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The influence of weather conditions on mid-field ponds situated in a reclaimed area in Sępopolska Plain

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Abstract

The investigations were conducted in northeastern Poland near Lidzbark Warmiński (54° 08" N, 20° 36" E). Five mid-field ponds situated on grasslands were chosen: four of them were dredged and deepened, and one of them remained as a natural reservoir. The aim of this paper was to assess the influence of weather conditions on the quantity and quality of water in mid-field ponds situated in agricultural areas. It was found that the quantity of water in mid-field ponds was related much more to the air temperature, which was responsible for either water evaporation or snow melting, rather than to the amount of precipitation. The reduction in the volume of water stored in the ponds during very dry years had a negative influence on its quality. During the

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observation period, the dredged ponds were characterized by permanent water tables, whereas the natural reservoir dried out in very dry years. Atmospheric conditions influenced the concentrations of ammonium nitrogen and calcium and chlorine ions in the studied water bodies. The volume of water retained in mid-field ponds influenced the concentrations of phosphorus and sulphates. Increased precipitation sums caused lower water pH; however in warmer periods, at increased pH and COD_{Cr}, a decrease in dissolved oxygen was noted. It was revealed that increases in precipitation sums during the year caused increases in the load of mineral nitrogen and calcium and magnesium ions in pond water.

INTRODUCTION

The young glacial landscape in the north of Poland is characterized by topography with numerous mid-field water reservoirs colloquially known as ponds. The volume of water in these reservoirs is limited by water supply from the water table, overland and subsurface flows, as well as water filtration from adjacent areas. Decreases in water stages in these reservoirs occurs from water surface evaporation and infiltration from ponds (Fiedler 2001). The retention of water in small reservoirs in agricultural areas stabilizes water resources in these areas, has a favorable influence on local microclimates, and supports biodiversity. It also prevents the unproductive outflow of water to receivers. Mid-field ponds are most often the only habitats in farmlands that protect natural species of flora, fauna, and their biocenoses (Koc et al. 2001).

In recent years, a continual decrease in the number of small water bodies has been observed. The reason for this is said to be unfavorable environmental conditions as well as human activity, such as drainage combined with intensive farming, which lead to the ponds becoming defunct or drained (Skwierawski 2005). In agricultural practice, the ponds are seen as obstacles, especially during agricultural or technical work, or as unnecessarily occupying tillage area.

Some reservoirs are components of reclamation systems. Dewatering devices, especially in spring, may cause the rapid outflow of excess water and decreases in ground water tables. However, when mid-field ponds dry out temporary water table deficits may occur in summer when unfavorable meteorological conditions coincide with decreased groundwater levels. Correctly designed and executed drainage systems ensure permanent water tables in reservoirs. Water from drainage systems may be used for reservoir supply. Nevertheless, outflows from drainage networks should not be viewed as reliable sources of water for ponds due to periodical shortages especially in dry periods when water supply is most desirable (Fiedler 2001).

The aim of this paper was to assess the influence of weather conditions on the quantity and quality of water in mid-field ponds situated in an agricultural area.

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MATERIALS AND METHODS

The area investigated is located in the southwestern part of the Sępopolska Plain near the town of Lidzbark Warmiński (54° 08" N, 20° 36" E). The relief of the terrain was shaped mainly by the Scandinavian glacier, and the surface of the terrain undulates with slopes up to 15%, but most are between 2 and 4%. The area is covered by fallows, with trees and shrubs growing only on pond shorelines. The investigated area is covered by brown soils comprised of medium and heavy clays and loams. The ponds investigated are situated in flat terrain with low surface outflow. The area of interest consists primarily of arable land (almost 60% of the area) and grasslands used as temporary pastures (about 31% of the area). The rest of the terrain is occupied by surface waters and built-up areas. During the investigated period of 1998-2004, the grasslands were fertilized each year with ammonium nitrate in four doses of 187 kg of N ha^{-1}. Only in 2000, due to financial difficulties, were these areas not fertilized. No pesticides were applied during the investigated period.

The area was drained in 1998. The drainage system was set at a depth of 0.9 m on both arable and grass lands. The distance between drains ranged from 9 to 22 m. During the reclamation process, each pond and swamp with stable water levels for the prevailing part of year was dredged and deepened to an average depth of 1.0 – 1.5 m. The pipelines were set in at least full distance from the banks to protect water levels in the reservoirs against the influence of the drainage system.

Five mid-fields ponds were chosen for the investigations. They are located on grasslands (four of them were deepened during reclamation works while one was left in its natural state). The basic morphological parameters of the reservoirs are presented in Table 1.

Table 1

Fundamental morphological parameters of the mid-field ponds

Type of pond		[m]	Width [m]	Maximal depth [m]	Mean depth [m]	Water level surface	Drainage basin surface area of pond [ha]
Dredged	1	17.0	16.2	2.66	1.14	244.0	4.05
	2	15.1	10.7	1.55	0.88	152.0	0.61
	3	21.0	19.5	1.46	0.91	330.0	3.70
	4	24.0	19.2	1.29	0.79	346.0	2.03
Not dredged	5	48.8	20.2	1.44	0.34	638.0	1.23

During the investigated period, physical and chemical water parameters were analyzed as follows: dissolved oxygen concentration was determined with the potentiometrical method; pH was determined with a WTW MultiLine P3

meter; electrolytical conductivity was determined with a Hanna Instruments Hi 8733 meter. The collected water samples were subjected to chemical analyses performed with methods described by Hermanowicz et al. (1999) as follows: nitrate (V) nitrogen; nitrate (III) nitrogen; ammonium nitrogen; total phosphorus; phosphorus phosphate; COD_{Cr}; sulphates; magnesium; chlorides; calcium.

Meteorological data recorded for 24-hour periods at stations in Lidzbark Warmiński administered by the Institute of Meteorology and Water Management (IMGW) regarding high precipitation, air temperature and relative humidity, and wind velocity of 10-15 m during the 1998-2004 period were used in the current paper. Evaporation from the water reservoirs was calculated using the Tichomirow and Iwanow formulas (Szwejkowski et al. 2002). Climatic water balance was calculated as the difference between the sums of precipitation and evaporation.

RESULTS AND DISCUSSION

In the 1998-2004 period, four humid hydrological years, one normal year (precipitation ±10% in reference to the average of 627 mm from 1971-2001), one dry year (2000), and one very dry (2003; Table 2) were designated according to criteria proposed by Kaczorowska (1962). The hydrological year of 2003 was characterized by the lowest annual precipitation sum (only 450 mm) and the lowest mean annual air temperature (6.7°C), which was lower by 0.5°C in comparison to the 1971-2001 period. The highest mean annual air temperature (8.7°C) was in 2002, which was classified as normal, and was 1.5°C higher than the long-term mean.

The results of evaporation calculated using the Tichomirow and Iwanow formulas showed some differentiation; however, there were some similar tendencies in changes. The highest evaporation value (790 mm) was noted in the year with the highest mean annual air temperature, which was classified as normal. Somewhat lower evaporation values were noted in 2003 which was very dry in terms of precipitation but had the lowest mean annual air temperature. In that year the largest rainfall deficit was -164 mm. Negative climatic water balances were noted in 2000 (dry) and 2002 (normal), while the climatic water balance was positive in humid years.

The retention capabilities of water reservoirs are determined foremost by their surface, depth, and basin shape (Hubbard and Lindner 1986). The capacity of ponds at medium water level in the hydrological years analyzed indicated considerable lability, which was independent of the precipitation quantity classifications of the year (Table 3).

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Table 2

Atmospheric conditions in the investigated period

Hydrological year	Precipitation		Mean annual air temperature	Evaporation calculated according to			Climatic water balance
	total	classification of year		Tichomirow	Iwanow	mean	
	mm	-	°C	mm	mm	mm	mm
1998	735	humid	7.8	460	388	424	311
1999	784	humid	7.4	531	465	498	286
2000	550	dry	8.2	587	590	588	-38
2001	751	humid	8.4	580	546	563	188
2002	675	normal	8.7	842	739	790	-115
2003	450	very dry	6.7	655	572	614	-164
2004	831	humid	7.7	543	531	537	294

Table 3

Water retention quantity in mid-field ponds during the investigated period [m^3]

Hydrological year		Dredged ponds				Non-dredged pond
		1	2	3	4	5
1998 humid	**mean**	236	129	278	290	-
	range	164-315	124-140	255-305	280-300	-
1999 humid	**mean**	313	138	324	285	-
	range	290-330	116-150	300-370	250-315	-
2000 dry	**mean**	275	111	312	264	238
	range	195-346	66-150	280-340	195-350	75-480
2001 humid	**mean**	258	107	315	276	84
	range	195-320	65-140	305-342	200-320	75-110
2002 normal	**mean**	309	138	375	328	162
	range	250-345	120-160	307-420	275-385	80-205
2003 very dry	**mean**	165	73	162	132	80
	range	115-223	43-116	130-195	80-205	0-150
2004 humid	**mean**	312	86	197	110	165
	range	250-330	50-104	175-205	80-120	0-200

- no data available

The highest and mean water retention levels in individual ponds were noted during years with diverse precipitation quantities (humid, normal, or dry years); meanwhile the lowest were in the dry year (2003). In August 2003, the pond that had not been dredged and was located outside of the reclaimed area dried up. The water table was renewed after five months. All of the dredged ponds maintained their water tables throughout the investigated period. Fiedler (2005) reported different results from studies of the Gnieźnieńskie Lakeland, where,

during years with precipitation shortages, mid-field water ponds dried up despite connections to reclamation systems. The annual amount of precipitation affected directly the retention level in mid-field ponds in very dry years only when other water sources were lacking, i.e., when the groundwater level decreased so much that infiltration into the reservoirs became impossible, or the water supply from reclamation systems stopped. This is confirmed by statistical analysis (Table 4), which proved that precipitation did not statistically significantly influence the quantity of water accumulated in mid-field reservoirs. Air temperature and evaporation related to temperature, however, did have an extremely significant influence on water quantity.

Table 4

Value of the parameters of Pearson linear correlation describing the influence of weather conditions on the volume of stored water in mid-field ponds

Variable		Air temperature	Atmospheric precipitation	Evaporation calculated with various methods	
				Iwanow	Tichomirow
Volume of retained water		-0.22**	0.05	-0.22**	-0.20**
Air temperature			0.43**	0.91**	0.91**
Atmospheric precipitation				0.29**	0.36**
Evaporation calculated according to	Iwanow				0.98**
	Tichomirow				1.00**

** level of significance $p < 0.01$; $N = 195$

Many investigations have shown that weather conditions are important factors that impact the quality of water in ponds (Fiedler 2005, Koc and Cymes 2004). Precipitation can have an impact in two ways; enrichment in nutrient compounds can occur when precipitation falls directly on the pond surface or when rafting (superficial or subsurface) supplies water that is more polluted than that in the pond (Arheimer and Linden 2000). However, if purer water reaches a pond it dilutes the water, thus improving quality. On the other hand, decreased pond water volume resulting from evaporation can cause increases in concentrations of various compounds, particularly those which have low environmental mobility. For this reason, concentrations of some substances measured in pond water were higher in humid years (nitrate (V) nitrogen, calcium and chlorine ions), while others were higher in the very dry year (ammonium nitrogen, total phosphorus, magnesium and sulfate ions; Table 5). However, the comparison of concentrations to the limits for water quality classification (Regulation 2004) indicated that the water in reservoirs in humid, normal, and dry years can be categorized as class IV, and only in the very dry

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Table 5

Means and ranges of values of physical and chemical indices in investigated waters during years differing in precipitation

Index		Year classification according to annual precipitation			
		humid	normal	dry	very dry
Electrolytic conductivity (μS cm^{-1})	mean	519	387	458	456
	range	170-1078	202-702	203-865	200-740
Reaction (pH)	mean	7.46	7.09	8.13	7.44
	range	6.35-9.30	6.52-7.37	6.98-9.93	6.95-9.63
Dissolved oxygen content (mg·dm^{-3})	mean	8.02	6.92	8.54	9.04
	range	1.94-28.40	2.63-11.58	2.99-18.40	3.77-15.12
Nitrate (III) nitrogen (mg dm^{-3})	mean	0.016	0.029	0.005	0.007
	range	0.001-0.564	0.001-0.204	0.001-0.018	0.004-0.018
Nitrate (V) nitrogen (mg dm^{-3})	mean	0.43	0.20	0.22	0.81
	range	0.01-13.28	0.01-0.99	0.03-1.82	0.06-5.12
Ammonium nitrogen (mg dm^{-3})	mean	0.60	0.51	0.39	0.24
	range	0.01-2.78	0.10-0.97	0.09-1.16	0.09-0.42
Total phosphorus (mg dm^{-3})	mean	0.60	0.32	0.47	0.69
	range	0.07-8.87	0.07-0.89	0.04-1.40	0.15-1.28
Phosphate phosphorus (mg dm^{-3})	mean	0.25	0.64	0.22	0.39
	range	0.01-1.72	0.03-2.76	0.01-0.98	0.06-0.74
Calcium (mg dm^{-3})	mean	66.4	53.7	63.5	59.8
	range	12.0-142.0	28.9-101.0	27.6-130.0	21.8-101.0
Magnesium (mg dm^{-3})	mean	11.5	7.8	8.0	14.3
	range	1.2-40.5	2.5-30.5	1.8-15.2	4.0-31.2
Chlorides (mg dm^{-3})	mean	19.8	12.9	18.0	9.0
	range	4.0-46.0	2.0-33.0	1.8-43.0	0.5-19.0
Sulphates (mg dm^{-3})	mean	114	54	90	189
	range	4-400	1-168	1-324	13-570
COD_{Cr} (mg dm^{-3})	mean	58	46	52	67
	range	19-214	13-154	14-180	33-154

year to class V (poor quality). The indicator which was the most detrimental to water quality was COD_{Cr}.

The relation between weather conditions and water quality in the studied mid-field ponds was assessed using correlation coefficients among the definite physical and chemical indicators and the qualification of precipitation sums, air temperature, evaporation, and the volume of retained water (Table 6).

The increase in precipitation and air temperature as connected with evaporation had a significant or even extremely significant influence on decreases of ammonium nitrogen, calcium, and chlorine concentrations.

Table 6

Values of Pearson's linear correlation coefficients that describe the influence of weather conditions on retained water quality in mid-field ponds

Variable	Atmospheric precipitation	Air temperature	Evaporation calculated according to		Volume of retained water
			Iwanow	Tichomirow	
Electrolytic conductivity	-0.11	-0.10	-0.13	-0.10	-0.28**
Reaction	-0.16*	0.26**	0.27**	0.17*	-0.10
Dissolved oxygen content	-0.14	-0.18*	-0.24**	-0.27**	-0.02
Nitrate (III) nitrogen	0.09	0.09	-0.00	0.01	-0.12
Nitrate (V) nitrogen	0.07	0.03	-0.02	0.01	0.01
Ammonium nitrogen	-0.19**	-0.43**	-0.38**	-0.37**	0.00
Total phosphorus	-0.03	-0.00	0.02	0.01	-0.19**
Phosphate phosphorus	0.03	0.07	0.11	0.10	-0.39**
Calcium	-0.20**	-0.17*	-0.18*	-0.17*	-0.05
Magnesium	-0.09	-0.09	-0.10	-0.06	-0.13
Chlorides	-0.17*	-0.20**	-0.28**	-0.29**	-0.14
Sulphates	-0.05	-0.06	-0.06	-0.05	-0.15*
COD_{Cr}	0.13	0.26**	0.23**	0.23**	0.11

* level of significance $p < 0.05$; ** level of significance $p < 0.01$; N = 195

Although increased precipitation decreased water pH, in warmer periods pH and COD_{Cr} values increased simultaneously with the decrease in dissolved oxygen content. Increases in retained water volume influenced decreases in the electrolytic conductance of the water in mid-field reservoirs as well as decreases in phosphorus and sulphate concentrations due to dilution.

The impact of precipitation on water quality in ponds appeared in the load of dissolved substances (Table 7). The mineral nitrogen and calcium and magnesium ion loads increased along with precipitation sums. The mid-field pond water was enriched with substances that came directly from rainfall but

Table 7

Influence of year precipitation classification on the dissolved substances load in the water of mid-field reservoirs (kg)

Parameter	Type of year in relation to annual precipitation			
	humid	normal	dry	very dry
Nitrate (III) nitrogen	0.003	0.010	0.001	0.001
Nitrate (V) nitrogen	0.102	0.059	0.062	0.136
Ammonium nitrogen	0.139	0.139	0.089	0.028
Total phosphorus	0.127	0.067	0.097	0.076
Phosphate phosphorus	0.049	0.172	0.042	0.040
Calcium	15.207	15.118	15.095	7.855
Magnesium	2.573	2.227	1.922	1.980
Chlorides	4.479	3.840	4.133	1.402
Sulphates	25.700	17.420	20.064	27.179

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also indirectly through leaching from the drainage basin through superficial or subsurface flows.

CONCLUSIONS

1. Annual precipitation had no significant influence (except in the very dry year) on the quantity of water accumulated in the mid-field reservoirs, while air temperature and evaporation had extremely significant influences on water retention in the analyzed ponds.
2. All the dredged ponds located in the drained area retained water throughout the investigation period; however, the natural reservoir that had not been deepened and was located beyond the reclaimed area dried up in the very dry year.
3. Water in the reservoirs in humid, normal, and dry years was class IV, and only in the very dry year was it class V (poor quality). The parameter that most often led to the deterioration of water class was COD_{Cr}.
4. Increased annual precipitation sums and air temperatures influenced decreases in concentrations of ammonia nitrogen and calcium and chlorine ions in the pond water. Increases in the water volume stored in the mid-field reservoirs caused decreases in the concentration of phosphorus and sulphates.
5. Although increased precipitation sums decreased water pH, in warmer periods pH and COD_{Cr} values increased with the simultaneous decrease in dissolved oxygen.
6. It was found that increased precipitation affected mineral nitrogen loads in pond water as well as calcium and magnesium ions.

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