Contemporary Problems of Management and Environmental Protection
Vol. 2, 2009. Wetlands - Their Functions and Protection: 187-204

Chapter XI

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Environmental effects of drainage of agriculturally-utilized areas

INTRODUCTION

The major source of water in the natural environment is precipitation. Its volume and time variability depend on its geographical zone, whilst the moisture status of habitats and ecosystems is determined by the topographic profile and geological structure of the crust of the Earth. The distribution of precipitation waters onto surface and ground flows is linked with the topographic features of the Earth, the compaction of the superficial and deeper underground layers of soil as well as with the presence and type of vegetation cover (ALLEN, CHAPMAN 2001; MIODUSZEWSKI 2006; OKRUSZKO 1997). Under climatic conditions of Poland, the greatest resources of surface and ground waters occur in the spring time, whereas the smallest ones occur in the autumn and winter. A consequence of this naturally-occurring high time variability of precipitation is a considerable fluctuation in the levels of ground and surface waters, which – in turn – results in both periods of extreme deficits and excesses of water. Nature, unlike agriculture, is naturally adjusted to such changes. In agriculture, both a deficit and excess of water may involve substantial reductions in crop yields (MIODUSZEWSKI 2006).

Changes in the structure of the water balance in the environment are affected, to a great extent, by the mode of land development, including the occurrence of water bodies, boggy areas and forests, as well as by agriculture. The greatest capability for retention of waters and biogenes is typical for peatlands not subjected to anthropopression. Unfortunately, the need to increase the cropping area has often been satisfied through a reduction of their number and range of their occurrence. As the result of drainage practices applied, a large number of small mid-field water bodies have been devastated, whereas swamps and wetlands have been drained, and finally those areas have been assigned for crop cultivation. Drainage of wetlands for agricultural management not only diminished their retention capacity but also accelerated mineralization of the accumulated organic mutter, thus contributing to the release of biogenic substances accumulated over a number of years (KOC et al. 2002; KIRYLUK 2002; PIAŚCIK et al. 2000; SZYMCZYK, SZYPEREK 2005).

The introduction of mineral fertilization and an increased population of animals (and thus the use of organic fertilizers) have elicited an expected increase in crop yield. Higher yields involve increased consumption of water for transpiration, which may significantly aggravate water deficit, especially in longer drought spell periods. More intensively exploited areas are usually subject to reclamation, which assures faster circulation of matter (water) and energy (heat). It is especially beneficial in the case of excessively moist heavy soils. Nevertheless, high time variability and volume of atmospheric precipitation enforces in-depth verification of needs and range of soil drainage (ALLAN, CHAPMAN 2001; MIODUSZEWSKI 2006; OKRUSZKO 1997; SOLARSKI et al. 2005).

Ecosystems functioning in the natural environment are usually characterized by a closed circuit of matter, the whole bulk of which remains in a particular ecosystem and is subject to slower or more rapid transformations (SAPEK 1996). Introduction and development of farming practices have disturbed the natural circuit of matter in the environment. Fertilization applied in excessive doses and inappropriate ways also contributes to the dispersion of high quantities of components in the environment and results in contamination of soils, ground and surface water. Water eutrophication leads to an intensification of primary production and diminished biodiversity (KOC et al. 2002; MIRANDA, MATVIENKO 2003; SAPEK 1996; SAPEK 1998; SZYMCZYK, GLIŃSKA-LEWCZUK 2007).

An important source of soil enrichment with chemical compounds is atmospheric precipitation, especially its volume, intensity, seasonal variability and chemical composition. It additionally affects the tendencies and intensity of edaphic processes and, consequently, determines the quality of ground waters. A potential detrimental effect of the load of substances reaching surface or ground waters is determined by its size and chemical composition, as well as the mode of land development. Contaminated precipitation waters are the most deleterious in areas where the upload of substances considerably exceeds the natural capabilities of their neutralization. Non-utilized components, especially in the areas with light soils, migrate rapidly thus contributing to the contamination of ground and surface waters (DURKIWSKI, KORYBUT WORONIECKI 2009; KOC et al. 2003; MIRANDA, MATVIENKO 2003; SZYMCZYK, CYMES 2005). Reclamation of soils, both mineral and organic, causes acceleration of the outflow of water and substances and restricts the feeding of locally-occurring boggy areas and small water bodies, thus contributing to their degradation (SAPEK, SAPEK 2004; SZYMCZYK, GLIŃSKA-LEWCZUK 2007).

ENVIRONMENTAL DETERMINANTS OF THE QUALITY OF WATERS

Water constitutes a dynamic system of water mixed with dissolved substances, suspensions and gases, which displays considerable variability in time and space. Processes ongoing in waters are interrelated with one another. Depending on their character, they may be divided into: physical, chemical, biogeochemical, biologically-chemical and others (MACIOSZCZYK, DOBRZYŃSKI 2002). The most significant environmental factors affecting the quality of waters include:

a) Land relief and topography – intensity of the process of the water exchange system determines its chemistry and mineralization;
b) Hydrography – density of a hydrographic network, depth of erosive incisions, chemistry of surface waters and contact of surface waters with ground waters;
c) Climate
    - atmospheric precipitation – its volume as well as time and spatial distribution of precipitation and its chemical composition determine the intensity of water infiltration and outflow of components from the aeration zone to ground and surface waters,
    - air temperature – modifies the intensity of evaporation, air humidity, generation of precipitation, generation of winds as well as the course of weathering and dissolution of minerals and development of soil and plant cover,
    - wind – transfer of air-masses determines the chemistry of precipitation and marine aerosols,
    - climatic circulation of waters – under the influence of solar energy, the water evaporates, then after condensation, it returns to land areas in the form of precipitation and forms superficial, under-superficial or under-ground outflow,
    - climatic zone – the variability of chemistry is affected by the climatic zone;
d) Soils – changes in the intensity of transfer and chemistry of precipitation waters infiltrating through the aeration zone are determined by: type, fertility, thickness and biological activity of soils, including: a change of gas equilibrium, reaction and salinity of precipitation waters (MACIOSZCZYK, DOBRZYŃSKI 2002; OKRUSZKO 1997).

At the current state of the environment, water is exposed to contamination at all stages of the hydrological cycle. An area's abundance with water depends on how much rainfall water will flow out on the land's surface and how much will soak into the ground and feed crustal, ground and underground reservoirs **(**CHEŁMICKI 2002**).** Precipitation waters infiltrating through the soil profile carry and shift various components to ground waters. These contaminants may be of natural origin – biochemical processes proceeding in the upper layer of soil or of anthropogenic origin – originating from both contaminated atmospheric air as well as agri-production. Infiltration feeding of ground waters is observed in the autumn-spring season and stops in the summer period (FIC, MIODUSZEWSKI 2003).

Highly valuable elements of the natural environment, constituting specific barriers to the spreading of contaminants especially on lakeland areas, are numerous water bodies, water-logged and swampy areas of various sizes, located usually in flow-devoid depressions. In the storage and protection of water reserves, of special significance are also marshy grounds constituting transition zones between inland and typically-aquatic ecosystems. From a hydrological perspective, they are acknowledged as territorial hydrographic objects and serve a variety of ecological functions (KIRYLUK 2002; KOC et al. 2002; SZYMCZYK, SZYPEREK 2005). Constantly or temporarily water-logged areas surrounding the mid-field water bodies are often covered with vegetation characterized by high biodiversity which, especially in the vegetative season, constitutes a good biogeochemical barrier that considerably reduces the inflow of contaminants to a water body (KOC et al. 2002). A lack of coastal vegetation around water bodies exposes them to the surface and ground inflow of various substances. The coastal vegetation of small water bodies accumulates high quantities of nitrogen, phosphorus, calcium and magnesium (KOC et al. 2007). The very good protection of waters of small mid-field reservoirs is provided by biodiversity conservation, *i.e.* the occurrence of different species, often constituting characteristic zones, *e.g.* belts of gramineous and rush vegetation as well as shrubs and coppices. The differing nutritional needs of various plant species constituting particular zones assure intensive bioaccumulation of components over the entire vegetative season (KOC et al. 2002; KOC et al. 2007; ZAJĄCZKOWSKI 1997).

ANTHROPOGENIC DETERMINANTS OF THE QUALITY OF WATERS ON RURAL AREAS

Next to the natural environment, the greatest consumer of water is agriculture (MIODUSZEWSKI 2006). Areas managed for agricultural crops, thus becoming a site of animal breeding and a place of living in proximity to humans, constitute the so-called “rural environment” that covers ca. 60% of the total area of the country. A close relationship occurs between various forms of activities conducted in rural areas and transformation of the natural environment (OKRUSZKO 1997). Of all anthropogenic activities, the development of agriculture is believed to have contributed most significantly to degradation of the natural environment. Despite various protective actions, it still exerts a negative impact, resulting, among others in: considerable landscape transformation, diminished biodiversity, disturbance of the water economy, water contamination and soil degradation. The development of agricultural has inseparably been linked with the boom in water reclamation systems, mainly targeting the acceleration of water outflow. In a number of cases, numerous marshy grounds, mid-field water bodies and even small lakes occurring mainly in lakeland areas have been drained off and devastated. A lack of provision of covering water deficits in a longer drought spell period affects not only the risks linked with reduced crop yields, but also initiates a number of edaphic processes, particularly, mineralization of organic matter. Owing to a lack of available water, nutrients released in excessive amounts are not subject to biosorption and are exposed to more intensive leaching with precipitation waters deep inside the soil profile. They reach ground waters and – by means of reclamation systems – rapidly migrate to surface waters where they are likely to pose a severe problem (KOC et al. 2007; SAPEK 1996; SZYMCZYK, SZYPEREK 2005; SZYPEREK et al. 2005; VAGSTAD et al. 2000).

The hazard posed by human agricultural and rural activity to the quality of the environment is determined by the coaction of a number of natural and anthropogenic factors. The most significant anthropogenic factors that may be generally controlled and modified include: the mode of catchment management, including the contribution and distribution of arable lands, permanent grassland, forest areas, bogs and marshy grounds, small water bodies, mid-field coppices and shrubs on its area, as well as the intensity of agricultural practices coupled with quantities and forms of fertilizers applied (ALLAN, CHAPMAN 2001; HEATHWAITE et al. 1998; LIPIŃSKI 2002; SPRUILL 2004; SZYMCZYK, CYMES 2005; SZYPEREK et al. 2005).

FARMSTEAD AS A SOURCE OF WATERS CONTAMINATION

An inseparable element of rural areas and farms are built-up areas organized in the form of a farmstead. Under almost all conditions, the presence of such facilities is linked with the appearance of sources, usually spot-like, of contamination of ground and surface waters. They usually occur in the form of the so-called "hot spots" which include, among others:

- inappropriately organized and unprotected sites of animal-keeping (yards), storage sites (dung pits, slurry and liquid manure tanks) as well as silos for silage,
- storage sites of mineral fertilizers and pesticides,
- sites of garages, conservation and repair of farming equipment,
- leaky cesspits for domestic sewage,
- non-organized waste dumps (SAPEK 2006).

Those pollutions may migrate both with the surface flow and with ground outflow. Unfortunately, once carried by ground waters they reach dug wells located in the area of farmsteads that often constitute the only source of drinking water and water for animals. It poses a severe threat to human and animal health. An especially high hazard linked with rapid distribution of farmstead-originated pollutions in the environment occurs in the case of the presence of reclamation systems (ditches and drain pipes) discharging waters from the area of farmstead or its vicinity. Often, the ground waters strongly contaminated with biogenic components (nitrogen and phosphorus compounds, potassium) reach local receivers of surface waters. Water reservoirs at the highest risk of contamination and degradation are those in which most of the inflowing contaminations are deposited in water, sediments and plants covering them (KOC et al. 2007; SAPEK, SAPEK 1998; SAPEK 2006).

According to Sapek B. and Sapek A. (1998), in the area of a farmstead ground waters contaminated to the greatest extent with $N\text{-}NO_3$ occur in the vicinity of dung pits and barns, whilst those contaminated with $N\text{-}NH_4$ are in the vicinity of dung pits. Contamination of ground waters outflowing from a farmstead is subject to a high seasonal variability. Previous investigations (SZYMCZYK 2005) showed that in the vicinity of farm facilities the highest concentrations of $N\text{-}NO_3$ and phosphorus compounds in ground water occur in the spring and in the summer, whereas the lowest occur in the winter (Table 1). A good biogeochemical barrier to biogene migration may be an extensively-managed meadow which provides favorable conditions for intensive transformation and bioaccumulation of mineral compounds of nitrogen and phosphorus (SZYMCZYK 2005).

Chemical compounds, including nitrogen, phosphorus, potassium, sodium, calcium and magnesium, are indispensable for the proper development of vegetation and high production of its biomass. The higher the crop, the greater the losses of compounds from soil and the resulting need for their incorporation in the form of fertilization (SAPEK 1996). Advancing anthropopression is accompanied by increasing concentration of biogenic components in ground and surface waters, especially in small water bodies and outflows from reclamation networks (KOC et al. 2007; LIPIŃSKI 2002; SAPEK 1996; SZYMCZYK, CYMES 2005).

Table 1

Effect of a farmstead on contamination of ground waters with compounds of nitrogen and phosphorus [mg dm^3] – *Source: SZYMCZYK 2005*

Compound	Distance from a farmstead	Season of the year				Average
		Autumn	Winter	Spring	Summer	
$N-NO_3$	20 m	2.10	0.73	6.18	5.00	3.50
	60 m	0.51	0.12	0.37	0.50	0.37
$N-NH_4$	20 m	1.30	3.17	2.28	2.15	2.23
	60 m	0.31	0.23	0.15	0.10	0.20
Total P	20 m	0.506	0.367	0.764	0.540	0.544
	60 m	0.204	0.260	0.493	0.370	0.332
$P-PO_4$	20 m	0.241	0.103	0.251	0.447	0.261
	60 m	0.090	0.058	0.090	0.285	0.131

INTENSITY OF FARMING VERSUS OUTFLOW OF COMPONENTS THROUGH RECLAMATION NETWORKS

The key factors contributing to increased fertility in the environment (particularly eutrophication of waters) are nitrogen and phosphorus. Nitrogen contained in the soil may be of natural or anthropogenic origin. In soil, its prevailing part occurs in its organic form, and the remainder in its mineral form. Mineral nitrogen is available to plants, yet it may easily be washed out to ground waters. The content of mineral forms of nitrogen in soil depends on its type and properties as well as on the course and intensity of mineralization of organic nitrogen compounds. The acidic reaction of soil facilitates the ammonification process and release of the ammonium form. However, the most significant role in nitrogen losses is ascribed to nitrification, for leaching usually refers to the nitrate form (KOC et al. 2003; SAPEK 1998; SAPEK, KALIŃSKA 2004; URBANIAK 2004). Apart from nitrogen, the growth of plants is affected to the greatest extent by phosphorus which, additionally, by stimulating the growth of papilionaceous plants and bacteria binding nitrogen from air, contributes intermediately to an increase in the nitrogen content of soil. In nature, phosphorus occurs exclusively in the form of phosphates of mineral or organic origin. They may be introduced from external sources in the form of mineral and organic fertilizers, after-harvest residues, green manure, and deposited with atmospheric precipitation. Plants may utilize only the available forms of phosphorus occurring in the soil in the form of phosphates in readily-soluble compounds. The availability of phosphorus is determined by the reaction (pH) of soil, the content of iron aluminum and manganese, content and degradation degree of organic matter, and activity of microorganisms. Phosphorus delivered with fertilizers transits through a soil solution to more or less soluble soil reserve. The release of bound phosphorus from links and its re-transition through the soil solution proceeds the most intensively in soil with pH 6-7 (SAPEK 2002; SMOROŃ 1996; STEINECK et al. 2002).

The outflow of nitrogen and phosphorus compounds from arable soils is determined by their type and the method of their management, meteorological conditions affecting the intensity of bioaccumulation and drainage system. It is of special significance in the case of drainage and farm management of hydrogenic soils which, having been drained, release a considerable quantity of biogenic compounds to the environment, often exceeding the bioaccumulation capacity of crops (IGRAS 2005; KOC et al. 2007; PULIKOWSKI et al. 2008; SAPEK 1996). According to Koc and Szymczyk (2003a), drainage waters outflowing from agriculturally-managed areas, unlike those discharged with ditches, are characterized by both a considerably higher concentration of $N\text{-}NO_3$ (8-fold on average) and a higher variability of its concentration over a year (tab. 2). In contrast to $N\text{-}NO_3$, a higher concentration of $N\text{-}NH_4$ and phosphorus compounds occurs in waters discharged with ditches. In the case of $N\text{-}NH_4$, this may result from putrefying processes ongoing at the bottom of a ditch and from transformation of organic compounds of nitrogen. In turn, the concentration of phosphates in ditch waters should be linked with their transportation with soil colloids that may originate from surface flows (IGRAS 2005).

Table 2

Concentration of biogenic compounds in waters outflowing with reclamation systems [$mg \cdot dm^{-3}$] – *Source: KOC, SZYMCZYK 2003a,b*

Specification		Compound			
		$N\text{-}NO_3$	$N\text{-}NH_4$	Total P	$P\text{-}PO_4$
Drains					
Average		6.26	0.37	0.173	0.107
min–max		0.17–33.12	0.02–5.44	0.022-1.188	0.016–0.550
Soil	light	13.91	0.29	0.196	0.117
	medium-textured	2.38	0.74	0.235	0.149
	heavy	2.51	0.08	0.089	0.057
Fertilization	high	8.47	0.48	0.242	0.150
	medium	4.02	0.47	0.152	0.095
Ditches					
Average		0.79	0.48	0.193	0.120
min–max		0.02–5.25	0.02–2.05	0.021–0.950	0.016–0.910
Soil	light	1.06	0.51	0.200	0.135
	medium-textured	0.41	0.48	0.203	0.116
	heavy	0.90	0.45	0.175	0.110
Fertilization	high	0.98	0.48	0.212	0.122
	medium	0.41	0.48	0.203	0.116

According to Koc and Szymczyk (2003a), increasing farming intensity causes an over 2-fold increase in the concentration of $N\text{-}NO_3$, and in the concentration of phosphorus compounds (up to 60%) both in waters outflowing with a drainage network and with reclamation ditches, yet it practically does not change the concentration of $N\text{-}NH_4$ in those waters (tab. 2). As claimed by Sapek (1996), a lack of a tangible effect of increased fertilization on $N\text{-}NH_4$ concentration in ground waters and reclamation outflows is due to rapid transformations of nitrogen compounds (nitrification to nitrates) delivered to soil with fertilizers.

According to Koc and Szymczyk (2003a,b), the highest concentrations of $N\text{-}NO_3$ in waters of drain pipes (up to 13.9 mg·dm^{-3}) and ditches (up to 1.06 mg·dm^{-3}) occur on light soils, but higher concentrations of $N\text{-}NH_4$ and phosphorus compounds are reported in drainage outflows from medium-textured soils. As reported by Koc et al. (2007), this may be linked with both more intensive infiltration of waters in light soils and with lesser bioaccumulation of nitrogen resulting from their lower fertility.

The quantity of nitrogen and phosphorus penetrating from arable fields to ground waters is very differentiated and affected by land topography, catchment management, type of cultivated plant, type of reclamation system and cultivation technology, including mainly the intensity of fertilization (Lipiński 2002; Koc, Szymczyk 2003a,b; Igras 2005; Pulikowski et al. 2008; Smoroń 1998).

According to Koc and Szymczyk (2003a,b), most of the load of biogenic components corresponds strongly with their concentrations in water and with water outflow intensity which, in turn, is determined by the type of reclamation system and soil compaction. Depending on these factors, the annual outflow per 1 ha of drain catchment may reach: 0.39-49.52 kg for $N\text{-}NO_3$, 0.01-1.8 kg for $N\text{-}NH_4$ and 0.016-0.488 kg for total phosphorus (tab. 3). It should be emphasized, however, that the size of mineral nitrogen outflow with a drainage network was largely affected by the concentration and load of $N\text{-}NO_3$. As compared to drainage networks, considerably lower loads of nitrogen and phosphorus are outflowing with drainage ditches (9-fold and 2-fold lower on average, respectively).

Table 3

Outflow of biogenes with reclamation systems from rural areas [kg·ha^{-1}] – *Source: Koc, Szymczyk 2003a,b*

Specification		Compound			
		$N\text{-}NO_3$	$N\text{-}NH_4$	Total P	$P\text{-}PO_4$
Drains					
Average		12.56	0.48	0.303	0.165
min–max		0.39–49.52	0.01–1.80	0.016–0.488	0.010–0.425
Soil	light	28.30	0.61	0.407	0.234
	medium-textured	4.39	0.72	0.340	0.181
	heavy	5.00	0.10	0.163	0.081
Fertilization	high	19.82	0.71	0.416	0.245
	medium	5.09	0.45	0.249	0.119
Ditches					
Average		1.28	0.30	0.159	0.060
min–max		0.06–3.64	0.11–1.02	0.019–0.441	0.009–0.417
Soil	light	1.84	0.33	0.183	0.075
	medium-textured	0.40	0.24	0.167	0.055
	heavy	1.60	0.33	0.127	0.049
Fertilization	high	1.27	0.28	0.196	0.085
	medium	0.85	0.29	0.155	0.068

The highest annual load of N-NO_3 (28.29 kg·ha^{-1} on average) outflows from drained light soils and the lowest load (0.39 kg·ha^{-1}) from medium-textured soils drained with ditches. More intensive drainage and oxygenation of soils, as well as restricted biosorption of nitrogen from waters inflowing to a drainage network, as compared to the system of ditches, result in a 10-fold higher load of N-NO_3 being discharged annually by drain pipes. The increased intensity of cultivation technology alone contributes to an almost 4-fold increase of N-NO_3 outflow to surface water. At a higher level of fertilization, it is almost 16 times higher in a drained area. In turn, at a medium intensity of mineral fertilization, a 6-fold higher load of N-NO_3 is discharged with the drain pipe system than with drainage ditches (KOC, SZYMCZYK 2003a,b).

The size of mineral nitrogen outflow from farm-forest catchments is determined by meteorological conditions, particularly the volume and distribution of precipitation (LIPIŃSKI 2002; PULIKOWSKI et al. 2008; SZYMCZYK, SZYPEREK 2005). According to Koc and Szymczyk (2003a), the size of mineral nitrogen outflow is subject to a strong seasonal variability, i.e. from 0.03 kg·ha^{-1} in the summer – from light and heavy soils drained with ditches to 10.31 kg·ha^{-1} in the winter – from light soil with the drain pipe system. Drainage of agriculturally-utilized areas, as compared to drainage with ditches, causes an over 8-fold increase (while intensification of farming causes an over 2-fold increase) in mineral nitrogen leaching from arable soils to surface waters. In view of this sum, N-NH_4 constitutes below 1%

The outflow of mineral compounds of nitrogen and phosphorus is subject to high seasonal variability (Fig. 1).

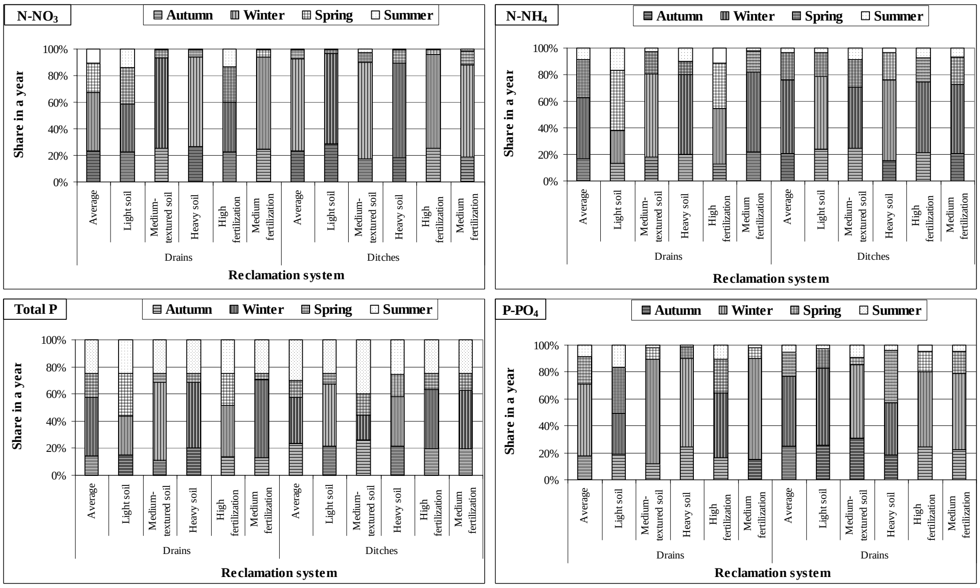

Fig. 1. Seasonal variability of the outflow of nitrogen and phosphorus compounds to waters [%] – *Source:* KOC, SZYMCZYK *2003a,b*

Taking into account the annual loads of those biogenes, the greatest losses of these compounds occur in the winter, whereas the lowest losses (except for total phosphorus) occur in the summer time. In the winter, a drain pipe network discharges on average 44% of N-NO_3, 46% of N-NH_4, and 43% of $P_{tot.}$– including as much as 54% of P-PO_4, whereas drainage ditches discharge 70% of N-NO_3, 53% of N-NH_4, and 34% of $P_{tot.}$, including 52% of P-PO_4. Similar tendencies (with the maximum noted in the winter) of the outflow of an annual load of biogenes are reported from heavy and medium-textured soils, whereas in the case of light soils, the greatest part of N-NO_3 load is outflowing in the winter (36% with drain pipes and 68% with ditches), in the spring – with drain pipes: N-NH_4 (46%) and phosphorus compounds (31%, including 34% of P-PO_4), and in the winter – with ditches: N-NH_4 (55%) and phosphorus compounds (46%, including 55% of P-PO_4). As reported by Koc et al. (2007), the lesser seasonal differences and, thus, a higher outflow of N-NO_3 with drain pipes than with ditches, are linked with more equalized outflow of waters from drained fields. The outflow of waters with a network of ditches is usually irregular throughout the year – greater in the winter half-year and even temporarily-suspended in the springtime.

Apart from the key biophilic components (N and P), a significant role in the environment is also ascribed to potassium, sodium, calcium and magnesium. Their primary source in soils and ground waters are minerals, from which they may be released at various rates. Out of these elements, calcium was found to occur in the highest concentration in ground waters. Potassium is one of the major components of fertilizers, whereas magnesium – like calcium – participates in the biological cycle of matter, and sodium takes part in the process of ionic exchange, often substituting for calcium. The immediate effect of potassium, sodium, calcium and magnesium on the eutrophication process of the environment has not yet been elucidated. However, their elevated concentrations in ground and surface waters may indicate the presence of contamination sources (CHEŁMICKI 2002; MACIOSZCZYK, DOBRZYŃSKI 2002).

Koc and Szymczyk (2003c,d) demonstrated that the concentrations of potassium, calcium, sodium and magnesium in waters discharged with reclamation systems were strongly modified by meteorological conditions as well as by the fertility and permeability of soils. Taking into account their mean concentrations in waters discharged with reclamation systems, these elements should be ordered as follows: Ca > Na > Mg > K. However, depending on differences in their extreme concentrations, a different order results in a drain pipe system (K 238-fold >Mg 70-fold > Na 45-fold > Ca 8-fold), than in the case of ditches (Na 78-fold >Mg 60-fold > K 41-fold > Ca 9-fold). Drainage with ditches, as compared to drain pipes, evokes a decrease in the concentration of potassium (by 48% on average), but increases that of sodium (by 9%), calcium (by 20%) and magnesium (by 30%), (tab. 4). The lower concentration of potassium in drain pipe outflows may be due to better air-water conditions in the drained ground, than in the case of drain ditches, which results in its more effective absorption by plants.

As reported by Sapek (2001), the issue of potassium is significant because under variable conditions of anthropopression the mechanisms of its absorption and release in soils may proceed with different intensity. Both an excess and deficit of elements, including potassium, in soil are likely to yield various production and ecological effects. Generally, the balance of potassium is positive on the national scale, but is usually negative on the field scale. Simultaneously, high concentrations of potassium appear in ground waters, which points to its substantial leaching from soils. This additionally indicates the great mobility of potassium introduced with fertilizers, as well as the ready transformation of potassium occurring in soil into forms available to plants.

Table 4

The concentration of biogenes in waters discharged with reclamation systems [mg·dm^{-3}] – *Source: KOC, SZYMCZYK 2003c,d*

Specification		Compound			
		K	Na	Ca	Mg
Drains					
Average		4.0	11.8	92	10.8
	min–max	0.2–47.9	1.0–37.0	22–178	0.4–28.1
Soil	light	4.9	10.3	100	8.9
	medium-textured	6.1	12.3	91	10.6
	heavy	0.9	12.7	86	12.9
Fertilization	high	5.3	12.7	84	10.1
	medium	4.4	10.7	102	10.7
Ditches					
Average		6.30	10.8	75	8.4
	min–max	0.5–20.5	0.7–31.8	22–202	0.4–24.5
Soil	light	6.4	14.9	58	7.8
	medium-textured	6.6	8.9	97	9.8
	heavy	6.0	8.8	71	7.5
Fertilization	high	6.2	11.8	64	7.7
	medium	6.6	8.9	97	9.8

Koc and Szymczyk (2003c,d) demonstrated that in drain pipe waters the highest concentrations of K occurred on medium-textured soils, those of Na and Mg on heavy soils, and those of Ca on light soils. In contrast, in waters discharged with drainage ditches, the lowest concentrations of K, Ca and Mg were reported on medium-textured soils, and those of Na – on light soils. Intensive fertilization increases the concentrations of K and Na in drain pipe waters and that of Na in waters discharged with ditches, while it decreases the concentrations of the other elements.

According to Koc and Szymczyk (2003c,d), up to 14.3 kg of K, 30.6 kg of Na, 268 kg of Ca and 23.4 kg of Mg are discharged annually with reclamation systems from 1ha of agriculturally-utilized areas (tab. 5). It is noteworthy that more intensive drainage of soils with drain pipe systems, as compared to drainage ditches, increases the leaching of K by 75%, that of Mg by 29%, that of Ca by 23% and that of Na by 9% on average.

On drained areas, considerably greater quantities of K, Na, Ca and Mg are outflowing from light soils than from more compact soils. In turn, on objects drained with the system of ditches, higher losses of K and Ca are observed from heavy soils, whereas losses of Na and Mg are observed from light soils. Increasing the mineral fertilization of drained soils causes an almost 3-fold increase in the outflow of K as well as increases the outflows of Ca, Na and Mg by 84%, 30% and 21%, respectively, while in areas drained with a system of ditches, higher fertilization contributes to a 2-fold increase of K outflow and to a decrease in Na, Ca and Mg loads.

Table 5

Outflow of biogenes with reclamation systems from rural areas [kg·ha^{-1}] – *Source: Koc, Szymczyk 2003a,b*

Specification		Compound			
		K	Na	Ca	Mg
Drains					
Average		6.0	16.8	129	15.3
	min–max	0.2-14.3	0.1–30.6	13–268	0.7–23.4
Soil	light	9.1	20.9	199	17.3
	medium-textured	7.6	14.0	91	12.9
	heavy	1.4	15.6	97	15.8
Fertilization	high	10.5	18.7	166	16.2
	medium	3.6	14.4	90	13.4
Ditches					
Average		4.6	8.3	60	6.2
	min–max	0.6–9.5	0.6–16.9	11–156	1.2–15.9
Soil	light	4.0	11.1	49	7.0
	medium-textured	3.6	5.7	61	6.2
	heavy	6.3	8.1	71	5.4
Fertilization	high	5.9	7.4	56	5.5
	medium	2.9	7.8	65	6.9

Seasonal variability of the outflow of minerals is determined by meteorological conditions affecting edaphic processes and by soil compaction and intensity of fertilization (Fig. 2).

Definitely the highest outflow of K, Na, Ca and Mg with reclamation networks was observed in the winter period (43 – 57% of annual load on average) and the lowest was in the summer time (from 4 to 11%, on average). The fact that the contribution of load outflowing in the winter was slightly lesser in a drain pipe network than in ditches, whereas an opposite tendency was observed in the summer is also very interesting. In the autumn and in the spring, the loads of outflows were similar and accounted, on average, for ca. 20% of the annual load each. In the case of K, Na, Ca and Mg minerals, the type of soil was found to exert the greatest effect on the seasonal variability of the outflow of potassium The greatest part of its annual load from medium-textured soils (73%) was outflowing in the winter, whereas that from heavy soils (60%) in the autumn. More intensive drainage of light soils with a drain pipe system, as compared to ditches, resulted in a considerable increase in the loads of K, Na, Ca and Mg only in the spring and summer.

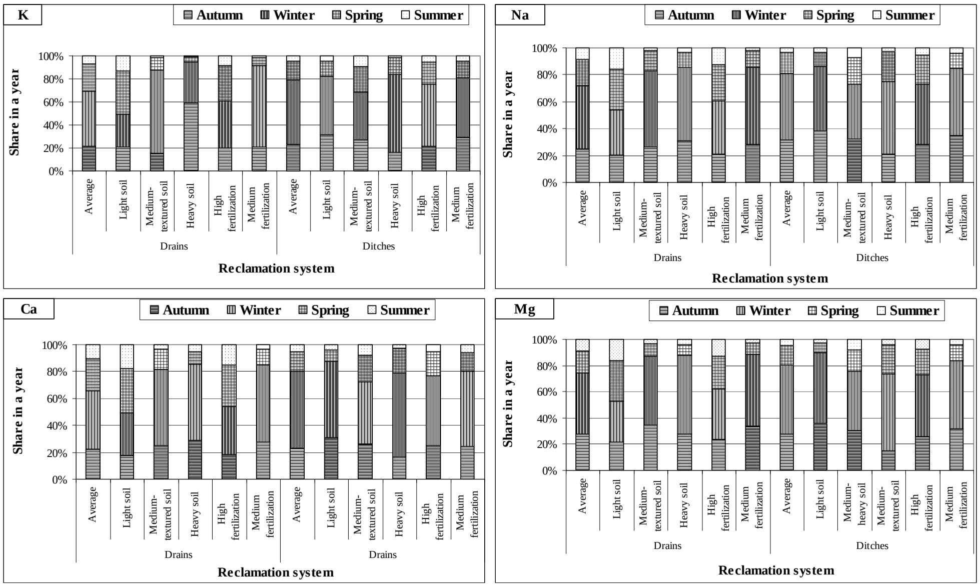

Fig. 2. Seasonal variability of the outflow of K, Na, Ca and Mg to waters [%] – *Source: KOC, SZYMCZYK 2003c,d.*

According to Koc et al. (2002), the occurrence of flow-devoid water bodies or their incorporation into the reclamation network exerts a positive effect on the fertility of waters discharged from a rural catchment. However, the biogenic compounds retained in water bodies as a result of phytosorption, or deposition in water deposits, are becoming the reasons for their intensive overgrowth and silting-up as well as disappearance of their water table. Extension of the functioning of water bodies in the environment may be provided by appropriately targeted actions undertaken while establishing reclamation systems. Such actions assume, among others, no direct introduction of reclamation waters to the water bodies. To this end, they should be surrounded with a belt of perennial gramineous vegetation, followed by a surrounding ditch being the first receiver of water from the reclamation network. Water infiltrating through the sodded belt of ground from the ditch to the water body is subject to preliminary purification. However, in order to make farm production feasible in areas around a water body, excess water should be discharged with drain pipes to a local receiver.

THE ROLE OF CONTEMPORARY RECLAMATION SYSTEMS IN MODELING THE OUTFLOW OF WATER AND BIOGENIC COMPOUNDS FROM RURAL AREAS

The directions of reclamation development in Poland should result from the real needs of the agricultural economy. The need for regulating air-water ratios in agriculturally-utilized soils is undisputable, for correctly-built reclamation systems assure the optimal level of moisture content of soil to particular habitat conditions and management methods. Unfortunately, most of the reclamation systems established so far in Poland have targeted drainage and have not always taken respective consideration of soil environment protection against drying out and of aquatic environment against excessive inflow of biogenic substances leading to accelerated degradation of surface waters. Agricultural irrigations are currently run on a relatively small area (in respect of needs). However, under free market conditions and in view of the need for preserving the competitiveness of agriculture, the size of irrigated areas will have to increase, especially in response to intensive field or pomicultural production (MIODUSZEWSKI 2007; NYC, POKŁADEK 2004; SOLARSKI et al. 2005).

The application of gravitational irrigations, based generally on a controlled outflow of waters from reclamation systems, in small rural catchments will effectively enhance ground retention. Simultaneously, improvement will be observed in the quality of waters, both those outflowing from the area of the rural catchment and those discharged to receivers (NYC, POKŁADEK 2004).

Contemporary and prospective directions of development and functioning of reclamation systems should be consistent with the Water Framework Directive (WFD) adopted by the EUROPEAN UNION in 2000. Actions provisioned in the Directive are directed towards counteracting successive deterioration of surface and ground waters and sustainable consumption of water reserves. From a wide array of actions stipulated in the Directive, those referring directly to reclamation include:

- catchment water management,
- prevention of contaminants outflow from rural areas,
- protection of drinking water reservoirs,
- protection of water-dependent ecosystems,
- promotion of effective and sustainable consumption of water (MIODUSZEWSKI 2007).

Rationalization of the use and increasing reservoirs of water available in agriculture are linked not only with the regulation of the volume of waters outflowing from a catchment, but also with building water tanks and water lifts on water-courses and with protection of natural resources of waters accumulated on marshy grounds and in mid-field aquifers (KOC et al. 2007; LIPIŃSKI 2002; MIODUSZEWSKI 2007).

In order to protect water resources in rural areas, a change should be made in the approach to the range of drainage applied. This problem pertains especially to moraine areas, on which systematic drainage should be abandoned in favor of partial or irregular drainage, *i.e.* performance of drainage only at sites with persistent excessive moisture content. A decreased number of systematic drainages will enable reduction of not only economic but also ecological costs through preservation of natural landscape conditions (SOLARSKI et al. 2005). For this reason, a variety of biogeochemical barriers should be introduced aimed at capturing biogenes migrating with ground waters and reclamation networks. Hence, it would be advisable to incorporate the existing and re-naturalized water bodies into the reclamation network and to introduce protective planting to restrict both the surface and ground outflow of biogenes from agriculturally-utilized catchments (ALLEN, CHAPMAN 2001; SZYMCZYK, CYMES 2005; KOC et al. 2007; KOC et al. 2002).

SUMMARY

The depleted water reserves of Poland require a sustainable approach to their exploitation and undertaking actions targeted at the preservation of existing and restoration of degraded marshy grounds and water bodies, and effectively counteracting the contamination of surface, ground and underground waters. The concentration of biogenic compounds in water and their outflow from agriculturally-utilized catchments are affected by meteorological conditions, soil compactness, type of the reclamation system as well as intensity and method of soil management. The greatest losses of mineral compounds of nitrogen, phosphorus as well as potassium, sodium, calcium and magnesium occur in the case of agricultural utilization of drained light soils. The greatest outflow of biogenic substances is from soils drained with a drain pipe system. As compared to drainage ditches, the drain pipe systems discharge over 8-fold greater loads of mineral nitrogen (mainly $N\text{-}NO_3$) and over 2-fold greater loads of phosphorus, sodium, calcium and magnesium compounds. An increase in farming intensity results in an increased outflow of $N\text{-}NO_3$ (4-fold), potassium (3-fold), compounds of phosphorus and calcium (2-fold) and, to a small extent, of sodium and magnesium with a drainage network. On rural areas, a severe environmental problem is posed by inappropriately organized farmsteads, which are a source of a number of contaminations migrating from its area to ground and surface waters. In rural areas, reduced dispersion of substances in the environment may be achieved through aptly-targeted actions linked with the performance of pro-ecological reclamation systems to afford possibilities of regulating the air-water conditions of soil and diminish the outflow of waters and biogenes, *e.g.* through restricting drainage to a necessary minimum, the application of controlled outflow as well as the re-naturalization of water bodies and their incorporation into reclamation networks.

REFERENCES

ALLAN A., CHAPMAN D. 2001. Impacts of afforestation on groundwater resources and quality. Hydrogeology Journal, 9: 390-400.

CHEŁMICKI W. 2002. Woda – Zasoby, degradacja, ochrona. Wyd. PWN, Warszawa, ss. 306. [In Polish: Water – Resources, degradation, protection].

DURKIWSKI T., KORYBUT WORONIECKI T. 2009. Dynamika stężenia wybranych składników chemicznych w opadach atmosferycznych w zlewni jeziora Miedwie. Woda – Środowisko – Obszary Wiejskie, 9, 2(26): 19-32. [In Polish, with English summary: The dynamics of concentration of selected chemical components of rainfalls in the lake Miedwie catchment basin].

FIC M., MIODUSZEWSKI W. 2003. Pionowa strefowość chemiczna wód podziemnych w rejonie Falent. Woda – Środowisko – Obszary Wiejskie, 3 (6): 39-50 [In Polish, with English summary: Vertical chemical zonation of ground waters near Falenty].

HEATHWAITE A.L., GRIFFITHS P., PARKINSON R.J. 1998. Nitrogen and phosphorus in runoff from grassland with butter strips following application of fertilizers and manures. Soil Use Management, 14: 142-148.

IGRAS J. 2005. Przeciętne i przewidywane zakresy stężeń składników biogennych w płytkich wodach gruntowych w Polsce. Journal of Elementology, 10(3) II: 711-719 [In Polish, with English summary: Average and expected levels of biogenic elements in shallow ground waters in Poland].

KIRYLUK A. 1999. Wody gruntowe na zmeliorowanym torfowisku niskim i ich wpływ na biocenozę łąkową. Roczniki Akademii Rolniczej w Poznaniu, 310, Melioracje i Inżynieria Środowiska, 20, I: 245-255. [In Polish, with English summary: The groundwaters in the reclaimed low peatland and their effect on the meadow biocenosis].

KOC J., GLIŃSKA-LEWCZUK K., SOLARSKI K. 2003. Opady atmosferyczne jako medium chemicznej denudacji gleb. Zeszyty Problemowe Postępów Nauk Rolniczych, 493: 159-166. [In Polish, with English summary: Rain water as a medium of chemical soil degradation].

KOC J., SKWIERAWSKI A., SZYPEREK U. 2007. Znaczenie ochrony małych zbiorników wodnych w aspekcie zrównoważonego rozwoju obszarów wiejskich. W: Ekologiczne aspekty zrównoważonego rozwoju regionalnego i lokalnego (Edited by K. Michałkowski). Wyd. WSE w Białymstoku: 141-153. [In Polish, with English summary: Significance of protecting small water reservoirs in the aspect of sustainable development of rural areas].

KOC J., SOLARSKI K., ROCHWERGER A. 2007. Effect of land reclamation on the system volume and seasonality of nitrate runoff from croplands. Journal of Elementology, 12(2): 121-133.

KOC J., SZYMCZYK S. 2003a. Wpływ intensywności rolnictwa na odpływ z gleb azotu mineralnego. Zeszyty Problemowe Postępów Nauk Rolniczych, 494: 175-181. [In Polish, with English summary: Effect of agriculture intensity on the mineral nitrogen outflow from soils].

KOC J., SZYMCZYK S. 2003b. Wpływ intensywności rolnictwa na odpływ z gleb fosforu do wód powierzchniowych. Zeszyty Problemowe Postępów Nauk Rolniczych, 459: 183-189. [In Polish, with English summary: Effect of agriculture intensity on the phosphorus outflow to surface water].

KOC J., SZYMCZYK S. 2003c. Wpływ intensywności rolnictwa na odpływ potasu i sodu z gleb. Journal of Elementology, 8(3): 151-158. [In Polish, with English summary: Effect of agriculture intensity on the potassium and sodium outflows from soils].

KOC J., SZYMCZYK S. 2003d. Wpływ intensywności rolnictwa na odpływ wapnia i magnezu z gleb. Journal of Elementology, 8(4): 231-238. [In Polish, with English summary: Effect of agriculture intensity on the calcium and magnesium outflows from soils].

KOC J., SZYMCZYK S., CYMES I., SZYPEREK U., SKWIERAWSKI A. 2002. Wpływ intensywności rolnictwa na stan wód małych zbiorników w krajobrazie rolniczym. Pamiętnik Puławski, 130: 357-362. [In Polish, with English summary: Effect of agriculture intensity on the condition of small water reservoirs].

LIPIŃSKI J. 2002. Odpływ składników chemicznych z gleby przez sieć drenarską. Woda – Środowisko – Obszary Wiejskie, 2, 2(5): 151-170 [In Polish, with English summary: Outflow of chemical components from soil through the drainage network].

MACIOSZCZYK A., DOBRZYŃSKI D. 2002. Hydrogeochemia strefy aktywnej wymiany wód podziemnych. Wyd. PWN, Warszawa, ss. 448. [In Polish: Hydrogeochemistry of the zone of active exchange of groundwater].

MIODUSZEWSKI W. 2006. Woda na obszarach wiejskich. Woda – Środowisko – Obszary Wiejskie, 6, 1(16): 277-295. [In Polish, with English summary: Water in rural areas].

MIODUSZEWSKI W. 2007. Uwarunkowania rozwoju melioracji wodnych w świetle Ramowej Dyrektywy Wodnej. Wiadomości Melioracyjne i Łąkarskie, 2(413): 51-55. [In Polish, with English summary: Conditions of water amelioration development in the light of Water Framework Directive].

MIRANDA S.A., MATVIENKO B. 2003. Rain and groundwater as phosphorus sources of small reservoir. Research and Management, 8: 27-30.

NYC K., POKŁADEK R. 2007. Celowość i kierunki rozwoju melioracji w Polsce. Wiadomości Melioracyjne i Łąkarskie, 3(414): 101-105. [In Polish, with English summary: Purpose and directions of amelioration development in Poland].

NYC K., POKŁADEK R. 2004. Rola systemu melioracyjnego w kształtowaniu zasobów małej retencji oraz poprawie jakości wód na przykładzie obiektu Miękinia. Roczniki Akademii Rolniczej w Poznaniu, 357: 413-420. [In Polish, with English summary: The role of exploitation of the land reclamation system in forming small retention resources and water quality improvement on the Miękinia site].

OKRUSZKO H. 1997. Woda a środowisko rolnicze. Zeszyty Edukacyjne, 4/97: 9-18. [In Polish, with English summary: Water and agricultural environment].

PULIKOWSKI K., HUS T., KOSTRZEWA S., PALUCH J., PĘCZKOWSKI G. 2008. Zawartość azotu i fosforu w wodach odpływających z małych zlewni użytkowanych rolniczo. Zeszyty Problemowe Postępów Nauk Rolniczych, 528, 157-164. [In Polish, with English summary: Concentration of nitrogen and phosphorus in the effluent waters from little agricultural catchments].

SAPEK A. 1996. Udział rolnictwa w zanieczyszczeniu wody składnikami nawozowymi. Zeszyty Edukacyjne, 1/96: 9-33. [In Polish, with English summary: Impact of agriculture on water pollution with nutrients.]

SAPEK A. 1998. Udział azotu atmosferycznego w zanieczyszczaniu zasobów wody. Zeszyty Problemowe Postępów Nauk Rolniczych, 458: 485-494. [In Polish, with English summary: Contribution of atmospheric nitrogen in water bodies pollution].

SAPEK A. 2002. Rozproszenie fosforu w środowisku, mechanizmy i skutki. Zeszyty Edukacyjne, 7/2002: 9-24. [In Polish, with English summary: Dispersion of phosphorus into environment – mechanisms and effects].

SAPEK B. 2001. Zagadnienie potasu w świetle oddziaływania rolnictwa na środowisko. Zeszyty Problemowe Postępów Nauk Rolniczych, 476: 281-292. [In Polish, with English summary: Problem of potassium in the aspect of agricultural impact on the environment].

SAPEK B., KALIŃSKA D. 2004. Mineralizacja organicznych związków azotu w glebie w świetle długoletnich doświadczeń łąkowych IMUZ. Woda – Środowisko – Obszary Wiejskie, 4, 1(10): 183-200. [In Polish, with English summary: Mineralization of soil organic nitrogen compounds in the light of long-term grassland experiments in IMUZ].

SAPEK A., SAPEK B. 2004. Wymywanie składników nawozowych z odwodnionych gleb torfowych po ich renaturyzacji. Przegląd Naukowy, 13(30): 260-268. [In Polish, with English summary: Nutrient leaching from drained peat soil after their restoration].

SAPEK B., SAPEK A. 1998. Monitoring jakości wody gruntowej w zagrodzie wiejskiej i jej otoczeniu. Zeszyty Problemowe Postępów Nauk Rolniczych, 458: 498-504. [In Polish, with English summary: Monitoring of groundwater quality on the farmstead and its vicinity].

SMOROŃ S. 1996. Obieg fosforu w rolnictwie i zagrożenie jakości wody. Zeszyty Edukacyjne, 1/96: 87-104. [In Polish, with English summary: The circulation of phosphorus in agriculture and threat to water quality].

STEINECK S., JAKOBSSON CH., CARLSON G. 2002. Fosfor – stosowanie, wykorzystanie przez rośliny uprawiane i nagromadzenie w glebach użytków rolnych. Zeszyty Edukacyjne, 7/2002: 25-36. [In Polish, with English summary: Phosphorus – application, utilisation by crops and accumulation in agricultural soils].

SOLARSKI H., BŁASZCZYK M., SOLARSKI K. 2005. Drenowanie gruntów ornych na obszarach morenowych Pojezierza Mazurskiego. Roczniki Akademii Rolniczej w Poznaniu, 365, Melioracje i Inżynieria Środowiska, 26: 401-407. [In Polish, with English summary: Drainage of arable land in moraine landscape of the Mazury Lakeland].

SPRUILL T.B. 2004. Effectiveness of riparian buffers in controlling groundwater discharge of nitrate to streams in selected hydrogeologic settings on the North Carolina Coastal Plain. Water Science and Technology, 49(3): 63-70.

SZYMCZYK S. 2004. Wpływ użytkowania terenów rolniczych na jakość wód gruntowych. Część 2. Azot i fosfor. Chemia i Inżynieria Ekologiczna, 11(S4): 399-406. [In Polish, with English summary: Influence of agricultural land use on quality of groundwater. Part 2. Nitrogen and phosphorus].

SZYMCZYK S., CYMES I. 2005. Wpływ ilości opadów i sposobu użytkowania terenu na odpływ sodu, wapnia i magnezu siecią drenarską z gleb ciężkich. Journal of Elementology, 10(2): 395-401. [In Polish, with English summary: Effect of precipitation and land use on the sodium, calcium and magnesium outflows from heavy soils via drainage network].

SZYMCZYK S., GLIŃSKA-LEWCZUK K. 2007. Causes of fading the water of the eutrophic lake Jagiełek with nitrogen and phosphorus compounds under the meteorological conditions of Olsztyn Lakeland. Journal of Elementology, 12(4): 347-360.

SZYMCZYK S., SZYPEREK U. 2005. Rola torfowiska w ograniczaniu odpływu składników biogennych ze zlewni rolniczej. Zeszyty Problemowe Postępów Nauk Rolniczych, 506, 485-495. [In Polish, with English summary: The role of peatland in limiting of the nutrient outflow from agricultural catchment].

SZYMCZYK S., SZYPEREK U. 2005. Erozja chemiczna gleb obszarów pojeziernych. Cz. 1. Odpływ mineralnych związków azotu. Acta Agrophisica, 5(1): 175-178. [In Polish, with English summary: Chemical erosion of soil on lakeland area. Part. 1. The outflow of mineral nitrogen compounds].

SZYPEREK U., SZYMCZYK S., ROCHWERGER A, SOBCZYŃSKA-WÓJCIK K. 2005. Wpływ opadów atmosferycznych na odpływ potasu i sodu z gleb obszarów pojeziernych. Journal of Elementology, 10(1): 167-176 [In Polish, with English summary: Influence of precipitation on potassium and sodium outflows from soil in young glacial areas].

URBANIAK M. 2004. Stężenie wybranych form azotu w roztworach glebowych i ich wymywanie z gleby w warunkach zróżnicowanego nawożenia oraz jej odczynu na trwałych użytkach zielonych. Przegląd Naukowy. Inżynieria i Kształtowania Środowiska, 13(30): 269-279. [In Polish, with English summary: The concentration of some nitrogen forms in soil solution and their leaching in various conditions of fertilization and soil reaction on permanent grassland].

VAGSTAD N., JANSONS V., LOIGU E., DEELSTRA J. 2000. Nutrient losses from agricultural areas in the Gulf of Riga drainage basin. Ecological Engineering, 14: 435-441.

ZAJĄCZKOWSKI K. 2007. Rola zadrzewień w ochronie środowiska i jakości wody. Zeszyty Edukacyjne, 3/97: 39-50. [In Polish, with English summary: The role of landscape plantings in environmental protection and water quality].

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