Original Research

Assessment of Water Retention Capacity of Small Ponds in Wyskoć Agricultural-Forest Catchment in Western Poland

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Abstract

The potential increase of water retention capacity in the ponds of the Wyskoć catchment in western Poland is estimated and presented. Only water bodies having area smaller than 2 ha were taken into consideration. There are 638 ponds in the Wyskoć catchment, from among wetland and grassland ponds are the most numerous (they both constitute about 59% of all water bodies). The analyzed ponds retain above $562x10^3$ m^3 of water. However, the amount of retained water could be increased by $886x10^3$ m^3 (in relation to current pond retention) if pond retention is considered and by other $880x10^3$ m^3 in case of groundwater retention in areas adjoining. The increase of water level in ponds from 0.5 to 1.5 m due to damming water in the outflow or retention of drainage water so far unproductively discharged out of the catchment area was considered as a potential source of retained water. The highest relative increase of water retention in ponds and in adjoining areas could be obtained in midfield and farmstead ponds with the smallest average area. However, for the smallest water bodies with surface area less than 0.5 ha, the potential relative increase of groundwater retention is higher than the retention increase in the pond itself. This means that the smaller the pond and the smaller value of current water body retention, the bigger relative increase of groundwater retention in the areas adjacent to pond in relation to the increase of the water level in pond. The results proved that the small ponds could be very valuable elements of a landscape influencing water regime of agriculturally managed areas. They should be protected and used for water storage. The presented method could be useful to fast, easy and cheap macro-scale estimation of potential water capacity of water bodies.

Keywords: small ponds, water retention, groundwater retention, retention capacity

Introduction

One of the top priorities regarding water retention is to maintain water from spring thaw and precipitation in all kinds of ponds, water holes, land lows and pits of gravel, clay and sand [1-3]. The aim of such procedures is mainly to prolong the method and time of water circulation in the water catchment [4], which consequently leads to an increase in water resources as well as an improvement of the effectiveness of the exploitation of the water gathered in the catchment area [1].

Small water bodies are the element of an agricultural landscape which enables increasing the amount of water retained in the catchment in a relatively easy and economical way without any costly investments [5-7]. These

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reservoirs are characterized by a big retention capacity [2, 3]. The use of such ponds for the retention of drainage waters, so far unproductively discharged out of the catchment area, can contribute to an increase of the amount of retained water even by several times which, in turn, can substantially improve the structure of water balance in arable lands [2, 4, 6, 8].

Hydrology of water bodies is closely related to the level of groundwaters in the area of their microcatchment [3, 9-15], thus water damming in a pond results not only in the increase of water retention in the reservoir, but also, above all, in the increase of groundwater retention in the adjoining area [3, 16-18]. The range of pond impact on the increase of groundwater retention depends on the kind of soil and the growth of the water level in the pond in relation to the level of the groundwater in the adjoining area [11, 19]. The impact of the water body on the adjoining area is much bigger in light soils than in heavy soils. Moreover, a small pond has a relatively stronger impact than a big one [18]. The range of such an impact may be as long as 200 m [20].

Despite the positive hydrological influence of small water bodies on water regime of their catchment and amount of stored water (useful e.g. to irrigation), their significance is very often minimized and since 1945 has progressively declined [21]. What is more, the existence of small ponds is endangered due to strong anthropogenic impact [5, 6, 22-25]. Many of them were completely degraded by human activities (intensive agriculture, urban encroachment, industrial development, expending transport infrastructure) and disappeared [26-30]. For example, losses of small ponds throughout the North Western Europe could even reach a value of 40-90%, depending on the region [27]. Thus, the aim of this study is to assess the existing and potential water resources retained in small ponds of Wyskoć agricultural-forest catchment in order to prove a high significance of ponds as water retention reservoirs. Approximate fluctuations of the water retention capacity of ponds and groundwater in the adjoining area were taken into consideration in the calculations.

Study Area

The study catchment is located about 50 km south of Poznań (southern part of the Wielkopolska Region) in western Poland. The total catchment area equals 182.5 km^2. Owing to significant differences of land use structure and geomorphology of the catchment area, this watershed was divided into two parts known as the Turew Region and the Dolsk Region (Fig. 1). The Turew Region (western part of the catchment) is a rural area, which besides a considerable share of arable lands is characterized by a lack of lakes. The Dolsk Region (eastern part of the catchment) is characterized by a big share of forests, lakes and wetlands, in relation to a relatively small area occupied by arable lands. The dominant form of the land configuration of this region is a rolling ground moraine which is abundant in non-outflow local hollows, among them terminal moraines and eskers occur.

The terrain consists of rolling plain, made up of slightly undulating ground moraine, with many drainage valleys. In general, light textured soils (Hapludalfs, Glossudalfs and less frequentlymet Udipsamments) with favorable water infiltration conditions are found in uplands. Deeper strata are poorly permeable and percolating water seep to valleys and ditches or main drainage canal. In depressions Endoaquolls, poorly drained, collect water runoff and discharge it to a surface drainage system [31].

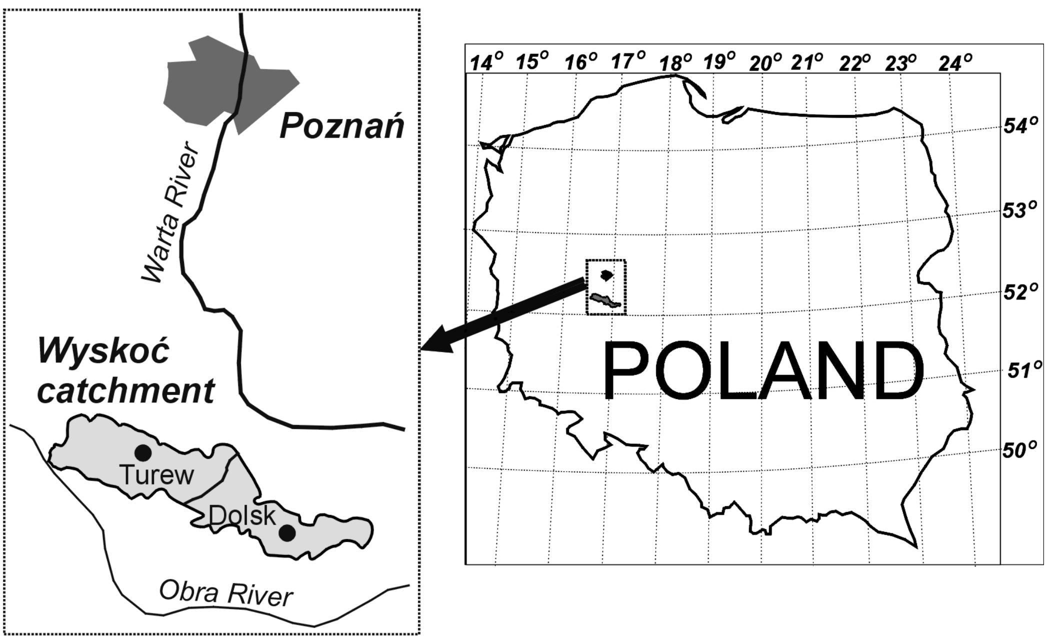

Fig. 1. Location of the Wyskoć catchment.

Methods

The inventory of the water bodies in the area of the Wyskoć catchment was carried out in the period 2003-04. Only water reservoirs of the area between 25 m^2 and 2 ha, which can be permanent or seasonal, natural or man-made were taken into account during analyses, since only such water bodies are recognized as "small" ponds, according to the classification of water bodies applied in Great Britain [32-37]. Each pond was characterized in detail, considering its morphological and ecological features. After the exact area of the water bodies had been established, their retention capacity and possible retention increase of water were estimated, both in the pond and in the groundwater adjoining it.

Current retention of pond V_w was calculated, assuming that a pond is a cylinder with radius *r* and depth *h*, according to the formula of a cylinder volume (eq. 1)

$$V_w = \pi \cdot r^2 \cdot h \quad (1)$$

Because it was not possible to measure a yearly dynamic of water level fluctuations in ponds (to calculate an average value of pond water depth), it was assumed in the calculations carried out in this study, that an average yearly depth of water in a pond is 0.5 m [38]. This value could not be precise.

The damming of water in a water body results in the increase of pond retention as well as retention of the groundwater in the area adjoining the pond (obviously, assuming that there is an undisturbed hydraulic connection between the water in a pond and the groundwater in the adjoining area) [39, 40]. The potential increase of retention in pond ΔV_o, was calculated using the truncated cone volume formula (eq.2):

$$\Delta V_o = \frac{\pi \cdot x \cdot \left((R + r)^2 - R \cdot r \right)}{3} \quad (2)$$

The height of the cone represents the height of water damming in pond *x*, and its bases have radiuses *r* and *R* respectively (Fig. 2). The maximum of water damming *x* depends on the height of the pond banks and is limited to the height which not lead to the flooding of the pond adjoining area (as a result of water damming). The maximum level of the water damming estimated during field survey is provided for up to 1.5 m in height. Radius *r* equals the radius of the cone, which represents the surface area of a pond. Radius *R* of the upper base of the truncated cone depends on the inclination angle of the pond banks. The smaller the inclination angle of the water body banks, the bigger radius *R* will be. Three kinds of banks were introduced: very steep, steep, and gentle. It was assumed that for very steep slopes, the height *x* of the right triangle inscribed into the section of a pond after water damming (a trapezoid) will be three times bigger than its base *a*, *x=3a* (Fig. 2). In such a case, the slopes of a pond are inclined at the angle not smaller than 67°. In the case of steep slopes, the height of this triangle will equal its base *x=a*, and the inclination angle of pond banks is about 45°. In the case of gentle slopes, the base of the right triangle will be three times bigger than its height, *x=1/3a*. In a pond with gentle slopes, the banks are inclined at an angle of about 22°. To sum up, for very steep slopes the radius *R=r+1/3x*, whereas for steep slopes *R=r+x*, and for gently inclined banks *R=r+3x*.

Catchment basin of most ponds usually has a shape of more or less visible hollows. That means that both soil surface and groundwater level are gentle slopes down to the pond [20, 40]. Considering this, it is obvious that after damming water in a pond (if there is a hydraulic connection of water in a pond with groundwater in adjoining area) the groundwater level will also increase. The figure one can see in cross section of a pond will be a cone (Fig. 2). The range of the impact of water damming in a pond on the level of groundwater in the adjoining area can vary from a few dozen to up to a few hundred meters, dependent on the shape of the catchment basin and soil types [11, 19, 40]. In Wielkopolska soil conditions, the range of such impact may even reach 200 m [20]. Thus, when calculating the average increase of groundwater retention it was assumed that the average range of water damming up is 100 meters, when the water level in the pond increases by 1 meter and depends on the height of the dam-up (the 100 m is multiplied by a height of water damming). It means that the higher increase of water level in a pond, the bigger the range of the impact of water damming and the other way round.

The potential increase of groundwater retention ΔV_g was calculated similarly to the one in the case of a water body, assuming that the range of water damming impact is the same in the whole circumference of a pond and is 100(m)*x*, while the geometric figure reflecting the process is a truncated cone with volume ΔV_{gz}. The height of the cone equals the height of water damming in a pond *x*, while the radiuses of its bases are *r* and R_p respectively. Radius *r* equals the radius of the cone, which represents the square area of a water body. Next, radius R_p of the top base of the truncated cone equals the sum of radius *R* and the range of water damming impact *Z=100x*. Radius R_p of the truncated cone with volume ΔV_{gz} was calculated according to the formula (eq.3):

$$R_p = R + 100 \cdot x \quad (3)$$

Volume of the truncated cone ΔV_{gz} was calculated according to the formula eq.4:

$$\Delta V_{gz} = \frac{\pi \cdot x \cdot \left((R_p + r)^2 - R_p \cdot r \right)}{3} \quad (4)$$

The increase of groundwater retention ΔV_g was calculated on the basis of the remainder of volumes of the two truncated cones. The volumes taken into consideration were respectively the volume of the truncated cone, which represents an increase of water in a pond ΔV_o (eq.2), and the volume of a truncated cone, which represents an increase of groundwater retention ΔV_{gz}, while water damming is *x* and the range of damming impact is *Z=100x* (eq.4). The amount of retained groundwater depends obviously on the porosity of soil. It was assumed in the calculations, that for the soils in the Wyskoć catchment area, the value of effective porosity coefficient n_e is 0.12 [19]. Thus, the increase of groundwater retention can be calculated using the following formula (eq.5):

$$\Delta V_g = \left(\Delta V_{gz} - \Delta V_o\right) \cdot n_e \quad (5)$$

Using equations 2 and 4 in equation 5, after reduction, we obtain the following formula (eq.6):

$$\Delta V_g = \left(\frac{\pi \cdot x \cdot \left(R_p^2 + R_p \cdot r - R^2 - R \cdot r\right)}{3} \right) \cdot 0.12 \quad (6)$$

This formula allows us to calculate an approximate increase of groundwater retention around a pond in which water damming is *x*. Also, the ratio of the increase of groundwater retention to the retention of water in a pond was calculated (eq.7):

$$K = \frac{\Delta V_g}{\Delta V_o} \quad (7)$$

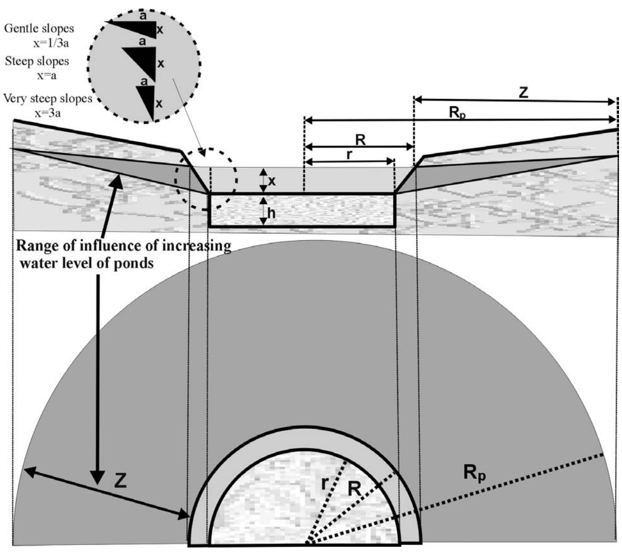

Fig. 2. Scheme used for the calculation of changes of pond and groundwater retention as a result of water level increase in a pond (r – a pond radius before water damming; **R** – a pond radius after water damming; $\mathbf{R_p}$ – a radius of an area where the increase of groundwater retention is observed; **x** – the height of water damming in a pond; **Z** – the range of impact of water damming; **h** – average depth of water in a pond

Using the method described above, all calculations were carried out for several types of ponds: midfield ponds, forest ponds, grassland ponds, wetland ponds and farmstead ponds (located directly near buildings) [5]. Each water body can be classified as one of the above types depending on the kind of land dominating within the area of the pond.

What is more, the assessment of the pond retention capacity as well as the assessment of retention increase were made by dividing the above-mentioned types of water bodies into three classes of ponds with different surface area <0.5 ha, 0.5-1.0 ha and >1.0 ha.

Results

There are 638 ponds with surface area smaller than 2 ha in the Wyskoć catchment. On average there are 3.5 ponds per one square kilometer. Most of them are ponds located in wetlands (212, i.e. 33.2%) and in grasslands (162, i.e. 25.4%). Then, 17.1% of water reservoirs were rated among midfield ponds whereas farmstead and forest ponds constitute 12.7% and 11.6% of water bodies respectively (Table 1). The most numerous in each of the above-mentioned reservoirs are ponds with areas smaller than 0.5 ha and they constitute about 90% of all water bodies of each kind.

The water bodies of the Wyskoć catchment belong rather to very small water ecosystems. The biggest of them are ponds located in wetlands and forests (their average areas are bigger than 2000 m^2), and the smallest of them are midfield ponds (1112 m^2). The average area of a pond in the class with the area below 0.5 ha, is 1050 m^2. Whereas the average area of a pond in the class from 0.5 to 1.0 ha is 7019 m^2 and in the case of water bodies bigger than 1.0 ha, it is about 1.5 ha (Table 1).

The analyzed ponds retain above 562×10^3 m^3 of water which, when calculated by the area of the studied catchment, gives the layer of water about 3 mm thick (Tables 1 and 3). The amount of water retained in the ponds located in wetlands is much bigger than the amount of water retained in other types of water bodies. These ponds retain as much as 41% of the whole amount of water gathered in the analyzed water bodies.

The average retention of a single pond is 881 m^3 (Table 1). The biggest individual retention is observed in wetland and forest ponds, where the average water retention capacity is above 1000 m^3, whereas in the smallest midfield ponds, it is barely 550 m^3. Ponds located in grassland and built-up areas retain about 800 m^3 of water on average. It is worth emphasizing that the smallest water bodies with areas not bigger than 0.5 ha, retain altogether from about 50% (wetland and forest ponds) to about 60% (midfield and farmstead ponds) of water retained in all ponds of a given type.

The shapes and the height of pond banks were analyzed in order to estimate possibilities of increasing the amount of water retained in them. On the basis of this analysis the maximum increase of water level in a pond was established and was found to oscillate between 0.5 to 1.5 m above the current water level in the pond. Thus the established average of the maximum possible increase of the water level above the average water level in a pond observed during the inventory studies is 0.73 m for grassland and wetland ponds, 0.79 m for forest ponds, 0.91 m for farmstead ponds and 1.0 m for midfield ponds (Table 2). Practically in each of the analyzed types of water bodies (apart from farmstead ponds) this parameter reaches the highest value in the class of the smallest ponds with the area smaller than 0.5 ha. Only in the case of farmstead ponds does the value of the parameter increase with the area of the water body and for ponds above 1 ha it is 1.25 m. However, this observation concerns only a very small fraction of ponds. The increase of the retention capacity of water bodies may be possible by the increase of the level of water in the non-outflow ponds (e.g. by retaining drainage outflows) or by water damming (by means of dams) on the flow of out-flow ponds. The assumed values of the water level increase (damming) directly influence the results of the analyses of the increase of the water volume in a pond as well as groundwater in adjoining areas. It was assumed that the accepted height of damming does not cause flooding of the area adjacent to the pond.

During the exploitation of the retention capacities of the water bodies in the studied catchment, it was observed that the volume of water retained in these ponds can be increased by as much as 158%, i.e. by 886×10^3 m^3 (in relation to the current pond retention) (Table 2). This figure calculated by the catchment area gives a layer of water almost 5 mm thick (Table 3). The highest relative increase can be obtained in farmstead (209%) and midfield (188%)

Table 1. Characteristics of ponds in the Wyskoć catchment regarding their area and the amount of water retained.

Types of water bodies	Number of ponds	Area		Current pond retention V_w	
		Total [ha]	Average area [m^2]	Total [10^3 m^3]	Average retention [m^3]
Midfield ponds	109	12.12	1112	60.60	556
< 0.5 ha	104	7.37	709	36.85	354
0.5 – 1.0 ha	4	3.15	7875	15.75	3938
> 1.0 ha	1	1.60	16000	8.00	8000
Grassland ponds	162	25.80	1593	129.00	796
< 0.5 ha	150	15.45	1030	77.25	515
0.5 – 1.0 ha	9	5.75	6389	28.75	3194
> 1.0 ha	3	4.60	15333	23.00	7667
Wetland ponds	212	46.28	2183	231.39	1091
< 0.5 ha	189	22.86	1209	114.29	13
0.5 – 1.0 ha	15	9.99	6660	49.95	3330
> 1.0 ha	8	13.43	16788	67.15	8394
Forest ponds	74	15.26	2063	76.32	1031
< 0.5 ha	67	7.91	1181	39.57	591
0.5 – 1.0 ha	4	3.30	8250	16.50	4125
> 1.0 ha	3	4.05	13500	20.25	6750
Farmstead ponds	81	13.00	1605	65.02	803
< 0.5 ha	75	7.81	1042	39.07	521
0.5 – 1.0 ha	4	3.08	7700	15.40	3850
> 1.0 ha	2	2.11	10550	10.55	5275
PONDS ALTOGETHER					
< 0.5 ha	585	61.40	1050	307.02	525
0.5 – 1.0 ha	36	25.27	7019	126.35	3510
> 1.0 ha	17	25.79	15171	128.95	7585
TOTAL	638	112.46	1763	562.32	881

Table 2. Potential state of water retention in ponds and groundwater retention of the adjacent areas possible to obtain after the damming of water in small ponds of the Wyskoć catchment.

Types of water bodies	Maximum height of damming [m]	Potential increase of water retention									
		In ponds ΔV_o [10^3 m^3]	Average value per pond [m^3]	% of current retention in pond	Groundwater ΔV_g [10^3 m^3]	Average value per pond [m^3]	% of current retention in pond	In ponds and groundwater $\Delta V_o+\Delta V_g$ [10^3 m^3]	Average value per pond [m^3]	% of current retention in pond	Ratio $\Delta V_g/\Delta V_o$
Midfield ponds	1.00	113.77	1044	188	250.88	2302	414	364.65	3345	602	**2.21**
< 0.5 ha	1.01	80.12	770	217	243.67	2343	661	323.79	3113	879	**3.04**
0.5 – 1.0 ha	0.70	22.41	5603	142	5.46	1365	35	27.87	6968	177	**0.24**
> 1.0 ha	0.70	11.24	11237	140	1.75	1752	22	12.99	12989	162	**0.16**
Grassland ponds	0.73	194.01	1198	150	156.66	967	121	350.66	2165	272	**0.81**
< 0.5 ha	0.73	120.09	801	155	140.05	934	181	260.15	1734	337	**1.17**
0.5 – 1.0 ha	0.70	40.92	4547	142	11.41	1268	40	52.33	5814	182	**0.28**
> 1.0 ha	0.70	32.99	10998	143	5.19	1731	23	38.18	12728	166	**0.16**
Wetland ponds	0.72	331.51	1564	143	199.68	942	86	531.19	2506	230	**0.60**
< 0.5 ha	0.72	169.62	897	148	167.15	884	146	336.77	1782	295	**0.99**
0.5 – 1.0 ha	0.70	71.51	4768	143	19.37	1291	39	90.88	6059	182	**0.27**
> 1.0 ha	0.70	90.38	11298	135	13.16	1645	20	103.54	12943	154	**0.15**
Forest ponds	0.79	111.39	1505	146	100.95	1364	132	212.33	2869	278	**0.91**
< 0.5 ha	0.81	63.10	942	159	92.04	1374	233	155.14	2315	392	**1.46**
0.5 – 1.0 ha	0.70	21.56	5391	131	4.76	1190	29	26.32	6581	160	**0.22**
> 1.0 ha	0.63	26.73	8908	132	4.15	1383	20	30.88	10292	152	**0.16**
Farmstead ponds	0.91	135.94	1678	209	172.15	2125	265	308.09	3804	474	**1.27**
< 0.5 ha	0.90	79.09	1055	202	145.32	1938	372	224.41	2992	574	**1.84**
0.5 – 1.0 ha	0.98	30.15	7537	196	14.17	3542	92	44.32	11079	288	**0.47**
> 1.0 ha	1.25	26.70	13349	253	12.67	6333	120	39.37	19683	373	**0.47**
PONDS ALTOGETHER											
< 0.5 ha	0.81	512.02	875	167	788.23	1347	257	1300.26	2223	424	**1.54**
0.5 – 1.0 ha	0.73	186.56	5182	148	55.17	1532	44	241.72	6714	191	**0.30**
> 1.0 ha	0.76	188.04	11061	146	36.92	2172	29	224.96	13233	174	**0.20**
TOTAL	0.80	886.62	1390	158	880.32	1380	157	1766.94	2769	314	**0.99**

ponds. The average relative retention increase obtained in grassland, wetland and forest ponds varies from 143% to 150%. The increase of pond retention capacity depends above all on the area of the pond and the height of its banks. The bigger the area and the higher the banks of ponds, the higher the absolute increase of pond volume retention. However, the relative increase of retention (expressed in the percentage of the current pond retention capacity) in the ponds located in agriculture and built-up areas are bigger than in other types of the analyzed water bodies mainly due to higher banks. Moreover, the relative increase of pond retention is the biggest (besides farmstead ponds) in the class of the smallest ponds, below 0.5 ha. In the scale of the whole catchment and all water bodies with surface area smaller than 0.5 ha, the increase is 167%, while in the ponds with area bigger than 1.0 ha, the increase is barely 146%. The results obtained indicate explicitly that the relative increase of pond retention capacity can be the biggest in the smallest ponds, which are the most numerous in the catchment area.

Water damming in a water body usually results in the increase of groundwater level in the area adjacent to the pond [12, 39, 40]. It was assumed in the calculations that the range of damming impact (*Z*) on the groundwater level is changeable and depends on height (*x*) of damming (*Z=100x*). The higher the level of water damming in a pond, the wider the range of its potential impact and at the level of damming 1 m high, the range of impact amounts to 100 m. The calculated average relative increase of groundwater retention (after the damming/increasing the water level in a pond) in the area adjoining the ponds amounts to 157% of the current pond retention capacity (i.e. $880x10^3$ m^3) (Table 2), which calculated by the area of the catchment gives a layer of water 4.8 mm thick (Table 3).

The highest increase of groundwater retention can be obtained for midfield ponds (as much as 414%) and farmstead ponds (265%). The average increase of groundwater retention calculated for grassland and forest ponds runs at the level of 121-132% and for wetland ponds barely 86% (Table 2). It is worth emphasizing that only in the case of midfield and farmstead ponds is the increase of groundwater retention higher than the increase of retention in the pond and assumes the values from about $30x10^3$ m^3 in the area adjacent to farmstead ponds to over $135x10^3$ m^3 in the area adjacent to midfield ponds. This means that a potentially obtainable groundwater retention increase in the area adjoining the midfield ponds (which have the smallest average areas) is over twice as high as the increase of water in the pond itself. Moreover, the highest absolute and relative increase of the state of groundwater retention is obtainable in the area adjoining the smallest water bodies, with an area not bigger than 0.5 ha. The average increase of the groundwater retention in the area adjacent to these water bodies amounts to 89% (in the scale of all ponds) and varies from 84% (wetland and farmstead ponds) to as much as 97% (midfield ponds) of water that can be gathered in the soil of the area adjacent to respective types of ponds. The relative increase of the groundwater level in the area adjacent to water bodies smaller than 0.5 ha amounts to 257% on average and oscillates from 146% for wetland ponds to as much as 661% for midfield ponds, while in the case of the biggest ponds (with the area above 1.0 ha) such an increase fluctuates from about 20% (midfield, grassland, wetland and forest ponds) to 120% (farmstead ponds). This situation is influenced not only by the surface area of a pond but also by the height of water damming (the higher damming the larger area where groundwater level may increase). The smaller area of a pond and higher the water damming, the bigger the relative increase of groundwater retention (obviously in relation to the current retention level of the pond).

As a result of purposeful actions aimed at increasing the water retention in ponds, the resources of water retained in the catchment can be increased by 1.76 million m^3 (the total increase of reservoir and groundwater retention), i.e. by 314% in relation to the current state of pond retention (Table 2). Such an amount of water gives a layer of almost 10 mm spread on the whole area of the catchment (Table 3). The highest increase of total retention can be obtained for midfield and farmstead ponds. The relative average increase of total retention (for both pond and groundwater) which can be obtained for midfield ponds amounts to 602% and for farmstead ponds up to 474%. Such an increase is even two or three times bigger than in other types of analyzed ponds located in grassland, wetland and forests. In the case of these water bodies, relative increase of total retention varies from 230% (wetland ponds) to 278% (forest ponds). Obviously, the potential relative increase of total retention is the highest for ponds with the area smaller than 0.5 ha and amounts to as much as 879% in the case of midfield ponds. Within each of the analyzed types of water bodies with an area smaller than 0.5 ha, the absolute average increase of total retention varies from 63% for wetland ponds to 89% for midfield ponds (on average 73% for all ponds) of all water that can be totally retained in the water bodies of a given type as well as groundwater in the adjoining areas.

To sum up, it should be emphasized that, in the case of the smallest ponds with the area less than 0.5 ha, a potentially obtainable relative increase of groundwater retention is higher than the increase of reservoir retention (reflected by the calculated ratio $\Delta V_g/\Delta V_o$). The value of the ratio amounts to 1.54 for the above-mentioned ponds in the scale of all ponds of the Wyskoć catchment and fluctuates from 0.99 for wetland ponds to as much as 3.04 for midfield ponds. The increase of groundwater retention that can be obtained after damming water in grassland, wetland and forest ponds is lower than the retention increase in the pond itself (ratio $\Delta V_g/\Delta V_o$ is about 0.6-0.9), mainly due to the bigger average area of these water bodies and lower banks (the lower banks the lower damming is possible and the area where groundwater level may increase is smaller). Taking all the above into consideration, it can be hypothesized that the smaller the pond and the smaller resources of current pond retention of a given water body, the higher the relative increase of

Table 3. Current pond retention and potential increase of water bodies and groundwater retention in the adjoining area, after water damming in the pond, expressed by the thickness (mm) of water layer flooding the area of the whole catchment.

Types of water bodies	Current pond retention V_w	Increase of water retention		
	Total [mm]	In ponds ΔV_o [mm]	In groundwater ΔV_g [mm]	In ponds and groundwater $\Delta V_o+\Delta V_g$ [mm]
Midfield ponds	0.3	0.6	1.4	2.0
Grassland ponds	0.7	1.1	0.9	1.9
Wetland ponds	1.3	1.8	1.1	2.9
Forest ponds	0.4	0.6	0.6	1.2
Farmstead ponds	0.4	0.7	0.9	1.7
PONDS ALTOGETHER				
< 0.5 ha	1.7	2.8	4.3	7.1
0.5 – 1.0 ha	0.7	1.0	0.3	1.3
> 1.0 ha	0.7	1.0	0.2	1.2
TOTAL	3.1	4.9	4.8	9.7

groundwater in the adjoining area can be, in relation to the retention increase in the reservoir itself.

Discussion of Results

The study analyzes retention capacities of small ponds located in the Wyskoć catchment. Moreover, the potentially obtainable increase of the states of groundwater and pond retention was estimated for water bodies located in fields, grassland, wetland, forest and built-up areas.

The obtained results indicate that the smallest ponds in agricultural landscape (with the area smaller than 2 ha) have significant retention capacities and that there are possibilities of increasing water resources in the studied catchment. Thus, these results confirm studies of other authors [2, 3, 16, 18, 41] investigating the problem of assessing morphological parameters and retention capacity of ponds. It should be emphasized that small ponds are very numerous in all landscape types. For example, in the USA the number of small water bodies with area larger than 25 m^2 reaches a value of $9x10^6$ and their average density is about 0.9 pond per km^2 [41]. In the lowland part of Great Britain, there are about $0.4x10^6$ ponds (average density 1.5 water bodies per km^2) [36]. The density of ponds of different landscapes of Europe differs significantly, usually reaching a value of about 0.3-1.5 ponds per km^2 [30, 36, 43, 44, 45]. However, in many areas there are about 10-20 ponds per km^2 [43, 44, 46, 47] or even 100 [48, 49]. As indicated by many authors, the surface area of the majority (even 90-98%) ponds does not exceed 1 ha [42, 50, 51]. Thus, considering that many small ponds have been lost on a large scale during the twentieth century [27], it would be reasonable to use these existing ponds to retain rainwater from drainage systems [2] because this could be one method of effective water body protection [6].

Using ponds with area smaller than 2 ha for retention of drainage water as well as damming water in the outflow ponds will allow an increase, by almost three times, of the amount of water currently retained in those water bodies. Is it much? If we calculate the amount of water retained in water bodies and the potential increment of water stored in them by mm and relate this value to the area of the whole catchment area, we can undoubtedly claim that these values are very small. Since the maximum thickness of water layer accumulated, due to retention procedures in ponds and groundwater of the adjacent areas, can amount only up to 10 mm (calculated by the area of the catchment). However, it should not be forgotten that water from small ponds is usually managed in much smaller areas, limited actually to the borders of their microcatchments. In such a context, the amount of retained water (related to the area of the microcatchments) can even be as thick as several dozen mm [2, 5, 38]. Therefore, the significance of ponds (as small water retention objects) in increasing water resources of the studied region can be very big.

It is a fact of great importance that the biggest relative increase of water pond retention and groundwater retention can be obtained in the case of ponds with the smallest area and the smallest resources of current pond retention. The relative increase of total retention (both pond and groundwater) possible to be obtained in midfield and farmstead ponds is two or even three times bigger than in the case of grassland, wetland and forest ponds. Moreover, this increase surpasses, almost by five or six times, the volume of water retained currently in those water bodies. Therefore, all retention procedures aimed at accumulating drainage water in ponds located in arable areas as well as in rural built-up areas allow to substantial increase of the absolute amount of water retained in the catchment, which is likely very important from the agricultural point of view.

When emphasizing a positive impact of small water bodies with an area smaller than 2 ha which are present in agricultural landscape, it should be stated that the smaller the value of current pond retention and the smaller the size of a pond as well as the higher water damming in a pond, the bigger (under given conditions) the relative increase of pond and groundwater retention capacity in the adjoining areas. Moreover, the smaller resources of current retention and size of a pond, the bigger the relative increase of groundwater retention in relation to the increase of water retention in the pond itself. This thesis is supported by the calculated value of the ratio of groundwater retention increase to pond retention increment.

The proposed method of estimation of pond retention capacity and groundwater retention, after damming (increasing) the water level above certain average annual level of water in a pond, provides fast and relatively easy, analysis of retention capabilities of water bodies. This method is of course based on certain simplifying assumptions, e.g. that there is a constant flow between pond and groundwater and the dynamics of water level fluctuations in a pond is closely connected with the fluctuations of groundwater level in the adjoining area [11, 12, 13, 14]; the average water level in all water bodies of the catchment amounts to 0.5 m [38], which can substantially influence the precision of calculations. Nevertheless, despite these limitations, this method can be an efficient tool used for the assessment of a potentially obtainable increase of water resources in ponds in big areas of river catchments.

Conclusions

1. The use of small ponds located in agricultural landscapes for the retention of drainage water, so far unproductively discharged out of the catchment area, may lead to an increase in the amount of water resources retained in these reservoirs even a few times.
2. For water bodies with surface area less then 0.5 ha, the potential increase of groundwater retention is higher than the retention increase in the pond itself. The smaller the area of the pond and the current retention value of the reservoir, the bigger the retention capacity increase. This means that the smaller the pond and the smaller the value of current water retention, the bigger the increase of groundwater retention in the areas adjacent to the water bodies in relation to the increase of the water level in the pond.
3. The highest increase of water retention capacity can be obtained in midfield and farmstead ponds. These ponds at first should be used for the retention of drainage water. Such a procedure will enable an increase of the water resources of the catchment, but more importantly will prolong the time and manner of water circulation in the landscape, which is the essence of so-called small water retention.
4. The presented method should be used to fast, easy and cheap macro-scale estimation of pond retention capacity as well as the potential possibility to receive increments of water volume stored in ponds and soils of areas adjoining ponds.

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References

1. MIODUSZEWSKI W. Protection of water-related ecosystems and their role as water suppliers. Polish National Report. Seminar on the role of ecosystems as water suppliers (Geneva, 13-14 December 2004). pp 1-9, **2004**.
2. NAKANISHI N. Potential rainwater storage capacity of irrigation ponds. Paddy Water Environment **2**, 91, **2004**.
3. JAIN A.K. The concept of bio-drainage in flood prevention and the avoidance of water scarcity. International Journal of Environmental Studies **63**(1), 39, **2006**.
4. KOWALCZAK P., FARAT R., KĘPIŃSKA-KASPRZAK M., MEGER P., PIETRAS W. Hierarchy of aerial small water retention need. Materiały Badawcze, Seria: Gospodarka wodna i ochrona wód **19**, 90, **1997**. [in Polish].
5. JUSZCZAK R. Inventory and valorization of small water reservoirs of the Wyskoć catchment [in Polish]. PhD Thesis. Dept. of Agrometeorology, Agricult. University of Poznań, Poland. pp 194, **2004**.
6. KĘDZIORA A., JUSZCZAK R. Aquatic ecosystems of rural areas. Postępy Nauk Rolniczych **3**(315), 87, **2005**. [in Polish].
7. RYSZKOWSKI L., BAŁAZY S., KĘDZIORA A. Management and protection of water resources of rural areas. Zakł. Bad. Środ. Roln. i Leśn. PAN: Poznań. pp 70, **2003**. [in Polish].
8. JUSZCZAK R., KĘDZIORA A. Water retention of small ponds in the western part of the Wyskoć catchment. Roczniki AR Poznań **25**, 193, **2004**. [in Polish].
9. WINTER T.C. Relation of streams, lakes, and wetlands to groundwater flow systems. Hydrogeology Journal **7**, 28, **1999**.
10. WINTER T.C. Ground water and surface water: the linkage tightens, but challenges remain. Hydrological Processes **15**, 3605, **2001**.
11. HAYASHI M, ROSENBERRY D.O. Effects of groundwater exchange on the hydrology and ecology of surface waters. Journal of Groundwater Hydrology **43**, 327, **2001**.

12. SOPHOCLEOUS M. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal **10**, 52, **2002**.
13. VAN DER KAMP G, HAYASHI M, GALLEN D. Comparing the hydrology of a grassed and cultivated catchments in the semi-arid Canadian prairies. Hydrological Processes **17**, 559, **2003.**
14. MACRAE M. L., BELLO R. L., MOLOT L. A. Long-term carbon storage and hydrological control of CO2 exchange in tundra ponds in the Hudson Bay Lowland. Hydrological Processes **18**, 2051, **2004**.
15. WOO M.K., GUAN X.J. Hydrological connectivity and seasonal storage change of tundra ponds in a polar oasis environment, Canadian High Arctic. Permafrost and Periglac. Process. **17**, 309, **2006**.
16. MIODUSZEWSKI W. Management of water resources in agricultural landscape. In: Protection and sustainable development of rural areas. (Ed. by Brandyk T.), Wyd. SGGW, Warszawa. pp 93-103, **1996**. [in Polish].
17. NYC K., POKŁADEK R. Role of small damming in moulding of groundwater resources. Zesz. Probl. Post. Nauk. Roln. PAN. **438**, 83, **1996**. [in Polish].
18. RYSZKOWSKI L., KĘDZIORA A. Small water retention in agricultural landscape. Zesz. Nauk. AR Wrocław, Konf. XI. **289**, 217, **1996**. [in Polish].
19. Drainage principles and applications. Ed. RITZEMA H.P., Inst. for Land Reclamation and Improvement. Wageningen, The Netherlands, ILRI Publication 16, Second edition, pp. 1107, **1994.**
20. KOSTURKIEWICZ A., SZAFRAŃKI CZ., CZOPOR S., KORYTOWSKI M., STASIK R. Relationships of water level of mid-forest ponds with ground water level in adjoining forest areas. In: Functioning of geo-ecosystems in differentiated morpho-climatolgical conditions – monitory, protection, education. Ed. by A. Karczewski, Z. Zwoliński, Stowarzyszenie Geomorfologów Polskich: Poznań. pp 237-250, **2001**. [in Polish].
21. The Pond Life Project. The Development and Implementation of a Conservation Model to Integrate Small Water Bodies into the Planning and Management of the Agricultural Landscape of North West England. LIFE94/A151/UK/00651/NOW. TECHNICAL REPORT. Liverpool John Moores University http://www.ljmu.ac.uk/pondlife/finreport.htm, **1999**.
22. NICOLET P. 25 years of change in the plant communities and conservation value of some Cheshire ponds. In: Proceedings of the ponds Conference 1998. Pond Action, Oxford, pp 49-55, **2000**.
23. Vanishing ponds in a Limestone landscape. A report produced for the Limestone Heritage Project Arnside/Silverdale Area of Outstanding Natural Beauty Arnside/Silverdale AONB Management Service, pp 36, **2003**.
24. OLDHAM R.S., SWAN M.J.S. Pond loss and amphibians: Historical Perspectives. In: British Pond Landscape, (Ed. by J. Boothby). Proceedings of the UK Conference of the Pond Life Project, 7-9 September 1997, Liverpool, **1997**.
25. JUSZCZAK R., KĘDZIORA A. Threats and deterioration of small water reservoir located within Wyskoć catchment. Polish Journal of Environmental Studies, **12**(5), 567, **2003**.
26. JUSZCZAK R., KĘDZIORA A., LEŚNY J., OLEJNIK J**.** Change in the number of ponds in the Wyskoć catchment during the period 1983-2003 and characteristics of the newly excavated ponds. Journal of Water and Land Development, **10**, 109, **2006**.
27. HULL A. The pond life project: a model for conservation and sustainability. In: British Pond Landscape (Ed. by J. Boothby). Proceedings from the UK conference of the Pond Life Project. Pond Life Project, 7-9 September 1997, Liverpool, pp 101-109, **1997**.
28. KALETTKA T. Die Problematik der Soelle (Kleinhohlformen) im Jungemoraenengebiet Nordostdeutschland. Naturschutz u. Landschftsplege in Brandenburg, Sonderheft "Soelle", pp 4-12, **1996**.
29. BÜLOW-OLSEN A. Disappearance of ponds and lakes in southern Jutland, Denmark 1954-1984. Ecological Bulleteins, **39**, 180, **1988**.
30. PIEŃKOWSKI P. Disappearance of ponds in the younger Pleistocene landscape of Pomerania. Journal of Water and Land Development, **4**, 55, **2000**.
31. BARTOSZEWICZ A. Chemical composition of surface water of intensive agriculturally managed catchment in climatic-soil conditions of the Kościan Plain. Roczn. AR Poznań, pp 60, **1994**. [in Polish]
32. BIGGS J., FOX G., NICOLET P., WALKER D., WHITFIELD M., WILLIAMS P. A guide to the methods of the National Pond Survey. Pond Action, Oxford, pp 22, **1998**.
33. BIGGS J., WILLIAMS P., BARR C., CUMMINS C., GILLESPIES M., RICH T., BAKER A., BAKER J., BEESLEY J., CORFIELD A., DOBSON D., CULLING A., FOX G., HOWARD D., LUURSEMA K., RICH M., SAMSON D., SCOTT A., WHITE R., WHITFIELD M. The ecological quality of ponds in Britain – the results of the DETR Lowland Pond Survey. In: Proceedings of the Pond Conference 1998. Pond Action, Oxford, pp 18-22. **2000.**
34. COLLINSON N.H., BIGGS J., CORFIELD A., HODSON M.J., WALKER D., WHITFIELD M., WILLIAMS P.J. Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. Biological Conservation **74,** 125, **1995**.
35. WILLIAMS P., WHITFIELD M., BIGGS B., BRAY S., FOX G., NICOLET P., SEAR D. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biological Conservation **115**(2), 329, **2004**.
36. WILLIAMS P., BIGGS J., WHITFIELD M., THORNE A., BRYANT S., FOX G., NICOLET P. The Pond Book: A Guide to the Management and Creation of Ponds. Ponds Conservation Trust: Oxford. pp 105, **1999**.
37. BROWN C.D., TURNER N., HOLLIS J., BELLAMY P., BIGGS J, WILLIAMS P., ARNOLD D., PEPPER T., MAUND S. Morphological and physico-chemical properties of British aquatic habitats potentially exposed to pesticides. Agriculture, Ecosystems and Environment **113**, 307, **2006**.
38. DRWAL J., LANGE W. Some limnological distinctions of ponds. Zeszyty Naukowe Wydz. Biol. Geogr. i Ocean. UG,

Geografia. **14**, 69, **1985.** [in Polish].
39. NYC K., POKŁADEK R. The significance of small dams in shaping of groundwater resources. . Zesz. Probl. Post. Nauk. Roln. PAN, 438, 83, **1996**. [in Polish].
40. FIEDLER M., SZAFRAŃSKI CZ. Variation of ground-water levels in the catchment of the midfield pond located at Gniezno Lakeland. Roczniki AR Poznań **20**, 403, **1999.** [in Polish].
41. PHILIPS P.J., SHEDLOCK R.J. Hydrology and chemistry of groundwater and seasonal ponds in the Atlantic Coastal Plain in Delaware, USA. Journal of Hydrology **141**, pp 157-178, **1993**.
42. SMITH S.V., RENWICK W.H., BARTLEY J.D., BUDDEMEIER R.W. Distribution and significance of small, artificial water bodies across the United States landscape. The Science of the Total Environment **299,** pp 21-36, **2002**.
43. BRIAN A.D., PRICE P.S., REDWOOD B.C., WHEELER E. The flora of the marl-pits (ponds) in one Cheshire parish. Watsonia **16**, 417, **1987**.
44. WILLIAMS P.J., BIGGS J., BARR C.J., CUMMINS C.P., GILLESPIE M.K., RICH T.C.G., BAKER A., BAKER J., BEESLEY J., CORFIELD A., DOBSON D., CULLING A.S., FOX G., HOWARD D.C., LUURSEMA K., RICH M., SAMSON D., SCOTT W.A., WHITE R., WHITFIELD M. Lowland Pond Survey 1996. Department of the Environment, Transport and the Regions, London, **1998**.
45. RICH T. A comparison of the ponds in the County of Cardiff with the national statistic from the lowlands Ponds Survey 1996. In: Proceedings of the Ponds Conference 1998. Pond Action, Oxford, pp 23-29, **2000**.
46. BOOTHBY J. Ponds and other small water-bodies in North-West England: an audit. In: Boothby J. (ed.) British Pond Landscape. Action for protection and enhancement. Pond Life Project, Liverpool, **1997**.
47. NOWICKI Z. Degradation of small ponds in the Mazurskie Lakeland. Roczniki AR Poznań, **19(2)**, 365, **1997**. [in Polish]
48. DYNOWSKA I., TLAŁKA A. Hydrography. Wyd. PWN, Poznań, **1982**. [in Polish]
49. WILLIAMS P., BIGGS J., WHITFIELD M., FOX G., NICOLET P. Ancient ponds and modern landscapes. In: Proceedings of the Ponds Conference 1998, Pond Action, Oxford, pp 10-17, **2000**.
50. SWAN M.J.S., OLDHAM R.S. Implication of the Lowland Pond Survey for the conservation of British amphibians. In: Proceedings of the Ponds Conference 1998, Pond Action, Oxford, pp 66-71, **2000**.
51. OERTLI B., JOYE D.A., CASTELLA E., JUGE R., CAMBIN D., LACHAVANNE J.B. Does size matter? The relationship between pond area and biodiversity. Biological Conservation **104**, 59, **2002**.