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WATER QUALITY IN AGRICULTURALLY USED CATCHMENTS IN LOWER SILESIA

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SPIS TREŚCI

1. INTRODUCTION

From the point of view of humans and our potential civilizational development, water is an essential element of the environment. Unfortunately, Poland belongs to countries with relatively low water resources, and, as such, is particularly responsible for the protection of the quality and quantity of water resources available to the society.

The quality of water is influenced by a series of factors: natural conditions, phenomena and human activity. Economic activity, both industrial and agricultural, constitutes a significant threat to the quality of water resources.

While it is relatively easy to monitor the impact of industry on the quality of waters, the evaluation of the influence of areal pollution, e.g. agricultural, is more difficult. This results from the complex nature of the process of transport of pollutants, e.g. from the surface of agriculturally used land to the watercourses, as well as from the qualitative and quantitative transformations that are particularly intense in the ecotonal zone [Banaszuk 2007]. One of the substantial links in the pollution transport chain is soil solution [Paluch et al. 2006].

For the purpose of analysis of groups of pollution components, it can be assumed that agricultural areas mainly supply biogenic elements to the waters. In comparison to other point- and area-related sources, their contribution to the pollution of waters with organic material and organic and mineral hazardous substances is lower [Pulikowski 2004].

Agricultural activity leads to the decrease in biodiversity in rural landscape, and, due to the fact that agricultural farms occupy 68.1% of total land area, agriculture should be particularly responsible for the protection of natural environment [Brodzińska 2005]. Limiting the amount of chemical components discharged from agricultural catchments has a substantial influence on the quality of water retained in various natural and artificial retention reservoirs.

Providing a suitable quality and quantity of water to meet the needs of municipal economy and industry is one of the key tasks faced by institutions responsible for the activities related to water protection. To stress the importance of the problem, in the year 2000 European Parliament adopted the Water Framework Directive (WFD) [Directive... 2000]. Activities aimed at the protection of water resources concern a widespread group of water users, and agriculture is one of the more important branches of the economy, significantly influencing the quality of water [Sojka et al. 2008].

The accession of Poland to the European Union brought several new mechanisms supporting environmental protection. Many of these are to a large extent related to agriculture, and some of them treat the activities aimed at environmental protection as a condition for providing financial support [Brodzińska 2005].

This study presents the results of several research projects conducted in Lower Silesia. The scopes of these projects were varied, although each of them was to some extent related to the quality of water in agriculturally used areas. As a result of these projects, a large amount of empirical data concerning relatively small areas was collected, which, as opposed to monitoring research, allows a precise evaluation of water quality changes in micro scale.

The aim of this study is to analyze and evaluate the results of research concerning the quality of ground and surface waters and drainage effluents from specific objects, shaped by various agricultural activities, as well as the determination of the impact of agricultural activity on the value of specific indicators characterizing water quality.

2. INFLUENCE OF AGRICULTURAL ACTIVITY ON WATER QUALITY

Agriculture is a significant factor in the anthropogenic influence on the environment, including the size and quality of water resources [Zhang et al. 2009, Holman et al. 2010, Malmaeus, Karlsson 2010, Sigua et al. 2010]. Vegetable and animal production uses large amounts of water of a relatively good quality. World demand for water in agriculture will grow in time, together with the demand for food, resulting, among others, from the increase of population and affluence and dietary changes. The growth of watered areas may lead to an increase in food production, but in many parts of the world this potential is limited, due to limited access to suitable water resources [De Fraiture, Wichelns 2010].

The concentration of fertilizer components in waters flowing out of agriculturally used catchments depends on the types of soil and the structure of their usage [Witkowski 1997]. The type and quantity of water retained in soil are subject to constant changes – from chemically bound water to water vapor and free water, whose movement is regulated mainly by gravity. Depending on the characteristics of the soil environment, water soluble substances may penetrate from the solid phase to ground waters [Paluch et al. 2006]. Fertilizer components supplied to the surface of soil are absorbed in the superficial layer within the aeration zone. A threat to ground waters appears only after the absorption capacity of the aeration zone has been exceeded [Biernacka, Pajnowska 1996]. Through soil and soil solution, agricultural activity impacts the composition of ground waters, which determine the composition of drainage effluents, and these, being discharged to the watercourses, impact the composition of water flowing out of agricultural catchments [Pulikowski 2004].

The presence and correct usage of melioration systems is a significant factor influencing the water quality in agriculturally used catchments [Nyc, Pokładek 2001, Pulikowski 2004, Koc et al. 2007, Szymczyk 2010]. The correct usage of objects with regulated outflow leads to an increase in water oxygenation and a decrease in BOD_5 [Nyc, Pokładek 2009].

The quality of water in rural areas is often connected to non-rational usage of fertilizers, incorrect storage of natural fertilizers (particularly in areas with high animal population) and sanitation negligence [Hus 1994, Sojka et al. 2008, Bonton et al. 2010]. Objects that may be particularly threatening are agricultural lands where wastewater is used for agricultural purposes [Czyżyk 1994, Paruch et al. 2001].

Field agricultural production influences first of all the formation of chemical composition of shallow ground waters. The content of fertilizer components, in particular nitrates, is related to the level of nitrogen fertilization. Research conducted in Slovenia showed that at an average level of nitrogen (N) fertilization of 47 $kg \cdot ha^{-1,}$ the concentration of $N\text{-}NO_3$ in ground waters amounted to 0.5 to 16.0 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Maticic 1999], whereas the concentration of nitrate nitrogen in ground waters in Canada, at nitrogen fertilization of 134-245 $kg \cdot ha^{-\cdot1}$, reached 45 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Zebarth et al. 1998]. Studies conducted in Pojezierze Gnieźnieńskie, where the level of nitrogen fertilization varies from 80–200 $kg \cdot ha^{-1.}$ showed that the average concentration of nitrates in ground waters did not exceed 10 mg $NO_3 \cdot dm^{-3.}$ or 2.26 mg $N\text{-}NO_3 \cdot dm^{-3}$. It is also worth noting that the concentration of other analyzed components also remained low [Fiedler et al. 2005]. Higher values were shown by Durkowski [2005]: average concentration in waters on arable fields reached 18.7 $NO_3 \cdot dm^{-3.}$ equivalent of 4.22 mg $N\text{-}NO_3 \cdot dm^{-3}$. Studies conducted in the valley of Narew showed a very high concentration of this form of nitrogen in ground waters on arable fields – on the average 33.85 mg $N\text{-}NO_3 \cdot dm^{-3.}$ whereas on grasslands the concentration was significantly lower, amounting to 5.40 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Banaszuk 2007]. The presented results of research do not show a direct connection between the amount of fertilization and the concentration of nitrogen in ground waters. Typically, the concentration of nitrogen compounds in ground waters is lower in grasslands in comparison to arable fields. This may suggest that the plant cover has a significant influence on the migration of nitrogen to ground waters.

Threats resulting from field production can be significantly reduced by using dosages of fertilizer adapted to the expected crops. For Polish conditions, 250 $kg \cdot ha^{-1}$ should be considered a safe dosage of mineral NPK fertilizers [Mazur 1996]. The application of higher doses, even when connected with watering, results in a significant decrease in fertilization efficiency.

A much more serious threat to the quality of ground waters in rural areas is caused by the management of organic fertilizers, in particular the manner of their storage. Tests of the composition of ground waters located in the proximity of manure piles have shown the following concentrations: of nitrate nitrogen reaching 170 mg $N\text{-}NO_3 \cdot dm^{-3}$ ammonium nitrogen 0.04÷70 mg $N\text{-}NH_4 \cdot dm^{-3}$ and phosphorus 0.01÷10.0 mg $P \cdot dm^{-3}$ [Sapek 1996]. The negative impact of fertilizer management within farms on the composition of ground waters was also proven by Durkowski [2005].

Another issue is the influence of disorderly water and wastewater management in rural areas on the composition of ground waters [Łomotowski 1992, Hus 1994, Aelion et al. 1997, Łomotowski, Skolimowska 2000]. Unfortunately, this cause of water pollution in rural areas often is not precisely identified, and all disadvantageous changes are typically ascribed to agricultural activity.

Ground waters can supply watercourses directly, or through melioration facilities, and their composition influences the quality of surface waters. One of commonly used types of drainage, providing correct water-to-air relations in the soil, particularly in arable lands, is drainage [Kostrzewa 1977, Shkinkis 1997, Orzepowski 2001, Pływaczyk 2003]. One of the main parameters constituting the basis for drainage design are outflow standards. For lowland areas in southwestern Poland, depending on the type of soil, land slope and the assumed probability of occurrence of outflow, these standards range from 0.05 to 0.70 $dm^3 \cdot ha^{-1} \cdot s^{-1}$ [Kostrzewa 1977]. In submontane areas of Lower Silesia with annual precipitation of approximately 800 mm and land slopes of 40 ‰ drainage outflows may be significantly higher – even to 2.25 $dm^3 \cdot ha^{-1} \cdot s^{-1}$. Drainage outflows occur, on the average, for 50÷80 days in lowland areas (precipitation 550÷600 mm), and in case of precipitation of 800 mm (submontane areas) this period is extended to 160÷220 days [Kostrzewa et al. 1999].

The chemical composition of drainage effluents depends on a series of factors: environmental conditions, water circulation in the soil, manner of land usage, amount of organic and mineral fertilization [Pawlik-Dobrowolski 1983], as well as the quantity and composition of precipitation [Cresser et al. 1997]. The composition of drainage effluents is also influenced by the soil reaction [Grieve 1999]. Borowiec and Zabłocki [1990, 1996] have determined the following hierarchy of factors determining the composition of drainage effluents: amount of atmospheric deposition, plant cover and level of fertilization.

Studies conducted in the region of West Carpathians have shown that the concentration of nitrate nitrogen in drainage effluents from arable lands reached only approx. 6 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Pawlik-Dobrowolski 1983]. At a similar level of NPK fertilization (in the amount of 200 $kg \cdot ha^{-1}$) in Albania, much higher concentrations were observed: 19.0÷30.3 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Grazhdani et al. 1996]. In the case of grassland drainage, the concentration of nitrate nitrogen in drainage effluents was significantly lower – ranging from 1.8 to 2.3 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Pawlik-Dobrowolski 1983].

The concentration of phosphorus in drainage effluents in Western Carpathians was very low (0.010÷0.065 mg $P \cdot dm^{-3}$) and not as significantly varied depending on type of usage, as it was in the case of nitrate nitrogen., whereas the concentration of potassium and calcium was slightly lower in effluents from grasslands than in those from arable land. No significant impact of the changes in drainage placement on the composition of drainage effluents was observed [Pawlik-Dobrowolski 1983]. In Pogórze Sudeckie the concentration of phosphorus in drainage effluents from four watersheds amounted to 0.36÷0.39 mg $P \cdot dm^{-3}$ [Hus et al. 1998] and it was significantly higher than the values obtained by Pawlik-Dobrowolski [1983].

Drainage effluents from objects watered with wastewater have a specific composition. As opposed to effluents from other agricultural lands, these contain much more organic material, although the average values of BOD_5 do not exceed 10 mg $O_2 \cdot dm^{-3}$. On the other hand, they contain much less nitrate nitrogen, which is particularly dangerous for recipient waters in excessive amounts [Paruch et al. 2001].

Drainage effluents play a significant role in the shaping of the chemical composition of water in recipients, in particular in drainage ditches of a low flow volume. The most threatened are ditches that directly drain arable lands, quite often supplied by drainage effluents rich in nitrate nitrogen. Research conducted in Lower Silesia has shown that generally, nitrates are the main threat to the water quality in agricultural catchments. Average concentrations of this form of nitrogen in waters flowing out of drainage ditches reach up to 15 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Kostrzewa et al. 2001], whereas Dojlido [1995] determines the range from 0.1 to 10 mg $N\text{-}NO_3 \cdot dm^{-3}$ as natural concentration for surface waters. The introduction of drainage effluents to the ditch led to an increase in the concentration of nitrate nitrogen, and in consequence of total nitrogen, while the concentration of phosphorus remained unchanged [Kostrzewa et al. 2001]. The amount of nitrates discharged in the spring with drainage effluents, from fields to watercourses, can be significantly limited by reconstructing drainage outlets so as to enable the regulation of outflow volume [Banaszuk 2007].

Surface waters, particularly stagnant ones, are prone to eutrophication. Sources of biogenic substances may be insufficiently treated or untreated wastewaters, outflows from urbanized or agriculturally used areas. In small catchments the quality of water depends mainly on the manner of usage and terrain formation [Paluch 1994, Rajda et al. 1994, Sojka et al. 2008. Czaban 2009]. Research conducted in the catchment of Struga Dormowska has shown that agricultural activity has the strongest impact among anthropogenic influences, although, in spite of intense agricultural usage, the waters of this course did not show an excessive pollution with biogenic substances, which may be explained by a large share of forest areas (over 40%) in that catchment [Sojka et al. 2008]. However the results obtained by Paluch [1994] concerning two adjacent catchments, of which one contains 100% agriculturally used lands, and the other one is in 70% covered by forest, did not show any significant differences in the composition of outflowing water. Slightly larger concentration of nitrate nitrogen, amounting to 2.5 mg $N\text{-}NO_3 \cdot dm^{-3.}$ was observed in water flowing out of the forest catchment. [Paluch 1994]. Similar values were obtained for agricultural and forest micro-catchments located in Pogórze Spiskie [Kanownik, Pijanowski 2002]. In a drainage ditch in Western Pomerania an average concentration of nitrate nitrogen was obtained in the amount of 3.38 mg $N\text{-}NO_3 \cdot dm^{-3}$, which was lower than in some small watercourses [Durkowski 2005]. Significantly higher concentrations of nitrate nitrogen (13.4 mg $N\text{-}NO_3 \cdot dm^{-3}$) were noted in Pogórze Sudeckie [Pulikowski 2004]. The quality of water in watercourses flowing through pastures and in small ponds located in pastures is much more influenced by direct access of animals to such course (pond) than by superficial flow [Hus et al. 1998, Declerk et al. 2006].

When analyzing the concentration of pollutants, in particular of nitrates, in waters flowing out of agriculturally used catchments, one should remember that they are of a seasonal nature. Highest concentrations of nitrate nitrogen are typically observed in early spring (in the so-called pre-spring season) [Durkowski 2005, Pulikowski et al. 2005, Banaszuk 2007]. Maximum concentrations occur in February through early March, before the start of agrotechnical works, and they coincide in time with the occurrence of highest flow volumes, causing the outflow of a major part of the annual load of nitrates during this short period. During that time, inflow of water from agriculturally used lands to water reservoirs used for supplying water to the population should be limited, and the water should be directed, for instance, to fish ponds instead [Pulikowski et al. 2005]

Stagnant waters, which are quite often retained in small, shallow water reservoirs, both on agriculturally used lands and in urban areas, are much more prone to eutrophication. Apart from the fact that they constitute an important element of the landscape and contribute to the preservation of biodiversity, they can also be used to increase retention ad to retain water for agricultural purposes [Declerk et al. 2006, Juszczak et al. 2007, Orzepowski et al. 2008b, Rugriero et al. 2008]. Agricultural activity causes a threat to such reservoirs. Studies conducted by Declerck and his team [2008] have shown that the 200 m wide zone surrounding the reservoir is particularly important. Temperature is one of the key factors determining the eutrophication of water in reservoirs [Balcerzak 2006].

Research conducted in Pojezierze Olsztyńskie and Równina Sępopolska, encompassing 36 reservoirs of various areas (25–15880 m^2) located in catchments used in various manners (arable land, grasslands, urban areas and forests), have shown the following ranges of value of basic pollutants: electrical conductivity – 18–816 $\mu S \cdot cm^{-1.}$ nitrate nitrogen – 0.005–2.43 mg $N\text{-}NO_3 \cdot dm^{-3.}$ total phosphorus – 0.14–1.70 mg $P \cdot dm^{-3}$ and chlorides – 9–44 mg $Cl \cdot dm^{-3}$. The highest values for electrical conductivity and nitrate nitrogen were obtained for ponds located in grasslands [Koc et al. 2001].

Small water reservoirs can perform various specific functions aimed at the improvement of surface water quality. They can play a significant role in limiting the outflow of biogenic components from the catchment [Wiatkowski 2010], as well as serve as elements of anti-erosion protection [Żmuda et al. 2001, Fiener et al. 2005]. If used as so-called preliminary reservoirs, they can serve to improve water quality in retention reservoirs, lowering the concentration of nitrates and phosphorus even by 50–60% [Wiatkowski et al. 2006, Czamara et al. 2008]. One quite specific application of small water reservoirs is using them to treat wastewater in areas where buildings are scattered [Gemitzi et al. 2007].

Similarly to the case of ground waters, disorderly water and wastewater management is an important factor influencing the quality of surface waters. It leads to the pollution of water with organic material (substantial increase in the value of oxygen indicators) and to an increase in the concentration of total nitrogen and phosphorus [Hus 1994].

Protection of water quality, both of ground waters and of surface waters, is one of the most important tasks a modern society faces. In order to achieve it, numerous economic processes have to be organized, both in municipal economy and in agricultural production. The success of these actions is essential for future generations. We cannot allow the poor environmental condition of water resources to hinder the development of our descendants. The importance of this issue is proven by various initiatives undertaken by the highest authorities of the European Union, which have adopted the Water Framework Directive [Directive... 2000] that obliges member states to take actions aimed at the improvement of the environmental condition of waters.

3. CHARACTERISTICS OF RESEARCH OBJECTS

This study presents the results of tests of water quality in nine agriculturally used catchments in Lower Silesia. Most of these objects are located in the proximity of Wrocław, only one of them is located on the border of Pogórze Bolkowsko-Wałbrzyskie and the Wałbrzyskie Mountains (Fig. 3.1). Due to differences resulting from land formation and type of usage, the objects have been meliorated in different ways.

3.1. Location of the objects

The first of the analyzed objects is located in the settlement Szewce, northwest from Wrocław, in the Silesian Lowland area, on the elevation of 114–132 m above sea level (Fig. 3.2.). The tests covered a part of the object of a total area of 411 ha, which has been partly drained, equipped with a semi-permanent rain barrel. In the years 1973–1991 it performed the function of an agricultural object using the wastewater from the city of Wrocław. After 18 years of usage, watering with wastewater was stopped, and grasslands were transformed into arable fields. After initial observations in the field had been conducted, the part of an area of 192.1 ha was designed for a direct study. This area was divided into two sub-catchments of the respective areas of 100.7 ha and 91.4 ha. The first of these catchments, which ends in the measurement cross-section Sz-1 consists of arable lands drained by means of drainage – sheds 1÷4 of a total area of 39.08 ha and other lands of an area of 61.62 ha, which have not been drained (Fig. 3.2). The areas of specific drainage sheds varied from 7.65 to 14.71 ha, drainage was spaced at 20 m, and the drains were placed at the average depth of approx. 1.0 m. The second catchment, of an area of 91.4 ha, reaching to the cross-section Sz-2 (Fig. 3.2) consists of arable lands drained by a network of ditches. Terrain slope inclination ranges from 2.5 to 4‰. Soils in the object consist of brown soils formed from sandy and sandy clay loam, at some points from clay loam. Small areas consist of soils formed from well-decomposed peats. Soil reaction varies from 4.5 to 7.5 pH.

Dominant cultivated crops have been corn and wheat, and, during the test period, also rape and potatoes on small areas. NPK fertilization of arable fields amounted to approx. 120-180 $kg \cdot ha^{-1}$. Water for the analysis was taken from a piezometric well, drainage outlet W1 and 2 cross-sections on the ditches (Fig. 3.2).

The second object (Miękinia) is a consistent complex of meliorated agricultural lands and forests of the area of 720 ha, located in a small catchment (27 km^2) of the basic watercourse Zdrojek, tributary to Jeziorka (Fig. 3.3). The course flows across the mid-

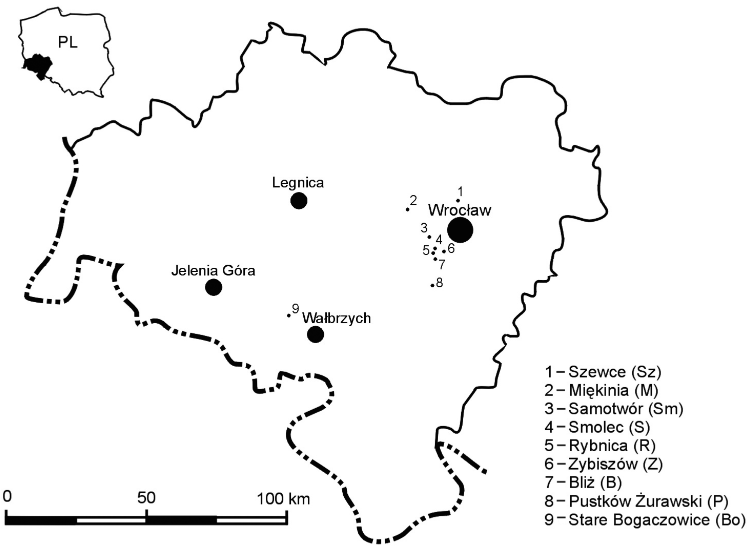

Fig. 3.1. Location of the tested objects

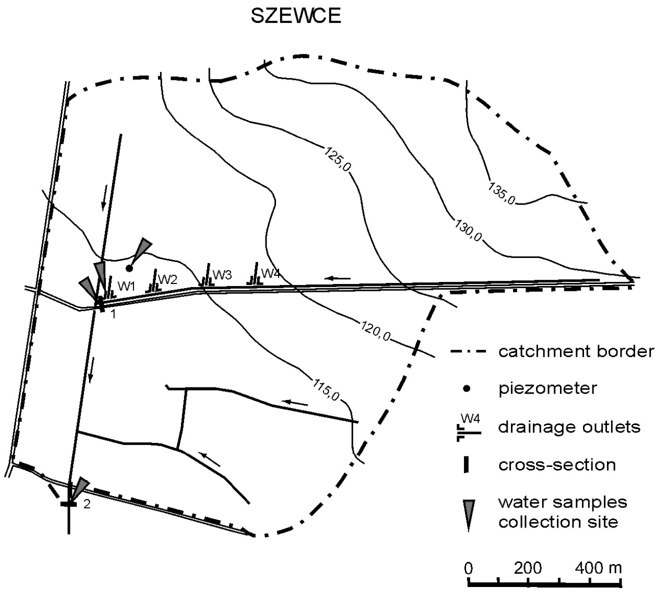

Fig. 3.2. Test object Szewce

dle of the object, and on the length of approx. 3 km constitutes the main source of water supply. In the 1980s–1990s the object was meliorated by means of regulating a section of the basic watercourse and regular placement of sluices, as well as the reconstruction of the inflowing, irregular network of specific ditches (Phot. 1). The layout of ditches and placement of sluices on the river Zdrojek, located centrally in relation to the borders of the object, allows efficient management of available water resources (Phot. 2, 3). During observations conducted in 1995–2007 the agricultural usage of land was subject to numerous changes. In recent years, due to socioeconomic transformations in the area of the analyzed catchment, the area of arable lands has significantly decreased, the area of extensive grasslands and forested areas has increased, and areas designed for non-agricultural economic activity have been introduced. By the end of the analyzed period the structure of usage of agricultural lands was as follows: grasslands (40.3%), arable lands (36.5%) and forests (23.2%), of which approx. 3% are newly planted.

The soils in the object are formed from mineral (52%) and organic (48%) formations, placed on the bedding consisting mainly of sands. The soils in permanent grasslands consist mainly of mineral muck soils, locally low peats, and in arable lands the main soils are degraded black earth and lessive soils of varied bonitation and good hydraulic conductivity.

Field and laboratory tests have proven that organic soils in grasslands are characterized by a specific density of 1.96 $g \cdot cm^{-3.}$ bulk density of 0.58 $g \cdot cm^{-3}$ and general porosity of 70%. Typical mineral soil on arable lands has the following characteristics: specific density – 2.59–2.60 $g \cdot cm^{-3.}$ bulk density – 1.55–1.68 $g \cdot cm^{-3.}$ total porosity – 35–40% and content of framework particles – 10–11%. The profile of these soils sometimes may contain a thin insert of organic formation, whose properties are similar to those of typical organic soils on grasslands. Field observations and measurements of the level and dynamics of ground waters also prove good hydraulic conductivity of the soils in object Miękinia.

Terrain slope inclination usually falls within the range from 3.0–6.0‰, and locally increases to 15 ‰. Water samples for analysis were taken from the watercourse Zdrojek below the object (Phot. 4) and from a piezometer in the central part of the object (Fig. 3.3).

The next analyzed object is Samotwór, located approximately 20 km west from the center of Wrocław, in the lower part of the catchment of Bystrzyca which is a left tributary of Odra. The tests were conducted on the area consisting of 100 ha of arable fields (Fig. 3.4), constituting at the same time a closed local hydrological catchment. Until 1998 part of the land was used by Agricultural Experimental Facility in Samotwór, belonging to the University of Environmental and Life Sciences in Wrocław. Now these lands are owned by individual farmers. In the lower part of the object, on main ditch A, a sluice is located for the purpose of regulation of water outflow throughout the year.

Terrain slope inclination ranges from 0.5–5‰. Initially the object was used as arable lands, but now nearly 40% are idle lands. This is a typical object watered from the resources of own retention depending on the amount of atmospheric deposition. Only periodical excessive precipitation was discharged outside the system [Pokładek 2001].

Soils of the object consist of permeable and medium permeable formations of granulometric density of loamy sand and sandy loam. In the southeastern part dominant soils are brown soils (62%), in the central and northern parts – lessive soils 18%), and in the

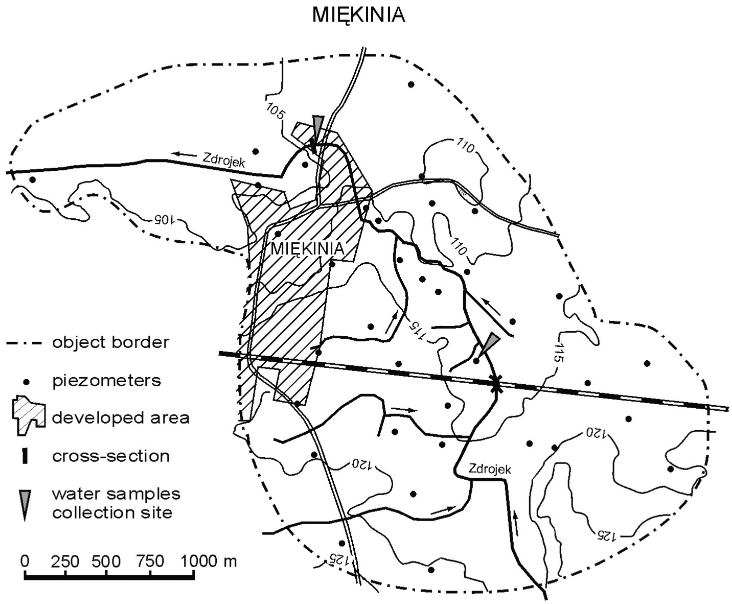

Fig.3.3. Test object Miękinia

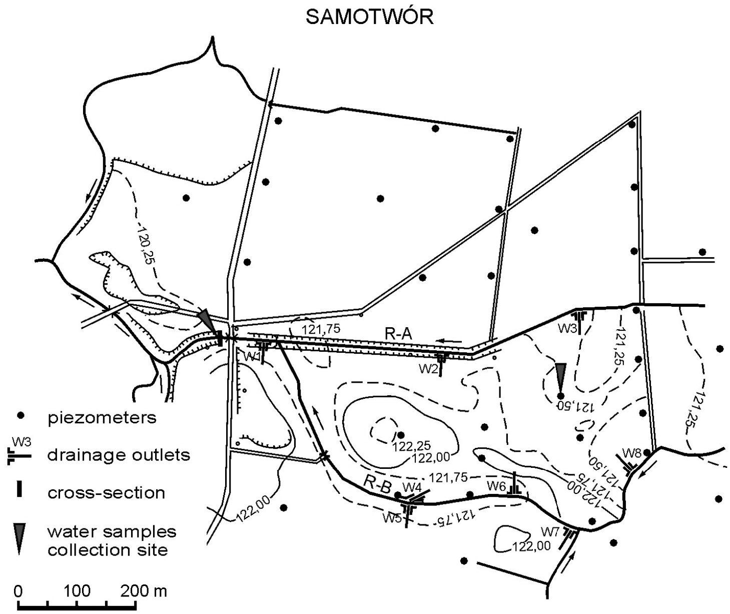

Fig. 3.4. Test object Samotwór

western part, close to the river Bystrzyca, also muds (20%). These soils are usually permeable, characterized by a slightly varied granulometric composition at humus level and are, on the whole area, located on the bedding of permeable formations, typically sand, and in some places gravel.

The laboratory tests of basic physical and hydrological characteristics of the soils have shown that the specific density of soil in object Samotwór falls within the range 2.42–2.76 $g \cdot cm^{-3}$ bulk density is 1.53–1.81 $g \cdot cm^{-3}$ and the porosity – 29–41% of volume.

In deeper soil levels a large content of framework particles was observed, in the amount of 25.7 to 91.4%, on the average 60%. Thus, the formations are permeable, and they create favorable conditions for the flow of ground waters. Water samples for analysis were taken from the watercourse below the object (Phot. 5) and from a piezometer located in the higher part of the object (Fig. 3.4).

The fourth object – Stare Bogaczowice – is located on the border of Pogórze Bolkowsko-Wałbrzyskie and the Wałbrzyskie Mountains, in the region of Central Sudety, approximately 80 km southwest from Wrocław. The analyzed area is located on the elevation of 400–500 m above sea level, on northern and northeastern slopes. Catchment inclination in this area ranges from 52 to 84‰. Since a new drainage system was created in 1990 arable lands have constituted approximately 80% of catchment area (Fig. 3.5). Soils that are present in the object are created from sandy clay loam and clay loam, with high framework content, in many cases exceeding 20%. Soil profiles are low, reaching down to 1.2 m and are located on the bedding of rock rubble. The soils are characterized by an increased content of iron compounds (Fe_2O_3) – from 3.1 to 4.4%; however no calcium carbonate was detected. The reaction (pH in 1 M KCl) is below 6.5. During the test period dominant crops were cereals: barley, wheat and corn, as well as oil-yielding rape and a mixture of papilionaceous plants. Fertilization fell within the range 100–150 kg NPK/ha. The area of individual drainage sheds varies from 1.08 to 8.85 ha. For the purposes of the study two variants of drain spacing were adopted: normative – 11 m (sheds 1 and 5), and double – 22 m (sheds 3 and 4). The depth of drain placement, calculated basing on binding guidelines, was 0.95 m in all drainage sheds. Drainage outlets constituting the endings of collectors discharging water from individual sheds to the main ditch "A" were constructed in from of heavy concrete structures. The ditch, 1.3 to 1.5 m deep, discharges water intermittently, and the inclination of its bottom, reaching up to 60 ‰, ensures proper flow capacity without the need to perform regular maintenance works. Water samples for analysis were taken from the ditch below the object, from outlets: W1. W3. W4 and W5 and from a piezometer situated in the lower part of the object (Fig. 3.5).

The analyzed object Pustków Żurawski is located in the Silesian Lowland. The arable lands on which tests were conducted, were previously owned by the Sugar Refining Plant "Pustków Żurawski" S.A. and later they were used by an individual farmer. They are located between the villages Pustków Żurawski and Gniechowice. The analysis of ground water composition encompassed grasslands of an area of 10.3 ha, directly adjacent to the bed of the river Czarna Woda, watered by sugar refining wastewater, provisionally treated in an accumulation reservoir. During the vegetation period the ground was watered 3–5 times, with a dosage of 30 mm. The object is located on the elevation

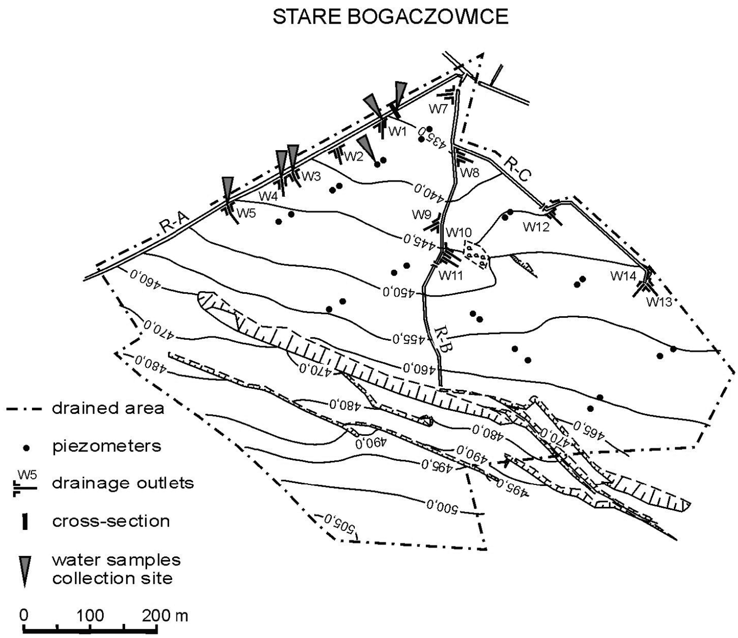

Fig. 3.5. Test object Stare Bogaczowice

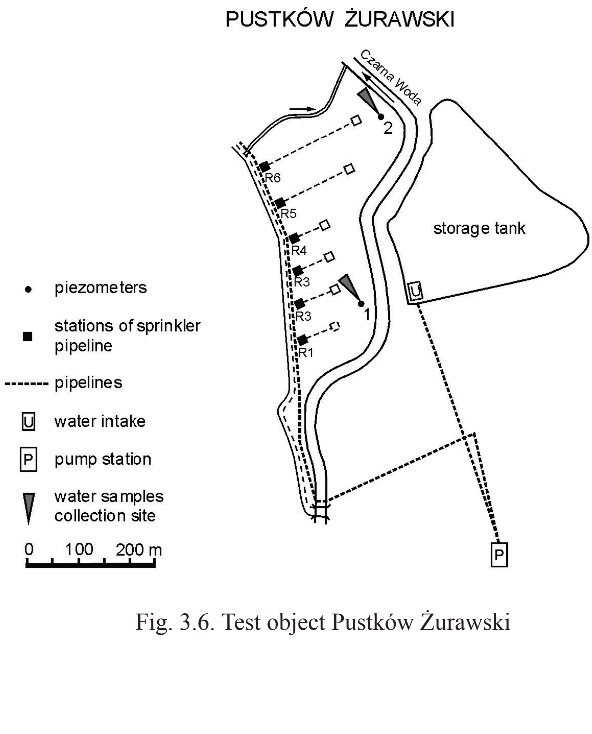

Fig. 3.6. Test object Pustków Żurawski

of 140–142 m above sea level. Terrain inclination ranges from 4 to 10‰. The land slopes gently in the northwestern direction, and then to the southwest, towards the river Czarna Woda (Fig. 3.6).

The object Pustków Żurawski contains soils whose top layer is characterized by a granulometric composition of silt loam. Deeper in the soil profile sandy formations appear with high framework content. Dominant crops are cereals (wheat and barley), corn and sugar beet. Applied level of NPK fertilization amounted to approx. 80–120 $kg \cdot ha^{-1}$. Water samples for analysis were taken from 2 piezometers located on the border of the river protection zone as defined for an object watered by wastewater (Fig. 3.6).

Four following objects are located in the settlements Bliż, Rybnica, Smolec and Zybiszów (Fig. 3.1) in the community Kąty Wrocławskie, from several to over ten kilometers to the south west of Wrocław. In the geographical aspect this area is situated in the eastern part of the Wrocławska Plain [Kondracki 1994], located on the left bank of Odra, between the valleys of Oława and Strzegomka.

Bliż is a small settlement with three small, interconnected water reservoirs situated in its northwestern part. From the west they are adjacent to lands used by individual farmers as arable land. The reservoirs are supplied mainly by precipitation and from an underground tributary located on the southern bank of the reservoir located in the center of the village (Fig. 3.7). The reservoir has an area of approx. 0.09 ha, and a depth of up to 1.8 m. It is stocked with fish and performs the function of a fishing pond for local residents. From this reservoir, water flows through a pipeline of the diameter of 20 cm to another small reservoir of an area slightly exceeding 0.05 ha and approx. 1.5 m deep. Then, the water flows out through an approximately 80 meter long ditch to the last, third reservoir, shaped in form of a quadrangle of an area of approx. 0.12 ha. It is filled with silt, and its average water volume does not exceed 1 m. excess water from this reservoir is discharged by an open ditch, over 200 m long, in the northeastern direction to a small watercourse Kasina. The watercourse is approx. 2 m deep, and its bottom is 1 m wide; during draught periods the flow often ceases.

The inclination of terrain adjacent to the reservoirs ranges from several to over ten per mill, only in the southern part of the settlement they are locally slightly higher. The soil conditions in the southern and northern part of object Bliż are slightly different. Generally, medium and heavy soil formations appear in the northern part and in the soil bed of the southern part permeable formations with the addition of framework particles were noticed. These formations contain from 31 to 68% clayey particles. On the other hand, soils in the central part of the object are characterized by higher permeability (loam, silt and loamy sand) and a significantly lower content of clayey particles (ranging from 17 to 46%). The content of silt fraction varies from 18 to 62%. In some layers of the soil profile the content of framework particles is insignificant, whereas in others it may reach even up to over ten percent. The specific density at humus level ranges from 2.51 to 2.58 $g \cdot cm^{-3}$, while in deeper layers it increases to 2.64–2.66 $g \cdot cm^{-3}$. Values of bulk density vary from 1.45 to 1.55 $g \cdot cm^{-3.}$ only locally from 1.73 to 1.77 $g \cdot cm^{-3}$. The porosity of most soil layers formed from heavy and medium fractions is not very varied and falls within the range from 41.1 to 46.0%, while the porosity of light formations, appearing in deeper layers of the profiles amounts to 33.5–34.5%. Water for analysis was taken from the first 2 reservoirs and from the piezometer (Fig. 3.7) (Phot. 6, 7).

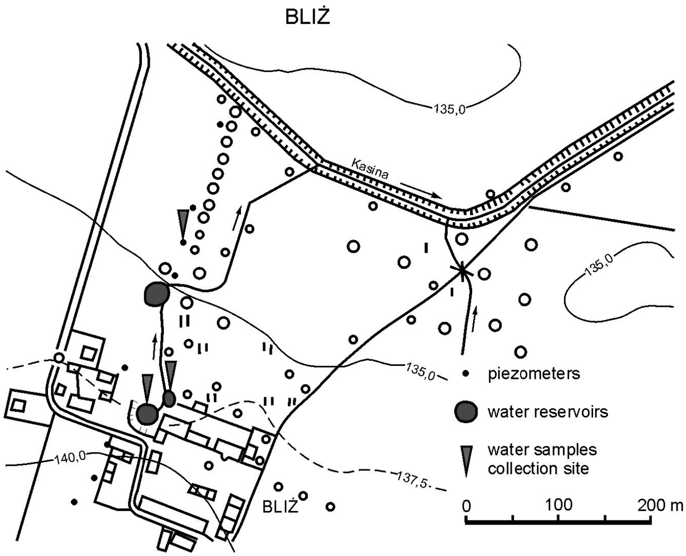

Fig. 3.7. Test object Bliż

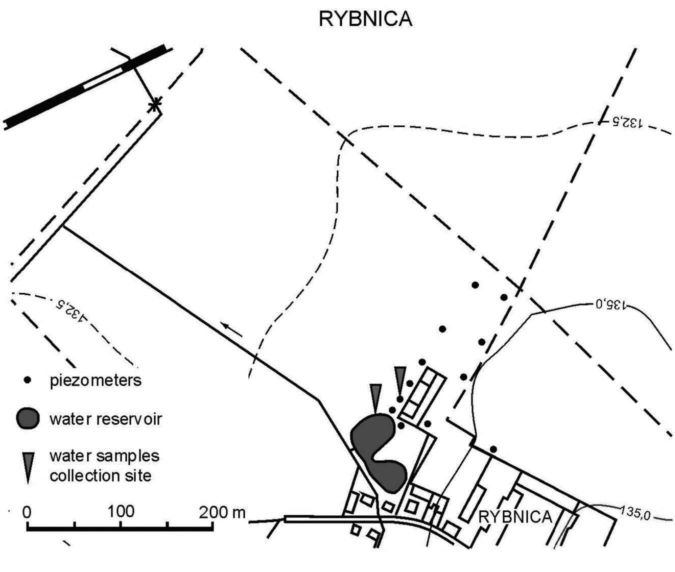

Fig. 3.8. Test object Rybnica

In the village Rybnica the tests were conducted in the surrounding of a small water reservoir being a remainder of a small excavation of clay that used to be mined here for the production of construction ceramics in the first half of the 20^{th} century (Fig. 3.8). The reservoir has an area of approx. 0.25 ha, and its depth does not exceed 1.5 m. The reservoir is supplied by precipitation and ground waters. Near the southwestern bank there is a ditch, separated from the reservoir by a dike. A pipeline of the diameter of 50 cm going across the dike and equipped with a sluice, allows to discharge water from the reservoir when needed. On the northeastern side of the reservoir piezometric wells were installed, to enable measurement of ground water level and taking samples for chemical analysis.

The terrain in Rybnica, where the study was conducted, is quite flat, with slope inclinations exceeding ten per mill. Agricultural areas adjacent to the reservoir are owned by individual farmers and are used as arable land.

The soils of the object are formed mainly from silt and silt loam on the bedding of sandy loam. These formations contain from 22 to 38% clayey fraction. They are also characterized by a high content of silt fraction, ranging from 30 to 58%. The content of clay varies from 2–7% and framework particles from 0.8 to 6.5%. Specific density of soils in the object Rybnica falls within the range 2.56–2.69 $g \cdot cm^{-3.}$ while the bulk density of the top layer of the soil is 1.41–1.53 $g \cdot cm^{-3.}$ and deeper increases to 1. 55–1.75 $g \cdot cm^{-3}$. The porosity of the said formations falls within the range from 40.2 to 44.9% in top layers of the profile and from 34.2 to 39.0% in deeper layers.

Water for analysis was taken from the reservoir (Phot. 8) and from the piezometer located close to its northern bank (Fig. 3.8).

Object Smolec is located several kilometers away from Wrocław, near the railroad to Wałbrzych; the reservoir located there is situated on the southwestern border of the settlement. This is a former clay excavation site, which has filled with water. The reservoir now has an area of approximately 2.2 ha, and its depth in deepest places in the western part reaches even to 10 m. The reservoir is supplied by precipitation and ground waters. It is used by a local angling club as a fishing site, and it serves as a recreational spot for local residents. The user of the adjacent arable land has ensured the technical possibility to use the western part of the reservoir for potential intake of water for watering purposes.

The analyzed area is a plain: small local inclinations vary from several to over ten per mill. Directly adjacent to the reservoir there is a narrow zone of trees and bushes, a few residential and farming buildings, and the whole site is surrounded by intensively used arable lands.

Soils in the object are created from silt formations. To the north side of the water reservoir they contain 20–41% clayey parts, while in soils from the southern part of the analyzed area the content of this fraction ranges from 19 to 35%. These are usually normal silt and silt loam, as well as sandy loam, locally on underlying loamy sand and sandy loam. These soils contain from 18 to 49% of silt fraction, only 3–11% clay fraction and few framework particles – 1.1–4.0%. The specific density of soils in the object falls within the range from 2.54 to 2.67 $g \cdot cm^{-3.}$ while bulk density is 1.42-1.60 $g \cdot cm^{-3}$ in the arable layer and 1.50–1.69 $g \cdot cm^{-3}$ in deeper layers. The porosity of soil formations does not significantly differ and it varies from 35.5–44.7%.

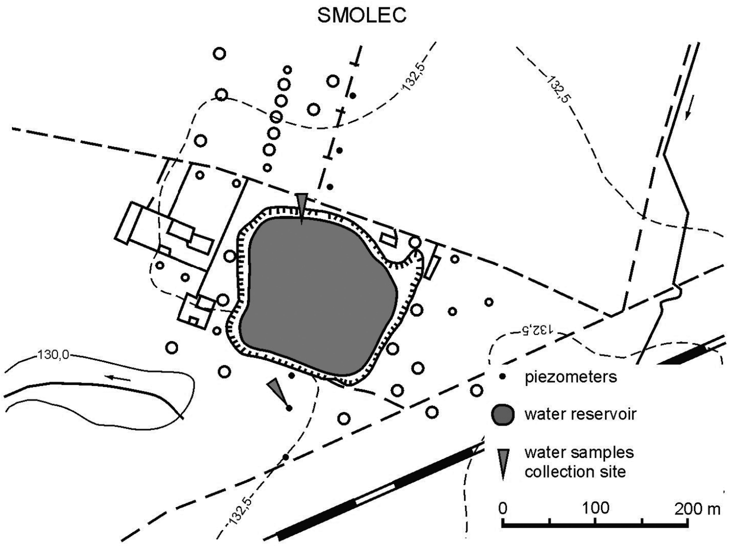

Fig. 3.9. Test object Smolec

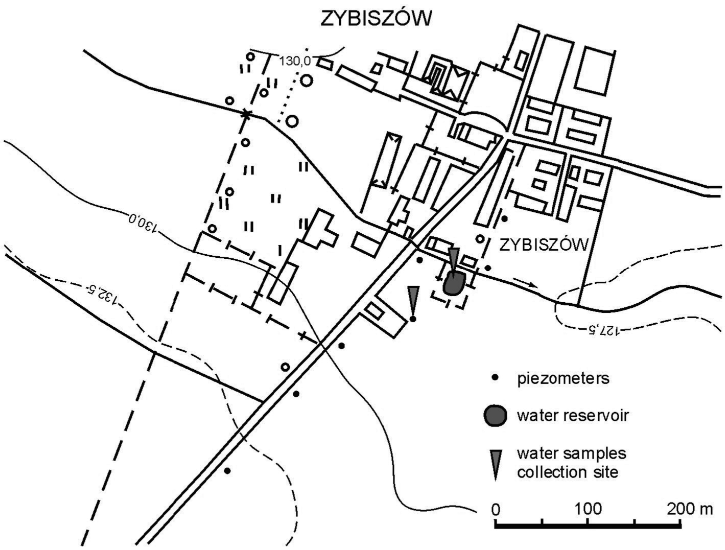

Fig. 3.10. Test object Zybiszów

Water for analysis was taken from the reservoir (Phot. 9) and from the piezometer located to the south from its bank (Fig. 3.9).

The last object – Zybiszów – is located in a small settlement surrounded by agricultural land used by the Experimental Station for the Evaluation of Varieties (SDOO). The terrain has the form of a plain, with small local declines – mostly ranging from several to over ten per mill.

On the southern edge of the settlement there is a small, artificial water reservoir of a roughly rectangular shape, of the area of 0.06 ha and a maximum depth up to 2 m. Along its southern bank a pipeline is located (Φ 50) which is connected, by means of a drain, to a discharge pipeline with a latch that enables the discharge of water from the reservoir if necessary. Apart from its recreational and aesthetical function in the local landscape, the reservoir can also constitute a source of water reserve for fire-protection purposes. It is supplied with water mainly from direct atmospheric precipitation, and by an underground inflow. The south-western, southern and eastern banks of the reservoir adjoin areas used for agricultural purposes as arable land by the Experimental Station for the Evaluation of Varieties in Zybiszów (Fig. 3.10).

Arable land in Zybiszów, in the test area, is used by the SDOO interchangeably, both for research purposes and to pursue commodity-based activity. Down to the depth of 150 cm the soil consists mainly of formations containing 31–40% clayey parts, with the following dominant granulometric groups: sandy loam and loam. They lay on a bedding of sand containing 6–16% clayey particles – sand, loamy and silt.

Specific density of soils in the object falls within the range 2.59–2.69 $g \cdot cm^{-3.}$ bulk density varies from 1.47 to 1.54 $g \cdot cm^{-3}$ in the arable layer and to 1.60–1.69 $g \cdot cm^{-3}$ in deeper layers. Water for analysis was taken from the reservoir (Phot. 10) and from a piezometer located approximately 50 m southwest to its bank.

In the objects: Bliż, Rybnica Smolec and Zybiszów the main cultivated crops were wheat, rape, and locally corn and root plants.

3.2. Meteorological conditions

The course of meteorological conditions (total precipitation and average temperatures) for the objects: Miękinia (1995–2007), Samotwór (1995–2007), Smolec (2002–2005), Rybnica (2002-2005), Zybiszów (2002–2005), Bliż (2002–2005) and Pustków Żurawski (1998–2002) were characterized basing on the data from station Wrocław Strachowice of the Institute of Meteorology and Water Management (IMGW) (Tab. 3.1 i 3.2); for Bogaczowice (1997–2002) from the station Szczawno-Zdrój (Tab. 3.3 i 3.4), and the precipitation for the object Szewce (2000–2002) from the IMGW station Ligota Piękna (Tab. 3.5).

Table 3.1

Monthly, periodical and annual precipitation totals for meteorological station
Wrocław Strachowice (mm)
Objects: Bliż, Rybnica, Mękinia, Pustków Żurawski, Samotwór, Smolec, Zybiszów

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	IV–IX	I–XII
1950–1989	**27**	**22**	**25**	**40**	**55**	**69**	**92**	**64**	**46**	**35**	**36**	**34**	**366**	**545**
1995–2007	**25**	**28**	**34**	**28**	**58**	**58**	**99**	**70**	**48**	**33**	**35**	**27**	**361**	**544**
1995	20	19	29	23	86	158	69	84	91	4	43	21	**511**	**647**
1996	5	25	20	36	58	53	95	92	60	42	13	11	**394**	**510**
1997	5	27	14	50	67	39	239	52	37	42	30	33	**484**	**635**
1998	48	22	36	49	26	69	79	37	88	76	21	14	**348**	**565**
1999	18	42	53	32	28	56	76	17	36	17	32	24	**245**	**431**
2000	32	37	73	11	104	22	124	35	31	9	36	19	**327**	**533**
2001	13	17	64	32	45	56	183	58	92	25	32	21	**466**	**638**
2002	21	40	16	27	28	40	63	108	50	48	47	16	**316**	**504**
2003	31	2	16	15	106	22	72	25	31	48	16	34	**271**	**418**
2004	28	23	45	18	35	45	58	55	18	38	68	15	**229**	**446**
2005	32	39	9	26	104	32	105	66	22	5	26	96	**355**	**562**
2006	24	35	24	46	21	68	23	229	21	54	59	23	**408**	**627**
2007	48	42	47	5	52	95	97	47	45	26	38	20	**341**	**562**

Table 3.2

Average monthly and periodical air temperatures for meteorological station
Wrocław Strachowice (°C)
Objects: Bliż, Rybnica, Mękinia, Pustków Żurawski, Samotwór, Smolec, Szewce, Zbiszów

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	IV–IX	I–XII
1950–1989	**-1.9**	-1.1	2.8	8.0	13.8	16.1	18.2	17.5	13.7	8.8	4.0	0.4	14.6	8.4
1995–2007	-0.8	1.2	3.4	9.1	14.5	17.5	**19.0**	**18.8**	**13.8**	**9.7**	**3.9**	**0.1**	**15.5**	**9.2**
1995	-0.5	4.5	3.5	8.7	12.8	16.0	20.9	18.7	13.1	11.3	1.2	-3.1	**15.0**	**8.9**
1996	-4.9	-4.1	-0.4	8.2	13.3	16.8	16.5	17.7	10.7	10.5	5.9	-4.2	**13.9**	**7.2**
1997	-4.4	3.5	4.3	6.0	14.0	17.4	17.9	19.4	14.2	7.6	3.3	1.6	**14.8**	**8.7**
1998	1.9	5.1	3.5	10.4	14.7	17.8	16.2	17.6	13.9	8.9	0.6	-0.2	**15.1**	**9.2**
1999	1.6	0.1	5.1	9.9	14.8	16.5	20.0	18.3	17.2	9.4	3.0	1.9	**16.1**	**9.8**
2000	-0.3	3.8	5.0	12.1	15.7	17.9	16.5	19.0	13.4	12.5	6.8	2.5	**15.8**	**10.4**
2001	0.6	1.1	3.5	8.0	14.8	15.1	19.2	19.3	12.5	12.7	3.4	-1.7	**14.8**	**9.0**
2002	0.6	4.9	5.3	9.0	17.0	18.2	20.1	20.6	13.6	8.2	4.9	-3.3	**16.4**	**9.9**
2003	-2.1	-3.5	3.1	7.7	15.7	19.5	19.7	20.2	13.6	5.4	4.9	1.2	**16.1**	**8.8**
2004	-3.5	1.5	4.0	9.5	12.8	17.0	18.5	19.6	13.9	9.9	4.4	1.1	**15.2**	**9.1**
2005	1.6	-1.9	1.0	9.3	13.8	16.9	19.7	17.5	14.8	9.9	3.2	0.9	**15.3**	**8.9**
2006	-6.0	-2.4	0.1	9.4	13.9	18.5	23.1	17.1	15.7	11.2	6.3	3.7	**16.3**	**9.2**
2007	4.6	2.5	5.9	10.5	15.3	19.5	19.0	18.9	12.9	8.0	2.8	1.1	**16.0**	**10.1**

Table 3.3

Monthly, periodical and annual precipitation totals for meteorological station
Szczawno-Zdrój (mm)
Object: Bogaczowice

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	IV–IX	I–XII
1972–1991	**31**	**28**	**34**	**47**	**66**	**87**	**93**	**85**	**52**	**44**	**46**	**42**	**430**	**655**
1997–2002	37	38	51	45	74	87	188	102	70	49	47	35	**566**	**823**
1997	12	32	37	61	79	57	431	41	32	63	49	47	**701**	**941**
1998	56	20	63	37	35	130	72	42	92	94	32	20	**408**	**693**
1999	27	41	37	45	65	136	88	24	40	40	40	26	**398**	**609**
2000	66	51	65	17	112	56	175	44	69	17	45	20	**473**	**737**
2001	34	40	70	77	50	80	201	114	122	21	52	57	**644**	**918**
2002	29	42	35	34	100	64	160	348	65	58	65	37	**771**	**1037**

Table 3.4

Average monthly and periodical air temperatures for meteorological station
Szczawno-Zdrój (°C)
Object: Bogaczowice

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	IV–IX	I–XII
1971–1991	**-1,8**	**-1,3**	**2,5**	**6,1**	**11,2**	**14,4**	**16,2**	**15,9**	**12,2**	**8,5**	**3**	**0,3**	**12,7**	**7,3**
1997–2002	**-1,2**	**1,6**	**3,0**	**7,7**	**13,5**	**15,6**	**17,1**	**17,2**	**12,4**	**8,5**	**2,5**	**-1,1**	**13,9**	**8,1**
1997	-4,5	1,6	2,9	4	12,3	15,5	16,3	17,4	12,8	6	2,7	1	**13,1**	**7,3**
1998	0,8	3,1	1,9	9,3	13,4	16,3	16,7	15,8	12,3	6,9	-0,9	-1,3	**14,0**	**7,9**
1999	0,2	-1,8	3,6	8,2	12,5	14,6	18,1	16	15,1	8	1,7	0,2	**14,1**	**8,0**
2000	-2	1,8	2,9	10,7	14	16,7	15	17	11,9	11,3	6,3	1,4	**14,2**	**8,9**
2001	-0,6	0,3	2,5	6,7	13,4	13,8	17,9	18,1	11	11,9	1,7	-3,7	**13,5**	**7,8**
2002	-0,8	4,4	4,1	7,5	15,6	16,8	18,3	18,6	11,4	7	3,5	-4,1	**14,7**	**8,5**

Table 3.5

Monthly, periodical and annual precipitation totals for deposition monitoring station
Ligota Piękna (°C)
Object: Szewce

Year	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**IV–IX**	**I–XII**
1950–1980	**35**	**32**	**30**	**39**	**58**	**64**	**85**	**70**	**45**	**41**	**43**	**45**	**361**	**587**
2000–2002	31	43	70	29	55	53	115	64	57	34	39	30	**373**	**620**
2000	50	40	94	11	64	25	127	41	28	8	42	33	**296**	**563**
2001	16	21	79	30	53	85	170	44	107	34	29	32	**489**	**700**
2002	27	68	37	46	48	48	49	107	36	59	45	26	**334**	**596**

According to the division of Poland into climate regions [Woś 1999], test objects located in the proximity of the station Wrocław Strachowice are characterized by the Central Lower Silesian region, encompassing the Silesian Lowland and Przedgórze Sudeckie, whereas the object Stare Bogaczowice is located on the border of the Kamiennogórski and Wałbrzyski regions. The first of these regions is characterized by moderately warm (131 days), very warm (87 days) and hoarfrost weather (83 days). There are 28 frosty days, including very frosty 1.4. The Kamiennogórski region the Kamiennogórska Basin consisting of two levels: b – moderately warm (400–600 m above sea level) and c – moderately cool (600–800 m above sea level). Winter lasts here for about 4 months and ends in the second decade of March, and the short, only 6 month vegetation period starts in mid-April. The Wałbrzyski region encompasses the Wałbrzyskie and Kamienne mountain ranges with level b – moderately warm (400–550 m above sea level) and level c – moderately cool (550–800 m above sea level) and the Sowie Mountains exceeding 800 m above sea level. Average annual temperature ranges from 5.5°C to 6.5°C, vegetation period starts in the second decade of April, and thermic summer practically does not occur in valleys and on ridges. Annual total precipitation ranges from 700-800 mm, and in the Sowie Mountains it reaches 1000 mm. An equivalent of this division, according to Schmuck [1959], is the region on the Odra (Wrocław and Legnica region) and the region Lubuski and Lower Silesian according to Wiszniewski and Chełchowski [1975]. According to Bac [1991], Wrocław and its surroundings are located in the agroclimatic region B-2. which can be characterized as moderately humid, warm and moderately sunny. In the winter months the region is significantly warmer than others, and the vegetation period is one of the longest in Poland.

Total precipitation for the period 1995–2007 amounted, on the average, to 544 mm and it was comparable to the total amount for the period 1950–1989, which was 545 mm. However, mean values from a long period do not present the core of the problem, which consists in a relatively high dynamics of change in deposition in specific months or years. During the analyzed period 1995–2007 monthly total deposition during vegetation period varied: in April from 5 to 50 mm, in May from 21 to 106 mm, in June from 22 to 158 mm, in July from 23 to 239 mm, in August from 17 to 229 mm and in September from 18 to 92 mm. In relation to average values from long periods, the monthly amounts ranged from 13% in April 2007 to 358% in August 2006. Such high variability of total monthly precipitation during vegetation period can hamper the development of efficient agricultural production.

During the test years the value of total annual precipitation during vegetation period varied from 229 mm (2004) to 511 mm (1995), which is the equivalent of, respectively, 63 and 140% of the average value (366 mm) from the long-term period. On some of the research objects the problem could be successfully solved by means of using water management systems of a watering and draining nature (open ditches and drainage systems with the possibility to accumulate water).

The course of total annual precipitation in recent years also confirms the variability. In the years 1995, 1997 and 2001 high precipitation was observed; respectively: 647, 635 and 638 mm, whereas the amount was relatively low in the years 1999 – 431 mm, 2003 – 418 mm, and in 2004 – 445 mm. The highest precipitation was the equivalent of 119%, and the lowest – of 77% of the value for the long-term period 1950–1989. The difference between extreme annual precipitations in the analyzed period was 229 mm, i.e. 40.7% of the average value from the long-term period.

Similar correlations were noted in reference to annual total precipitation for the object Szewce from the station Ligota Piękna in the commune Wisznia Mała. The villages Szewce and Ligota Piękna are located in the same agricultural and climatic region B-2. as previously analyzed objects. Research was conducted in the years 2000–2002 and the values of total precipitation presented in Table 3.5 have been referred to the long-term period 1950–1980. The variability of total precipitation amounts for the vegetation period ranged from 296 mm in 2000 to 489 mm in 2001, which constitutes the equivalent of respectively, 82 and 135% of the average value from the long-term period (361 mm). The annual total precipitation varied from 563 mm in the year 2000 to 700 mm in 2001 r., whereas average from the long-term period was 587 mm.

Significantly higher differences in the annual total precipitation for the period 1995–2002 were noted in the object Stare-Bogaczowice located nearly 80 km to the southwest of Wrocław. The variability of precipitation was analyzed basing on data from the station Szczawno-Zdrój. According to Schmuck [1959], object Bogaczowice is located in the submontane pluviothermic region, on the border of the Wałbrzyski region. Annual total precipitation in this region is approximately 100 mm higher than on the previously discussed objects, whereas the vegetation period is nearly 2 weeks shorter than in lowland areas of Poland.

The observed fluctuations of monthly total precipitation ranged from 12 mm in January 1997 to 431 mm in July 1997. Record precipitation that occurred in July 1997 were the direct cause of the great flood that took place in large areas of Lower Silesia in that year. For the vegetation period (IV–IX) this variability ranged from 398 mm (1999) to 771 mm (2002), with an average of 430 mm and annual range from 609 mm (1999) to 1037 mm (2002) with an average of 655 mm.

Field research conducted on objects characterized by varied conditions of foreign water supply (different sizes of hydrological catchments) has shown that the deposits of ground retention and the volume of flow in watercourses were significantly influenced by the distribution of atmospheric deposition, where the deposition from months not included in the vegetation period were of particular importance [Orzepowski et al. 2008a, Orzepowski 2010, Pokładek 2010]. The deposition from these months, occurring in the conditions of low soil evaporation, enabled efficient replenishment of soil water resources, exhausted after the preceding vegetation period. The distribution of monthly and periodical total precipitation presented here is disadvantageous from the agricultural point of view, and it proves the necessity to use efficient drainage and watering systems, as well as retention systems for periodical excess supply of water resources.

The distribution of temperatures determines the terms of introduction of activities related to field cultivation. The determination of the dates of beginning and end of the so called farming activity period (air temperature above 2.5°C) informs about the period when field works can be conducted. Temperatures above 5.0°C are the vegetation period which is very important for the development of field cultivation. Distribution of temperatures is also an essential factor that determines the usage of fertilizer components by the cultivated plants. In objects, where the distribution of temperatures was analyzed basing on observations from the IMGW station Wrocław Strachowice, the farming activity period starts as early as the end of February/beginning of March, and lasts until the end of November. The vegetation period starts here usually in the third decade of March and ends in the first decade of November. This area is one of the warmest in the whole country.

For the purposes of evaluation of thermal conditions on the analyzed objects we have adopted the criteria set forth by Kaczorowska [1962]. In the years 1995–2007 as many as 10 vegetation periods (IV–IX) were qualified as warm, i.e. with temperatures exceeding the long-term period average by 0.5–2.0°C (Table 3.2). The average temperature for the long term period 1950–1989 during the vegetation period (IV–IX) was 14.6°C, and for the whole year 8.4°C. Average values obtained during the research period were higher respectively by: 0.9 and 0.8°C. The analysis for individual months has shown that from January to August and in October the increase of temperature compared to the long-term average exceeded 0.5°C. During the 13-year period the coldest month proved to be January, with an average temperature of -0.8°C, whereas the warmest was July, with an average temperature of 19.0°C. The highest variability of average monthly temperatures was also noted in January, and it ranged from -6°C in 2006 to 4.6°C in 2007, whereas the lowest was in August: from 17.1°C in 2006 to 20.6 in 2002.

The distribution of temperatures in the object Bogaczowice was characterized by similar variability tendencies as in the case of station Wrocław Strachowice. According to the adopted criteria, the average temperature for the vegetation period (IV–IX) and for the whole year, throughout the 6-year research period (1997–2002) allows us to classify five cases of vegetation periods and of the whole year as warm, and only one as normal. During the vegetation period the deviation from the long-term average (1971–1991) ranged from 0.8°C (2001) to 1.5°C (2000), while for the year it varied from 0.5°C (2001) to 1.6°C (2000). Basing on these data a conclusion may be drawn that the farming activity period usually starts in mid-March and lasts until the second half of November. This period typically lasts for 225 to 290 days –250 days on the average, and it is approximately 30–40 days shorter than in lowland areas of central Poland. The vegetation period starts at the end of the first decade of April, and lasts until the end of October-beginning of November. It lasts, on the average, for 210 days.

4. METHODOLOGY AND SCOPE OF RESEARCH

Field studies, conducted in the years 1995–2007 in agriculturally used objects located in Lower Silesia included the analysis of the quality of ground and surface waters and of drainage effluents. Samples of water for chemical analysis were collected from piezometric wells, drainage ditches, small water reservoirs and drainage outlets. The number of samples collected from specific measurement points in subsequent years varied from 4 to 18. whereas the amount in each measurement series ranged from 17 to 89.

Chemical analysis was performed in the Water and Wastewater Laboratory at the Institute of Environmental Protection and Development of the Wrocław University of Environmental and Life Sciences, with use of methods recommended by standards and literature [Dojlido, Świetlik 1999]. The scope of chemical analysis was adjusted to fit specific types of water, and the tests determined:

- Electrical conductivity – with use of conductometric method,
- Dissolved oxygen – with use of Winkler method,
- $BOT_{5.}$ direct method or dissolution method, determination of the concentration of dissolved oxygen with use of Winkler method before and after 5 day incubation period,
- COD-Mn,
- Nitrate nitrogen – spectrophotometric method with 2.6-dimethylphenol,
- Ammonium nitrogen – spectrophotometric method with use of sodium salicylate,
- Total nitrogen – method according to Kjeldahl mineralization with selenium,
- Phosphorus – spectrophotometric method with ammonium molybdate,
- Potassium – flame photometric method,
- Sodium – flame photometric method,
- Calcium – complexometric titration method,
- Magnesium – complexometric titration method,
- Sulphates – weighing method,
- Chlorides – argentometric titration.

Spectrophotometric analysis was conducted with use of spectrometer Cintra 5 produced by GBC. A detailed list of measurement points is presented in Table 4.1.

Table 4.1

Characteristics and marking of measurement points

Object (test period)		
Ground waters	Drainage effluents	Surface waters
Bliż (2001–2003)		
B – water from piezometer	–	B_1, B_2 – water from small reservoirs
Bogaczowice (1997–2002)		
Bo – water from piezometer	Bo_W1, Bo_W3, Bo_W4, Bo_W5 – drainage effluents	Bo – water from drainage ditch, cross-section closing the catchment
Miękinia (1995–2007)		
M – water from piezometer – drawing of samples to the 2004	–	M – water from drainage ditch, cross-section closing the catchment
Pustków Żurawski(1998–2001)		
P_1, P_2 – water from piezometers on the object irrigated wastewater	–	–
Rybnica (2001–2003)		
R – water from piezometer	–	R – water from small reservoir
Samotwór (1995–2006)		
Sm – water from piezometer	–	Sm – water from drainage ditch, cross-section closing the catchment
Smolec (2001–2003)		
S – water from piezometer	–	S – water from small reservoir
Szewce (2000–2002)		
Sz – water from piezometer	Sz_W1 – drainage effluents	Sz_1 water from drainage ditch, cross-section below drained lands; Sz_2 water from drainage ditch, cross-section closing the catchment
Zybiszów (2001–2003)		
Z – water from piezometer	–	Z – water from small reservoir

5. GROUND WATERS

The content of additives in ground waters depends directly on a series of factors, including: the geological structure of the formation where these waters appear, existing redox conditions, ways of usage of land surface – whether it is used as urban area, industrial area or for agricultural cultivation, etc.

Washing out of mineral fertilizers unused by plants and products of soil mineralization of organic matter leads to an increase in the content of nitrate nitrogen, chlorides, sulphates, calcium and magnesium in shallow ground waters [Banaszuk 2007]. The influence of type of land usage on the composition of ground waters depends to a large extent on the permeability of the formations located above the top of the aquifier and on the depth of the level of ground waters. However, for shallow waters, located above 3.0 m below land surface, no significant correlations between water composition and depth are observed [Pulikowski 2004].

The depth of the level of ground waters in the analyzed objects was typical for agricultural lands. The depth varied within the range from 0.03 to 2.45 m (Fig. 5.1). The shallowest levels of ground water were observed in the objects Bogaczowice, Miękinia and Samowtór, whereas the deepest levels of ground waters were found in the object Pustków Żurawski, which is adjacent to the river Czarna Woda, cutting deep into terrain surface. In the case of objects where the period of observation was longer, a rise in the level of ground waters can be noticed in object Bogaczowice and a change to the contrary in the object Miękinia (Fig. 5.1).

Electrical conductivity of water is a very universal indicator characterizing the total pollution by mineral substances and highly correlated with the total content of dissolved substances. For ground waters the range 200–700 $\mu S \cdot cm^{-1}$ is determined as hydro geochemical background [Resolution... 2008]. The conducted tests have shown that a significant majority of the obtained results fell into that range (Fig. 5.2). The range was exceeded in reference to average value only in Rybnica in the year 2003. The maximum value in that object was as high as 996 $\mu S \cdot cm^{-1}$. Also the maximum values in the objects Smolec and Samotwór exceeded the upper limit of the range of natural hydro geochemical background (Fig. 5.2). The significantly higher values obtained for the object Rybnica are probably connected to the fact, that the well might have been located within the reach of settlements using a disorderly wastewater management. One should also note the systematic increase of electrical conductivity in the object watered with wastewater from the sugar refining plant in Pustków, in the subsequent years. Supply of an additional amount of water (as the content of fertilizer components in the wastewater was low) could have accelerated the migration of mineral elements from the superficial layer of soil to ground waters.

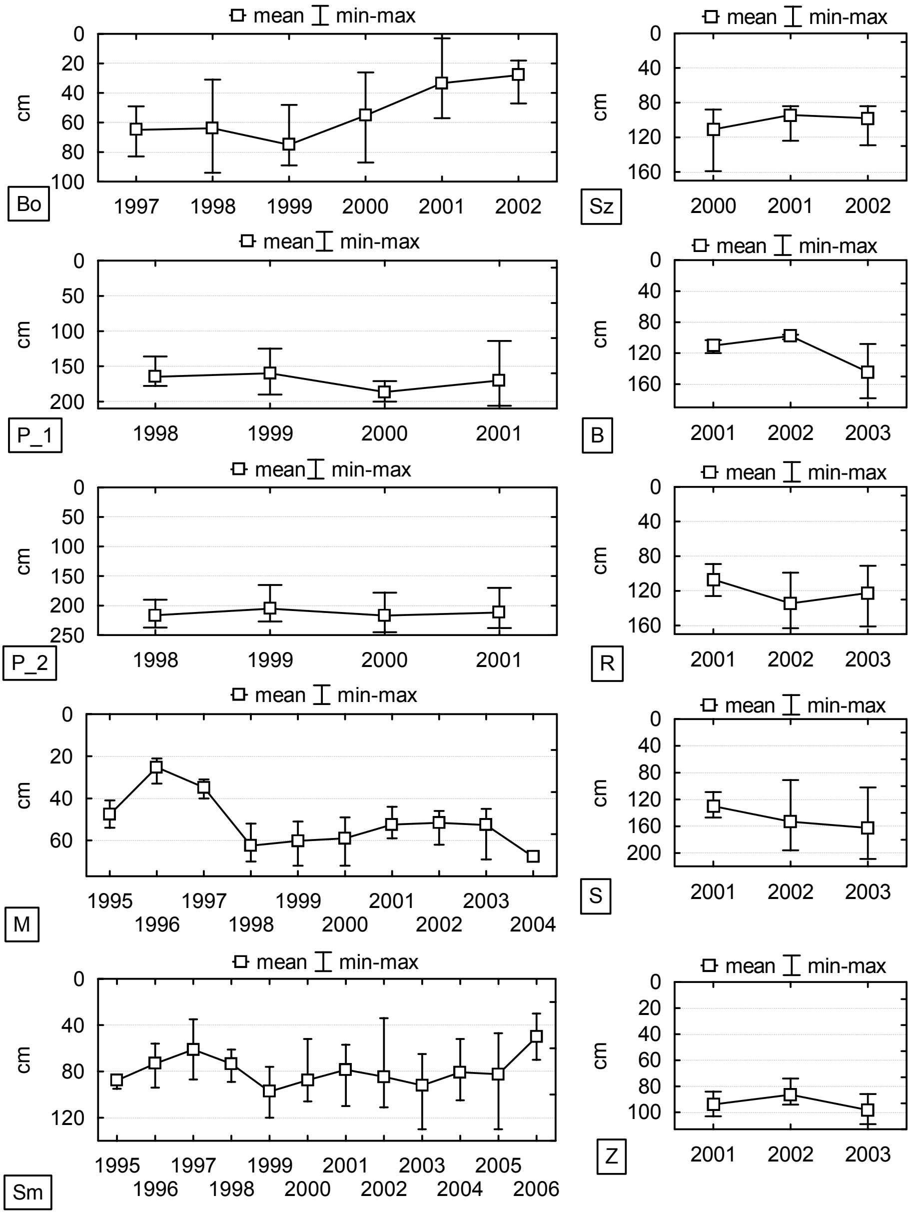

Fig. 5.1. Depth of ground water level; markings as in Table 4.1

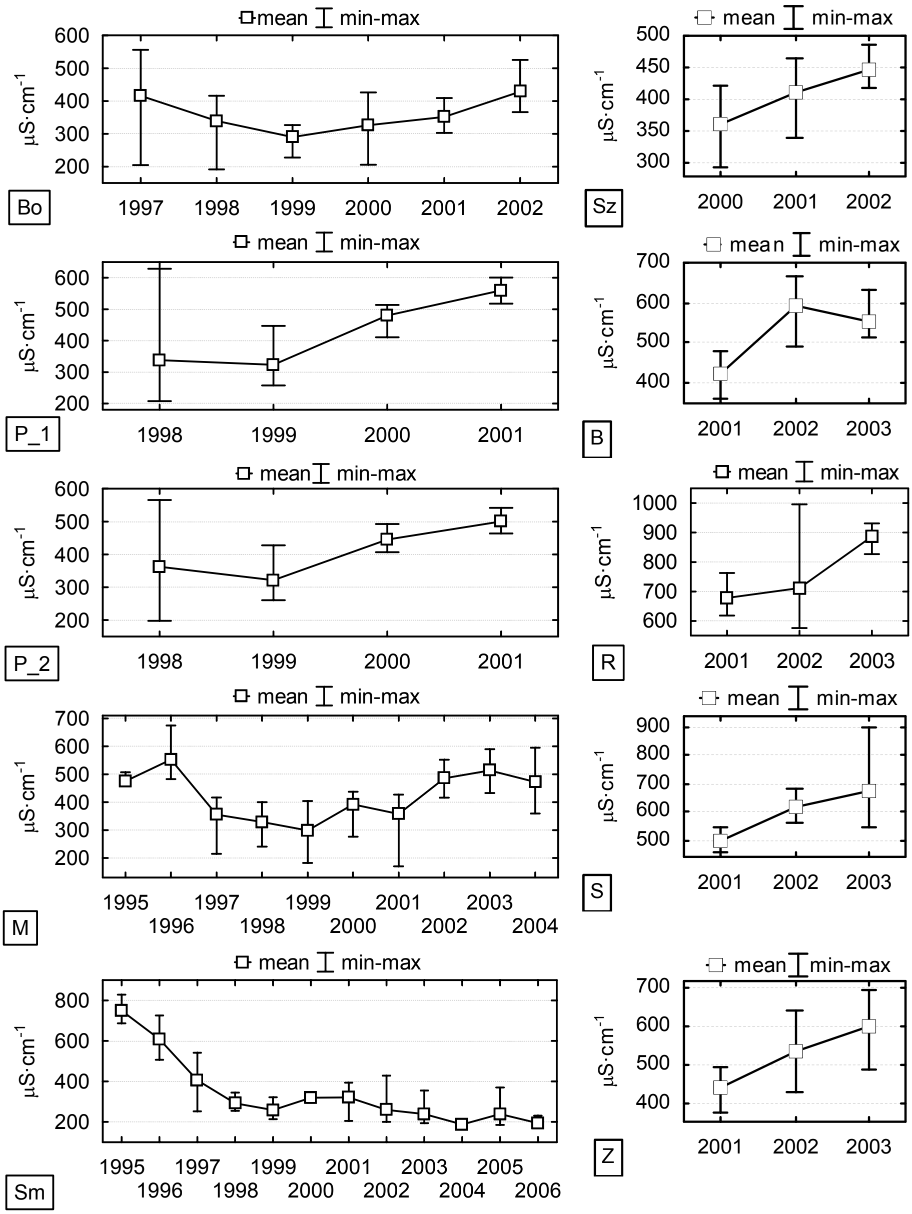

Fig. 5.2. Electrical conductivity of ground waters; markings as in Table 4.1

The obtained values of electrical conductivity should be considered as definitely low, as the typical mean values obtained for waters coming from agricultural lands usually significantly exceed 1000 $\mu S \cdot cm^{-1}$ [Durkowski 2005, Banaszuk 2007], and the range of variability presented by Durkowski [2005] is 500–3470 $\mu S \cdot cm^{-1}$.

Chemical oxygen demand determined with use of the permanganate method (ChZT-Mn) is a relatively reliable indicator characterizing the pollution of water by organic matter. The tested samples of water from most of the objects were characterized by relatively low values of this indicator (Fig. 5.3). Slightly higher values were obtained in Bogaczowice and Rybnica. In the case of the latter this may be a result of the well location, as was mentioned earlier. Decidedly high values were obtained in two objects – Miękinia and Samotwór. Maximum values exceeded the level of 100 mg $O_2 \cdot dm^{-3}$ (Fig. 5.3). In the case of Miękinia this may be caused by the existence of peat soils and resulting increased concentration of organic matter in ground waters. It is noteworthy that the values obtained in the object watered by wastewater in Pustków were low and did not vary significantly in time. This proves that there is no direct inflow of pollutants from the wastewater to ground waters.

The threat that agricultural activity poses for water quality is related to the usage of pesticides, as well as to excessive nitrogen fertilization. Nitrogen, particularly its nitrate form that is highly soluble in water, creates a major threat for the quality of surface and ground waters. The analyzed waters were characterized by very varied content of nitrate nitrogen (Fig. 5.4). In most of the cases the obtained values concentrations remained at levels that could be considered as natural – not exceeding 1.5 mg $N\text{-}NO_3 \cdot dm^{-3.}$ whereas in three objects (Zybiszów, Bogaczowice and Rybnica) very high values were obtained: average concentrations exceeded 10 mg $N\text{-}NO_3 \cdot dm^{-3.}$ and maximum values reached 30 $N\text{-}NO_3 \cdot dm^{-3}$. This might have been the result of the fact that the wells were located directly on agricultural lands, where mineral nitrogen fertilization is used. These values fall within the range described in literature [Matic 1999, Durkowski 2005, Fiedler et al. 2005, Banaszuk 2007]. concentrations of nitrate nitrogen noted on intensely agriculturally used lands in Wielkopolska reached 94 mg $N\text{-}NO \cdot dm^{-3}$ [Bartosiewicz 1990]. However, waters where the concentration exceeds 50 mg $NO_3 \cdot dm^{-3.}$ or 11.3 $N\text{-}NO_3 \cdot dm^{-3}$, are considered as polluted [Directive... 1991].

Agricultural lands do not constitute a serious threat to the quality of waters as far as the content of ammonium nitrogen is concerned. Average concentrations of this form of nitrogen observed on a vast majority of objects were lower than 1 mg $N\text{-}NH_4 \cdot dm^{-3}$. Significantly higher concentrations were found in ground water from Rybnica, which only confirms the hypothesis that the increased values of some indicators in these waters resulted from the fact that the waters were polluted by sanitary wastewaters from adjacent land (Fig. 5.5). Periodically (in the years 1995–1998) higher concentrations of ammonium nitrate were also noted in the object Samotwór. The obtained maximum values, which were significantly divergent from average values, should be considered as random and without influence on the general evaluation of the content of this component in the analyzed ground waters. The observed average values are similar to those presented in literature [Durkowski 2005, Banaszuk 2007]. The research conducted by Durkowski [2005] definitely shows that more serious threats occur within the farmstead, in particular in the vicinity of manure storage areas, where the average concentration of this form of nitrogen exceeded 5 mg $N\text{-}NH_4\ dm^{-3.}$ and maximum concentration reached 69 mg $N\text{-}NH_4 \cdot dm^{-3}$.

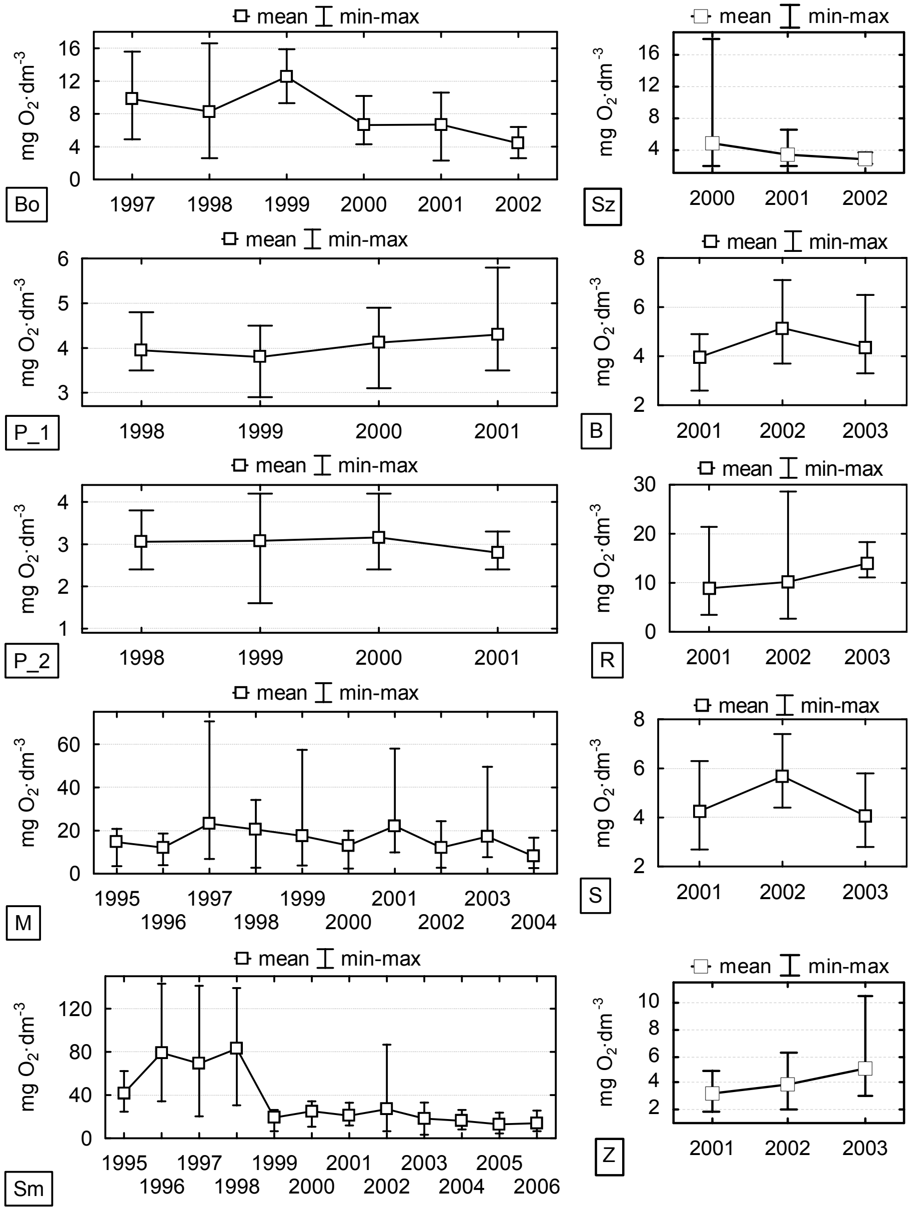

Fig. 5.3. Chemical oxygen demand – COD- Mn in ground waters; markings as in Table 4.1

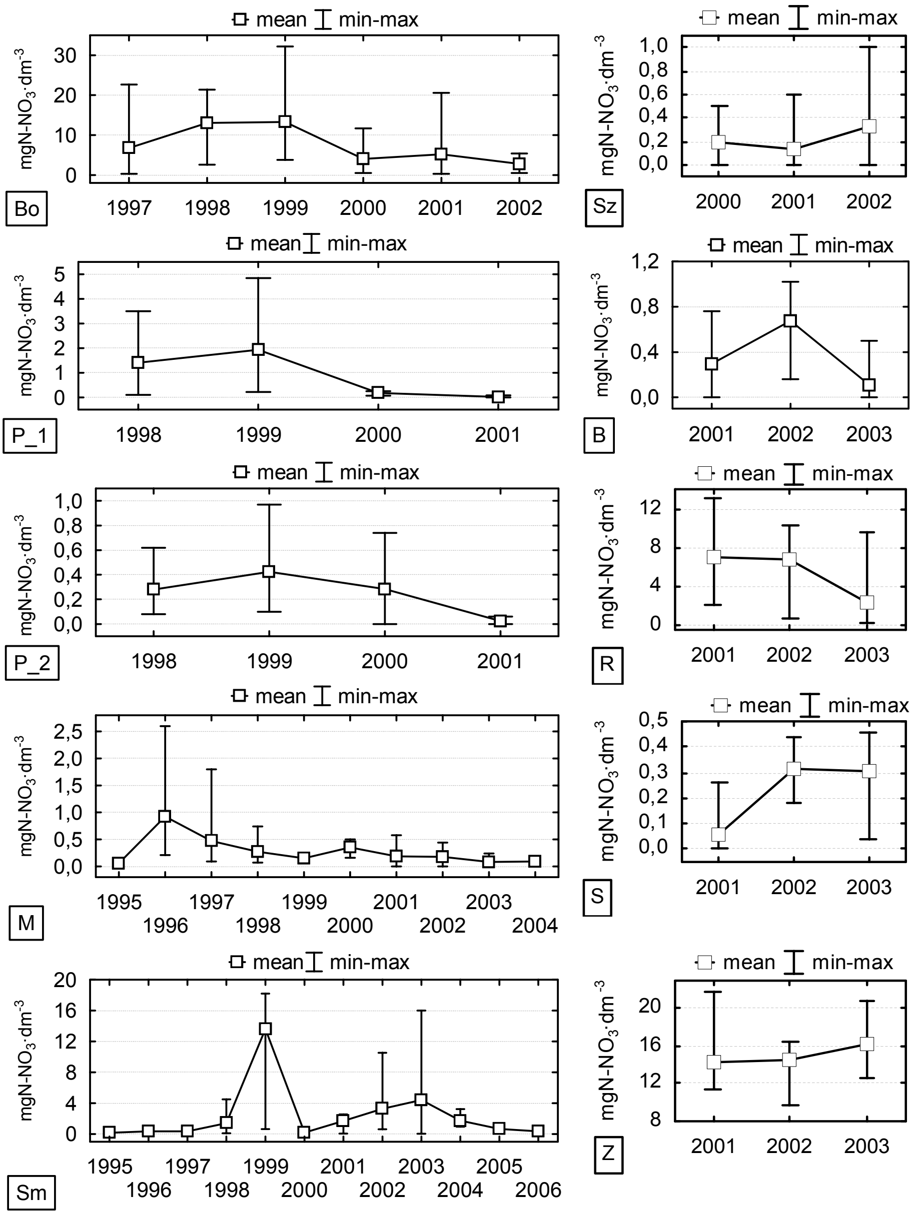

Fig. 5.4. Concentration of nitrate nitrogen in ground waters; markings as in Table 4.1

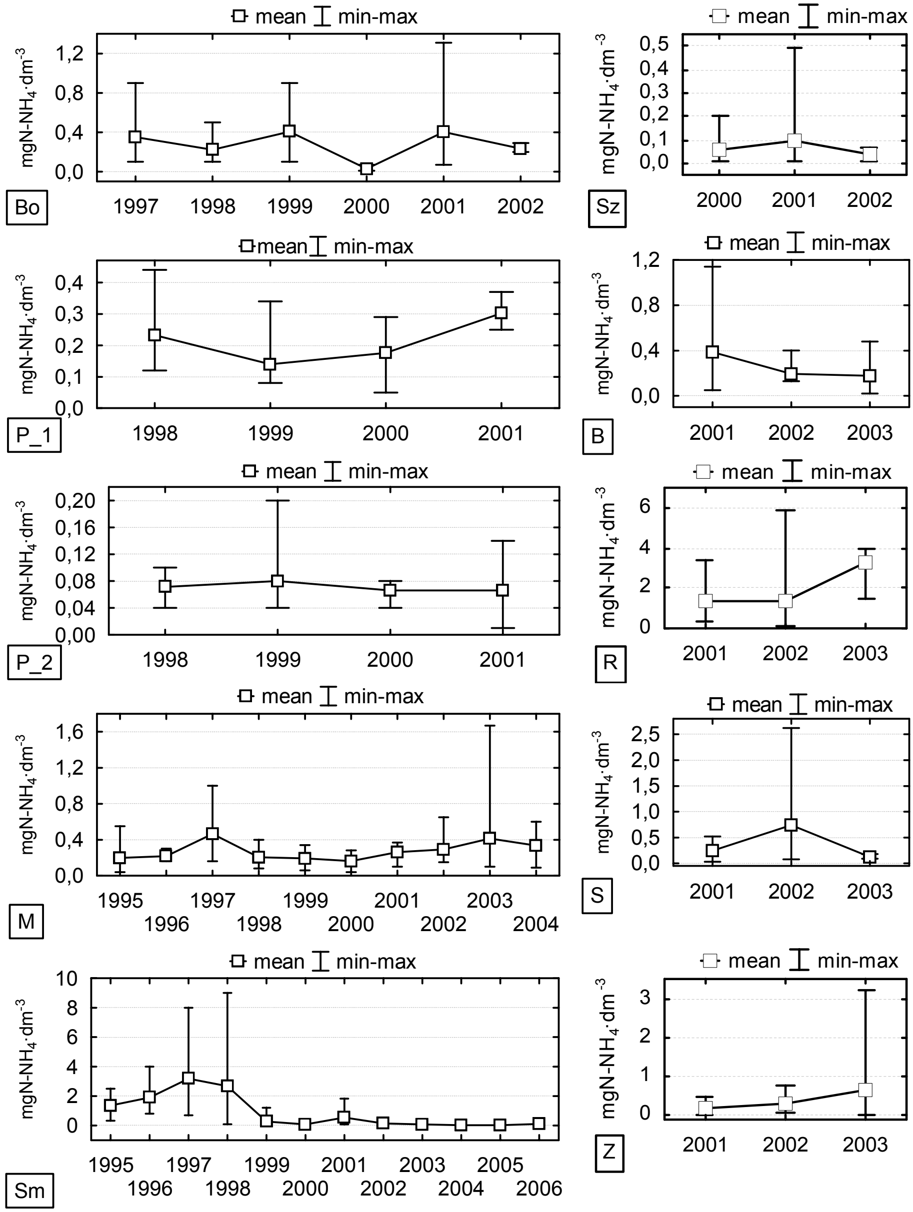

Fig. 5.5. Concentration of ammonium nitrogen in ground waters; markings as in Table 4.1

Phosphorus, as an element that is very well absorbed in soil environment, does not pose a significant threat to the quality of ground waters. In nine out of ten analyzed piezometric wells the average concentration of this element fell within the range 0.2–0.5 mg $P \cdot dm^{-3}$. Significantly higher values were obtained in water samples collected from the piezometric well located in the object Rybnica (Fig. 5.6), although it is unlikely that it was caused by the proximity of agricultural lands.

Generally, the content of sodium in analyzed water samples did not exceed the range 1-60 mg $Na \cdot dm^{-3}$ considered as hydro geochemical background [Resolution... 2008]. Similarly to the other indicators, also here significantly (several times) higher concentrations were obtained for object Rybnica (Fig.5.7). One should note the significant differences in tendencies for objects observed for longer periods: in Miękinia the average concentrations were steadily growing, whereas in Samotwór they are decreasing (Fig. 5.7).

Another analyzed component – potassium – showed a high variability depending on the given object. The lowest average concentrations, ranging from 2–4 mg $K \cdot dm^{-3.}$ i.e. lower than values considered as natural, were found in objects Szewce and Miękinia (Fig. 5.8). Significantly higher values (above natural) of average concentrations were observed in objects Pustków Żurawski and Rybnica. A high dynamics of changes in the concentration of this element was noted in object Samotwór. The average concentration changed from 4.3 mg $K \cdot dm^{-3}$ in 1995 to 19.9 mg $K \cdot dm^{-3}$ in 1999 and later it started falling to reach the value of 13.5 mg $K \cdot dm^{-3}$ by the end of the research period (in 2006).

The tested ground waters were characterized by a typical concentration of calcium, with average concentrations of this element ranging generally 100–200 mg $Ca \cdot dm^{-3}$. Slightly lower values were noted in Samotwór, and annual average values exceeding 200 mg $Ca \cdot dm^{-3}$ were found in the piezometric well P_1 in Pustków (Fig. 5.9). In the second well located on this object (P_2) the average annual concentration oscillated around the value of 200 mg $Ca \cdot dm^{-3}$. The increased concentration of calcium was probably connected with the geological structure, although one cannot exclude the possibility that it resulted from watering with wastewaters rich in that macro element.

Most of the calculated average concentrations of magnesium fell within the range 10–40 mg $Mg \cdot dm^{-3.}$ which allows to classify these waters as natural (Fig. 5.10). Similar results were obtained on other objects [Fiedler et al. 2005, Banaszuk 2007]. Slightly lower concentrations were noted on objects Miękinia and Samotwór, whereas in Rybnica the average annual concentration of magnesium in the year 2002 was as high as 80.4 mg $Mg \cdot dm^{-3}$.

The tested waters were characterized by a high concentration of sulphates. In Pustków the average annual values even exceeded 500 mg $SO_4 \cdot dm^{-3.}$ which classifies these waters as highly polluted (Fig. 5.11). However, the increased concentration of sulphates was likely to be caused by the geological structure and did not result from agricultural activity, and the obtained values were higher than those presented by Banaszuk [2007]. In spite of high concentration of sulphates, the tested waters were not excessively polluted with chlorides, as the mean concentration of the latter classifies the waters as natural. The exception is Rybnica, where the concentration of chlorides exceeded 200 mg $Cl \cdot dm^{-3}$ (Fig. 5.12).

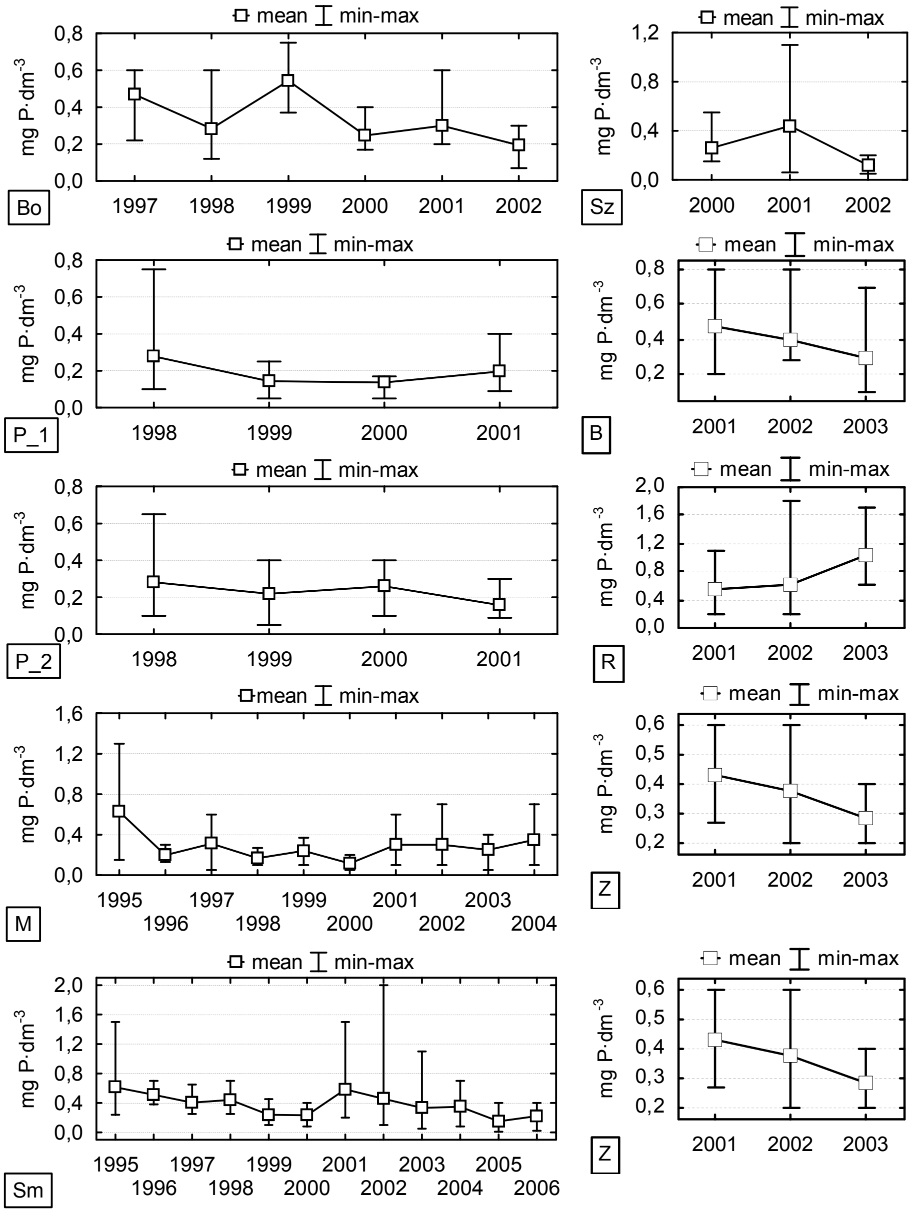

Fig. 5.6. Concentration of phosphorus in ground waters; markings as in Table 4.1

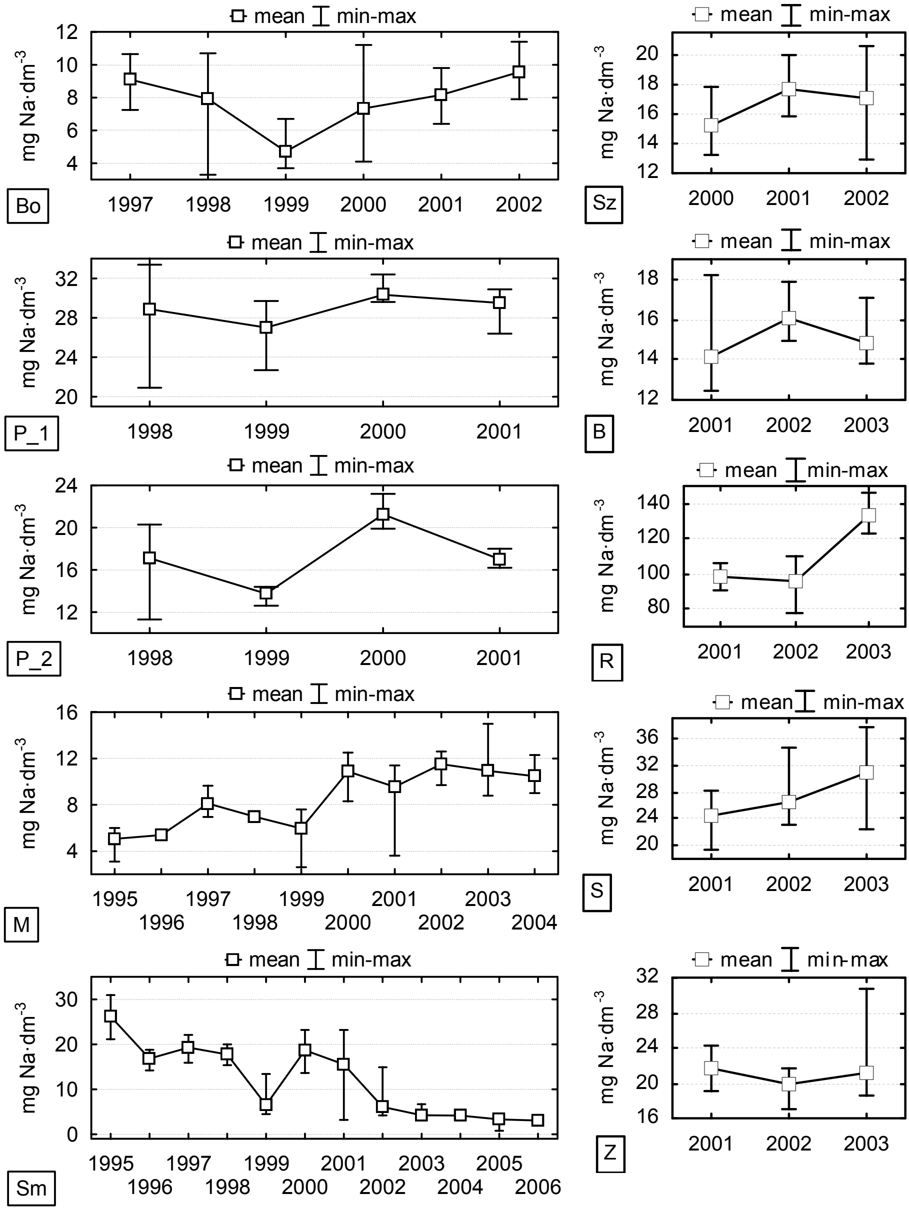

Fig. 5.7. Concentration of sodium in ground waters; markings as in Table 4.1

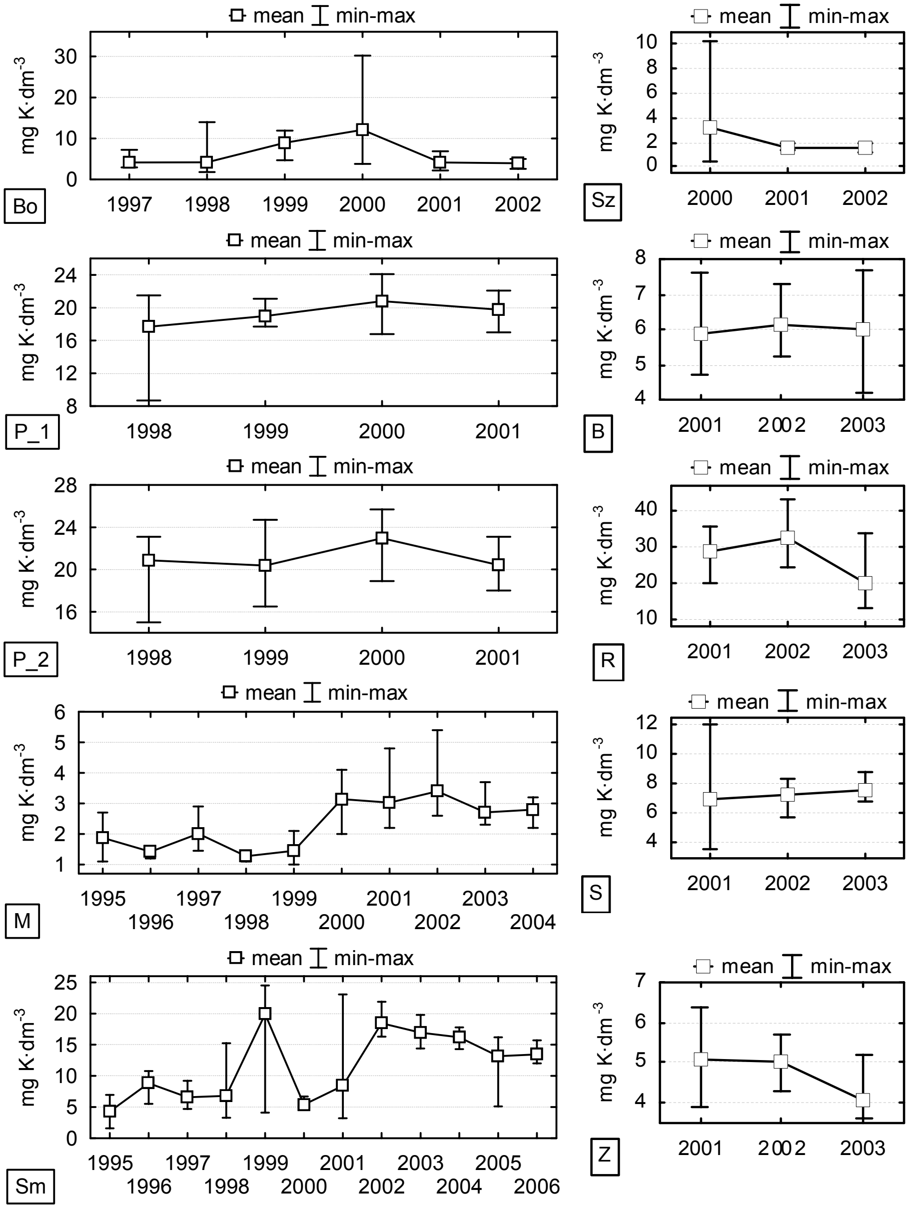

Fig. 5.8. Concentration of potassium in ground waters; markings as in Table 4.1

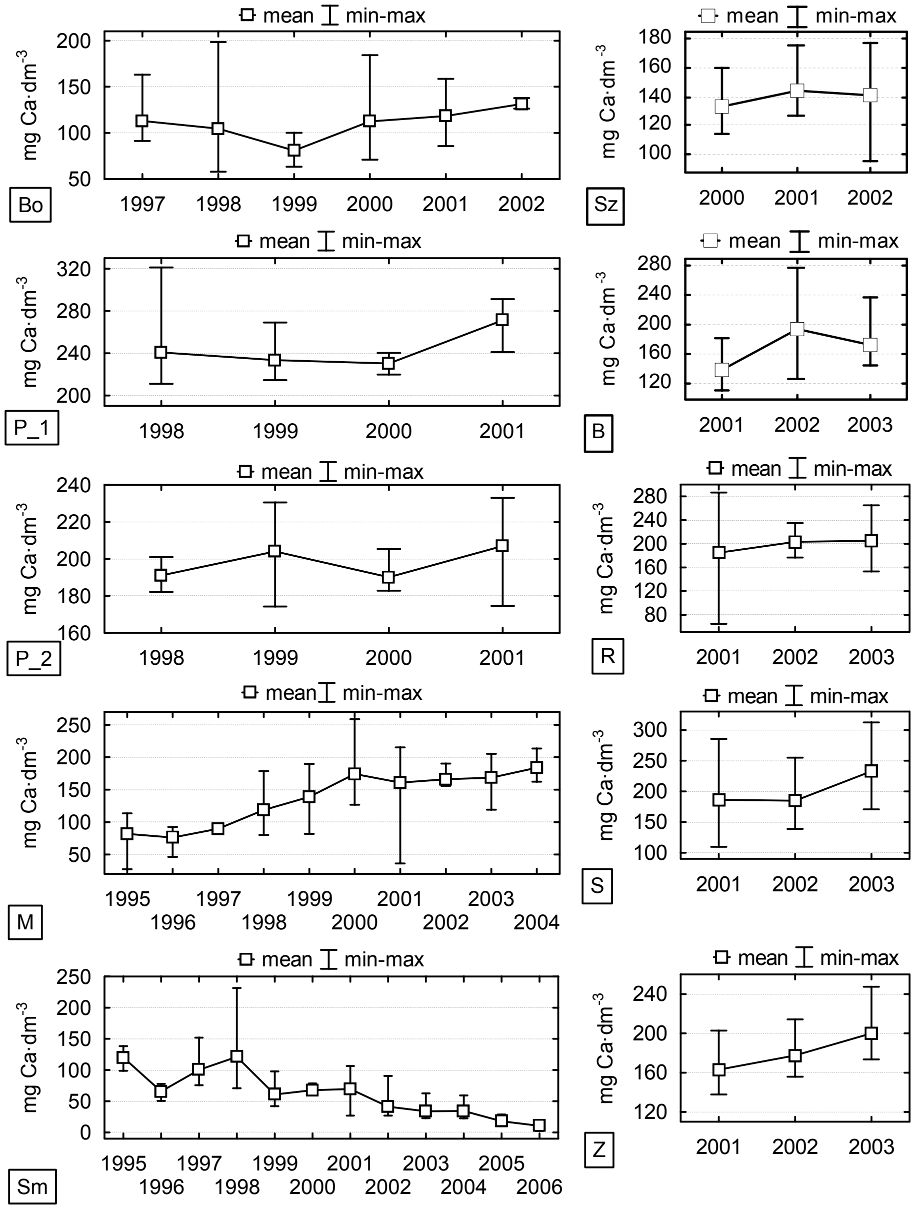

Fig. 5.9. Concentration of calcium in ground waters; markings as in Table 4.1

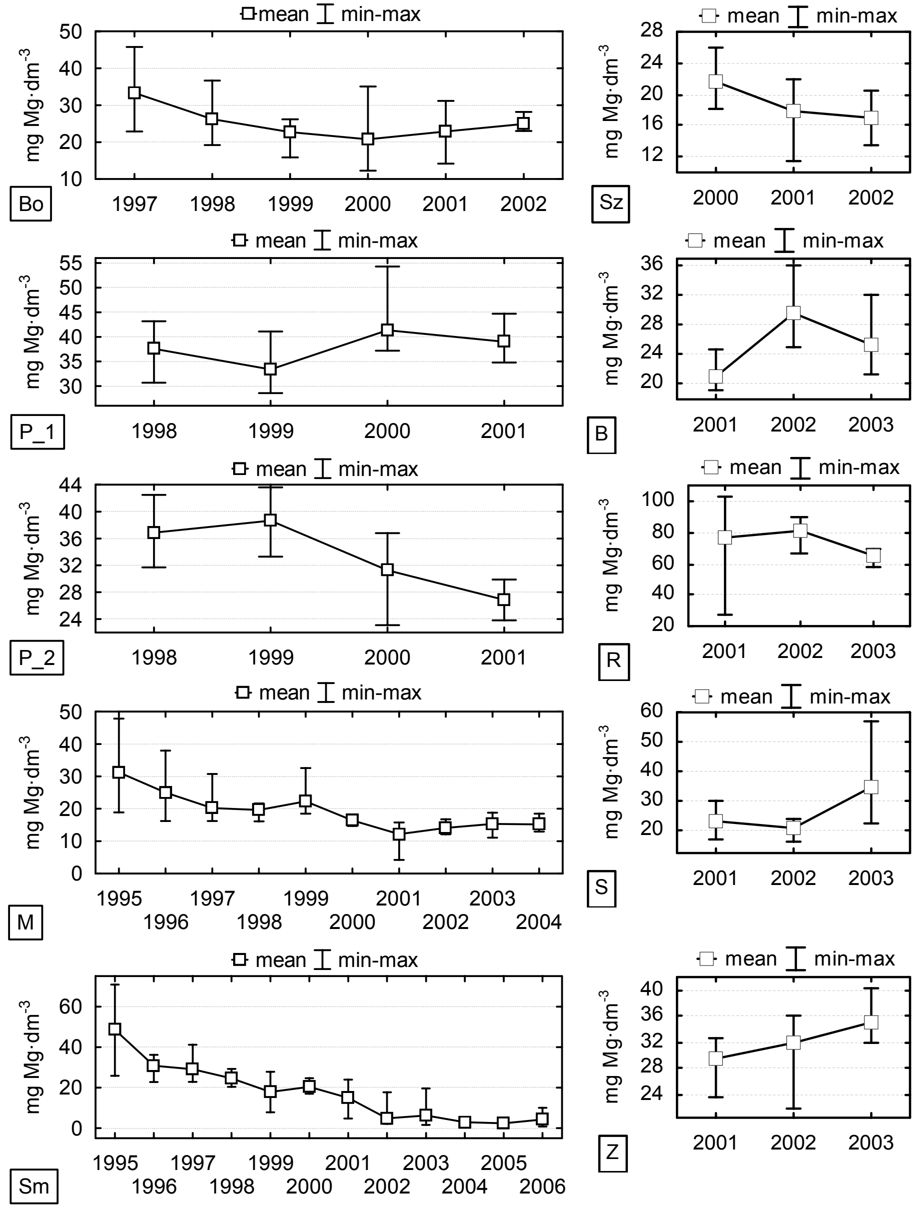

Fig. 5.10. Concentration of magnesium in ground waters; markings as in Table 4.1

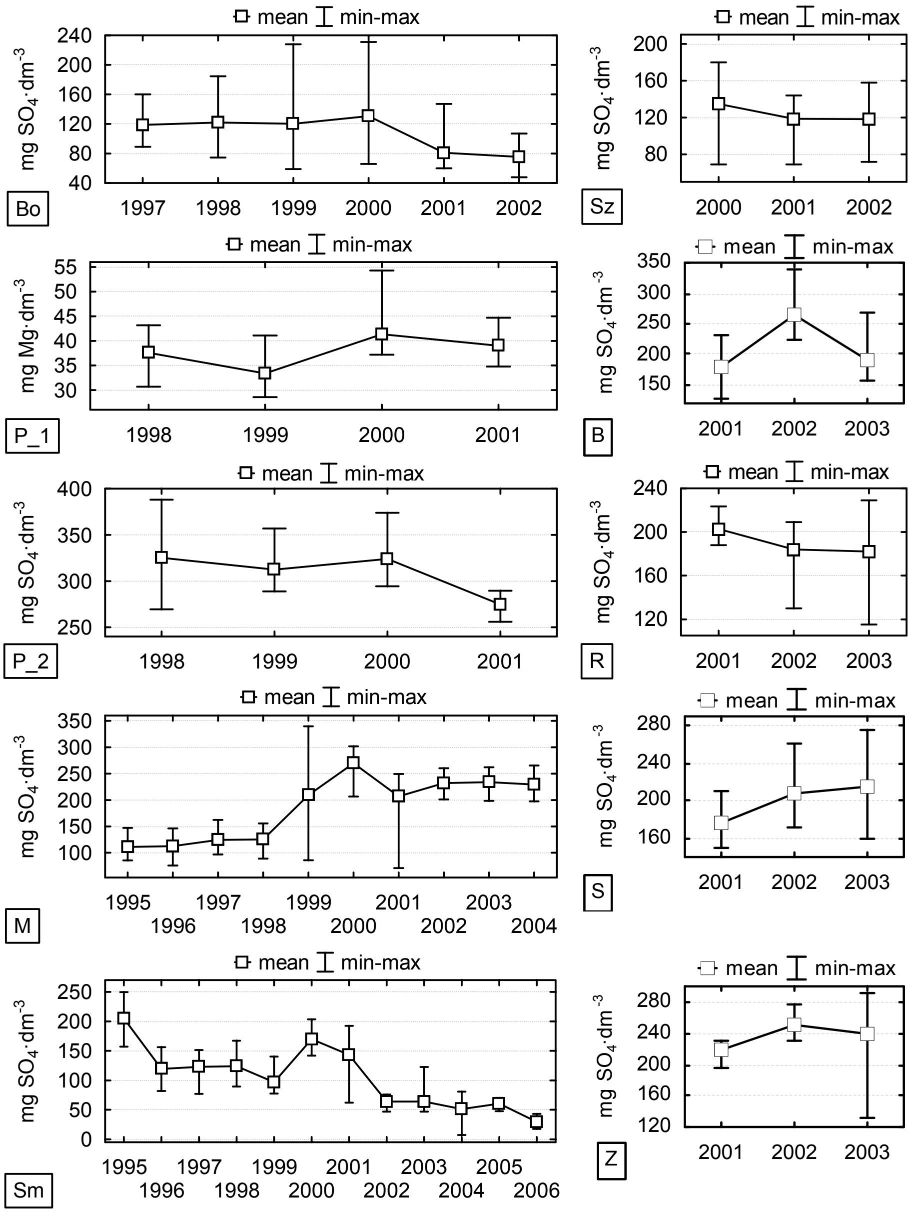

Fig. 5.11. Concentration of sulphates in ground waters; markings as in Table 4.1

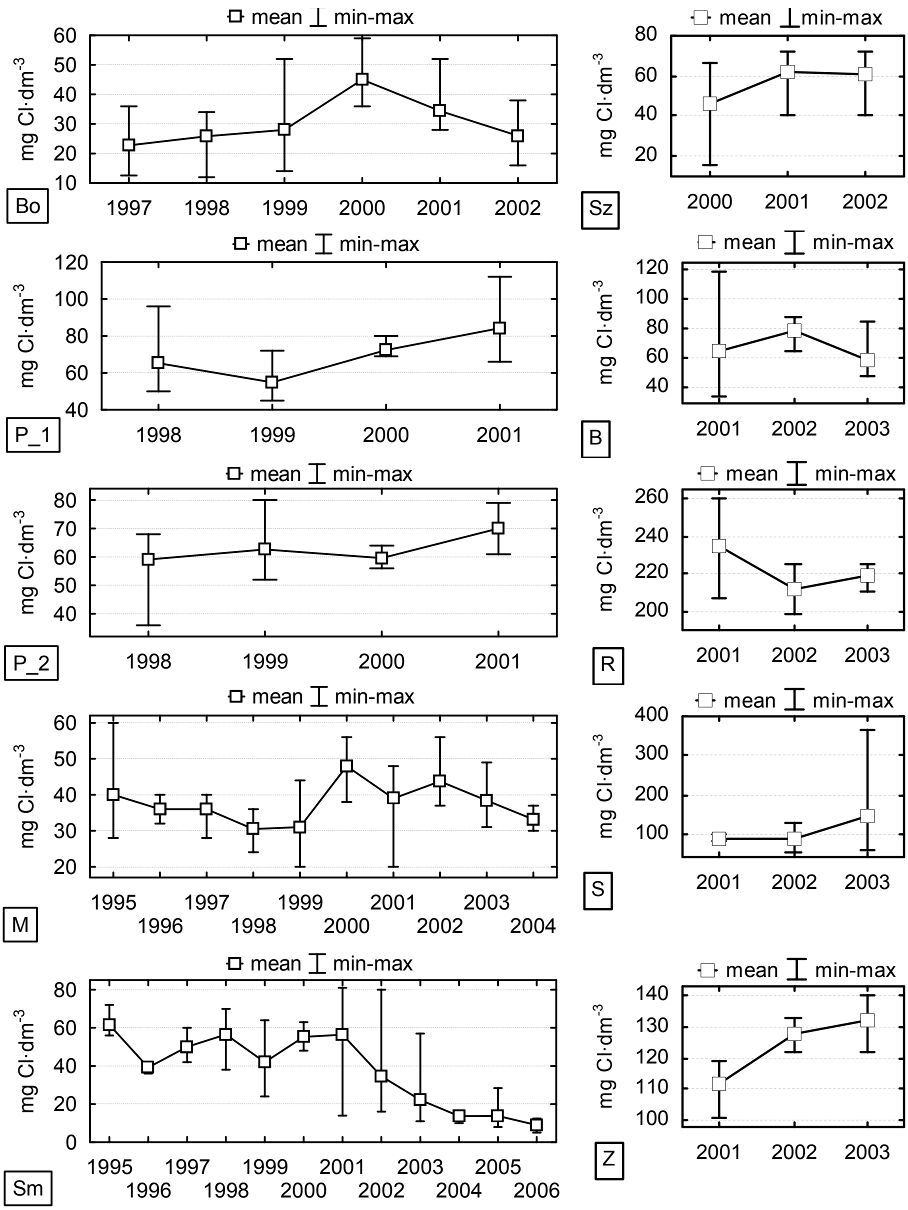

Fig. 5.12. Concentration of chlorides in ground waters; markings as in Table 4.1

The conducted tests of the composition of ground waters in agriculturally used areas allow us to claim that these waters are relatively clean. The main threat resulting from agricultural activity for the ground water from the first aquifier level is the increased content of nitrate nitrogen. However, this does not apply to all the tested objects. The concentrations did not always exceed the value of 50 mg $NO_3 \cdot dm^{-3}$ (11.3 mg $N\_NO_3 \cdot dm^{-3}$) which is considered as safe for water consumed by humans [Directive... 1991]. The increase in the value of the other indicators can seldom be connected with agricultural activity. When analyzing test results, single values that significantly diverge from the average should be evaluated carefully. Provided that the analysis was free from errors, it can be assumed that such values result from haphazard environmental factors that are difficult to determine.

When planning the protection of ground waters in rural areas, special attention needs to be paid to objects used for the storage of natural fertilizers and preparation of silages. Another important aspect is the regulation of sanitary wastewater management in rural areas. The example of one of the analyzed objects (Rybnica) clearly illustrates the threats that may result from an uncontrolled discharge of sanitary wastewater, even in comparison to the objects watered by wastewater (Pustków Żurawski), or used agriculturally in a traditional manner. If these two factors are analyzed jointly, the result is quite often charging the agriculture with excessive blame for the deterioration of ground water quality.

6. DRAINAGE EFFLUENTS

Drainage waters (drainage effluents) are a quite specific type of water, which is not subject to any classification, and, as such, is not controlled in any way. This is a transitional type of water, between ground waters and surface waters, inseparably connected with the drainage of agricultural lands. In the year 2009 the total area of agricultural lands in Poland that were drained, amounted to 4 382.7 thousand hectares [Annals ...2010]. Drainage waters discharged from urban areas constitute a minimal fraction.

The amount of water discharged by drains is determined by a large number of factors: amount of precipitation, distribution of air temperature, placement of drains, land slope inclination and terrain formation, type of soil, agro technology, type of cultivated plants etc. [Kostrzewa 1977, Kostrzewa et al. 2001]. The composition of drainage effluents is connected with the type of drained soil and cultivated plants, level of fertilization etc.

The content of substances dissolved in the tested drainage effluents, expressed as the value of electrical conductivity, allows us to classify these waters as relatively clean. In most of the cases the average annual value of this indicator did not exceed 500 $\mu S \cdot cm^{-1.}$ and the maximum value was below 600 $\mu S \cdot cm^{-1}$ (Fig. 6.1). The obtained values of this parameter fell into a relatively narrow range, which leads to the conclusion that the total content of substances dissolved in the tested effluents was relatively stable and did not fluctuate significantly throughout the year. These waters contained also small amounts of organic substances. The average values of COD-Mn, ranged from 2–8 mg $O_2 \cdot dm^{-3}$. Only the maximum values in specific years and drainage sheds in the object Bogaczowice exceeded the value of 10 mg $O_2 \cdot dm^{-3}$ (Fig. 6.2). The evaluation of these two indicators allows us to classify these effluents as waters of low pollution level.

The average concentration of nitrate nitrogen in drainage effluents in individual years fell into the range 10–30 mg $N\text{-}NO_3 \cdot dm^{-3}$, whereas the maximum concentration in 1998 in shed 4 in Bogaczowice was as high as 43.2 mg $N\text{-}NO_3 \cdot dm^{-3}$ (Fig. 6.3). The obtained values significantly exceeded the value determined for waters polluted by nitrate nitrogen [Directive...1991]. The obtained concentrations of nitrate nitrogen are similar to those found in other objects [Koc 1998, Lipiński 2002]. This form of nitrogen is dominant in drainage effluents and it accounts for over 80% of the total mass of nitrogen compounds discharged to surface waters with drainage effluents. The concentrations of total nitrogen, presented in Figure 6.4. are characterized by an identical distribution of results as that for nitrate nitrogen. Nitrogen compounds present in drainage effluents create a significant threat for the recipient waters. However, it should be remembered, that they occur periodically, in lowland areas not longer than 80 days a year [Kostrzewa et al. 1999].

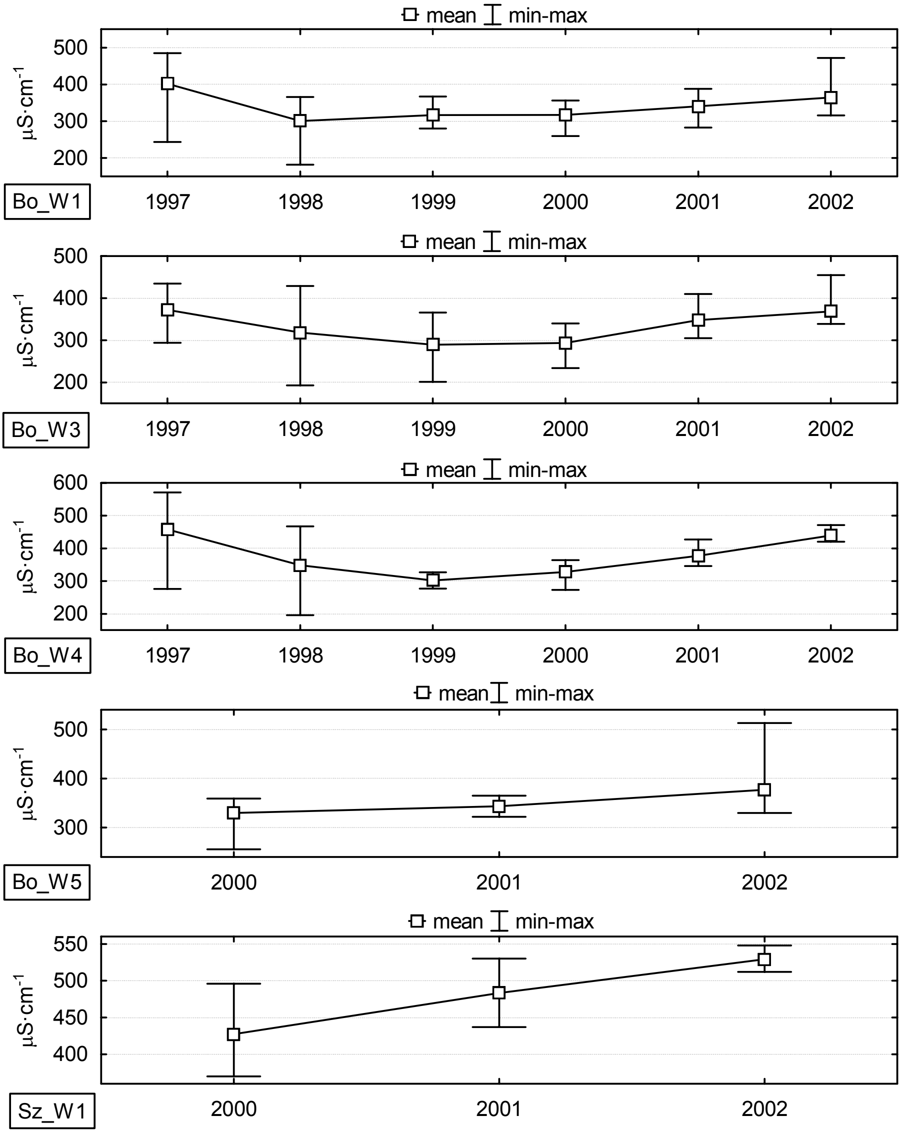

Fig. 6.1. Electrical conductivity of drainage effluents; markings as in Table 4.1

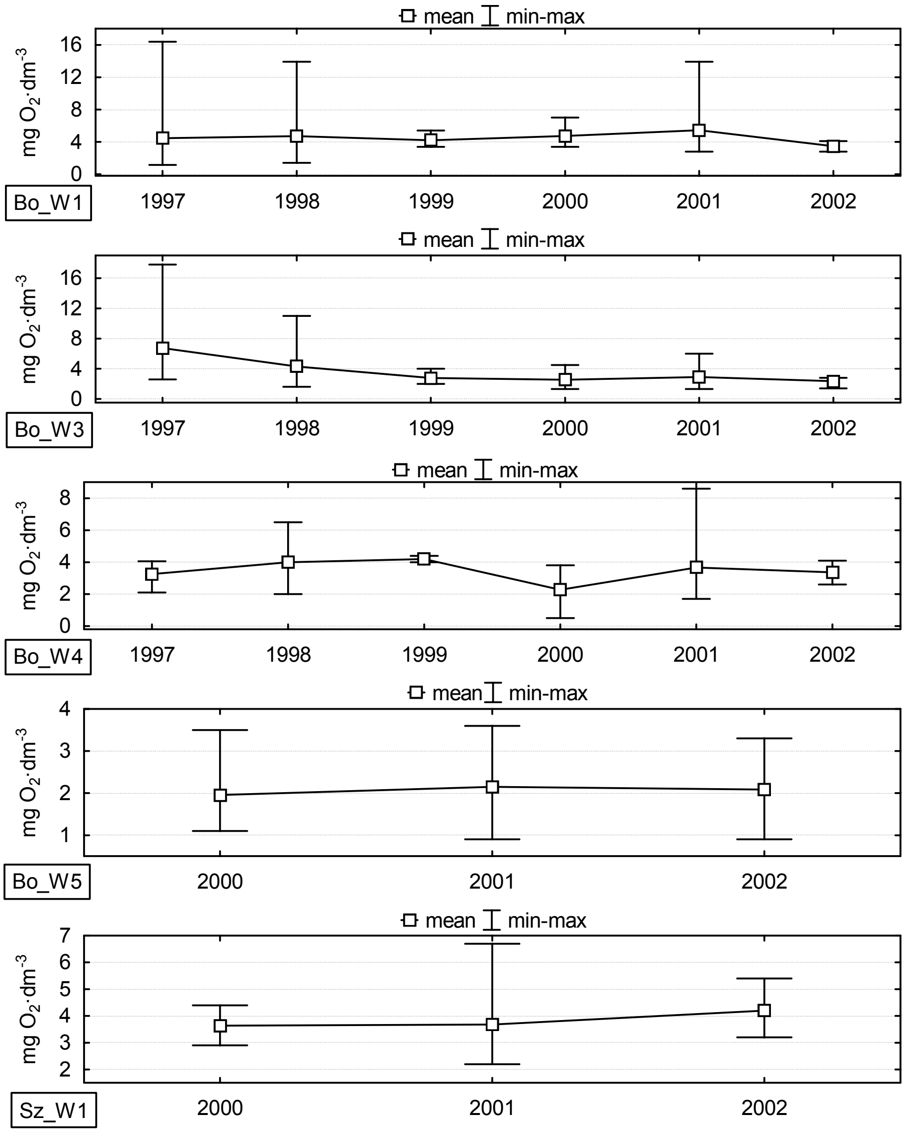

Fig. 6.2. Chemical oxygen demand – COD-Mn in drainage effluents;
markings as in Table 4.1

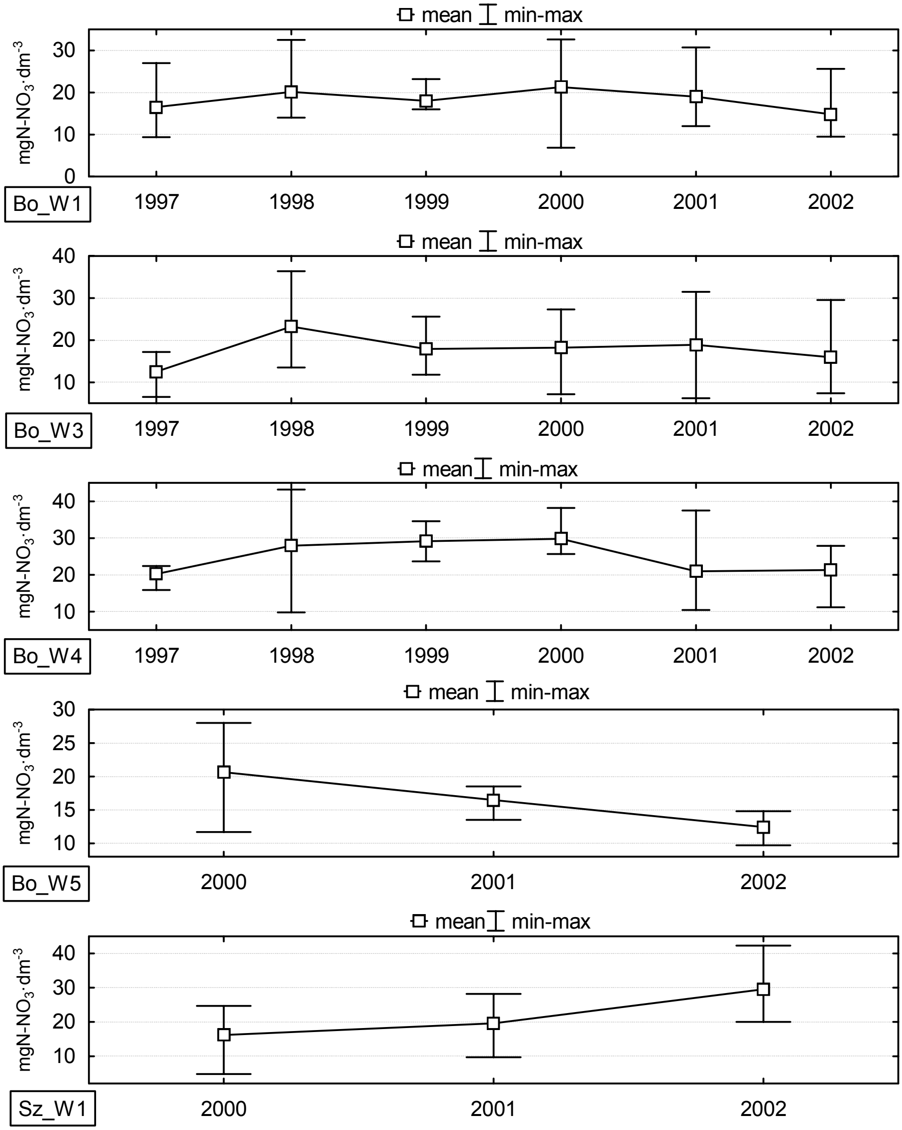

Fig. 6.3. Concentration of nitrate nitrogen in drainage effluents; markings as in Table 4.1

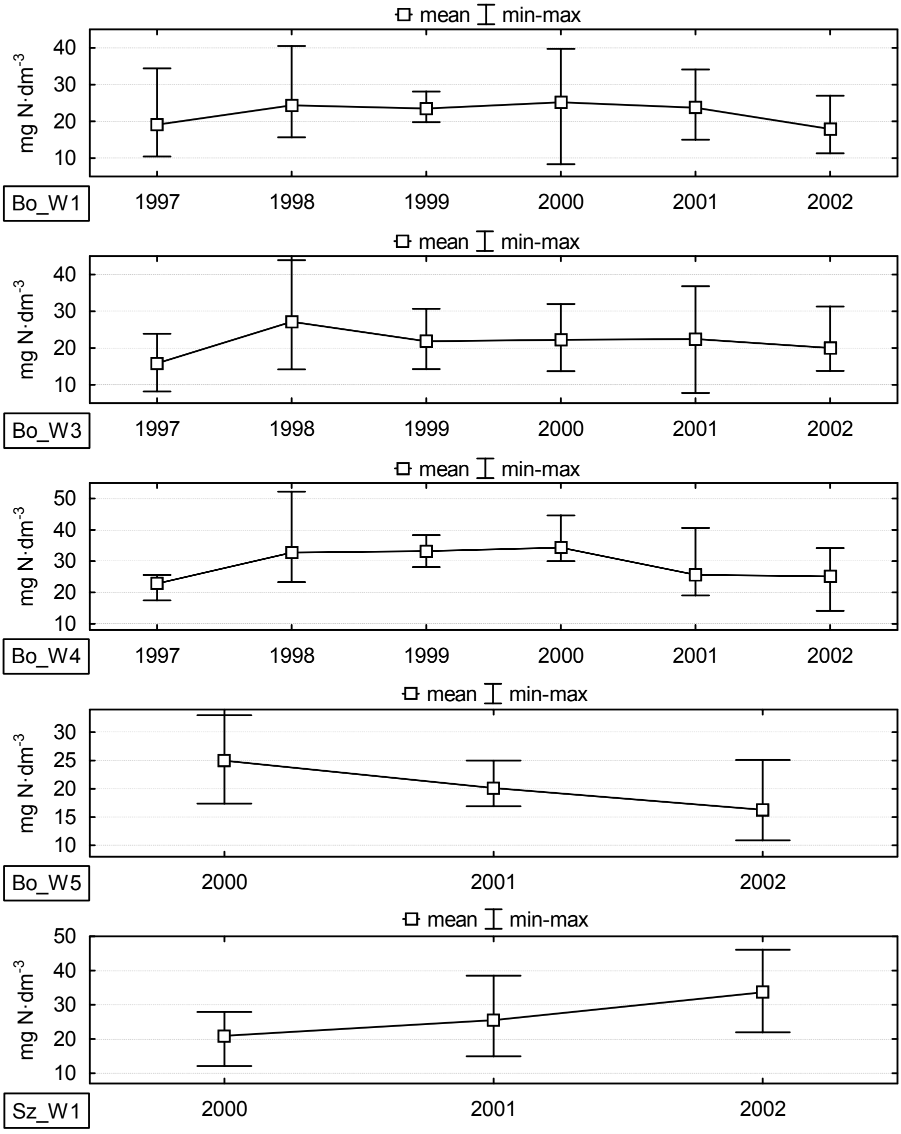

Fig. 6.4. Concentration of total nitrogen in drainage effluents; markings as in Table 4.1

Drainage waters discharged by the drainage network were characterized by a high concentration of phosphorus: average annual concentration of this element ranged from 0.20 – 0.40 mg P·dm^{-3}. The maximum concentration, noted in 1998 in effluents outflowing from shed 4 in Bogaczowice, was as high as 1.25 mg P·dm^{-3}. Such high concentrations of phosphorus may be caused by a high content of this macro element in the soil. The content of the general form of this element fluctuated from 0.11% to 0.20%, whereas the content of the soluble form varied from very low concentrations – 0.002% to extremely high values – 0.046% [Paruch et al. 2002]. Increased content of phosphorus in soils is a much more common problem in Poland. According to research conducted by Sapek [2001], excessive phosphorus fertilization in the second half of the previous century has led, in European countries , to an enrichment of agriculturally used soils in this element, on the average by 1000 kg P_2O_5·ha^{-1}. The average surplus of phosphorus in Polish farms amounted to 25.3 kg P·ha^{-1} (kg P_2O_5·ha^{-1}) [Sapek 2001].

One should note the significant variability of sodium content in the tested drainage effluents. In the object Bogaczowice the average annual values seldom exceeded 10 mg Na · dm$^{-3.}$ while values obtained in object Szewce were 3–4 times higher (Fig. 6.6). This can be explained by the fact that wastewater from Wrocław had been used for agricultural purposes in the object for over 20 years, which resulted in a contamination of the soils with sodium. These waters were also characterized by very low concentrations of potassium: average annual concentrations did not exceed 4 mg K·dm^{-3} (Fig. 6.7).

The content of calcium and magnesium (Fig. 6.8 and 6.9) can be generally considered as typical for drainage effluents [Koc 1998, Lipiński 2002], some discrepancies were found only in the recent years in the object Szewce, where the mean annual concentration of calcium oscillated around the value of 200 mg Ca·dm^{-3} and was significantly higher than the concentration found in ground waters on the same object. One should also note the steady decrease of the concentration of magnesium in waters discharged from object Bogaczowice. This may point to a decrease of the content of this element in a form accessible for plants in soils that are not fertilized by magnesium fertilizers (Fig. 6.9).

Drainage effluents were characterized by low concentrations of sulphates. The value of average annual concentration did not exceed 150 mg SO_4·dm$^{-3.}$ whereas the maximum values reached 200 mg SO_4·dm^{-3} (Fig. 6.10). Higher variability was found in chlorides. While the concentrations in the object Bogaczowice were very low, those in Szewce, although approximately two times higher, did not point to a significant pollution of these waters by chloride ions either (Fig. 6.11) and can be considered typical. High values of concentration on this object are most likely to be related to the previous type of usage of this area.

Although drainage waters discharged from agricultural lands occur only for several dozen days in a year, they can constitute a serious threat for recipient surface waters. Direct threats result from the load of discharged nitrates and phosphorus. This threat is particularly serious in relation to objects located in submontane areas, characterized by higher outflow rates in comparison to lowland areas, which additionally increases the load of discharged biogenic substances. On such objects the volume of discharged water should be limited with use of such means, as non-systematic drainage. Moreover, some other solutions to be considered include the retention of water discharged from watershed areas and the usage of such water in summer for the watering of crops located in the lower parts of the catchment [Pulikowski et al. 2001].

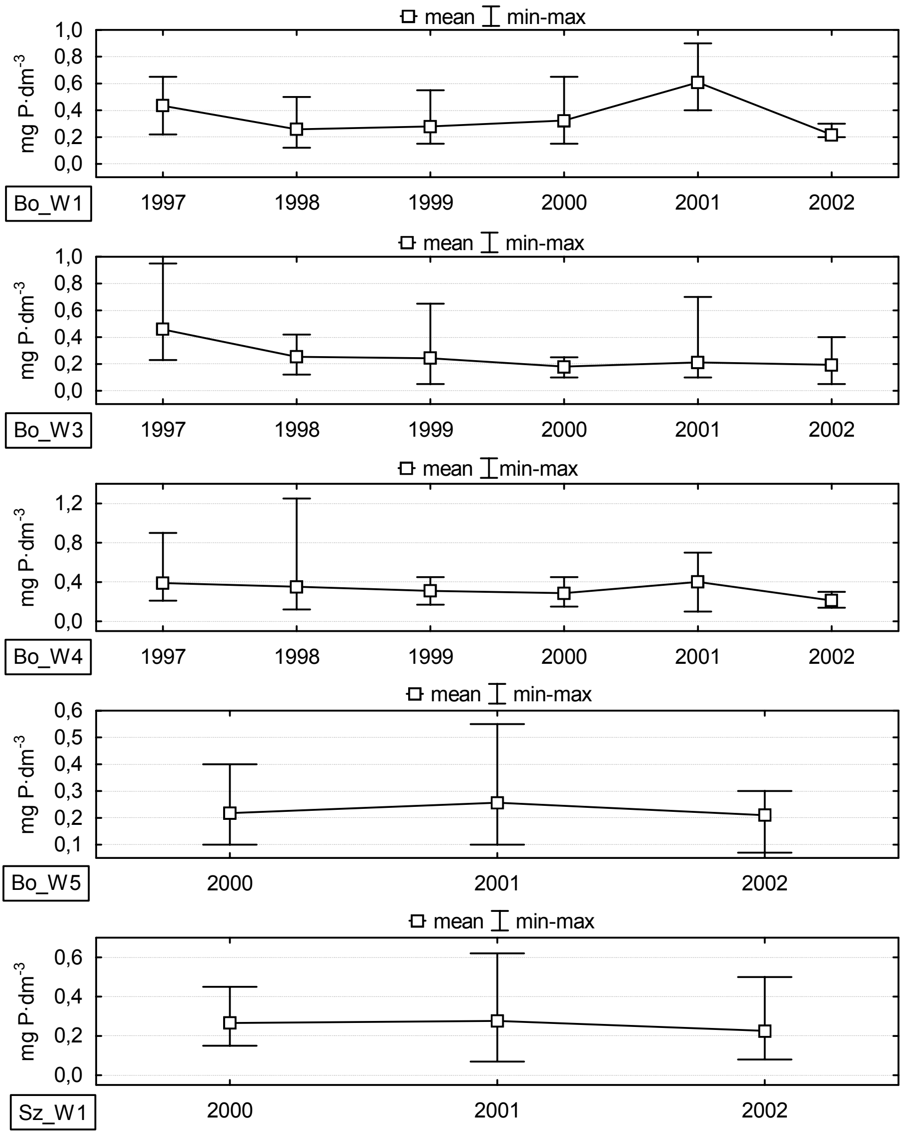

Fig. 6.5. Concentration of phosphorus in drainage effluents; markings as in Table 4.1

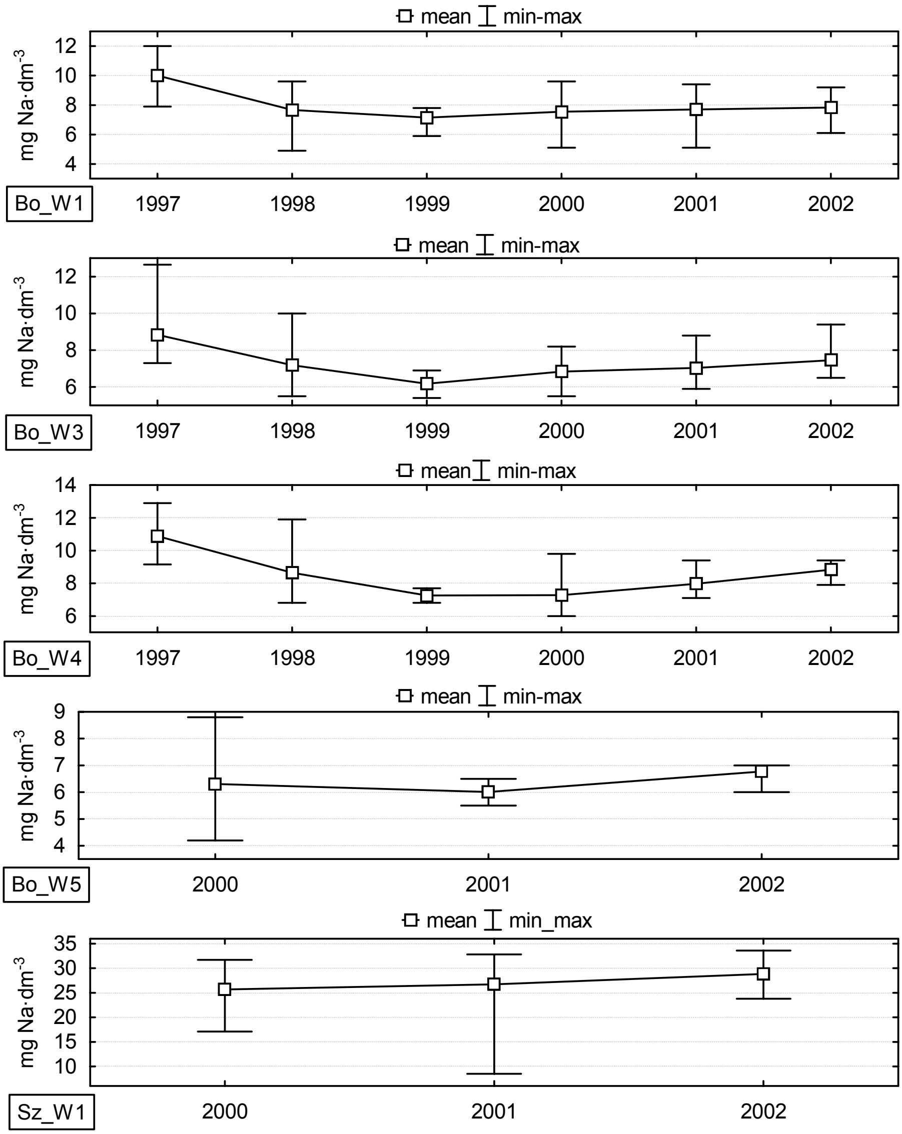

Fig. 6.6. Concentration of sodium in drainage effluents; markings as in Table 4.1

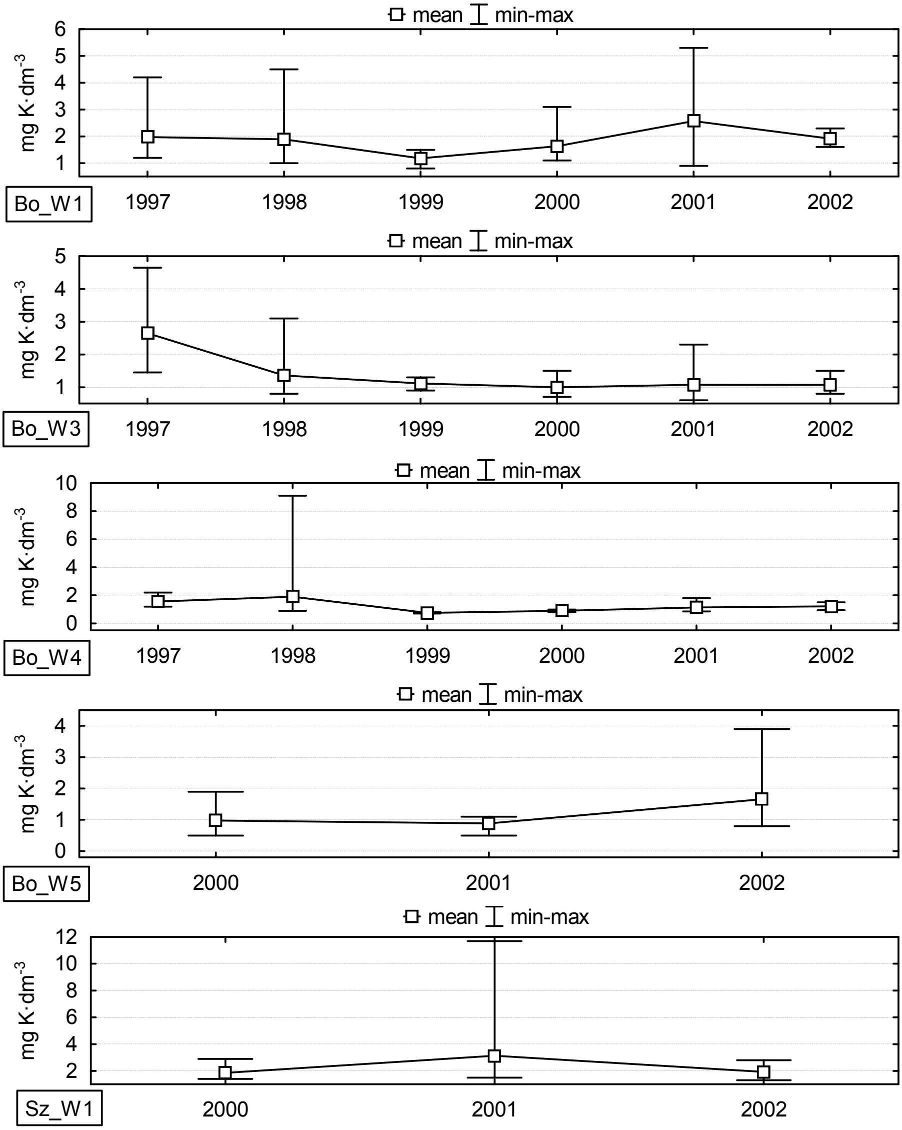

Fig. 6.7. Concentration of potassium in drainage effluents; markings as in Table 4.1

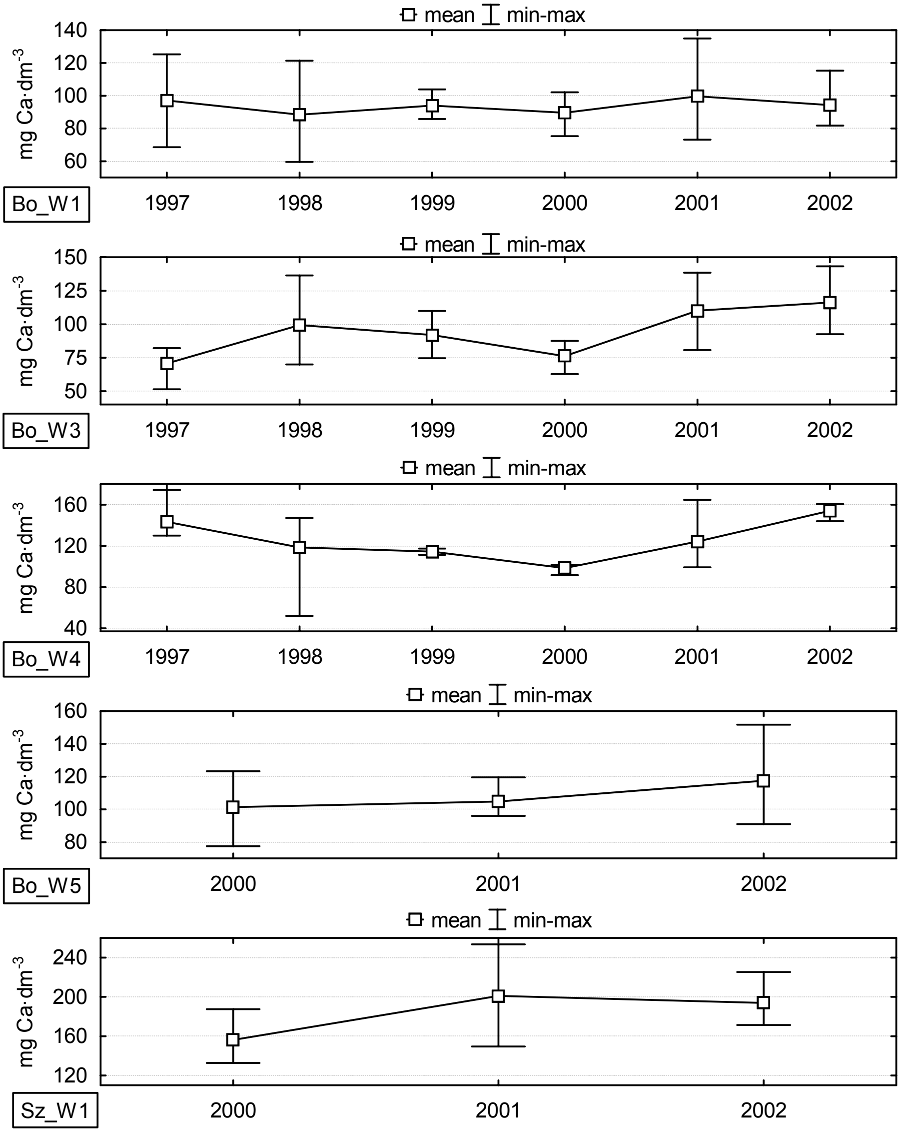

Fig. 6.8. Concentration of calcium in drainage effluents; markings as in Table 4.1

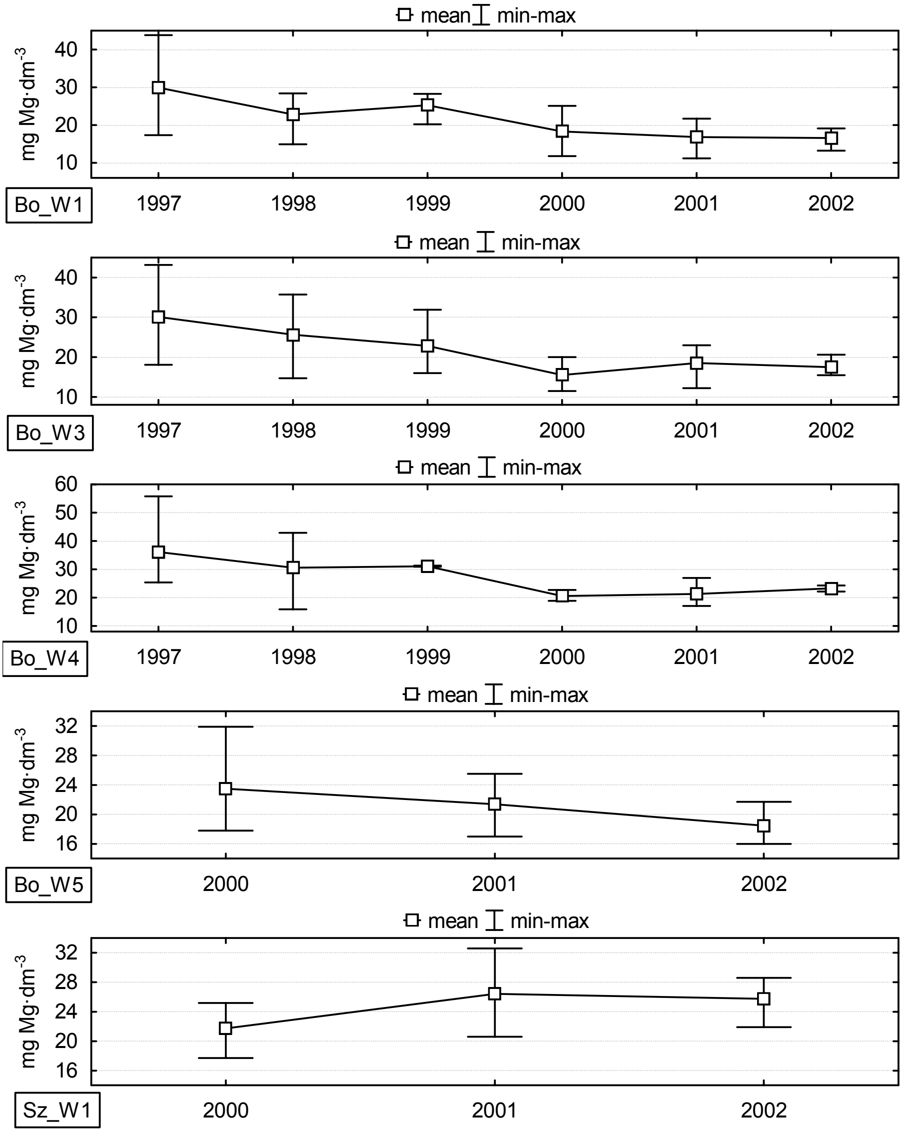

Fig. 6.9. Concentration of magnesium in drainage effluents; markings as in Table 4.1

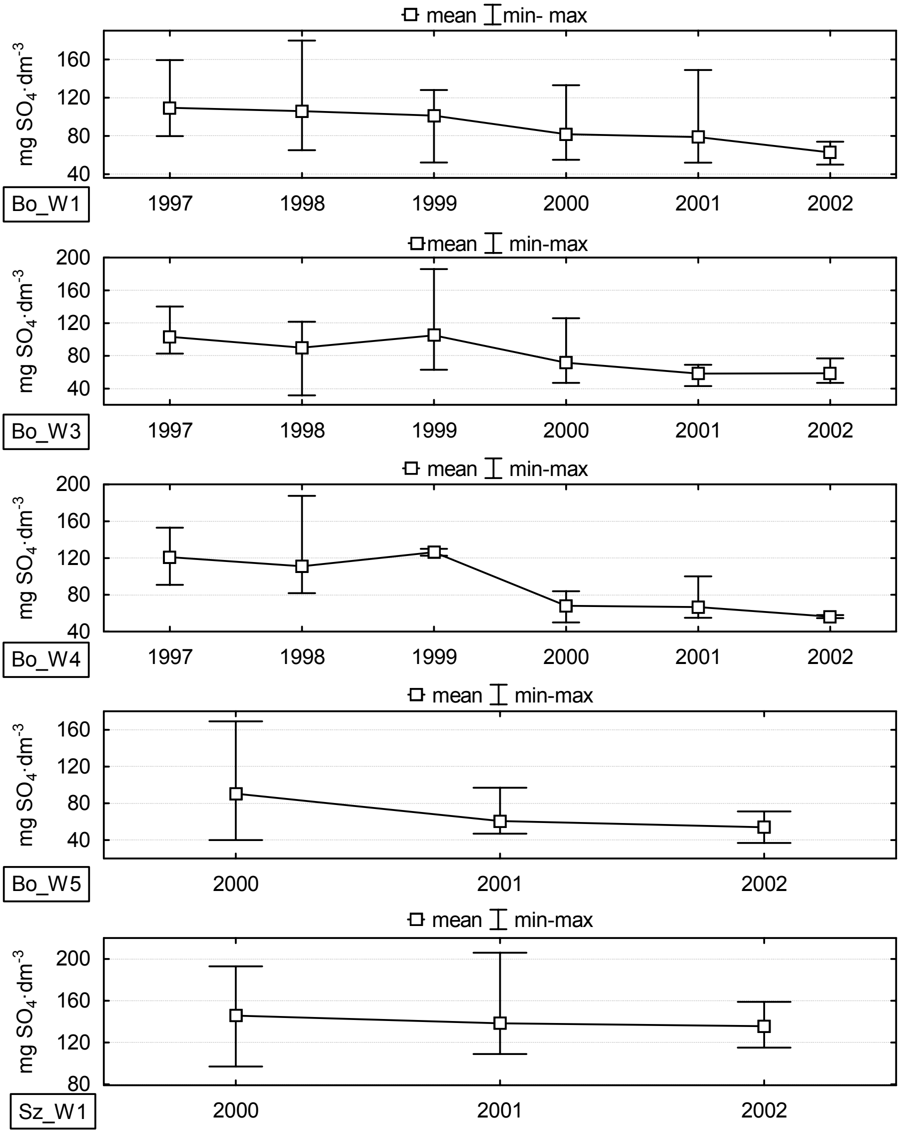

Fig. 6.10. Concentration of sulphates in drainage effluents; markings as in Table 4.1

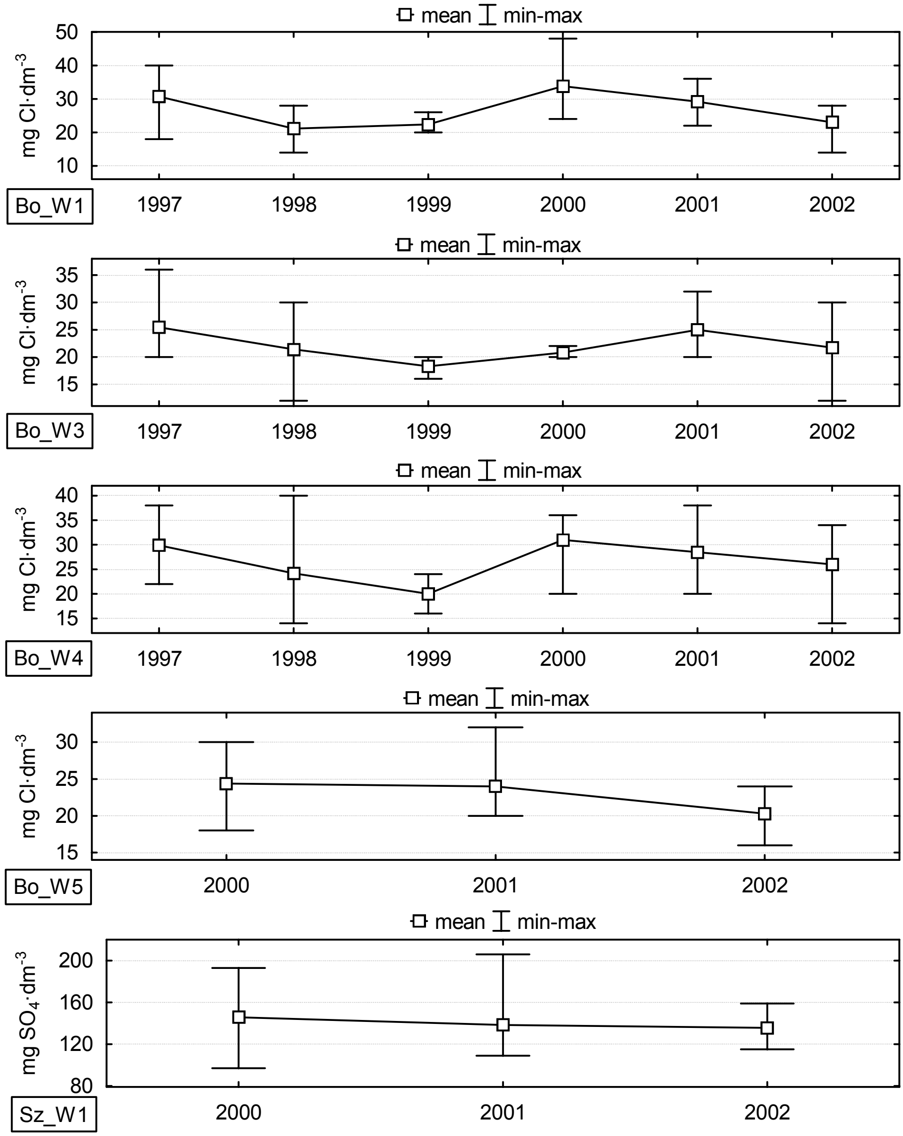

Fig. 6.11. Concentration of chlorides in drainage effluents; markings as in Table 4.1

7. SURFACE WATERS

Both stagnant and flowing surface waters are of particular importance to the society. The deterioration of their quality is directly noticed also by those, who do not possess expertise in the field of ecology or environmental protection, while the quality of ground waters, not to mention drainage effluents, does not attract general interest of the society, even in cases when ground waters drawn from wells constitute a source of water supply for farming purposes. Water consumers quite often do not even realize how polluted the water is – most often with nitrogen compounds. Thus, the protection of the quality of surface waters, which is influenced by a series of co-existing factors, is an important task faced by modern society.

Stagnant waters, which are significantly more prone to pollution in comparison to flowing waters, require special protection. Only within the limits of Wrocław County there are over 1300 small water reservoirs, most of them anthropogenic, created in former clay, sand or gravel excavation sites and used as fishing ponds, fire protection reservoirs or for decorative purposes. These reservoirs are usually located in the vicinity of developed areas and old river beds. Only a relatively small number of such reservoirs was covered by the small retention programme in the Lower Silesian voivodship, which does not cover reservoirs of a water area lower than 1 hectare [Fatyga et al. 2007, Drabiński et al.2008].

The main factor influencing the composition of water flowing out from small agricultural catchments is human activity related to farming cultivation. However, in larger catchments the dominant factor is quite often the disorderly water and wastewater management in urban areas [Pawlik-Dobrowolski, Durkowski 1998]. Even in catchments that are intensely agriculturally used it is possible to retain and maintain a suitable quality of water in the watercourse [Sojka et al. 2008]. Discharge systems, in particular drainage, can significantly contribute to the eutrophication of surface waters [Pulikowski 2004, Koc, Solarski 2006], while drainage systems designed for the limitation of outflow and increasing retention have a positive influence on the quality of water flowing out of such objects [Nyc, Pokładek 2009].

Both waters flowing out of agricultural catchments and those retained in small reservoirs (ponds), were characterized by an average annual electrical conductivity lower than 800 $\mu S \cdot cm^{-1}$ with two exceptions (years 1995 and 2005) in Miękinia, where this value approached 1 000 $\mu S \cdot cm^{-1}$ (Fig. 7.1). This object was characterized by the highest and rather haphazard dynamics of fluctuations of this indicator. As for stagnant waters, the highest values were obtained for reservoirs located closer to buildings (B_2 and R), which might suggest a connection with the disorderly wastewater management in the discussed area. The obtained values of conductivity fall into the range determined by

Dojlido [1995] as typical for surface waters. At the same time they are lower than those found by Durkowski [2005] in water from small watercourses in the catchment of the Miedwie lake, and by Staniszewski and Szoszkiewicz [2005] in lakes and watercourses located in the Kujawy region.

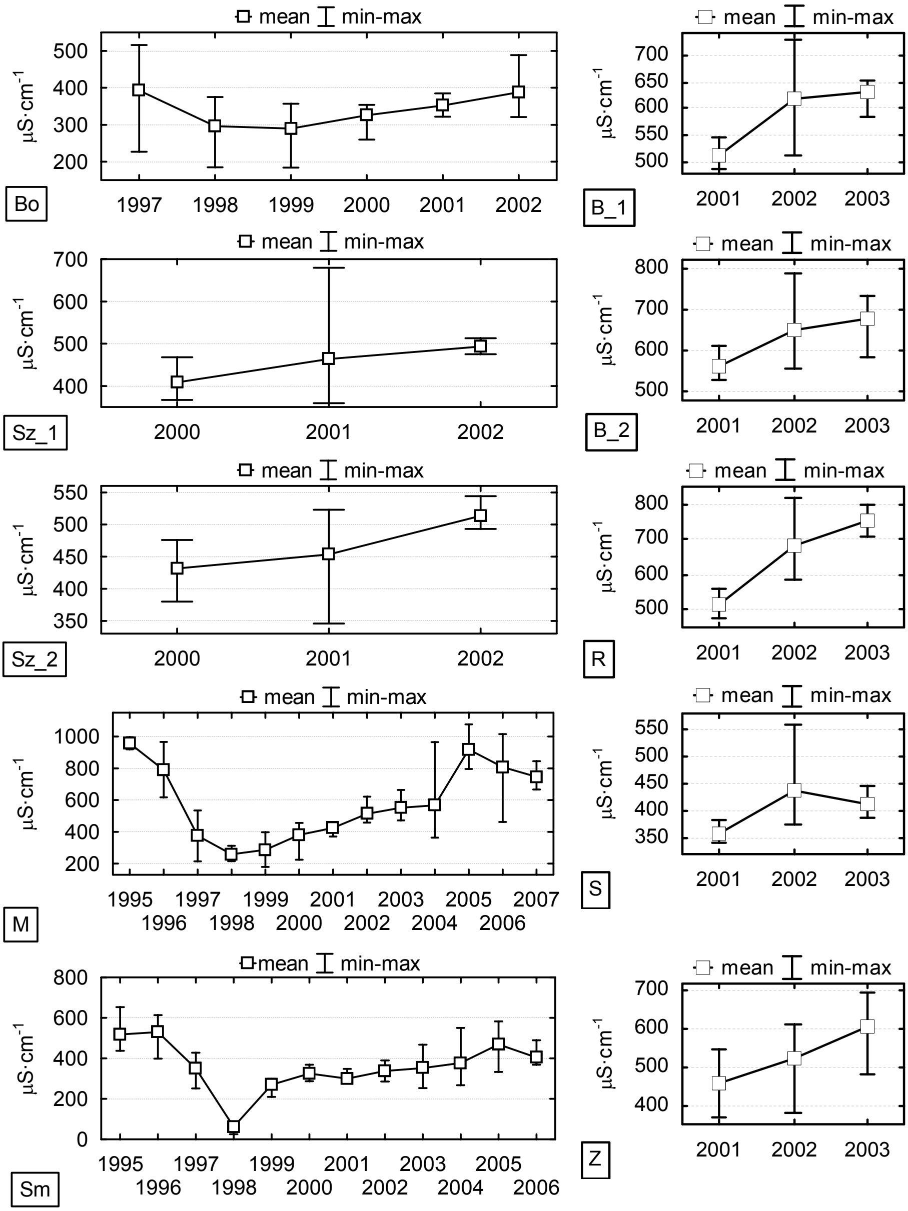

Fig. 7.1. Electrical conductivity of surface waters; markings as in Table 4.1

Waters flowing out of the catchment were characterized by high oxygen content. Only two instances were found, in the object Samotwór, when the average annual value was lower than 4 mg $O_2 \cdot dm^{-3}$ (Fig. 7.2). Similar results were obtained for four reservoirs, significantly lower concentrations of dissolved oxygen were found in the pond B_2 in Bliż, where the average annual concentration ranged from 1.9 to 3.7 mg $O_2 \cdot dm^{-3}$ and was significantly lower than the other values as well as the values presented in literature [Kanownik, Rajda 2010]. It should be assumed that this fact is not related to agricultural activity, and that the pollution originates from the urbanized area.

The analyzed oxygen factors – COD-Mn and BZT_5 are highly convergent for most objects, although the values obtained in specific measurement points are quite varied. Waters flowing out from objects Szewce and Bogaczowice as well as those retained in the ponds in Smolec and Zybiszów were characterized by low values of COD-Mn and BZT_5 (Fig. 7.3 and 7.4), which allows to classify them as slightly polluted with organic substances. For stagnant waters the highest average annual values of $BOD_{5,}$ ranging from 9.8 to 14.3 mg $O_2 \cdot dm^{-3.}$ were found in water from reservoir B_2. Similarly high values were obtained in this reservoir for the COD-Mn indicator. For waters flowing out of Mięknia and Samotwór the obtained values of BOD_5 were slightly higher than for the other catchments, although these waters are characterized by several times higher values of COD-Mn (Fig. 7.3). This proves that they contain large amounts of hardly soluble organic matter, which may originate from such sources as decomposing peats. The obtained results prove that agriculture does not pose a significant threat of polluting the water with organic substances.

The concentrations of ammonium nitrogen allow us to claim without any doubt that correctly used agricultural lands do not constitute a direct threat of pollution with this element. In nine out of 10 analyzed cases the average annual value, as well as a significant majority of maximum values, did not exceed 0.50 mg $N\text{-}NH_4 \cdot dm^{-3}$ (Fig. 7.5). In a polluted pond adjacent to urban areas the concentration of this form of nitrogen ranged from 1.80 to 7.00 mg $N\text{-}NH_4 \cdot dm^{-3.}$ while the average annual concentration in the 3 year test period was as high as 3.45 mg $N\text{-}NH_4 \cdot dm^{-3}$. Water from this pond has to be classified as highly polluted with ammonium nitrogen.

From the point of view of water quality protection, in agriculturally used catchments a definitely more important role is played by those nitrogen compounds that adopt the form of nitrates, which is better soluble in water and at the same time is only to a minimum extent retained by the absorption complex of the soil. Waters flowing out of the smallest catchments, nearly wholly drained, contained very high amounts of nitrates. The average annual concentrations of this form of nitrogen in objects Szewce and Bogaczowice ranged from 8.0–16 mg $N\text{-}NO_3 \cdot dm^{-3}$ (Fig. 7.6).

In two remaining catchments the content of nitrate nitrogen was significantly lower, and the concentrations only occasionally exceeded 2 mg $N\text{-}NO_3 \cdot dm^{-3}$. Similar concentrations were found in the study by Kanownik and Rajda [2008] conducted on a small watercourse in Małopolska. Water flowing out of 15 small agriculturally used catchments in Lower Silesia contained 1.69 to 9.43 mg $N\text{-}NO_3 \cdot dm^{-3}$ [Hus, Pulikowski 2011]. This data shows, how seriously the waters are threatened by drainage effluents discharged from agriculturally used lands, as they are the main source of nitrate nitrogen in surface waters flowing out of agriculturally used catchments. However, concentrations found in larger areas with a share of non-agricultural lands can be considered as relatively safe [Sojka et al. 2008].

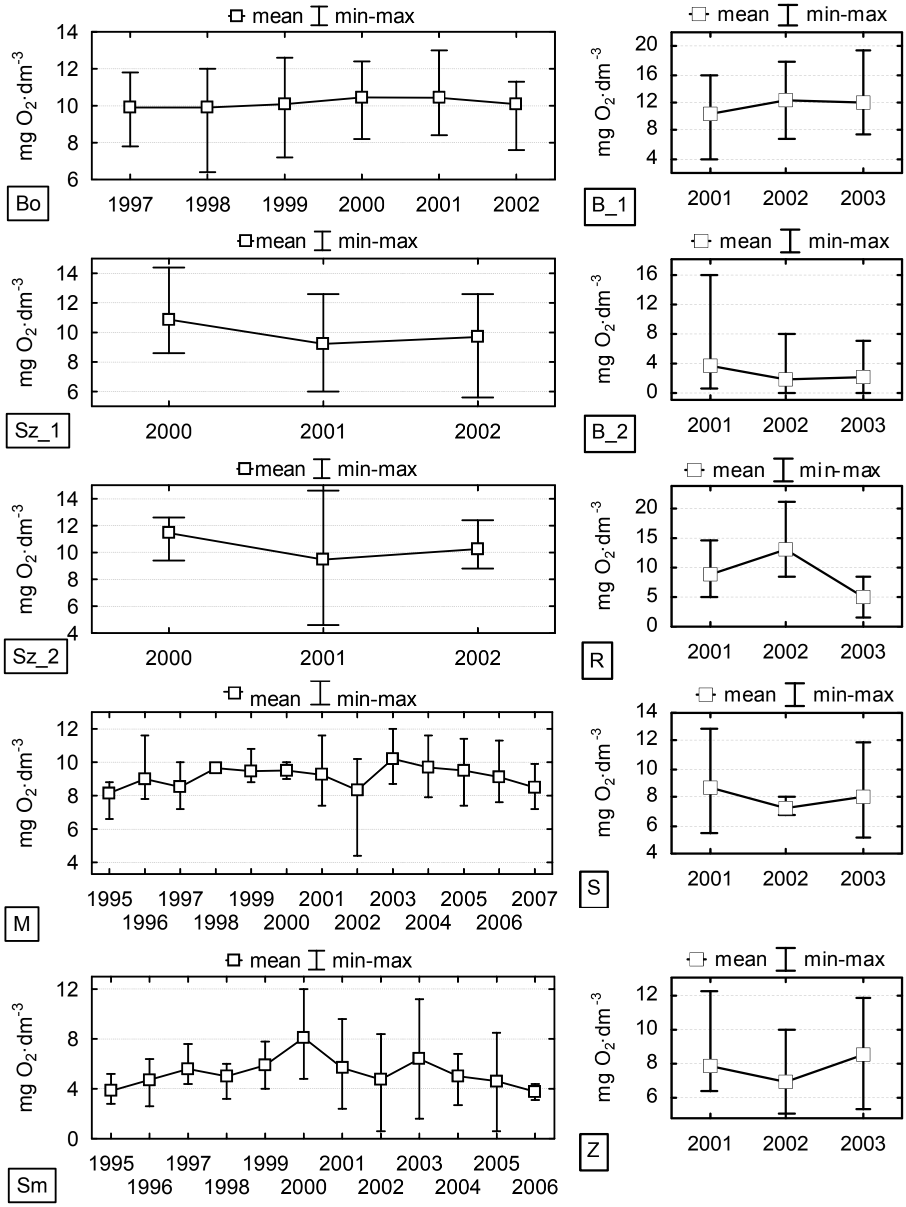

Fig. 7.2. Concentration of dissolved oxygen in surface water; markings as in Table 4.1

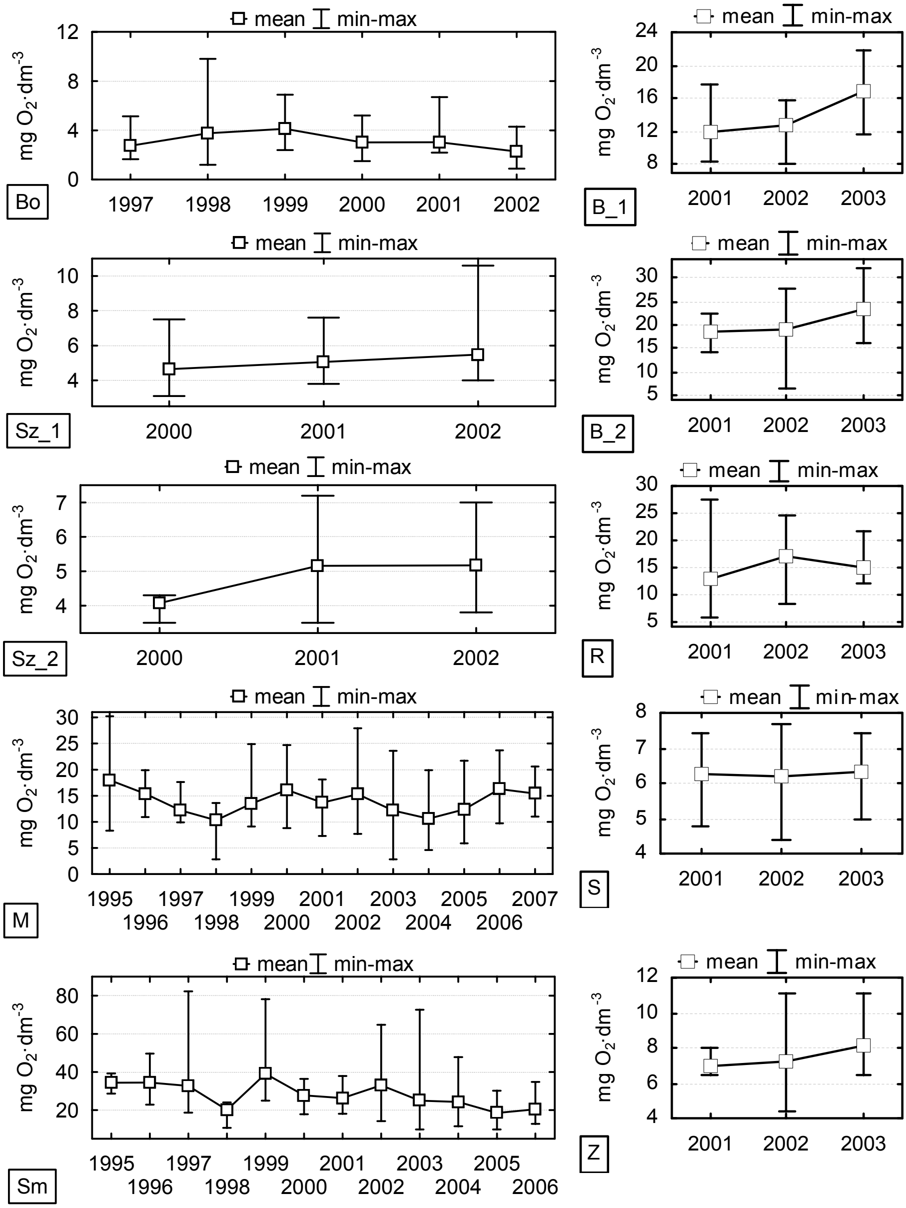

Fig. 7.3. Chemical oxygen demand – COD-Mn of surface water; markings as in Table 4.1

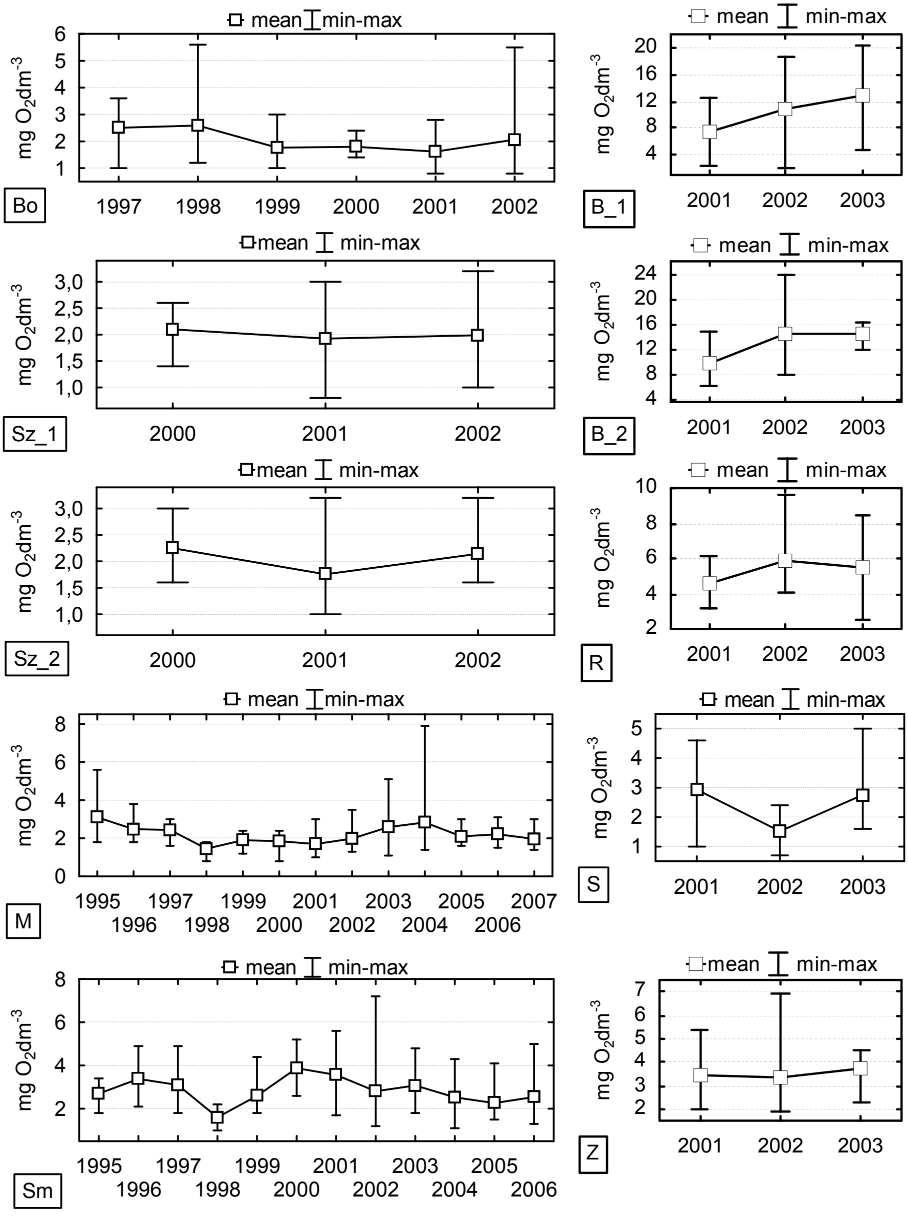

Fig. 7.4. Biochemical oxygen demand – BOD_5 of surface water; markings as in Table 4.1

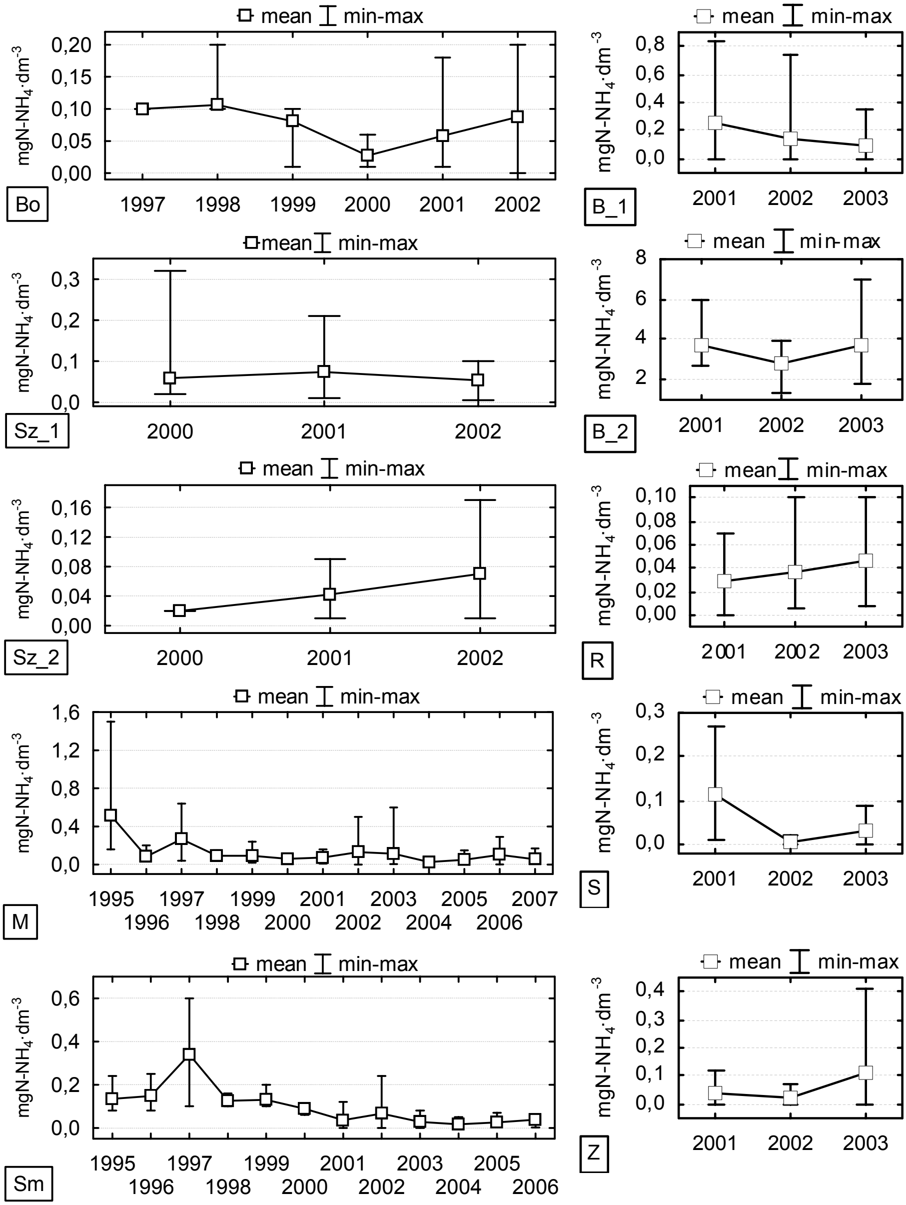

Fig. 7.5. Concentration of ammonium nitrogen in surface water; markings as in Table 4.1

Waters retained in small ponds did not contain an excessive amount of nitrogen in its nitrate form. Only in one of them (reservoir B-1 in 2001) average annual concentration exceeded the value of 1.0 mg $N\text{-}NO_3 \cdot dm^{-3}$ (Fig. 7.6). The concentrations of nitrate nitrogen were similar to those presented by Koc et al. [2001], whereas Durkowski and Woroniecki [2001] found values that are nearly 10 times as high for ponds located in rural areas. Also, higher concentrations of nitrate nitrogen are found in larger reservoirs [Kanownik, Rajda 2010].

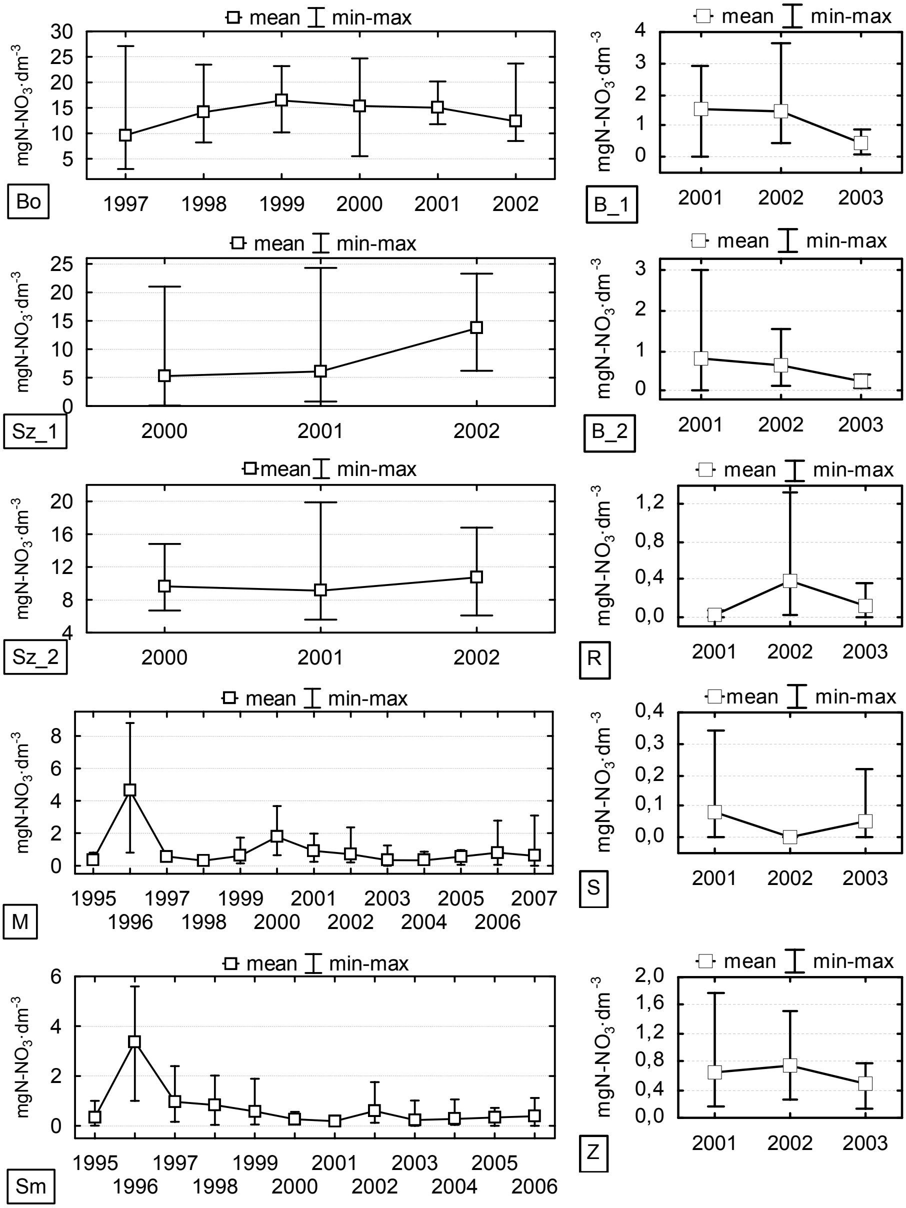

Fig. 7.6. Concentration of nitrate nitrogen in surface water; markings as in Table 4.1

In waters flowing out through ditches a high concentration of total nitrogen was found, particularly in watercourses supplied by drainage effluents characterized by high contents of nitrates (Fig. 7.7). One should also note the very high average concentrations of total nitrogen in stagnant waters. The average annual concentrations, in spite of low concentrations of the analyzed mineral forms, fell into a wide range: from 3.0 to 16 mg $N \cdot dm^{-3}$ (Fig. 7.7). This proves that these waters are highly polluted by organic substances containing nitrogen.

Another important component, whose excessive amounts in water can lead to eutrophication, and, as a consequence, to a major deterioration of quality and a limitation of possibilities to use the water for different purposes is phosphorus. The obtained values should be classified as dangerous. A significant majority of the annual concentrations ranged from 0.1–0.4 mg $P \cdot dm^{-3}$ (Fig. 7.8). Only in the case of pond B-2 located in the vicinity of buildings, the concentrations were 3–4 times higher than in the remaining objects, which is another proof of the fact that water in this reservoir is influenced by a disorderly wastewater management system in the adjacent area.

The discharge of drainage effluents rich in phosphorus to ditches did not cause an increase in the concentration of this element in the cross-sections below drainage outlets, as it was in the case of nitrate nitrogen. This is probably a result of the fact that drainage limits the amount of superficial flow, and thus of the amount of phosphorus being supplied to the watercourse. As compared to results obtained in other objects, the concentrations that were found are relatively high [Rajda et al. 1992, Grant et al. 1996, Kowalik et al. 2009].

Higher concentrations of sodium were found in stagnant than in flowing waters (Fig. 7.9). The highest concentrations were noted in Rybnica, where the content of this element in the pond significantly increased during the period of study. The content of sodium in water flowing out through watercourses and retained in ponds was equivalent to the average range of concentrations determined by Dojlido [1995], and at the same time lower than that presented by Kanownik and Rajda [2008].

The concentrations of potassium were much more varied. The smallest amount of this element flowed out of the object in Bogaczowice (average annual concentration fell into the range 1–2 mg $K \cdot dm^{-3}$), while the highest concentrations were found in object Szewce, below the drained part, where they fluctuated around the value of 20 mg $K \cdot dm^{-3}$ (Fig. 7.10). Very low concentrations of potassium in the object Bogaczowice are a direct result of the low content of the soluble form of this element in the soil [Paruch et al. 2002], whereas in Szewce this may be a consequence of the fact that the soil used to be watered by municipal wastewater. One should note the concentrations obtained in two ponds – R and B_2. which significantly exceeded the value of 30 mg $K \cdot dm^{-3}$. Such dramatic increase of the concentration of potassium might be a result of the supply of polluted waters from the adjacent developed area to these ponds.

The concentrations of calcium and magnesium (Fig. 7.11. and 7.12) in the water flowing out of the catchment can be considered as typical [Dojlido 1995]. Slightly lower values, although only in reference to calcium in flowing waters, are presented by Kanownik and Rajda [2010]. It is worth noting that the concentration of magnesium in waters flowing out of three catchments gradually decreases (Fig. 7.12). This may be an evidence of the decreasing content of this element in its soluble form, (i.e. in the form accessible for plants) in soil.

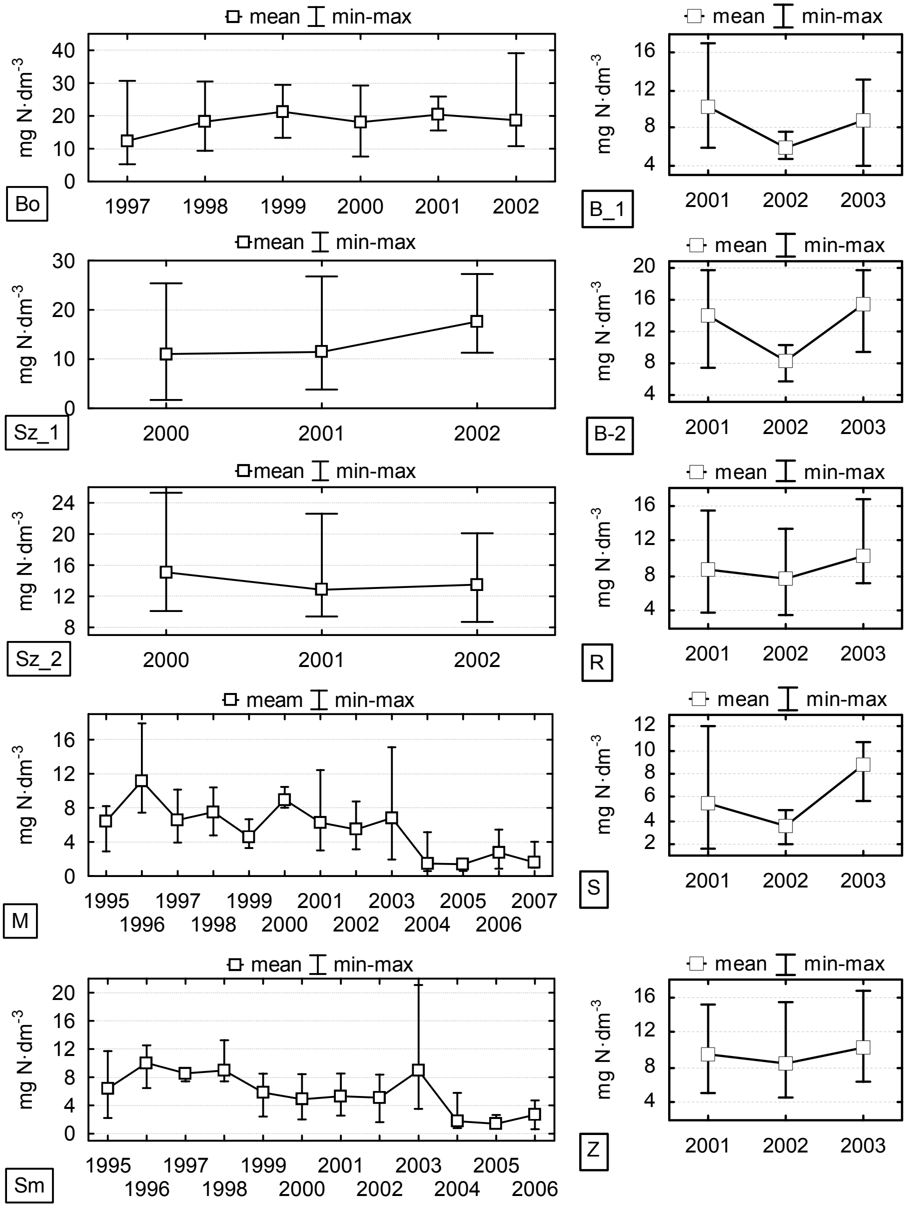

Fig. 7.7. Concentration of total nitrogen in surface water; markings as in Table 4.1

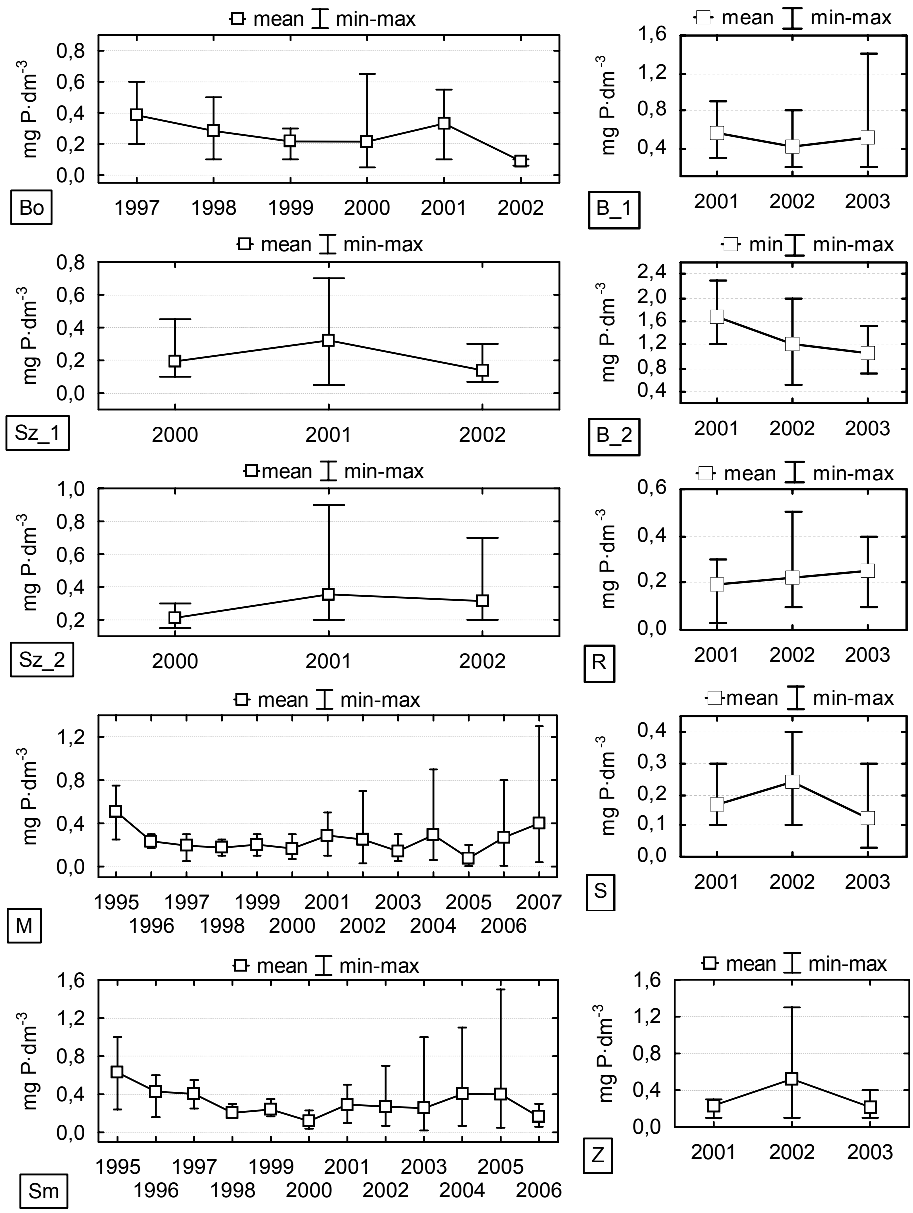

Fig. 7.8. Concentration of phosphorus in surface water; markings as in Table 4.1

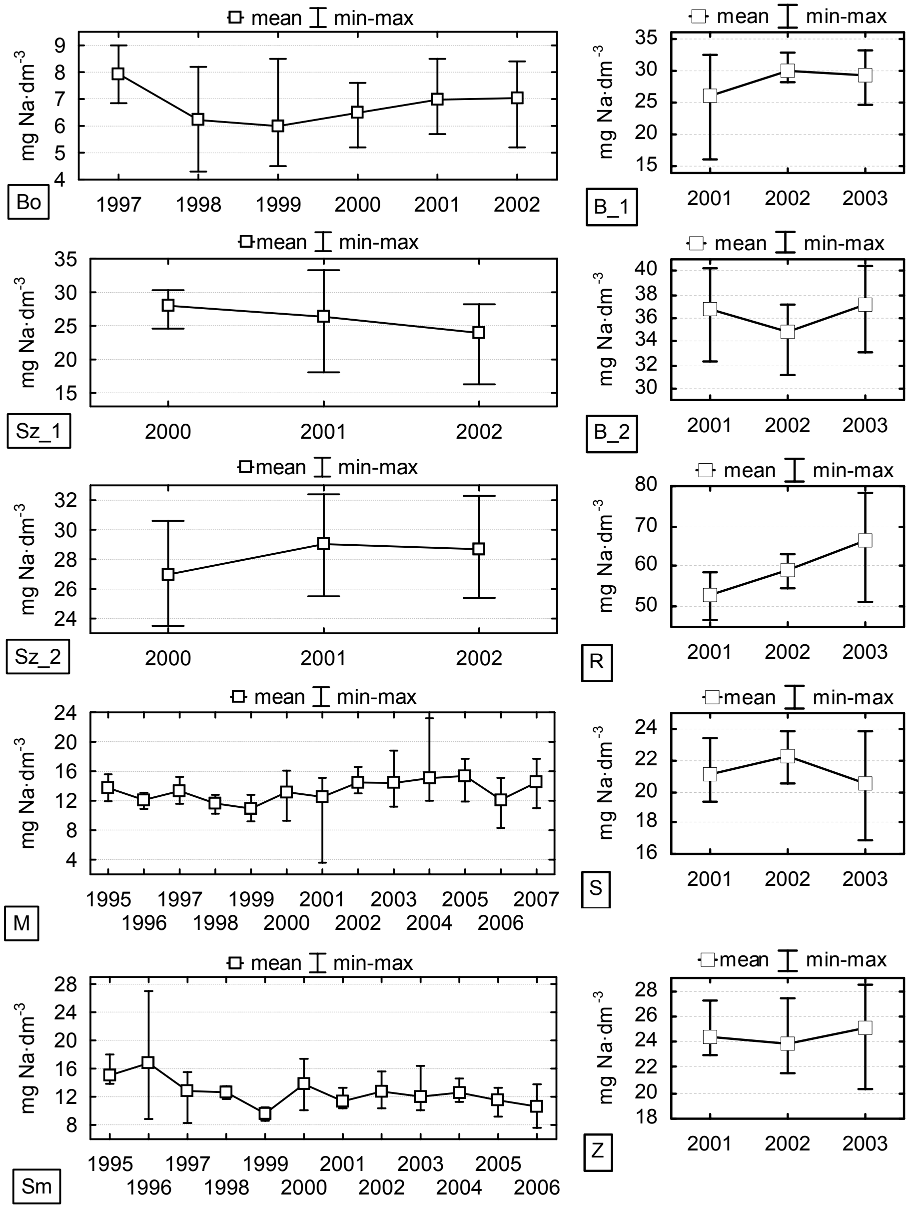

Fig. 7.9. Concentration of sodium in surface water; markings as in Table 4.1

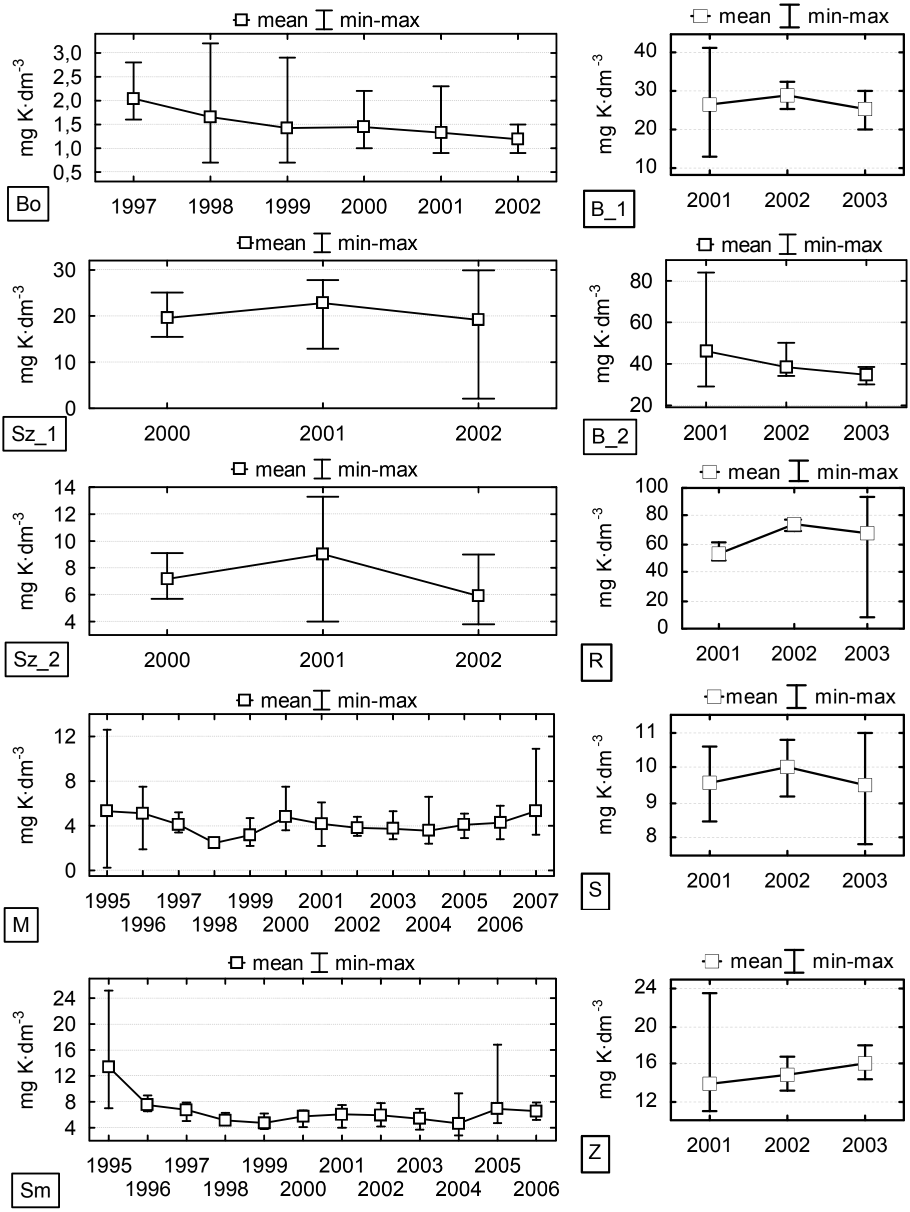

Fig. 7.10. Concentration of potassium in surface water; markings as in Table 4.1

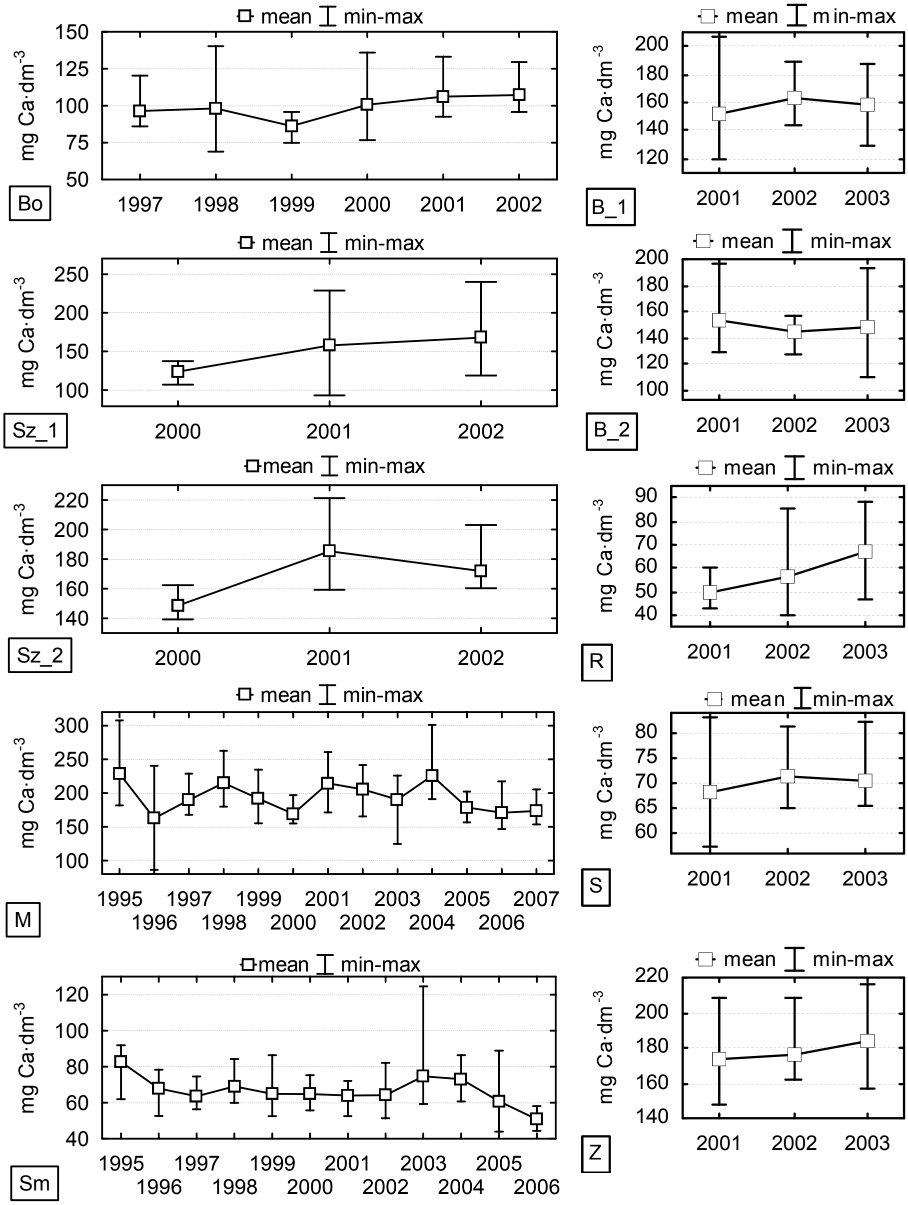

Fig. 7.11. Concentration of calcium in surface water; markings as in Table 4.1

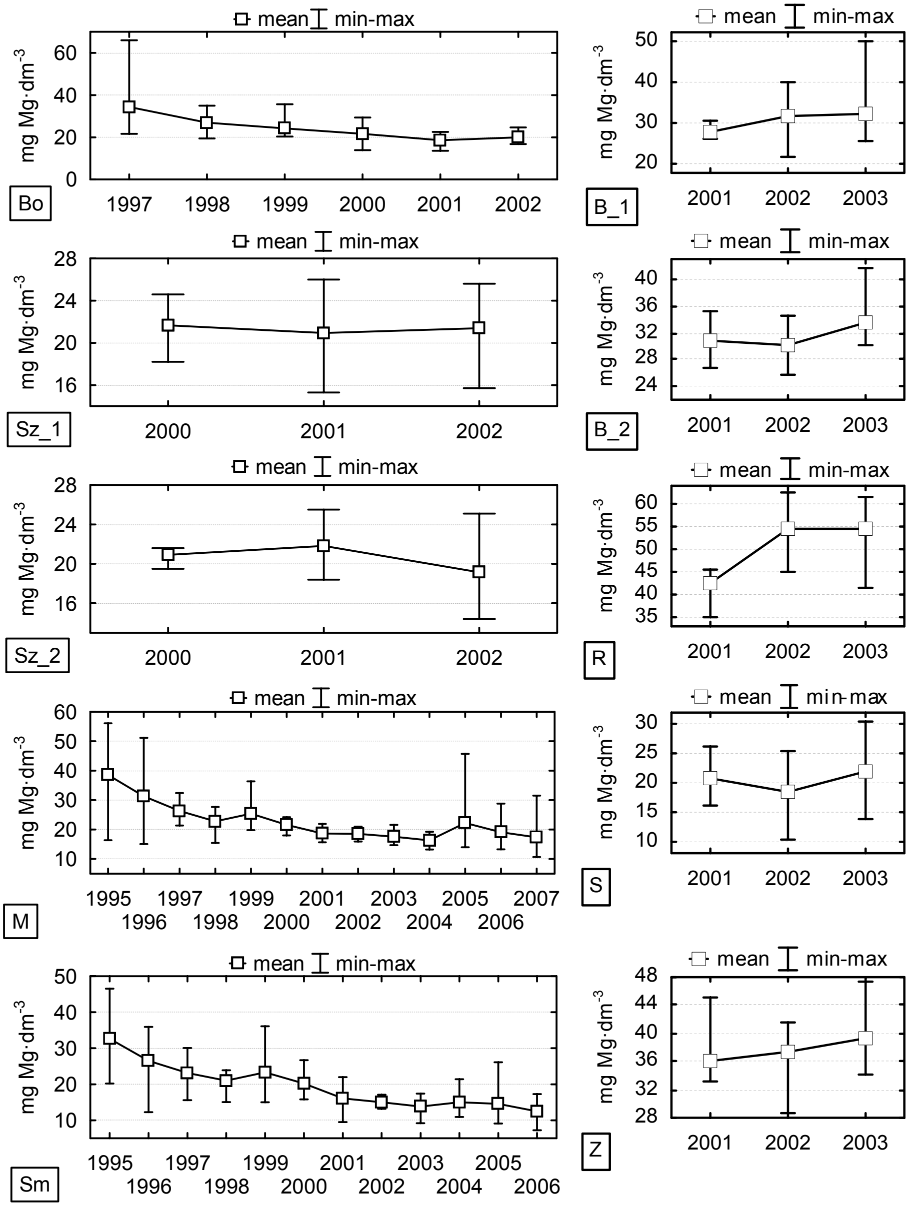

Fig. 7.12. Concentration of magnesium in surface water; markings as in Table 4.1

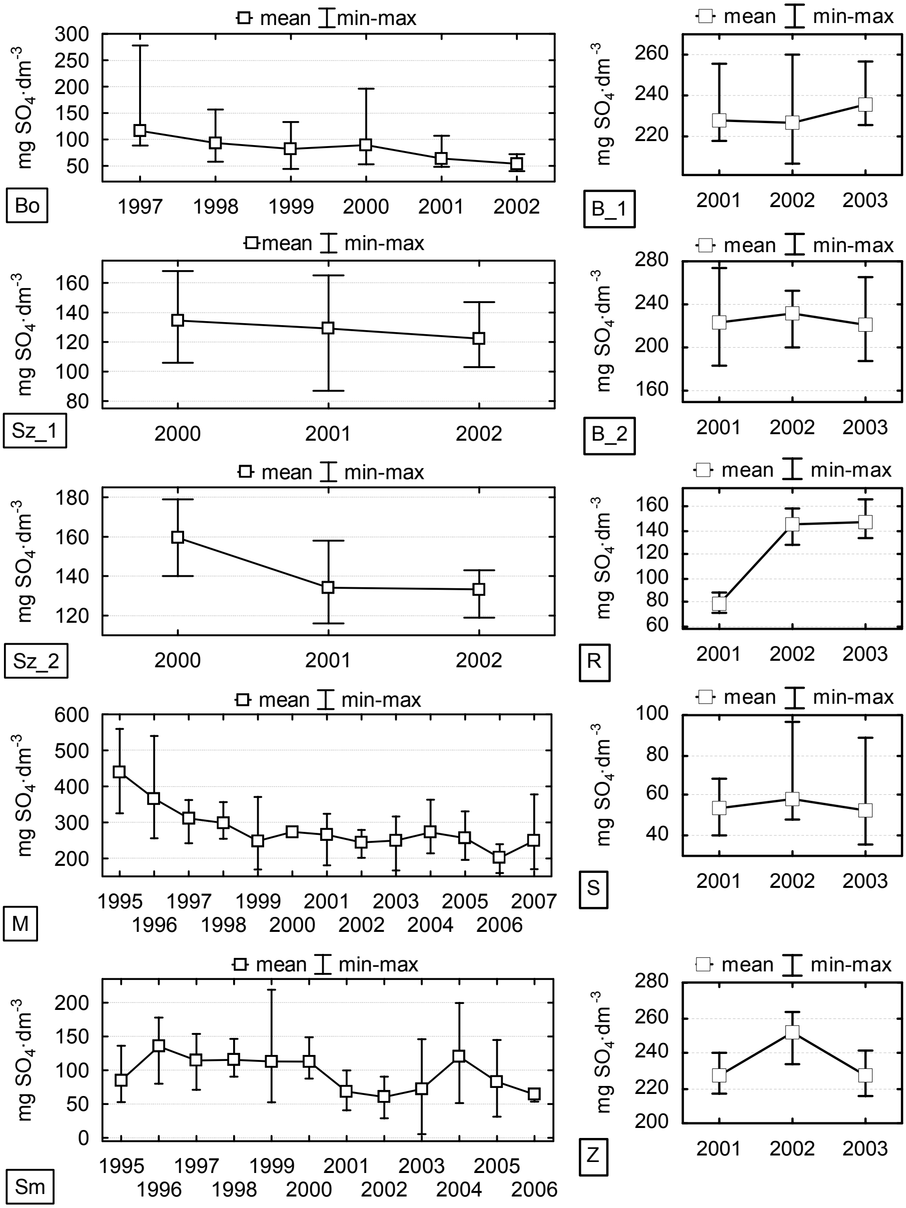

Fig. 7.13. Concentration of sulphates in surface water; markings as in Table 4.1

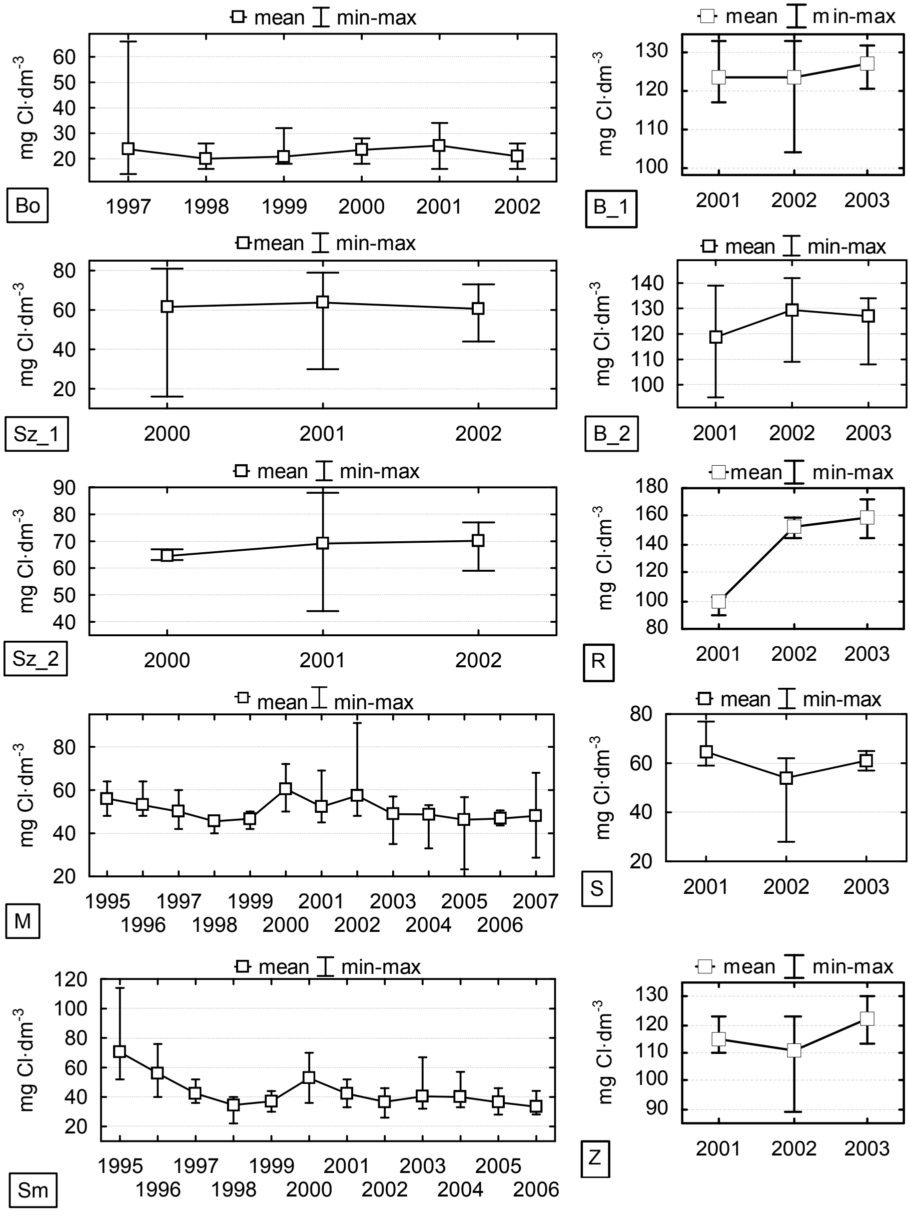

Fig. 7.14. Concentration of chlorides in surface water; markings as in Table 4.1

The content of sulphates in the analyzed waters varied within a wide range (Fig. 7.13). Lowest annual concentrations (below 60 mg $SO_4 \cdot dm^{-3}$) were found in pond S, and the highest (exceeding 400 mg $SO_4 \cdot dm^{-3}$) in water flowing out of Miękinia, where peat soils are present. Research conducted in the region of Małopolska showed similar concentrations for stagnant waters and significantly lower values for water from watercourses [Kanownik, Rajda 2010]. The content of chlorides oscillated around the value of 60 mg $Cl \cdot dm^{-3.}$ with the exception of Bogaczowice, where the annual concentration did not exceed 30 mg $Cl \cdot dm^{-3}$ (Fig. 7.14). Surface waters (except for pond S) were characterized by approximately 2 times higher concentrations of chlorides. The obtained concentrations of sulphates and chlorides fall within the range presented by Dojlido [1995].

In order to limit the load of biogenic components carried with waters flowing out of agricultural catchments, natural barriers should be created that would limit the inflow of these components. One of the basic actions to be taken could be to shape the catchment usage structure in a more rational way. One of the natural solutions is to use the lowest part of the valley, adjacent to the watercourse, with the highest level of ground waters, as grasslands, and the higher parts as arable land. In the case if such solution is difficult, grasslands could be replaced with belts of meadows along the bank, with a possible coverage of bushes and trees [Koc, Szyperek 2001].

8. SUMMARY AND CONCLUSION

This study presents the results of several research projects conducted in Lower Silesia, focusing on the influence of land usage on the quality of ground and surface waters and drainage effluents.

The content of additives in ground waters in agriculturally used areas allows us to classify these waters as relatively clean. The main threat for ground waters of the first aquifier level, resulting from agricultural activity, is an increased concentration of nitrate nitrogen. This threat is not present in all of the objects, quite often the concentration of 50 mg $NO_3 \cdot dm^{-3}$ (11.3 mg $N\text{-}NO_3 \cdot dm^{-3}$) is not exceeded. The increase of the content of the remaining indicators cannot always be explicitly linked to agricultural activity.

Drainage waters are a transitional type of water, between ground and surface waters, and they are closely connected to the functioning of drainage systems on agricultural lands. Although drainage effluents discharged from such agricultural lands occur only for several dozen days per year, they can constitute a real threat for recipient surface waters. The direct threat is created by the discharged load of nitrates and phosphorus. It is particularly significant in the case of objects located in submontane areas characterized by significantly higher outflow indicators than in lowland objects, which additionally increases the load of discharged biogenic substances. The volume of water discharged from such objects should be limited, for example by means of application of unsystematic drainage. Other methods that could be considered include the retention of water discharged from watershed areas and the use of such water during summer for watering crops cultivated in lower parts of the catchment.

Surface waters in agricultural catchments are not characterized by excessive pollution with organic substances. Water flowing out of such catchments contains significant amounts of nitrate nitrogen, with maximum concentrations often exceeding 11.3 mg $N\text{-}NO_3 \cdot dm^{-3}$ (50 mg $NO_3 \cdot dm^{-3}$), so they should be classified as highly polluted. The obtained results prove that the threat for stagnant waters is not significant and results mainly from the location adjacent to arable lands. A much more dangerous factor influencing the quality of such waters is caused by disorderly wastewater management.

The evaluation of the real influence of agricultural lands on the content of nitrates in surface waters requires the monitoring of small watercourses, which are the direct recipient of water from these areas, as the threat is of a local nature. Monitoring conducted on larger rivers does not always allow to identify such small, but still dangerous enclaves.

Both in the case of surface waters and ground waters one of the main factors causing the deterioration of water quality is the disorderly wastewater management in rural areas and incorrect methods of storage of natural fertilizers. A much more serious threat is caused by uncontrolled discharge of wastewater (Bliż, Rybnica), which is noticeable even in comparison with objects watered with wastewater (Pustków Żurawski), or agriculturally used in a traditional way. If these factors are analyzed jointly, often agriculture is charged with excessive responsibility for the deterioration of water quality.

The conducted analysis of test results in the context of literature allows us to reach the following conclusions:

1. The quality of ground waters on the first aquifier level on agricultural lands does not raise any reservations in the aspect of the content of both mineral and organic pollutants. Only an increased content of nitrate nitrogen was found.

2. Drainage waters (drainage effluents) are a quite specific type of water, which is not subject to any classification, or control. Drainage effluents discharged from agricultural lands contain high amounts of nitrate nitrogen and sometimes of phosphorus, which makes them a serious threat for the quality of recipient waters.

3. Surface waters flowing out of agricultural catchments are not polluted with organic substances, although they contain very high amounts of nitrogen compounds, mainly in form of nitrates. The concentration of such nitrates very often exceeds the value of 50 mg $NO_3 \cdot dm^{-3}$, which is generally considered dangerous.

4. When planning the protection of ground waters in rural areas, one should pay particular attention to objects used for storage of natural fertilizers and for the preparation of silage. Another important aspect is to efficiently order the wastewater management in rural areas.

ANNEX

Photo 1. Water stage on the Zdrojek stream, Miękinia area

Photo 2. Culvert with damming up on the Zdrojek stream, Miękinia area

Photo 3. Culvert on the Zdrojek stream

Photo 4. The Zdrojek stream in Miękinia area, sampling site (M)

Photo 5. Water stage on the stream in Samotwór area, sampling site (Sm)

Photo 6. Bliż area, the south reservoir, sampling site (B_1)

Photo 7. Bliż area, the middle reservoir, sampling site (B_2)

Photo 8. Reservoir in Rybnica, sampling site (R)

Photo 9. Reservoir in Smolec, sampling site (S)

Photo 10. Reservoir in Zybiszów, sampling site (Z)

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WATER QUALITY IN AGRICULTURALLY USED CATCHMENTS IN LOWER SILESIA

S u m m a r y

Municipal economy, industry and agriculture (plant and animal production) use large amounts of water of relatively high quality. The demand for water throughout the world is systematically growing, which makes the protection of world fresh water resources an even more important challenge. This study presents the results of several research projects conducted in Lower Silesia, covering the issues related to the influence of agricultural land usage on the quality of ground waters, surface waters and drainage effluents.

Waters present on agricultural lands are not significantly polluted with organic substances. However, special attention should be paid to the content of nitrates, whose concentrations often exceed 50 mg $NO_3 \cdot dm^{-3}$, which classifies these waters as polluted. One of the factors that significantly influences the content of nitrates and phosphorus in waters flowing out of agriculturally used catchments is the usage of drainage. Waters discharged through drainage systems are characterized by a particularly high content of nitrates, reaching even up to 190 mg $NO_3 \cdot dm^{-3}$.

In order to limit the load of biogenic substances carried out with waters flowing out of agricultural catchments, it should be attempted to create natural barriers limiting the inflow of such components. One of the basic actions to be taken is to shape the catchment structure in a more rational way. One of the natural solutions is to use the lowest part of the valley, adjacent to the watercourse, with the highest level of ground waters, as grasslands, and the higher parts as arable land.

Both in the case of ground waters and of surface waters, an important factor influencing the deterioration of water quality is disorderly water and wastewater management in rural areas, and sometimes incorrect manner of storage of natural fertilizers. The threat resulting from the uncontrolled discharge of wastewater is serious, even in comparison to objects watered with wastewater or objects used agriculturally in a traditional manner. If these factors are analyzed jointly, often agriculture is charged with excessive responsibility for the deterioration of water quality.

Key words: catchment, water, agriculture, pollution, nitrogen

JAKOŚĆ WODY W ZLEWNIACH UŻYTKOWANYCH ROLNICZO NA DOLNYM ŚLĄSKU

Streszczenie

Gospodarka komunalna, przemysł i rolnictwo (produkcja roślinna i zwierzęca) pochłaniają znaczne ilości wody o stosunkowo wysokiej jakości. Światowe zapotrzebowanie na wodę ciągle wzrasta, co sprawia, że troska o ochronę światowych zasobów wody słodkiej staje się coraz większym wyzwaniem. W pracy przedstawiono efekty kilku projektów badawczych realizowanych na Dolnym Śląsku, obejmujących swym zakresem kwestie wpływu rolniczego użytkowania gruntów na jakość wód podziemnych i powierzchniowych oraz odcieków drenarskich.

Wody występujące na obszarach użytkowanych rolniczo nie wykazują znaczącego zanieczyszczenia substancją organiczną. Szczególną uwagę należy zwracać na zawartość azotanów, których stężenia często przekraczają 50 mg $NO_3 \cdot dm^{-3}$, a więc są to wody zanieczyszczone. Znaczący wpływ na stężenie azotanów i fosforu w wodach odpływających ze zlewni użytkowanych rolniczo ma stosowanie odwodnienia za pomocą drenowania. Wody odprowadzane systemami drenarskimi cechują się szczególnie wysoką zawartością azotanów, dochodzącą nawet do 190 mg $NO_3 \cdot dm^{-3}$.

W celu ograniczenia ładunku składników biogennych wynoszonych wraz z wodami odpływającymi ze zlewni rolniczych należy dążyć do tworzenia naturalnych barier ograniczających dopływ tych składników. Jednym z podstawowych działań może być racjonalne kształtowanie struktury użytkowania zlewni. Naturalnym rozwiązaniem jest zagospodarowanie najniższej części doliny przylegającej do cieku, o najwyższym poziomie wody podziemnej, jako użytki zielone, a wyższych partii jako grunty orne.

Zarówno w przypadku wód podziemnych, jak i powierzchniowych ważnym źródłem pogorszenia ich jakości jest nieuporządkowana gospodarka wodno-ściekowa na terenach wiejskich oraz nie zawsze prawidłowy sposób przechowywania nawozów naturalnych. Zagrożenie wynikające z niekontrolowanego odprowadzania ścieków bytowych jest znaczne, nawet w porównaniu z obiektem nawadnianym ściekami czy tradycyjnie użytkowanym rolniczo. Analizowanie tych czynników łącznie prowadzi dość często do nadmiernego obciążenia rolnictwa odpowiedzialnością za pogorszenie jakości wód.

Słowa kluczowe: zlewnia, woda, rolnictwo, zanieczyszczenie, azot