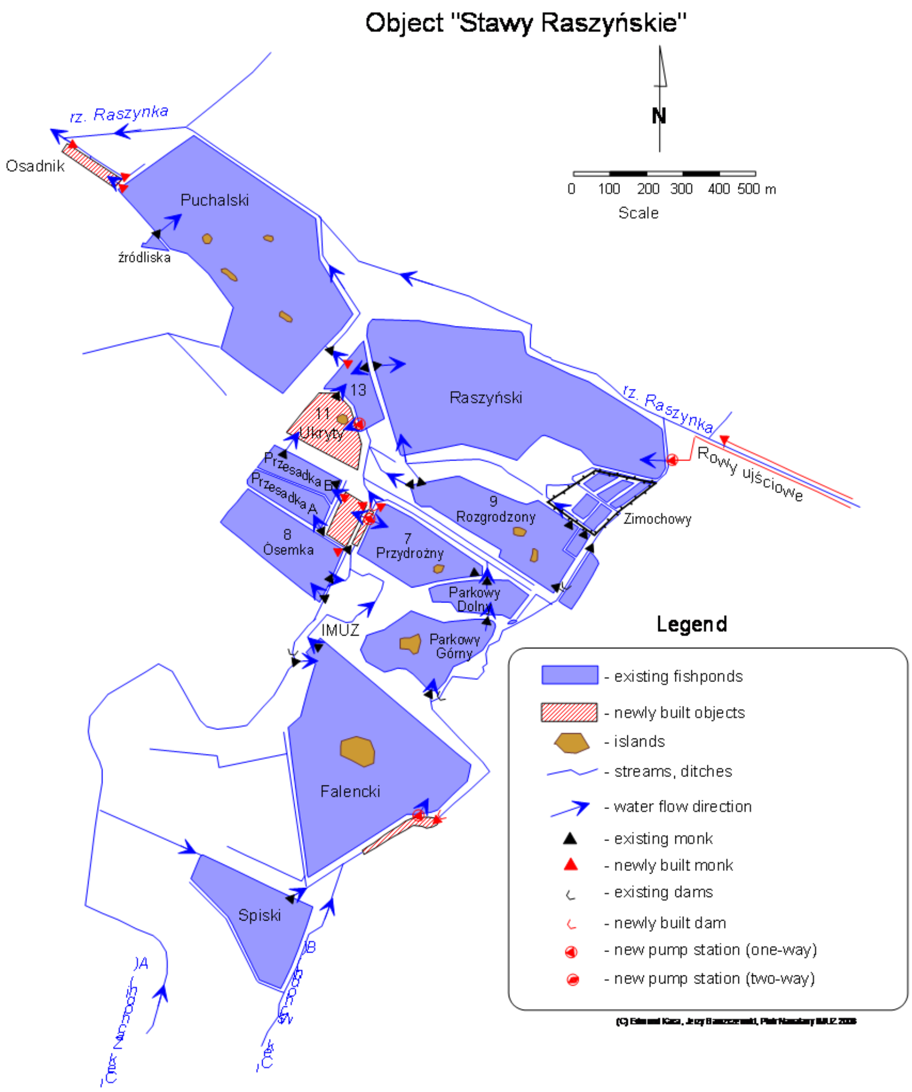


Fig. 1. Fishpond complex „Stawy Raszyńskie"

performed in the Department of Soil and Water Chemistry of the Institute for Land Reclamation and Grassland Farming (later – Institute of Technology and Life Sciences) with the flow-through analyser using spectrophotometric methods.

To answer the question whether the concentration of analysed components changes along the pond from the inlet to outlet monk, statistical analysis was applied based on differences $\Delta = C_{Do} - C_{Od}$ in the concentration of a given component at the inlet $C_{Do}$ and outlet $C_{Od}$. Null hypothesis was that no such differences existed ($H_o$: $\Delta = 0$). Rejecting such hypothesis should prove the working hypothesis that ponds – through their retention capability – affect the quality of water in the recipient. This hypothesis was tested with the method of paired samples using Student's t-test [OKTABA 1966]. Application of this test was possible since there was no ground for rejecting normal distribution N ($\Delta sr$, $SD$) of the differences $\Delta$ having a mean of $\Delta sr$ and standard deviation $SD$ at $\alpha$ = 0.01 (Kołmogorow-Smirnow test) [KUKIEŁKA 2002].

When answering the third question, measured concentrations of a given component $C$ and the volume of water $V$ flowing to (or out of) the pond were considered. Partial load $L$ and total load $L_w$ flowing into (or out of) the pond were calculated based on the trapezoid method described in detail in KACA (in press 2012). The standard and then extended uncertainty of obtained results at the confidence level of 95% was also calculated using principles described *i.a.* by KACA [2011; 2013 in press].

To answer the last question, the load of pollutant removed from aquatic habitat $L_{us}$ was calculated based on the balance of loads acc. to equation:

$$L_{us} = L_{Rp} + L_z - L_{Rk} \tag{3}$$

where:

$L_{Rp}$ – load of a given substance in water retained in the beginning of the carp growth period, kg;

$L_{Rk}$ – load of a given substance in water retained at the end of the carp growth period (load drained to the recipient), kg;

$L_z$ – load retained in the pond during the carp growth period, kg.

The load of a substance retained in water in the beginning of the carp growth period was calculated acc. to equation:

$$L_{Rp} = \frac{R_p(C_{pDo}+C_{pOd})}{2} \tag{4}$$

where:

$R_p$ – initial water retention in the pond (in the beginning of the carp growth period), m$^3$;

$C_{pDo}$, $C_{pOd}$ – concentration of a substance in the beginning of the carp growth period at the inlet and outlet, respectively, kg·m$^{-3}$.

The load of pollutants in drained water was calculated acc. to the equation:

$$L_{Rk} = \frac{0.3R_k(C_{k1}+C_{k2})}{2} + \frac{0.7R_k(C_{k2}+C_{k3})}{2} \tag{5}$$

where:

$R_k$ – final water retention in the pond (before water drainage), m$^3$,

$C_{k1}$, $C_{k2}$, $C_{k3}$ – concentration of a given substance in the beginning of drainage, after draining 30% of retained water and at the end of drainage, respectively, kg·m$^{-3}$.

In the carp growth period of 2009, the sum of rainfall was 426.3 mm being higher by c. 100 mm than the long-term mean. In 2010 the sum of rainfall was 715.1 mm. An unintentional and not controlled discharge of water from pond 7 happened in 2010. With the storage curve of the pond, the volume of discharged water was estimated at c. 80 thousand m$^3$. For this reason, the amount of discharged water and other parameters calculated from this volume were taken as approximate.

## RESULTS AND DISCUSSION

Fishponds are filled with water in spring without the loss for users and water consumers situated downstream the ponds. This procedure may even reduce the risk of flood. Later, since the middle of April till the middle of September, in the period of carp growth, water in ponds was only supplemented to maintain the height of water table in the pond (Fig. 2). Water taken in excess during this period flows through the pond and is discharged to the recipient (Tab. 1, pond 9). Water flowing through the pond is subject to partial self-purification, which will be discussed later. In the case of stabilised water level, the demand for water $V$ in a pond equals the deficit of rainfall and infiltration water. In the studied ponds, the deficit for the whole balanceperiod was c. 500 mm in three cases and 1300 mm once. These values calculated for rainfall intensity ranged from 3 to 8 mm·d$^{-1}$ being slightly higher than those observed on intensive permanent grasslands or forests in moist habitats. DRABIŃSKI [1991], who studied three pond objects in the Barycz River catchment basin near Milicz, arrived at the same conclusion. This means that the impact of fishponds on water flow in a stream is similar to that of an intensively used meadow or forest in moist habitats. The impact may be minimised by over-damming in a pond as it was the case in the wet year 2010 (Fig. 3). If water is raised by a height equivalent to the deficit of rainfall and infiltration water than the pond may not take water during the period of carp growth and hence will not decrease water flow in the supplying stream.

Due to biochemical, physical and chemical processes, basic dissolved components are transformed in the water of fishponds. Statistically significant reduction in the concentration of all analysed components was found in ponds (Tab. 2). This particularly pertains to nitrate-nitrogen, phosphate-phosphorus and calcium. Decreasing nutrient concentration during fish farming indicates the advancement of water purification (self-purification). Much lower concentrations of N-$NO_3$ and P in outflowing water confirm the

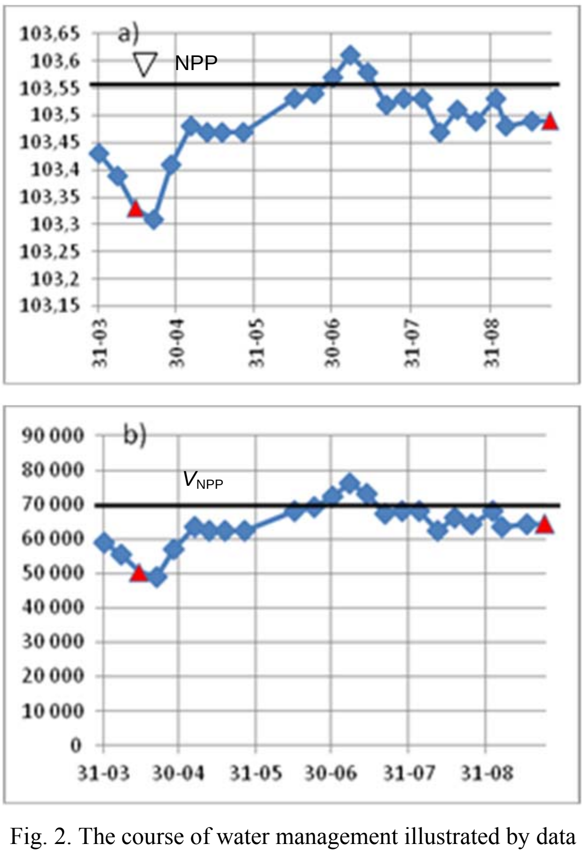


Fig. 2. The course of water management illustrated by data from pond 9 in 2009: a) water stages in m a.s.l., b) volume of retained water in m$^3$ (triangles denote the beginning and end of the balance period), NPP – normal level of water damming, $V_{NPP}$ – water volume at NPP)

**Table 1.** Elements of water balance in fishponds (*V*, *P*, *R*, *N* and *Z* in m). Inflow and outflow values are supplemented with their uncertainty at a confidence level of c. 95%

| No of pond | Balance period | Number of days | Inflow $V_{Do}$ | Outflow $V_{Od}$ | Rainfall *P* | Retention in the beginning $R_p$ | Retention at the end $R_k$ | Change of water retention in the pond $\Delta R$ | Deficit of rainfall and infiltration water *N* | Demand for water in the pond *Z* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 = 8 – 7 | 10 wzór (1) | 11 = 9 + 10 |
| 7 | 14.04–23.09.2009 | 162 | 0.89±0,21 | 0 | 0.414 | 1.022 | 1.041 | 0.019 | 0.867 | 0.886 |
| | 14.04–16.09.2010 | 155 | 4.45±0.59 | $2.10^{1)}$ | 0.680 | 1.121 | 1.211 | 0.090 | $2.266^{1)}$ | $2.356^{1)}$ |
| 9 | 14,04–23.09.2009 | 162 | 6.59±774 | 4.74±0.65 | 0.416 | 0.755 | 0.963 | 0.208 | 1.645 | 1.853 |
| | 14.04–16.09.2010 | 155 | 4.75±0.56 | 4.17±0.62 | 0.656 | 1.109 | 1.286 | 0.177 | 0.406 | 0.583 |

$^{1)}$ Approximate values.

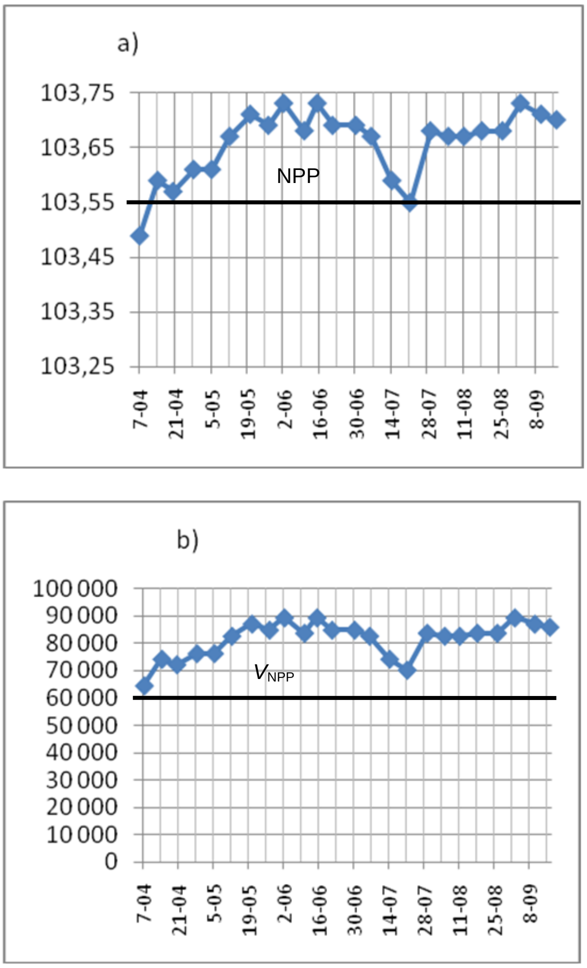


Fig. 3. The course of water management illustrated by data from pond 9 in 2010: a) water stages in m a.s.l., b) volume of retained water in m$^3$; explanations as in Fig. 2

results of earlier studies by KOSTURKIEWICZ and MURATOWA [1993], LEWKOWICZ [1994], KANCLERZ [2005], ZYGMUNT [2006], BARSZCZEWSKI *et al.* [2008] and by CUPAK and KRZANOWSKI [2009].

As a result of retention and transformation in the pond, substantial loads of pollutants may periodically or permanently be not discharged to the recipient. Processes that operate during fish breeding pertain mainly to the basic nutrient – nitrate-nitrogen – but also to other substances (Tab. 3). During the 150–160-day period, pond waters retained from 102±24 to as much as 360±53 kg nitrate-N per ha. Large amounts of calcium and magnesium are also retained. Phosphate-P may be not retained in the pond and if, than the amounts are small (1–7 kg·ha$^{-1}$ on average). Slightly more potassium will be stored in the pond. Obtained results confirm the reduction of nitrate-N estimated by some authors [KANCLERZ 2005] at c. 20 % and in waters from sewage treatment plants at even 70 % [CUPAK, KRZANOWSKI 2009]. Similarly, phosphorus may also be reduced by c. 20 % [KANCLERZ 2005]. Results presented in tab. 3 show smaller reduction of phosphate-P.

During water drainage from the pond, concentrations of chemical components usually increased. Electrolytic conductivity increased in every case which meant an increase of salt concentration in water. The concentration of magnesium also increased. The concentration of ammonium-N and calcium increased in three out of four cases (Tab. 4) and that of nitrate-N, phosphate-P and potassium – increased in two out of four cases. In the final period of pond drainage i.e. just before catching the fish, the highest increase of

**Table. 2.** Characteristics of differences in the concentration of substances between water inflow to and outflow from the pond (calculated from data of the years 2009 and 2010)

| No of pond | Statistics | Difference in concentration in mg·dm$^{-3}$ | | | | | | Conductivity mS·cm$^{-1}$ | pH |
|---|---|---|---|---|---|---|---|---|---|
| | | $N\text{-}NO_3$ | $N\text{-}NH_4$ | P | Mg | Ca | K | | |
| 7 | *Δsr* | $6.71^{**}$ | –0.12 | $0.10^{**}$ | $1.67^{**}$ | $27.54^{**}$ | $-1.19^{*}$ | 0.24 | –0.04 |
| | *SD* | 3.64 | 0.24 | 0.08 | 1.19 | 10.18 | 1.70 | 0.44 | 0.24 |
| 9 | *Δsr* | $4.98^{**}$ | $2.71^{**}$ | $0.05^{*}$ | 0.41 | $24.44^{**}$ | –0.57* | $0.08^{*}$ | 0.01 |
| | *SD* | 2.03 | 2.82 | 0.06 | 1.49 | 14.71 | 0.84 | 0.10 | 0.20 |

$^{*}$ Difference significantly different from zero at α = 0.05.
$^{**}$ Difference significantly different from zero at α = 0.01.

**Table 3.** Unit load of substances ($Mg \cdot ha^{-1}$) retained in ponds in the period of carp growth (mean ± extended uncertainty at the confidence level 95%)

| No of pond | Balance period | Component | | | | | |
|---|---|---|---|---|---|---|---|
| | | $N\text{-}NO_3$ | $N\text{-}NH_4$ | P | Mg | Ca | K |
| 7 | 14.04–6.09.2009 | 0.102±0.024 | 0.0017±0.0026 | 0.0008±0.0021 | 0.070±0.020 | 0.48±0.13 | 0.0169±0.0046 |
| | 28.04–16.09.2010 | 0.320±0.054 | 0.003±0.010 | 0.007±0.010 | 0.244±0.076 | 2.24±0.53 | 0.070±0.023 |
| 9 | 14,04–6.09.2009 | 0.360±0.053 | 0.020±0.024 | 0.007±0.020 | 0.230±0.140 | 2.24±0.80 | 0.058±0.052 |
| | 28.04–16.09.2010 | 0.272±0.042 | –0.010±0.016 | 0.002±0.015 | 0.031±0.110 | 1.27±0.70 | –0.028±0.042 |

**Table 4.** Chemical composition of water during its drainage from ponds

| No of pond | Year | Amount of water in pond | pH | Analysed water constituents $mg \cdot dm^{-3}$ | | | | | | Conductivity $\mu S \cdot cm^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $N\text{-}NO_3$ | $N\text{-}NH_4$ | P | Mg | Ca | K | |
| 7 | 2009 | 1) | 7.90 | 3.07 | 0.12 | 0.014 | 5.10 | 26.80 | 2.80 | 0.298 |
| | | 2) | 6.29 | 0.72 | 0.40 | 0.105 | 5.80 | 13.80 | 5.00 | 0.321 |
| | | 3) | 6.70 | 0.77 | 5.19 | 0.043 | 8.00 | 17.60 | 8.60 | 0.483 |
| | 2010 | 1) | 6.99 | 1.16 | 0.20 | 0.120 | 6.20 | 42.10 | 5.10 | 0.357 |
| | | 2) | 7.54 | 4.34 | 3.89 | 0.674 | 6.40 | 40.40 | 4.60 | 0.348 |
| | | 3) | 7.59 | 21.57 | 7.78 | 3.241 | 6.90 | 50.30 | 4.60 | 0.591 |
| 9 | 2009 | 1) | 7.50 | 0.56 | 0.10 | 0.136 | 9.43 | 57.50 | 4.30 | 0.514 |
| | | 2) | 7.05 | 0.38 | 0.59 | 0.111 | 11.50 | 60.70 | 3.80 | 0.516 |
| | | 3) | 7.20 | 0.21 | 2.63 | 0.127 | 13.40 | 71.70 | 4.30 | 0.556 |
| | 2010 | 1) | 7.55 | 0.99 | 2.08 | 0.140 | 9.80 | 64.80 | 5.50 | 0.463 |
| | | 2) | 7.59 | 3.25 | 1.18 | 0.462 | 10.70 | 64.00 | 6.00 | 0.497 |
| | | 3) | 7.64 | 4.59 | 1.73 | 0.662 | 11.20 | 73.90 | 5.90 | 0.598 |

1) Chemical composition of pond water before its drainage.
2) Chemical composition of pond water after draining 30% of water.
3) Chemical composition of pond water at the end of drainage, before fish catching.

concentrations of most analysed elements was recorded confirming the results of earlier studies by BARSZCZEWSKI *et al*. [2008]. Obtained results on the discharge of ammonium-N and phosphorus during pond drainage are largely concordant with those obtained by ZYGMUNT [2006].

Balance made from data in tables 3 and 4 shows that, due to water retention in the pond, 200–400 kg $N\text{-}NO_3 \cdot ha^{-1}$, up to 2300 kg $Ca \cdot ha^{-1}$ and up to 250 kg $Mg \cdot ha^{-1}$ will not be discharged to the recipient. The discharge of ammonium-N may, however, increase or decrease (by c. 50 $kg \cdot ha^{-1}$). Similar trend (increase or decrease) pertains to other analysed substances (Tab. 5).

**Table 5.** Loads of components removed from ponds during autumn water discharge, $kg \cdot ha^{-1}$

| No of pond | Component | | | | | |
|---|---|---|---|---|---|---|
| | $N\text{-}NO_3$ | $N\text{-}NH_4$ | P | Mg | Ca | K |
| 7 | 203 | –6.5 | 0.6 | 74 | 639 | –18.9 |
| | 287 | –52 | –10 | 249 | 2 302 | 39 |
| 9 | 397 | 48 | 7 | 182 | 1 883 | 52 |
| | 270 | –25 | –3 | 1 | 948 | –50 |

## CONCLUSIONS

1. Ponds play a water retaining function in the catchment basin and, in periods of intensive rainfalls, also act as flood control measures. Through periodical over-damming or water discharge one may actively affect water flow regime in the recipient stream.

2. Significant transformation of substances dissolved in pond water takes place along the pond. There was statistically significant reduction of the concentrations of all analysed components, particularly of nitrate-N, phosphate-P and calcium.

3. In the period of carp growth (150–160 days) from 102±24 to 360±53 kg of nitrate-N remains in the pond. Retained substances include also large amounts of calcium and magnesium.

4. After fish growth and water drainage only part of stored load of substances is released to water recipient. From 200 to 400 kg $N\text{-}NO_3$, 600 – 2300 kg Ca and up to 250 kg Mg per ha of pond surface area is not discharged to the recipient. The outflow of ammonium-N, phosphate-P and potassium may, however, increase or decrease.

5. Obtained results were characterised by a low repeatability i.e. a high variability between both ponds and study years. Explanation of these differences requires more detailed and hence costly studies.

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**Retencjonowanie wody w stawach oraz poprawa jej jakości w procesie produkcji karpiowej**

STRESZCZENIE

**Słowa kluczowe:** *amoniak, azot azotanowy, fosfor fosforanowy, magnez, potas, zmniejszenie ładunku, zmniejszenie stężenia, wapń*

Stawy pełnią liczne funkcje, zarówno produkcyjne, jak i pozaprodukcyjne. W pracy wykazano, że stawy pełnią funkcję retencyjną w zlewni, a w okresach nasilonych opadów również funkcję przeciwpowodziową. Staw jest zbiornikiem, w którym następuje samooczyszczanie się wody. Stwierdzono istotne statystycznie zmniejszenie stężenia azotu azotanowego (N-$NO_3$), fosforu fosforanowego (P-$PO_4$) i wapnia (Ca) w wodzie stawów. W okresie odrostu ryb na powierzchni hektara stawu zatrzymuje się od 102±24 do nawet 360±53 kg azotu azotanowego. Wśród zatrzymanych substancji są również duże ilości wapnia i magnezu. Fosfor fosforanowy może nie być zatrzymywany w stawie, a jeżeli będzie – to w niewielkiej ilości (przeciętnie od 1 do 7 $kg \cdot ha^{-1}$). Nieco więcej będzie pozostawać w stawie potasu. Po okresie wzrostu ryb w wyniku spustu wody tylko część zgromadzonego ładunku substancji trafia do odbiornika wody. Do odbiornika nie odpływa średnio od ok. 200 do 400 $kg \cdot ha^{-1}$ azotu azotanowego i do 2300 $kg \cdot ha^{-1}$ wapnia. Może natomiast zwiększyć się lub zmniejszyć odpływ azotu amonowego, fosforu i potasu.