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INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

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EDITED BY
HENRYK MARUSZCZAK & LESZEK STARKEL

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FOREWORD

Systematic studies on anthropogenic impact on water circulation were undertaken by Polish geographers and hydrologists in the 50's and 60's in connection with hydrographic mapping. In the 80's, within the main research programme "Evolution of geographical environment in Poland" co-ordinated by Prof. L. Starkel from the Institute of Geography and Spatial Organization of the Polish Academy of Sciences, a research project concerning natural and anthropogenic changes of water conditions was completed. The results of this work, under the direction of Prof. I. Dynowska, were published in a monograph entitled "Changes of water conditions in Poland as a result of natural and anthropogenic processes" (Kraków 1993).

In the years 1994–95, Prof. H. Maruszczak from the Institute of Earth Sciences of Maria Curie-Sklodowska University initiated preparation of a number of papers describing the present tendencies of anthropogenic influence on hydrochemical conditions and sediment transport in rivers. After World War II the quality of surface waters and groundwater was drastically deteriorating in Poland. This was connected with introducing a "planned" socialist economy. This system was characterized by rapid but extremely extensive industrialization and urbanization realized largely at the cost of the natural environment. Therefore, besides some results of planned actions favourable for the environment (e.g. afforestation of waste lands and some arable lands), pollution of surface waters with sewage was rapidly increasing with fast urbanization and the building of big factories without necessary sewage treatment plants.

The direct or indirect (e.g. connected with agricultural chemization) supply of wastewater, increased the amount of dissolved and suspended load transported by rivers. Quantitative and qualitative analyses of this load allow for the defining of the degree of anthropogenic transformation of river waters and indirectly also of the whole natural environment. Other very big anthropogenic changes were connected with extensive exploitation of groundwater. Therefore, the previously proposed title for this set of papers was: "Anthropogenic impact on groundwater and dissolved and suspended load yields in the Vistula River basin".

The presented results of studies concern also anthropogenic changes of water conditions on a larger historical scale. Such an approach allows us to estimate more exactly the character and degree of the environmental degradation resulting from the extensive socialist economy after World War II.

The extensive character of this economy is accounted for by the fact that the quality of water started to improve after the change of the social-political system in the 90's. The increasing improvement, despite the short period of observations, has already been signalled in some papers of this volume.

The problem of anthropogenic impact on water conditions in Poland is presented using the examples of a few selected areas (catchments). The first two papers refer to the Vistula River catchment. The influence of hydrotechnical works on sediment transport is presented by A. Łajczak; he has found that Vistula channel regulation works caused increased sedimentation rates of the suspended load in recent decades. The balance and structure of the solute yield in the Vistula River basin is presented by H. Maruszczak and M. Wilgat, who found that during the last several dozen years the amount of "synthetic" substances (introduced to circulation by man) has increased several times. The authors of the other two papers present changes of water conditions in the past in the areas of old, big town centres existing since the early Middle Ages: Poznań in Wielkopolska — in the western part of the Middle Polish Lowlands (A. Kaniecki), and Lublin in Małopolska — in the eastern part of the South Polish Uplands (Z. Michalczyk and M.J. Łoś). A research group of Prof. T. Wilgat have described the Łęczna–Włodawa Lake Region, where the natural water conditions were rather well-preserved till the middle of the 20th century, and then changed rapidly and deteriorated due to unreasonable drainage works, intensified recreational utilization and the digging of mines in the new coal basin at the border of this region. A.T. Jankowski has studied the great increase in the dissolved load supplied to rivers with mine wastewaters from the old coal basin in Upper Silesia; in the late 80's and early 90's about 35% of sulphates and 50% of chlorides transported by Polish rivers came from this coal basin. The paper by A. Świeca gives information about rapidly-increasing pollution of a small river with wastewaters from Zamość — a middle-sized town, with fast development of the administrative centre of the new district established in 1975.

Henryk Maruszczak
Leszek Starkel

GEOGRAPHIA POLONICA 68, 1997

ANTHROPOGENIC CHANGES IN THE SUSPENDED LOAD TRANSPORTATION BY AND SEDIMENTATION RATES OF THE RIVER VISTULA, POLAND

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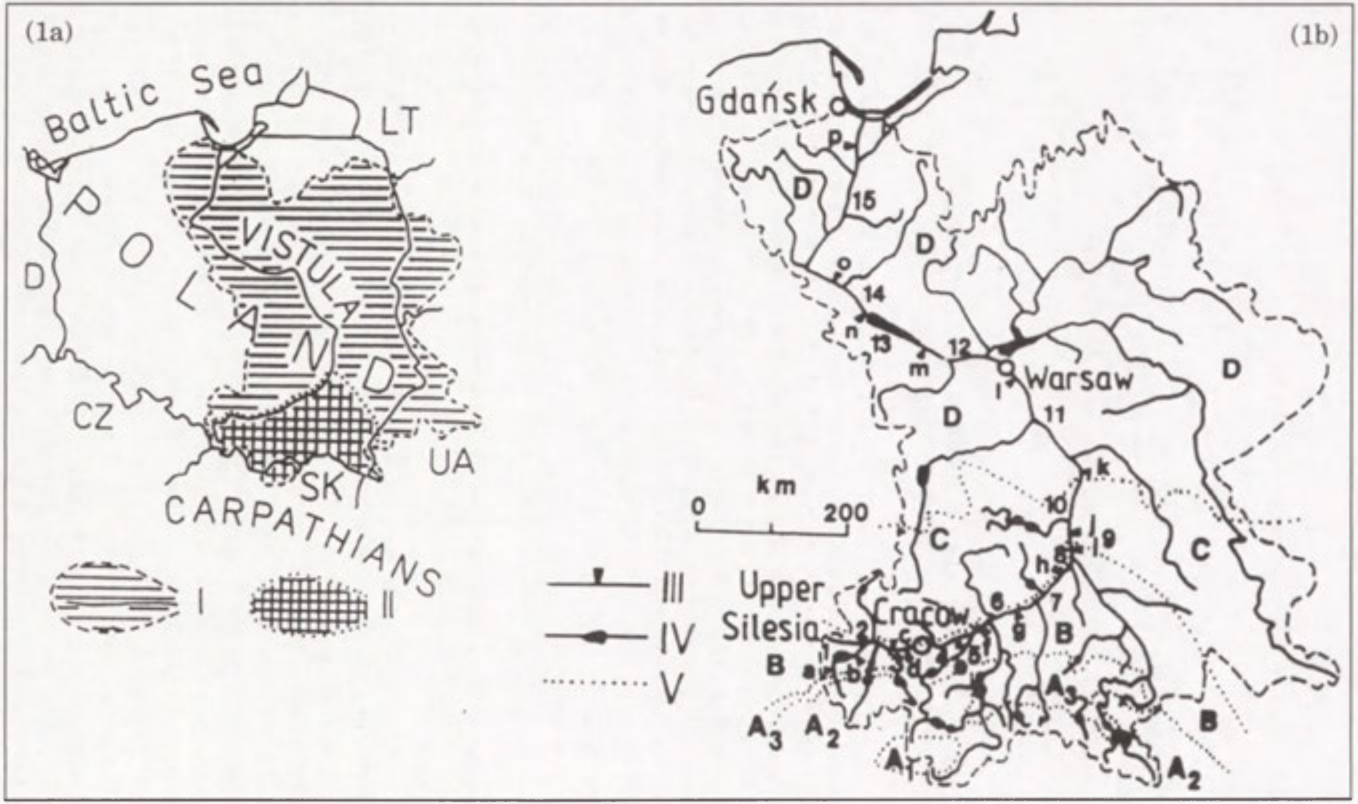
ABSTRACT: Evidence is presented that regulation works on the Vistula channel have introduced very significant and rapid changes in the magnitude of river load transportation and sedimentation. It is acknowledged that human interference represents the most significant cause of change in the Vistula catchment within historical times. The alluviation of the Vistula valley floodplain as described here, which was initiated about 150 years ago, may be compared with the equally rapid changes of load transportation by and sedimentation rates of other rivers influenced by intensive urbanization.

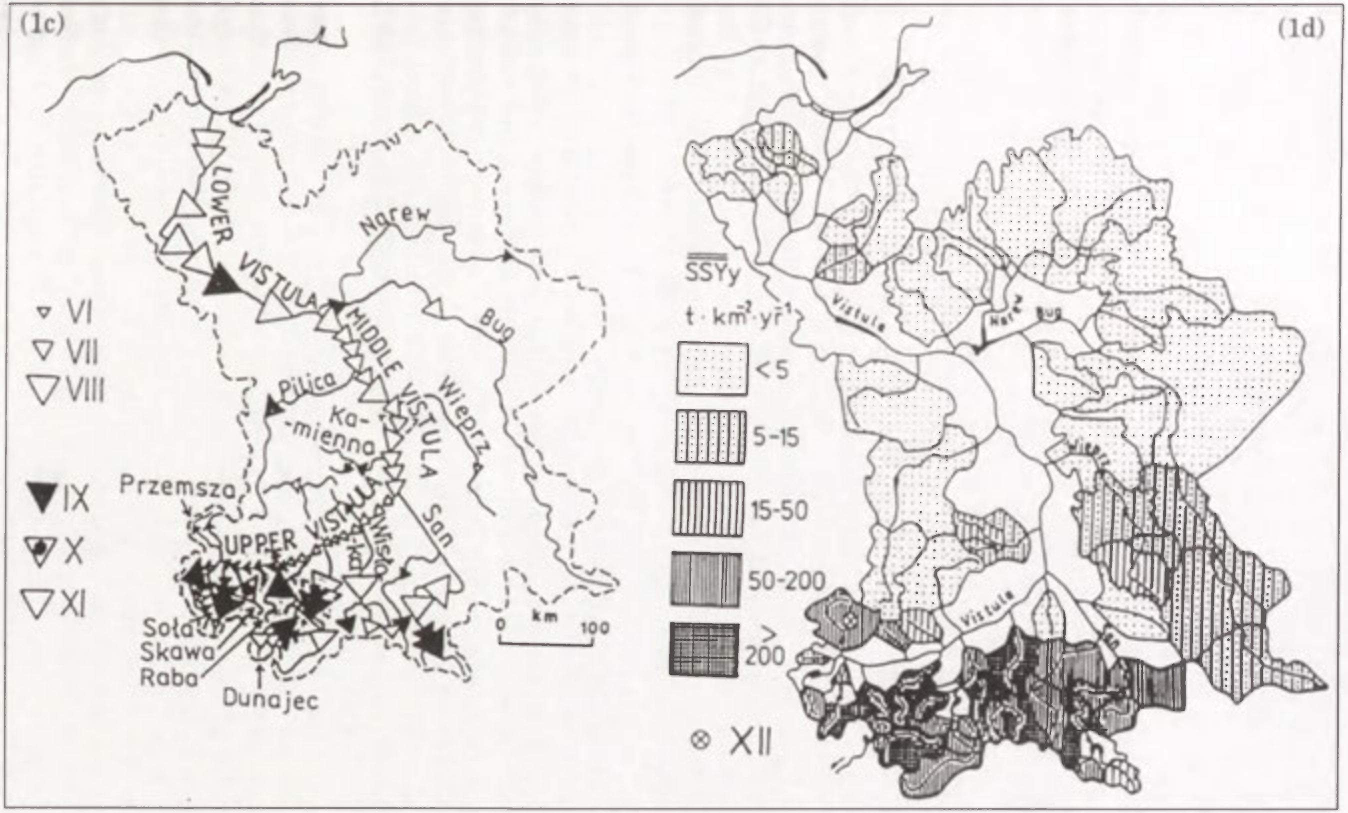
KEY WORDS: bedload, channelization, overbank sedimentation, reservoir siltation, suspended load, Vistula River.

INTRODUCTION

Changes in river processes and adjustments to river channel and floodplain morphology can be induced by both climatic fluctuations and human activity. Man's impact on fluvial processes is generally manifested by marked changes in transportation and sedimentation rates. On a time scale of hundreds, or even thousands of years, the impact has probably been the most important factor in promoting changes of sediment transportation. The end-products of this are changes in the river pattern and rapid alluviation of floodplains. Short-term morphological changes of valley floors and channels are often quickly manifested in strongly populated areas where deforestation, more intensive cultivation, over-grazing, and burning of degraded pastures has taken place (Strahler 1956; Starkel 1960, 1983, 1988, 1990; Trimble 1970, 1974; Butzer 1971; Schumm 1977; Maruszczak 1982; Sundborg and White 1982; Sundborg 1983, 1986; Sundborg and Rapp 1986; Gębica and Starkel



I — Vistula River catchment basin, II — Carpathian part of the basin, III — gauging stations with suspended load measurements (a — Skoczów, b — Goczałkowice, c — Smolice, d — Tyniec, e — Sierosławice, f — Jagodniki, g — Szczucin, h — Sandomierz, i — Zawichost, j — Annopol, k — Puławy, l — Warszawa, m — Płock/Kępa Polska, n — Włocławek, o — Toruń, p — Tczew), (1–15) — river stretches between mentioned gauging stations, IV — dam reservoirs of larger size (existing and under construction), V — borders of main morphological units within the river basin (A — Carpathians: A1 — Tatra Mts., A2 — Beskidy Mts., A3 — Carpathian Foothill zone; B — fore-Carpathian basins, C — Middle Poland Upland, D — Polish Lowland);



volume of reservoirs: VI — < 10 ($\times 10^6$ m^3), VII — 10–100 ($\times 10^6$ m^3), VIII — > 100 ($\times 10^6$ m^3); reservoirs: IX — existing, X — under construction, XI — planned (state from the 1970s), XII — increased rates of SSY_y in mining areas

Fig. 1. The study area: location of the Vistula River catchment basin in Poland (1a), location of analysed gauging stations on the Vistula (1b), location of dam reservoirs (existing, under construction and planned) within the river basin (1c), suspended sediment yield $\overline{SSY_y}$ in subbasins (1d)

1987; Klimek 1987, 1988; Dai 1988; Babiński and Klimek 1990); they are accelerated by mining, urbanization and, especially, river channelization and dam construction (Wolman 1967; Walling 1974; Klimek 1987; Knighton 1989, 1991; Klimek and Macklin 1991; Babiński 1992; Łajczak 1995a).

Changes in fluvial transportation and sedimentation rates can be estimated either on the basis of suspended load measurements and repeated river cross-section levelling (during recent decades), or by field measurements of the thickness of the newly-formed overbank sediments. Both methods permit the recognition of the periods which have more intensive fluvial transportation and also provide for quantitative determination of the present-day changes in that transportation.

STUDY AREA

The Vistula River is 1047 km long, drains an area of 194,424 km^2 and has a mean discharge at its mouth of 1250 m^{3}s^{-1}. It flows throughout several areas with very varied suspended sediment loads. Suspended matter constitutes ca. 65–70% of the mechanical work performed by the river; variations are recorded daily at 16 gauging stations on the river and at 69 gauging stations on its tributaries (Fig. 1). Recording began as early as the 1940s–1950s. The Carpathian part of the drainage basin produces the largest amount of suspended load input to the river (Łajczak 1995a).

The history of man's impact on the transportation by and sedimentation rates of the Vistula may be characterized thus:

1) The first long phase, typified by increased transportation and sedimentation rates, started before the Bronze Age and continued well into the second half of the 19th century (Starkel 1983, 1988; Gębica and Starkel 1987; Kalicki and Starkel 1987; Klimek 1987, 1988; Szumański and Starkel 1990; Pożaryski and Kalicki 1995). The river channel became much shallower and wider and, downstream of mouth of the San tributary, it changed into a braided system (Falkowski 1975, 1982; Maruszczak 1982; Sokołowski 1987; Babiński and Klimek 1990),

2) The river training works since the middle of the 19th century: river length shortening (19th century), the building of stone groynes for river channel narrowing (since the middle of the 19th century), the construction of embankments for flooded area narrowing (since the end of the 19th century), the building of bedload trap dams on streams in the Carpathians (since the 19th century), the building of dams on the river and its tributaries (in the Carpathians especially) (since the 1920s), typify the second phase.

These regulation works initiated swift changes in river channel morphology which have subsequently tended towards a new state of equilibrium in the channel. One consequence was that the channel of the upper and lower stretches of the river was subjected to fast downcutting, typically now about 1–2 m on average, and as much as 4,5 m near Cracow (Punzet 1978; Klimek

1987; Babiński and Klimek 1990; Babiński 1992; Łajczak 1995a). The shortening, deepening and narrowing of the channel has resulted, on average in a two-fold increase in the flow velocity of the Upper Vistula. The end product of this is a much-enlarged bankful discharge of this river stretch, possibly as much as three-fold compared with pre-regulation times (Łajczak 1995a). A much larger load, including sand and gravel originating from continuous channel deepening, was thereby created and this sediment was transported over longer distances than previously,

3) Lastly, the decreasing trend in the river load which was first noted about 1920, and which was later intensified. The increasing number of dams within the river catchment (which trap large amounts of incoming load), changes in land use (afforestation), the gradual disuse of the numerous cart roads on the flysch slopes in mountain areas, and a significant reduction in downcutting rates in some stretches of the Vistula which started about 1950, are all considered to be factors responsible for this.

Thus, man's impact on fluvial processes in the Vistula have to some extent both enlarged and diminished the river load. Figure 2 shows the relative changes of selected factors which have influenced the transportation by and sedimentation rates of the river, all of which have occurred in the last millennia.

Until now, only data relating to the changes in sedimentation rates which have occurred in the Vistula valley during the first phase of Man's impact on fluvial processes, have been available (Maruszczak 1982; Starkel 1983, 1988, 1990, 1995; Klimek 1987, 1988; Gębica and Starkel 1987; Kalicki and Starkel 1987; Pożaryski and Kalicki 1995; Kalicki 1996). Also, the increasing rates of sedimentation at certain places on the valley floor which occurred before the end of the 19th century have been analysed by Falkowski (1975, 1982). By contrast, we have few details of the long-term changes of river load and sedimentation rates of the Vistula during the second and third phases. In this case, the following questions are particularly pertinent:

— what is the role of river channel regulation in long-term changes in the transportation rates, and in the spatial distribution of sedimentation rates?

— what is the role of the dam on the Vistula and its tributaries in respect of sediment trapped in reservoirs and in the reduction of sediment supply to the Vistula downstream of these barriers?

— what are the outflow rates due to reservoir shallowing, flushing and dredging practices over long periods?

— in the light of further dam construction, what is the prognosis for sediment input to the Vistula from its various tributaries, and also that to the Baltic Sea via the Vistula over long time periods?

The aim of the paper is to assess quantitatively the anthropogenically-induced changes in the transportation and sedimentation rates of the Vistula. It focuses on the effects of channel regulation, dam construction and reservoir exploitation.

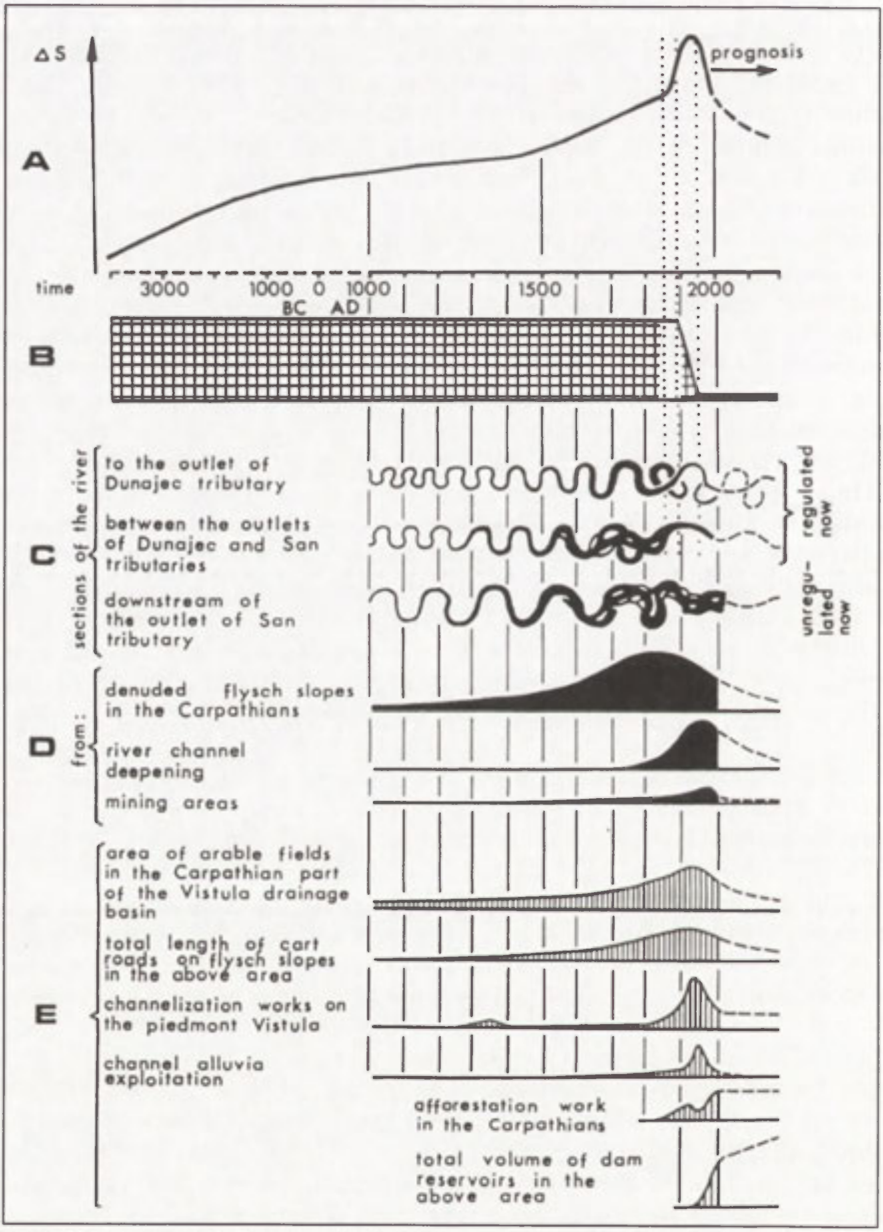


Fig. 2. Relative changes in the magnitude of transportation and sedimentation by the Vistula during the last millennia initiated by human impact
(after Falkowski 1975, 1982 and Łajczak 1995a)
A — relative changes in the magnitude of transportation and sedimentation, B — relative changes in flooded area width, C — changes of river pattern, D — relative changes in sediment supply rates to the river from various sources, E — relative changes in selected factors influencing this supply

DATA USED AND CALCULATION METHODS

Analysis of the present-day transportation and sedimentation rates of the Vistula is based on detailed measurements made over the last 90 years. The following data have been recorded: the daily suspended load transportation at all gauging stations in its drainage basin (from 1946–1990); records of daily water discharges at all gauging stations on the river (from 1931–1990); results from repeated levelling of all gauging profiles on the river (from 1905–1990).

The average rates for suspended load show a decreasing trend along those river stretches which do not have a large tributary in flows (Fig. 3). A balance in the suspended load has permitted an estimation of the average rates of the overbank suspended matter which has been deposited, ΔS, to be made. On this basis, it is possible to obtain information about changes in sedimentation rates since 1946. Balances have been computed separately for each stretch of the Vistula between successive suspended load gauging stations. The methodology for this is explained in the author's paper (Łajczak 1995b). Information relating to the sedimentation rates which occurred before 1950 has been derived from analysis of repeated cross-section levelling of the inter-embankment zone at successive gauging stations on the river, from

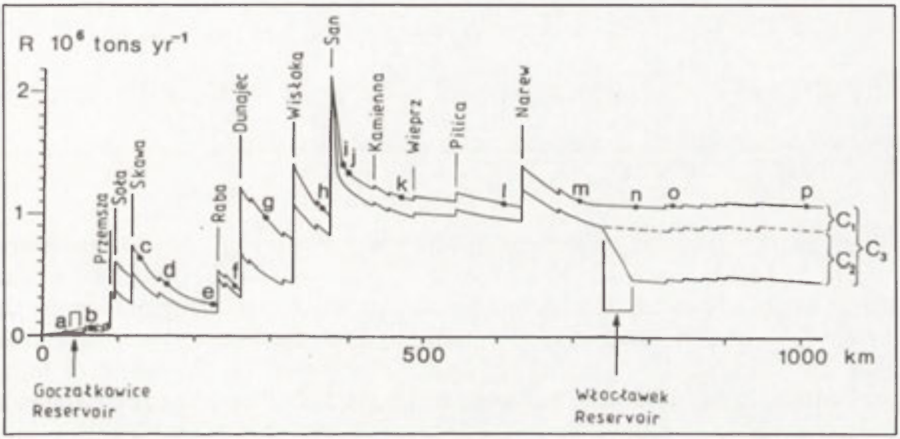


Fig. 3. Average rates of suspended load transportation, R, along the longitudinal profile of the Vistula. Lower continuous line presents the current state of transportation rates, upper continuous line presents estimated rates of that transportation, when the suspended load is not trapped by dams (before 1938). Broken line presents the rates of transportation of the Lower Vistula before 1968 (without the Wloclawek Reservoir)
C_1 — reduced rates of transportation from the 1930s until 1968, C_2 — reduced rates of transportation after 1969; C_3 — reduced rates of suspended load supply by the Vistula to the Baltic Sea due to sedimentation processes in reservoirs; (a–p) — gauging stations with suspended load measurements on the river. Mouths of main tributaries to the river are marked

large-scale morphological mapping of selected stretches of the floodplain, analysis of old topographic maps, and from drilling of infilled meanders and inter-groyne basins.

The rates of reservoir siltation and of annual sediment output from the reservoirs have also been computed using the input-output formula of the author (Łajczak 1995b). The trap efficiency, $\beta(\%)$, of reservoirs for suspended load has been derived from Brune's (β_1), Drozd's (β_2) and Hartung's (β_3) formulae and by means of the balance equation of load transport (β_4). The real trap efficiency of reservoirs (β_5) (for total load), has also been estimated. The average rates of deposition, ΔS, have been extrapolated for longer time periods. On this basis, using the author's own computing methodology (Łajczak 1995c), it becomes possible to calculate the useful lifetime of any particular reservoir.

RESULTS

ESTIMATING THE GENERAL TRENDS IN TRANSPORTATION AND SEDIMENTATION RATES

The current rates of suspended matter sedimentation, ΔS, in successive stretches of the inter-embankment zone of the Vistula (limited by gauging stations with suspended load measurements) are exactly dependent on the amount of sediment supply to the river stretch from upstream and from tributaries (Fig. 4). Regression lines were computed on the basis of mean 5-year values from a 45-year measurement period. These results permit at least a rough correlation to be made between the transportation and sedimentation rates (within the inter-embankment zone) which had occurred prior to the measurement of suspended load which was initiated in the river.

Three main phases in the long-term history of transportation and sedimentation by the river may be distinguished (N.B. these are directly related to man's impact on fluvial processes).

1. *Stage prior to general regulation works on the river channel.* During this first phase, increased rates of transportation and sedimentation by the river occurred. Prior to the end of the Middle Ages significant aggradation occurred on the valley floor. Later, both climatic changes and more intensive cultivation accelerated transportation and sedimentation rates in the river valley. The wide and shallow channel thus created became bordered by wide silt-sand levees. Non-active channels and oxbow lakes neighbouring the active channel were partially or completely infilled. This trend towards accelerated sedimentation continued until well into the second half of the 19th century. Falkowski (1975, 1982) showed that the rates of overbank sedimentation increased in several places along the Middle Vistula valley floor prior to the general introduction of regulation works on the river channel.

2. *Stage initiated by intensive regulation works on the river channel.* Cross-section levelling of the inter-embankment zone started after the regulation works on the river channel had been initiated and was repeated every few years, on average. This has permitted an estimate of the increased sedimentation rates during the first decades of the 20th century to be made. Later, as discussed previously, the sedimentation rates decreased, and this trend continues. It must be emphasized that the river stretches neighbouring gauging stations where repeated levelling has been made, represent rather spontaneous overbank sedimentation. Figure 5 shows the generally decreasing trend in overbank sedimentation rates which have been computed from the data compiled at those gauging stations and river stretches used in the survey. The sedimentation rates refer to the zones which have the most intensive overbank sedimentation, i.e. the overbuilt banks (including the fast filling inter-groyne basins) and the levees. The rates of sedimentation pertaining to the period before 1920 are not known exactly, but they were probably not less than those after 1920. The data presented here show that the maximum overbank sedimentation rates within the Vistula valley floor occurred during the first years after the completion of river confinement. In fact, river regulation is the most important reason for the acceleration of the transportation and sedimentation rates, especially in the first year period after river-shortening and groyne-construction works had been initiated.

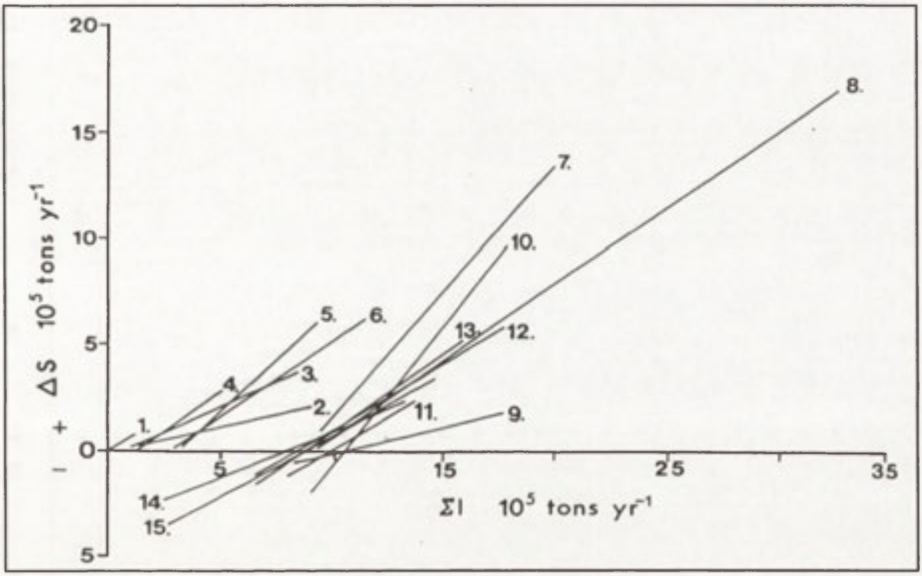


Fig. 4. Relationships between values of mean annual suspended load supply, ΣI, to successive stretches of the Vistula (1–15) and quantity of suspended load sedimentation, ΔS, on the Vistula valley floor (= inter-embankment zone). For numbering of the river stretches see Fig. 1

3. *Present-day stage: a decreasing trend in transportation and sedimentation rates.* Figure 6 illustrates the obvious decreasing trend in the magnitude of suspended load transportation and sedimentation, the results of measurements at gauging stations on the whole course of the Vistula during the period 1946–1990. This trend probably started about 1920 and is continuing. After several large dams had been built within the river basin, the magnitude of sediment transportation and sedimentation by the river decreased markedly. The non-regular distribution of deep reservoirs within the river basin, which trap large amounts of incoming sediments, is signified by varying intensities of the decreasing trend at particular gauging stations

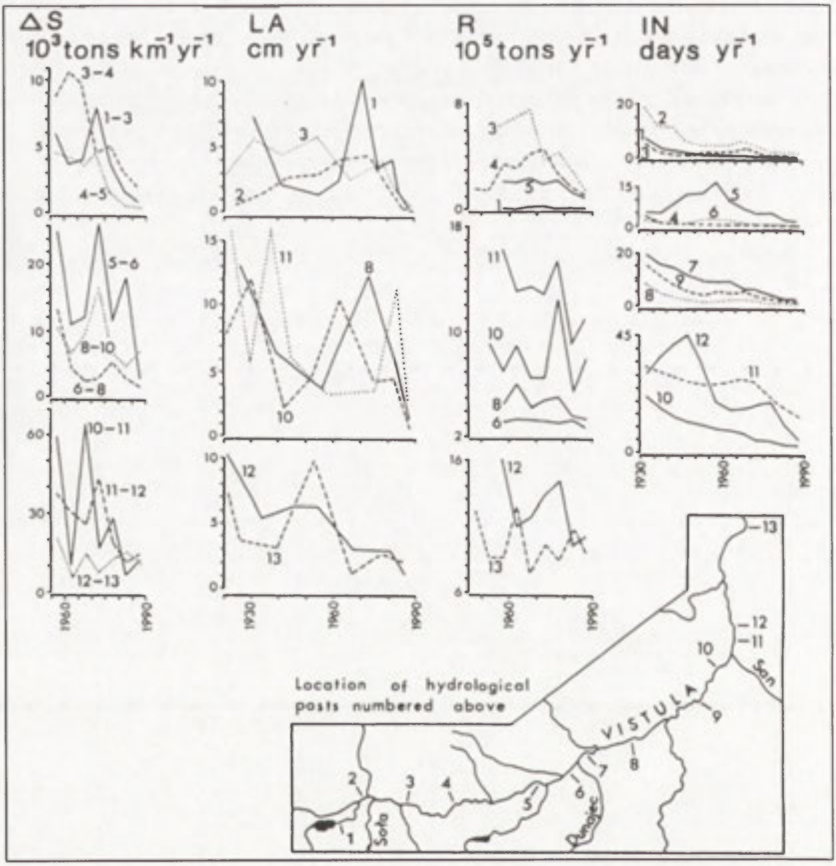


Fig. 5. Decreasing trend in rates of suspended load transportation, R, and its sedimentation, ΔS, the time of the inter-embankment floodplain inundation, IN, and the levee growth, ŁA, which have occurred in successive analysed gauging stations and floodplain stretches of the Vistula River in the Carpathian Foreland for the last decades (after Łajczak 1995a)

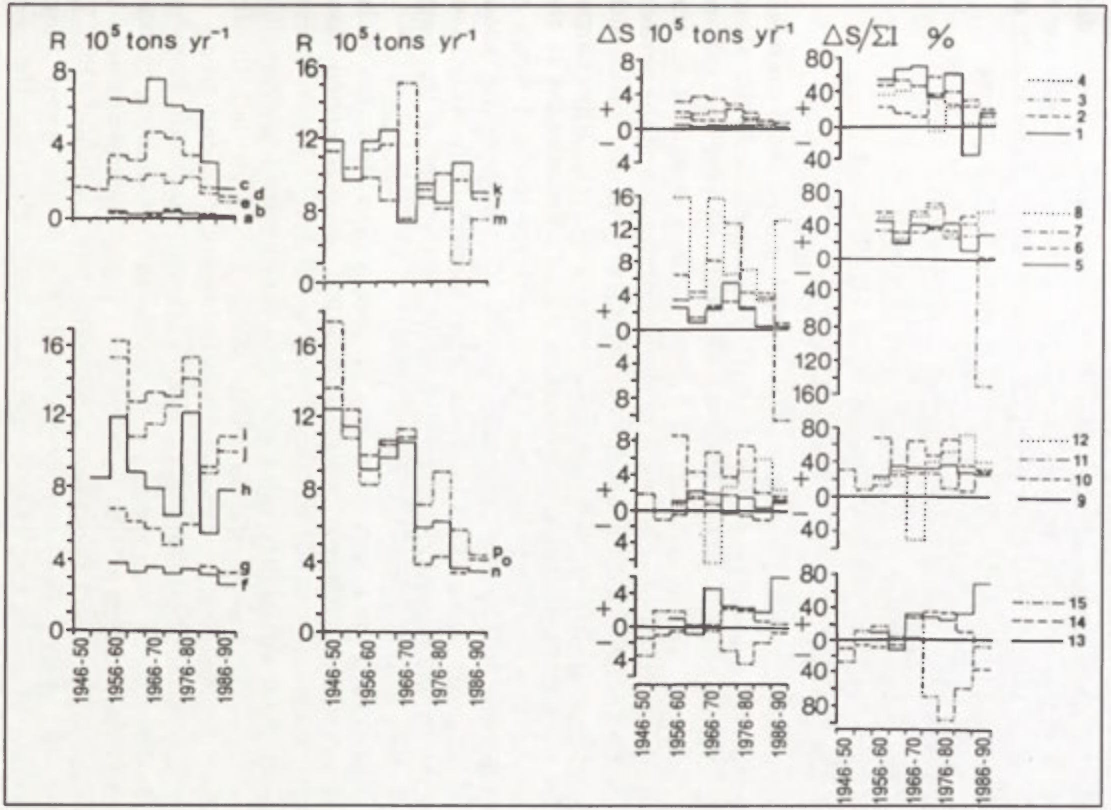


Fig. 6. Mean 5-year rates of suspended load transportation, R, and its sedimentation (ΔS — absolute rates, ΔS/ΣI — relative rates) in successive gauging stations on the Vistula and in successive stretches of the river inter-embankment zone. The data indicate lowering rates in the transportation and sedimentation processes of the river during recent decades. Gauging stations and river stretches numbered as in Fig. 1

and along particular river stretches. Particularly severely decreased rates have been recorded in the upper and lower stretches of the Vistula, where deep reservoirs on the river and its tributaries have been completed during the last few decades. The trend is independent of cyclic changes in the discharge of the river recorded in the past decades, and reflects only man's impact. Only in that stretch of the Vistula upstream from Cracow did suspended load transportation and sedimentation increase markedly for a second time after the 1940s–1950s (Fig. 5), undoubtedly as the result of large coal dust supply from the wastewaters of mines in that region.

REFLECTION OF PRECIPITATION FLUCTUATIONS IN RIVER LOAD TRANSPORTATION BY AND SEDIMENTATION RATES OF THE VISTULA

Secondary changes in transportation rates of the Vistula, which considerably modify the decreasing trend for that transportation, occur in about 10-year and, additionally in the Upper Vistula, about 30-, 40-year fluctuations in sediment transportations. Adoption of 5-year running means of annual rates of that transportation has allowed for the discrimination of the periods which have increased suspended loads, which can easily be correlated with the fluctuations which have appeared in the mean and mean high discharges (Fig. 7). The 10-year fluctuations in discharge (to be approximated to the 11-year cycles of the Sun's activity) are typical for large lowland rivers of Central and North-East Europe (Boryczka et al. 1992). Longer, i.e. about 20-, 30- and 40-year, fluctuations have not been identified in every river studied and the same situation seems to be true in the case of the large rivers of Western Europe (Probst 1989).

The fluctuations in the long-term plot of the mean high discharge of the Vistula are better correlated with fluctuations of suspended load transportation, when compared with the plot of mean discharge. The frequency and size of the flood waves determine the rates of sediment transportation by the river; also, the total inundation time of the floodplain and, thirdly, the overbank deposition rates. Despite the obvious decreasing trend in inundation time of the floodplain being associated with deepened stretches of the channel, or of an increasing trend in the time when both channel stretches and floodplains are being aggraded, the recognized fluctuations to the inundation time of the floodplain are climatically controlled (Fig. 7). This explains the short cyclic changes in floodplain deposition rates, which are independent of man. According to Starkel (1983, 1988) the Holocene sedimentation rates recognized in the Upper Vistula valley are cyclic in 1000-, 100- and 10-year periods; they were climatically controlled and have intensified in historical time due to increasing human impact.

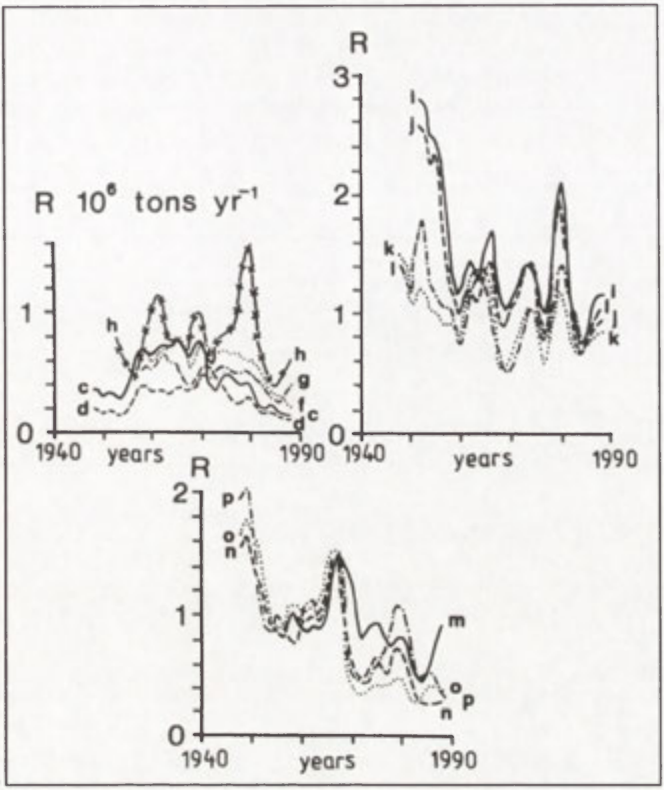


Fig. 7. 5-year running means of annual suspended load transportation in successive gauging stations on the Vistula in years 1946–1990. For numbering of gauging stations see Fig. 1

EXPLANATION OF THE ANTHROPOGENIC INFLUENCES WHICH HAVE CAUSED CHANGES IN THE TRANSPORTATION AND SEDIMENTATION RATES OF THE VISTULA

1. *Channel downcutting. Downstream effects*. Long deepened stretches of the Upper and Lower Vistula channel, together with a short stretch of the channel near Warsaw, supply large amounts of coarse material which is only partially deposited on the floodplain. As a result of the increased river competency due to the channel remodelling initiated by channel regulation, the rest of that material is transported longer distances. The material is aggraded downstream, where a wide braided channel is still being formed. Thus, the present-day Vistula is typified by an alternation of relatively deep and relatively shallow stretches of the channel (Fig. 8). By recording the rates of channel downcutting, channel narrowing, levee growth, and channel aggradation, it is possible to estimate, at least approximately, the amounts of sediment transportation and deposition which have occurred

after general regulation works were initiated on the Vistula channel. The solution of this problem can be approached by measuring the rates of vertical change of mean channel level (downcutting, aggradation) and the mean thickness of overbank deposition which have occurred at successive gauging stations on the Vistula since the start of general regulation works on the river channel (Fig. 8).

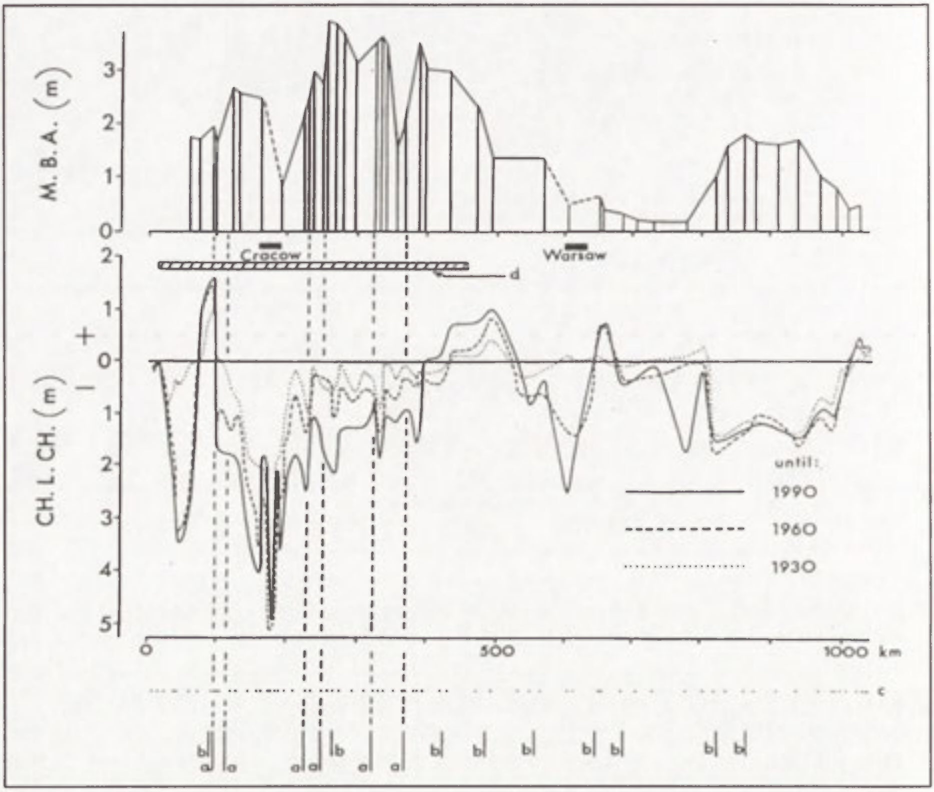


Fig. 8. Mean thickness of overbank sedimentation (M.B.A.), represented by mean rates of inter-groyne basin filling-up and levee growth, which have occurred along the whole course of the Vistula since the beginning of regulation works on the river channel (after Łajczak 1995 a).
The data are presented on the background of the vertical channel level changes (CH.L.CH.) occurred in the same time
a — mouths of larger Carpathian tributaries, b — mouths of larger upland and lowland tributaries,
c — location of gauging stations on the Vistula with river cross-section levelling,
d — stretch of the Vistula between Skoczów and Puławy gauging stations

The Upper Vistula is typified by high rates of channel downcutting. Material originating from the channel deepening (and also that contributed by the Carpathian tributaries) is partly deposited within the Middle Vistula channel and this river stretch has been recognized as the main depocentre of bedload within the entire river basin. Further, the floodplain of the Upper Vistula (which has a much reduced width) is the main zone of overbank deposition in the entire river drainage basin (Łajczak 1995b).

2. *Ephemeral deposition effects within the river channel due to catastrophic floods*. The Carpathian tributaries play a dominant role in the bedload and suspended load supply to the Vistula. Before 1980, catastrophic floods occurred in the river every several years or so and delivered large amounts of sediment, which overbuilt the floodplain and, periodically, aggraded the channel. Rates of aggradation have decreased downstream from the mouth of these tributaries as recorded by repeated river cross-section levelling. Man's influence on the channel downcutting counteracts the aggradation rates within the Upper Vistula channel over longer time periods, and the large volumes of the bedload deposited there are removed after a few years.

3. *Dam construction and reservoir exploitation. Downstream implications*. Since the 1920s, numerous dams have been built within the Vistula drainage basin, eight being located on the main river (Fig. 1). Exploitation of the dams has introduced significant changes in bedload and suspended load transportation:

a) *River load trapping by dams*. Reservoirs within the Vistula basin are typified by very various geometric parameters and hydrological properties and, in particular, by different amounts of sediment supply. The intensity of reservoir siltation, dependent on the initial volume and rapidity of water exchange in the reservoirs, and on rates of sediment supply, is greatest in the deep reservoirs in the Carpathians; these are major sediment traps. In the Carpathians, shallow reservoirs associated with upstream deep ones are infilled more slowly, and are periodically, net exporters of sediment. Large shallow lowland reservoirs on the Vistula and tributaries are rather silted up at quite slow rates, as are the shallow reservoirs (which have a rapid water exchange) on the Upper Vistula (Łajczak 1995c).

The rates of river load trapping by dams are well indicated by the "*trap efficiency parameter*", β, which can be computed using several different methods. The average values of the β parameter of deep reservoirs, calculated for the whole period of their existence and using different computing methods, reach 77–97% (β_1), 82–98% (β_2), 93–100% (β_3), and 82–98% (β_5). For shallow reservoirs the β parameter reaches the following rates: 0–53% (β_1), 0–55% (β_2), 0–55% (β_3), and 0–56% (β_5).

Much decreased rates of average transportation loads in the river stretches studied downstream from dams, versus those measured before dam construction, can be demonstrated in only a few cases. Reductions in sediment supply to the Vistula by the Carpathian tributaries due to reservoir construction have reached the following values, for example: the Soła — 90%, the Dunajec — 55%, the San — 10%. Reductions in sediment supply to the river by other tributaries which have only rather shallow reservoirs in them has reached much lower rates. Only the Włocławek Reservoir on the Lower Vistula, one of only eight on the main river, considerably reduces the suspended load in the river downstream (Fig. 3).

b) *Long-term course of reservoir siltation and estimation of the useful lifetime of reservoirs. Downstream effects.* Detailed data resulting from repeated reservoir levelling and, also, from the balance of sediment transportation provides evidence of a downward trend in reservoir siltation rates as a result of continuous reservoir shallowing. An intensive erosion of bottom deposits due to density currents and wave-induced sediment resuspension, causes increasing rates of sediment outflow across the dams. The rates of outflow are often independent of incoming sediment supply to the reservoirs. The sediment outflow from deep reservoirs, particularly those being rapidly silted-up (Rożnów Reservoir, for example), increases continuously. By contrast, the sediment outflow from shallow reservoirs, regardless of river size, reaches a more-or-less stabilized value after 5–20 years of reservoir use. The further course of outflow rates has fluctuated round the average amounts of sediment coming into the reservoirs (Fig. 9). Two main stages in the siltation of reservoirs have been recognized (Łajczak 1996):

— siltation of relatively deep reservoirs, when the bedload is totally trapped by a dam. As a result of reservoir shallowing, the trap efficiency for suspended load decreases progressively to zero. This phase is concurrent with the useful lifetime of an initially deep reservoir, i.e. when its operational properties are fulfilled. The time has been computed using a method previously proposed by the author (Łajczak 1995c, 1996), and, for deep reservoirs in the Carpathians, it varies between 260 and 11 000 years. When compared to the reservoirs situated in cultivated lower parts of the mountains, the reservoirs located in forested catchments are sedimented much more slowly,

— much slower siltation, mainly by the bedload, of initially-shallow reservoirs or of much-shallowed, initially-deep reservoirs. The trap efficiency for suspended load fluctuates around zero but, in specific hydrological conditions, the reservoir can become a net exporter of sediments, including large quantities of bedload. In the case of a quick partial emptying of the upstream associated deep reservoirs during a summer flood event, exceptionally high rates of sediment outflow, which originates from intensive bottom sediment erosion, can occur. The life of shallow reservoirs can be prolonged by flushing and dredging practices. Until now, the flushing of reservoirs in Poland has been employed only infrequently.

The data presented here demonstrates the much decreased quantities of river load in rivers downstream of deep reservoirs, and this reduction is preserved for a long time after the river has been dammed. Shallow reservoirs do not reduce the river load for long periods, but, over short time scales, can introduce considerable fluctuations in sediment transportation rates.

c) *Effects of dredging practices.* Dredging practices are used only in certain lowland reservoirs. The most intensive dredging operations started in the Włocławek Reservoir in 1982, with a view to increasing reservoir depth, particularly in its upper stretch. The resultant increase in the volume of the reservoir, which continues, has stopped a decreasing trend in the trap efficiency for suspended load. The β parameter has increased for the last 10 years, a fact reflected in the decreasing amounts of the suspended load outflow from the reservoir (Fig. 9).

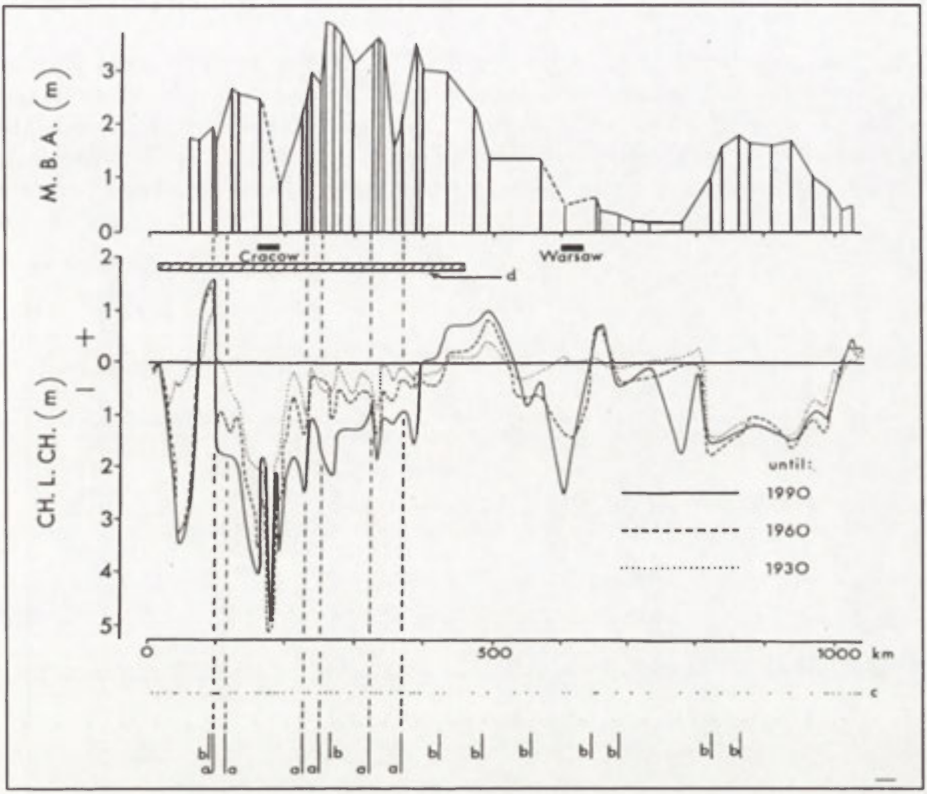


Fig. 9. Increasing rates of the suspended load outflow, O_{tm}, from chosen dam reservoirs indicating lowering trap efficiency, β, for suspended matter in shallowed reservoirs. Locations of the reservoirs are: the Rożnów Reservoir on the middle stretch of the Dunajec River, the Włocławek Reservoir on the Lower Vistula, and the Dębe Reservoir on the lower stretch of the Narew (for distribution of the reservoirs within the river basin see Fig. 1). Intensive dredging practices in the Włocławek Reservoir started after 1982 are followed by an increased rate of trap efficiency for suspended load, β

CURRENT RATES OF SUSPENDED LOAD TRANSPORTATION AND SEDIMENTATION ALONG THE VISTULA

1. *Average rates of suspended load transportation.* As a result of an intensive sediment supply from the strong denudation of the Carpathians, the average rates of suspended load in the Vistula generally increase

downstream as far as the mouth of the last Carpathian tributary, at the present time. Directly below this tributary outlet, the Vistula is almost critically overburdened with suspended load. Further down the course of the river, however, the amount transported has become stabilized (Fig. 3). Due to dam construction work, suspended load transportation has been reduced in the Upper Vistula in recent decades by 20–50%, and in the Lower Vistula by 50%.

2. *Average rates of suspended load sedimentation*. The area limited by a hypothetical transportation curve for suspended load (a situation without sedimentation) and the real transportation curve, indicates the suspended load sedimentation rates along the Vistula. The detailed data concerning depositing rates in successive river valley stretches between the suspended load gauging stations or between the mouths of the

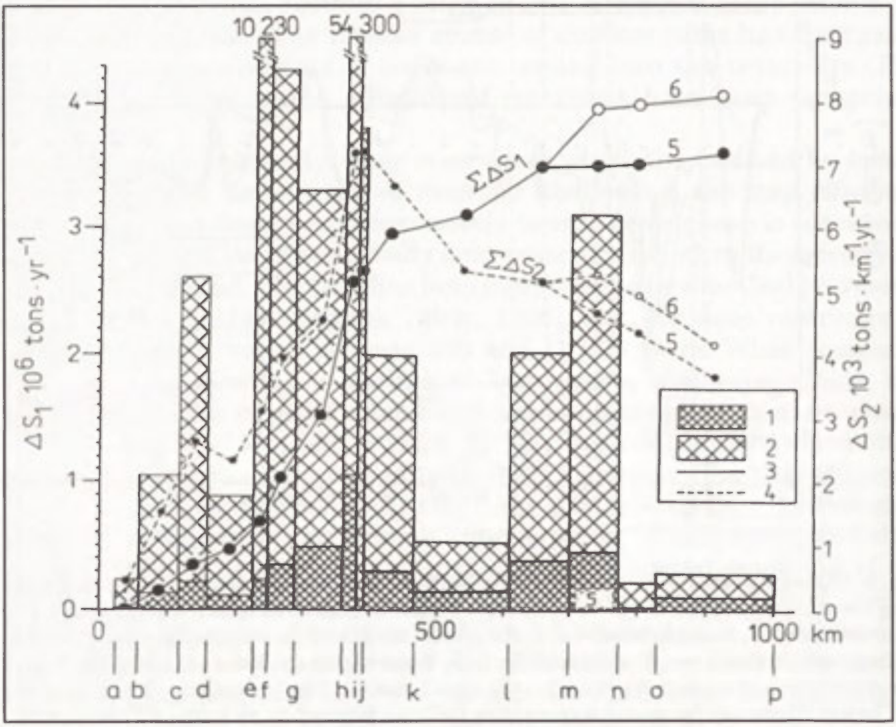


Fig. 10. Average rates of suspended load sedimentation, ΔS, in successive stretches of the inter-embankment zone of the Vistula between gauging stations for load measurements. The rates of sedimentation are expressed:
ΔS_1 — t yr^{-1} (for the whole stretch of the inter-embankment zone), ΔS_2 — t km^{-1} yr^{-1} (for 1 km of the zone length). $\Sigma\Delta S_1$ and $\Sigma\Delta S_2$ — cumulative rates of sedimentation, 1 — sedimentation expressed as ΔS_1, 2 — sedimentation expressed as ΔS_2, 3 — $\Sigma\Delta S_1$ values, 4 — $\Sigma\Delta S_2$ values, 5 — sedimentation rates before 1968, 6 — sedimentation rates after 1969 (downstream of the Płock/Kępa Polska gauging station), (a–p) — gauging stations for suspended load measurement on the Vistula (for their location see Fig. 1)

tributaries, have been obtained using equations for the suspended load balance. Fig. 10 shows the results from these calculations.

The degree of sedimentation within the valley floor shows the river downstream differentation, which is analogous to the sediment delivery from tributaries. Mean values for sedimentation are greatest in the Upper Vistula and are of the order of 10,000 t km $^{-1}$yr^{-1}. These values increase downstream to the mouth of the last Carpathian tributary. Directly below this tributary outlet, the sedimentation reaches as much as 45,000 t km^{-1}yr^{-1}. Downstream from here, the supply of suspended sediment and sedimentation rates fall to a minimum. Up to 77% of the suspended load which is deposited in the whole Vistula valley floor forms upstream from the Zawichost gauging station. Due to regulation works, intensive overbank sedimentation processes in the Upper Vistula valley floor are significantly influenced by river channel deepening. Downstream, sedimentation decreases markedly.

3. *Relationship between sediment delivery and overbank deposition, as exemplified by the upper stretch of the river.* During the last several decades, the mean duration of inundation of the inter-embankment floodplain, IN, and the average number of flood waves causing inundation, show a pattern in the downstream part of the river which is similar to that for suspended material supply from tributaries. Simultaneously, when compared to river channel deepening due to regulation work, the pattern is reversed; this shows that larger Carpathian tributaries provide a huge input of sand to the Vistula which counteracts channel deepening in certain sections. Therefore, due to the shallower channel in this area, the floodplain is inundated more frequently The magnitude of absolute and relative overbank sedimentation is also greatest in this area. Therefore, the pattern for the magnitude of sedimentation downstream from the Upper Vistula coincides closely with the pattern for material delivery to the river.

PROGNOSIS FOR RIVER LOAD IN THE VISTULA

The progressive decrease in the trends for transportation and sedimentation rates as well as for siltation of existing shallow reservoirs, will be prolonged by building new dams on the tributaries. The location of the dams should be carefully determined in order to reduce river loads to a minimum.

1. *Criticism of the existing reservoir distribution within the river basin.* The deep dam reservoirs on the Carpathian rivers should as far as possible reduce the river load downstream which is further supplied to the Vistula. In this respect, their location in the middle stretches of the tributaries is correct. From a practical point of view, their useful lifetime, which varies between 260 and 1300 years, is sufficient for the Vistula river, to be protected against intensive sediment supply. The role of deep reservoirs located in upper forested stretches of the Carpathian valleys which are slowly being

silted-up, and also the shallow reservoirs on mountainous, upland and lowland rivers, in providing reduced rates of load to the Vistula, is minimal.

2. *Proposal for the correct location of new dams*. The best solution to the problem of the silting of new reservoirs, as outlined above, must take into account the following:

— firstly, the deep reservoirs in the middle stretches of the large Carpathian rivers should be completed to achieve minimum supplies of river load from the Carpathians to the Vistula,

— secondly, if this programme is finished, a new reservoir on the Vistula should be built downstream from Cracow. If dredging practices in the reservoirs located in the Upper Vistula start at the beginning of reservoir operation, the siltation of the reservoirs located downstream will be very limited.

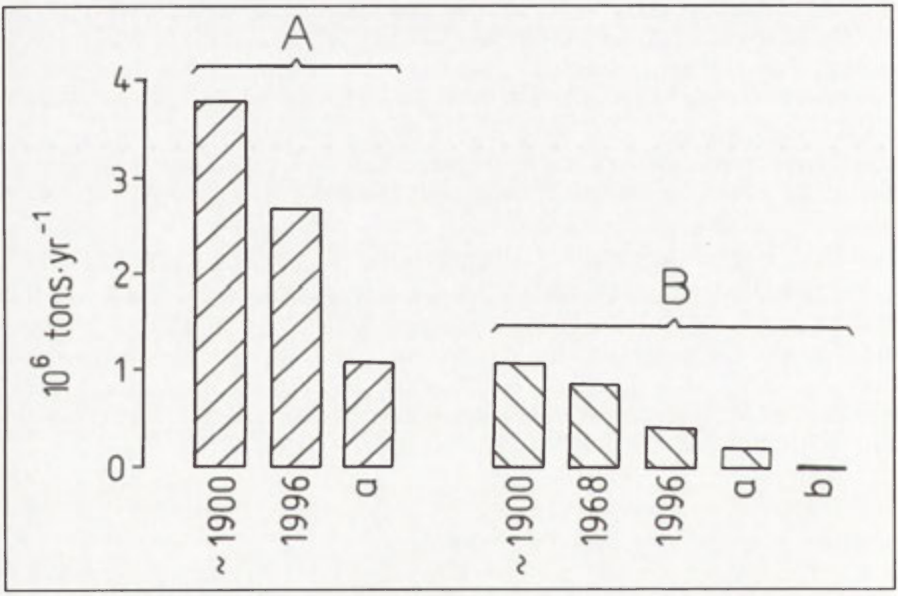


Fig. 11. Estimated total supply of the suspended load to the Vistula by the Carpathian tributaries (A) and supply of the load to the Baltic Sea by the river (B) in 1900, 1968 and 1996
a — supply of suspended load to the river and the Baltic Sea
when planned deep reservoirs on the Carpathian rivers are completed,
b — supply of suspended load by the Vistula to the Baltic Sea when the above
reservoirs and planned ones on the whole course of the river are completed

3. *Estimated changes in suspended load transportation rates by the Vistula as a result of man's impact on fluvial processes. Prognosis*. Up to the beginning of the 20th century the suspended load transportation rates of the Vistula increased in the previous millennium more than 10-fold (Maruszczak 1988). Due to reservoir siltation, the sum of suspended load supply to the Upper Vistula by the Carpathian tributaries has decreased between the 1930s–1950s

and 1990 by 30% and is now only 2,700,000 t yr^{-1}. Concurrently, the load at gauging stations on the Upper Vistula has been reduced by 20–50%, whereas, in the river stretch directly below the mouth of the last Carpathian tributary, it has decreased from about 1,450,000 to 1,300,000 t yr^{-1}. Simultaneously, the suspended load at the mouth of the Vistula has decreased from about 1,100,000 to 900,000 t yr^{-1} in 1968, and, after completion of the Włocławek Reservoir, the load was reduced by 50%. This trend will doubtless continue. If those deep reservoirs planned and under construction on the Carpathian rivers are completed, the total suspended sediment supply to the Upper Vistula will reach only 1,100,000 t yr^{-1}, and the rates of the transportation in the Upper Vistula could be reduced by more than 50%. At the mouth of the river, the load will be approximately 250,000 t yr^{-1}, and, if the reservoirs on the Vistula are completed, it could be reduced more by five times (Fig. 11). Finally, when those constructions on the Vistula already planned are finished, river channel deepening will cease and the total suspended load entering the Baltic Sea could be reduced by a minimum of 10-fold, when compared with the present-day picture. The Vistula will no longer be the primary source of polluted matter in the Baltic Sea. Intensive dredging practices in the reservoirs on the river will prolong their useful lives and river loads will be much reduced.

CONCLUSIONS

The history of the recent alluviation of the Vistula floodplain is very similar to that of river valleys and alluvial plains (Wolman 1967; Trimble 1970, 1974, 1976; Walling 1974; Gregory 1987; Knox 1987; Dai 1988). The results presented show that river regulation introduces very significant and swift changes in the magnitude of the river load and sedimentation; this regulation is acknowledged as the most significant cause of the changes which have occurred in the Vistula catchment in the course of man's impact on the fluvial processes operating here. Firstly, during the initial years after groyne construction had begun, the rates of transportation accelerated; secondly, the cascade building system drastically reduces the rates of that transportation. The Vistula channel regulation work magnified the river load and initiated considerable overbank sedimentation within the inter-embankment floodplain of the Upper Vistula, together with intensive channel aggradation and overbank sedimentation in the river downstream, effects which occurred in a short period. Rates of alluviation of the Vistula valley floor, which were accelerating several decades ago, have now been slowing down for recent decades and this process will be intensified in the future. The history of alluviation in the Vistula valley floodplain, which was initiated about 150 years ago, may be compared with the equally swift changes of river load transportation and sedimentation rates noted in respect of other rivers impacted by urbanization, as described by Wolman (1967), Walling (1974), Trimble (1976) and Gregory (1987).

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REFERENCES

Babiński Z., 1992, *The present-day fluvial processes of the Lower Vistula River* (in Polish), Prace Geogr. IGiPZ PAN, 157.

Babiński Z., Klimek K., 1990, *The present-day channel and floodplain of the River Vistula*, [in:] Starkel L. (ed), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 5.

Boryczka J., Stopa-Boryczka M., Kicińska B., Żmudzka E., 1992, *Atlas of interdependence of meteorological and geographical parameters in Poland, VII, Secular changes of Poland's climate*, Warszawa.

Butzer K.W., 1971, *Fine alluvial fills in the Orange and Vaal basins of South Africa*, Proc. of Amer. Geogr. 3.

Dai Shensheng, 1988, *Analysis of sediment yields during the historic period in the loess region of the Yellow River basin*, IAHS Publ. 174.

Falkowski E., 1975, *Variability of channel processes of lowland rivers in Poland and changes of the valley floors during the Holocene*, Biul. Geol. UW 19.

Falkowski E., 1982, *The pattern of changes in the Middle Vistula valley floor*, [in:] Starkel L. (ed), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 1.

Gębica P., Starkel L., 1987, *Evolution of the Vistula River Valley at the northern margin of the Niepołomice Forest during the last 15,000 years*, [in:] Starkel L. (ed), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 4.

Gregory K.J., 1987, *River channels*, [in:] Gregory K.J., Walling D.E. (eds), *Human Activity and Environmental Processes*, J. Wiley and Sons, Chichester.

Kalicki T., 1996, *Overbank deposits as indicators of the changes in discharges and supply of sediments in the Upper Vistula valley — the role of climate and human impact*, [in:] Starkel L. (ed), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 9.

Kalicki T., Starkel L., 1987, *The evolution of the Vistula River Valley downstream of Cracow during the last 15,000 years*, [in:] Starkel L. (ed), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 4.

Klimek K., 1987, *Man's impact on fluvial processes in the Polish Western Carpathians*, Geogr. Annlr. 69 A, 1.

Klimek K., 1988, *An early anthropogenic alluviation in the subcarpathian Oświęcim Basin, Poland*, Bull. Pol. Acad. Sci., Earth Sci. 36, 2.

Klimek K., Macklin M., 1991, *The impact of metal mining on the upper Vistula floodplain, Southern Poland*, Sven. Geol. Undors. Rep. Med. 69.

Knighton A.D., 1989, *River adjustment to changes in sediment load: the effects of tin mining on the Ringarooma River, Tasmania, 1875–1984*, Earth. Surf. Proces. Landforms 14.

Knighton A.D., 1991, *Channel bed adjustment along mine-effected rivers of northeast Tasmania*, Geomorph. 4.

Knox J.C., 1987, *Historical valley floor sedimentation in the upper Mississippi Valley*, Ann. Ass. Am. Geogr. 77.

Łajczak A., 1995a, *The Impact of River Regulation, 1850–1990, on the Channel and Floodplain of the Upper Vistula River, Southern Poland*, [in:] Hickin E.J. (ed), *River Geomorphology*, J. Wiley and Sons, Chichester.

Łajczak A., 1995b, *A study on silting of dam reservoirs in the Vistula River catchment basin* (in Polish), The Monograph of the Water Res. Committee, Pol. Acad. Sci. 8.

Łajczak A., 1995c, *Potential rates of the present-day overbank sedimentation in the Vistula Valley at the Carpathian Foreland, Southern Poland*, Quaest. Geogr. 17/18.

Łajczak A., 1996, *Reservoir sedimentation problems in the Vistula River basin, Poland*, IAHS Publ. 236.

Maruszczak H., 1982, *The Vistula River near Lublin District* (in Polish), *The Monograph of the Vistula River*, Warszawa.

Maruszczak H., 1988, *Changes in natural conditions of Poland in historical times* (in Polish), [in:] *Changes in the geographical environment of Poland*, Wszechnica PAN, Warszawa.

Pożaryski W., Kalicki T., 1995, *Evolution of the gap section of the Vistula valley in the Late Glacial and Holocene*, [in:] Starkel L. (ed.), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 8.

Probst J.L., 1989, *Hydroclimatic fluctuations of some European rivers since 1800*, [in:] *Historical change of large alluvial rivers: Western Europe, Chichester*.

Punzet J., 1978, *Changes in the course of water stages in the Upper Vistula basin over a century 1871–1970*, (in Polish), Folia Geogr., ser. Geogr.-Phys. 14.

Schumm S.A., 1977, *The fluvial system*, J. Wiley and Sons, New York.

Sokołowski T., 1987, *Vistula valley between the outlets of Dunajec and Breń rivers*, [in:] Starkel L. (ed.) *Evolution of the Vistula River Valley during the last 15,000 years, Geogr*. Studies, Spec. Issue 4.

Starkel L., 1960, *The development of the flysch Carpathians relief during the Holocene*, (in Polish), Prace Geogr. IG PAN 22.

Starkel L., 1983, *The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15,000 years*, [in:] Gregory K.J. (ed.) *Background to Palaeohydrology*, J. Wiley and Sons, Chichester.

Starkel L., 1988, *The development of river valleys during the Holocene* (in Polish), [in:] *Changes in the geographical environment of Poland*, Wszechnica PAN, Warszawa.

Starkel L., 1990, *Fluvial environment as an expression of geoecological changes*, Z. Geomorph., Suppl-Bd. 79.

Starkel L., ed., 1995, *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 8.

Strahler A.N., 1956, *The nature of induced erosion and aggradation*, [in:] Thomas W.L. (ed.), *Man's role in changing the face of the Earth*, Univ. of Chicago Press.

Sundborg A., 1983, *Sedimentation problems in river basins*, Nature and Resources 19, 2, UNESCO.

Sundborg A., 1986, *Sedimentation processes*, Proceedings of the International Symposium on Erosion and Sedimentation in Arab Countries, Baghdad.

Sundborg A., White W.R., 1982, *Sedimentation Problems in River Basins*, Studies and Reports in Hydrology 35, UNESCO, Paris.

Sundborg A., Rapp A., 1986, *Erosion and Sedimentation by Water: Problems and Prospects*, Ambio 15, 4.

Szumarski A., Starkel L., 1990, *Channel pattern changes and attempts to reconstruct the hydrological changes*, [in:] Starkel L. (ed.), *Evolution of the Vistula River Valley during the last 15,000 years*, Geogr. Studies, Spec. Issue 5.

Trimble S.W., 1970, *The Alcovey River swamps. The result of culturally accelerated sedimentation*, Bull. Georgia Acad. Sci. 28.

Trimble S.W., 1974, *Man-induced Soil Erosion on the Southern Piedmont, 1700–1970*, Soil Cons. Soc. Amer.

Trimble S.W., 1976, *Modern stream and valley sedimentation in the Driftless area, Wisconsin, USA,* Intern. Geogr. 76, 1.

Walling D.E., 1974, *Suspended sediment and solute yields from a small catchment prior to urbanization*, Inst. Br. Geogr. Spec Publ. 6.

Wolman M.G., 1967, *A cycle of sedimentation and erosion in urban river channels*, Geogr. Annlr. 49 A, 2–4.

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STRUCTURE OF THE SOLUTE YIELD IN THE VISTULA RIVER BASIN WITH SPECIAL REGARD TO ANTHROPOGENIC COMPONENTS

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ABSTRACT: On the basis of data concerning small catchments not polluted by municipal and industrial sewage we calculated the solute yield from rural areas. Calculations were carried out in a simplified way, taking into consideration the mean solute concentrations from data for the years 1976–1985, and mean discharges of river waters. For 20 selected larger catchments of the Vistula tributaries we also calculated the total solute yield, i.e. including the sources of municipal and industrial wastewater. On the basis of these and other data we attempted to analyse the balance of the solute yield. Components taken into account come from: precipitation, agricultural chemicals, farm sewage, municipal and industrial wastewater, and chemical denudation of the lithosphere. Results were considered in relation to regional differentiation. Essential changes in the solute yield structure were also noted in comparison with the period of the 1930's.

KEY WORDS: anthropogenic impact, chemical denudation, municipal and industrial wasterwater, solute concentration and yield, Vistula River, Eastern Poland.

INTRODUCTION

In natural conditions the dissolved load transported by rivers comes mainly from chemical denudation of the lithosphere, i.e. from soils and their bedrocks; a minimal part comes from the atmosphere in precipitation. As land use is more and more intensive a bigger role is played by anthropogenic components, i.e. man-made (synthetic) substances.

An analysis of the hydrometric data illustrating the total concentration of substances dissolved in river waters and their chemical composition is the basis for quantitative estimation of the percentage of components of different origin. In Poland investigations of this kind have been carried out mainly in smaller, subordinate catchments. For example, J. Wilamski and Z. Śliwa (1978) tried to calculate the percentage of components coming from soil fertilization in the total solute yield from the catchments of Przymorze.

A. Swieca (1984) presented the percentage of components coming from municipal and industrial wasterwaters estimated for the Uherka river catchment. The first attempt at balancing the solute yield from the whole Vistula river basin was made by H. Maruszczak (1986, 1990). In that balance — on the basis of hydrometric data from the gauging stations at Tczew and Kiezmark in the 70's — account was taken of the components of the solute yield coming from: precipitation, agricultural chemization, municipal and industrial wasterwaters and natural chemical denudation. The percentage of the last component was calculated at 48%, on the basis of data from the 70's.

In this paper we present the results of balance analysis of the river solute yield from the catchments of selected tributaries, and also from the whole Vistula river basin. They were obtained in the Department of Physical Geography and Paleogeography of Maria Curie-Sklodowska University, Lublin. We used the results of analyses of the solute concentration in river water samples collected every month at control points of Provincial Centres for Studies of the Environment and its Control (about 1000 points in the Vistula river basin). These data were collected in connection with a research programme realized by several departments on "Changes of the geographical environment in Poland" (in the years 1981–1985: MR.I.25, and in the years 1986–1988: CPBP.03.13). They were measurement data for the years 1976–1983. To calculate the balance, mean monthly values of discharges of waters ($dm^3s^{-1}km^{-2}$) in selected rivers in the same period were also necessary. As the results of discharge measurements were published till 1983 only, we also used unpublished archival data of the Institute of Meteorology and Water Management.(1) It should be stressed that we compiled basic data not for hydrological but for calendar years, because the records made at Provincial Centres concern calendar years.

RIVER SOLUTE YIELD FROM RURAL AREAS

The basic material for calculation of the balance is shown on our map of solute yield from rural areas (Fig. 1). The isolines plotted on it illustrate indices of solute discharge estimated for small catchments (of subordinate tributaries) in which bigger sources of municipal and industrial wasterwaters are absent.

The solute yield from these catchments was calculated in a simplified way from the formula:

$$SY\,(t\cdot km^{-2}\cdot y^{-1}) = \frac{SC\,(mg\cdot dm^{-3})\cdot Q\,(dm^{3}\cdot s^{-1}\cdot km^{-2})\cdot 31536000}{10^{9}}$$

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(1) Most of the analytical data from the Provincial Centres for Studies of the Environment and its Control were offered without charge; for a few provinces we obtained the necessary data against payment from the Informatical Centre of Environment Protection and Water Management in Płock. We wish to express our gratitude to the directors of the Provincial Centres who agreed to offer the measurement data free of charge. We are also indebted to the director of IMiGW for offering without charge the unpublished data on discharges from the years 1983–85 in the rivers we studied.

where:
SY — solute yield,
SC — solute concentration (i.e. concentration of substances dissolved in river water),
Q — discharge from the catchment.

It is a unit index simple to calculate, which makes possible direct comparison of the catchments of different areas.

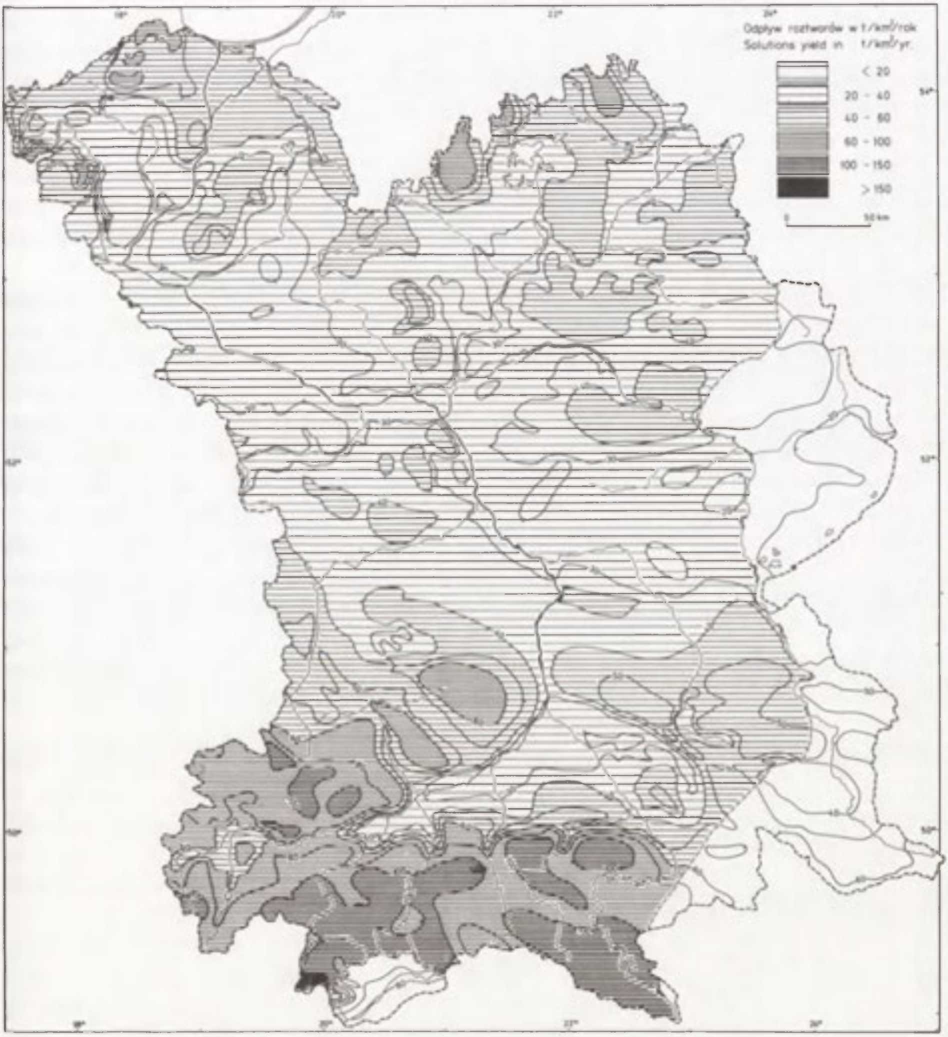

Fig. 1. River solute yield from rural areas in the Vistula river basin; isolines show the indices of this yield calculated in relation to the average solute concentration in the years 1976–1985, and mean discharges of many years.
Elaborated by H. Maruszczak and M. Wilgat, 1989

Indices of the solute concentrations of river waters were calculated as mean values from the measurement series we had for the years 1976–1985. Data of that decade did not concern the whole Vistula river basin, because work on the map was started in 1981. We began in the south–east part of the basin and the work was continued successively in the following years. So, for the mentioned part of the basin we used data from the years 1976–1980.

Discharges of river waters were estimated according to the map worked out for Poland's area by J. Stachy (1966). It shows the mean values of many years calculated from empirical formulae, which define the dependence of discharges on climatic conditions. These formulae allow us to calculate discharges at each point for which the required meteorological data are known. We could also use a more recent map (Stachy et al. 1977) on which isolines were plotted on the basis of the actual discharge measurements from the years 1951–1970. However, points of discharge measurements are considerably fewer than meteorological offices. Thus, isolines plotted from discharge measurements give a more generalized picture. This fact induced us to use the map from an earlier paper.

It seems that the level of precision of the presented method of solute yield calculations is sufficient for the determination of a balance. This can be proved by the results of calculations of the solute yield from twenty selected catchments in the Vistula river basin (see Table 1). These calculations were made not only in the way presented (by multiplication of mean indices of ten years), but also by adding monthly values of the solute yield. In the case of weakly industrialized catchments the results obtained the first way — used in the preparation of our map for rural areas — differ by not more than several percent from the results obtained the second way — more precise but requiring more measurement data and relatively large amounts of time for calculations. Thus, the errors resulting from the usage of a more simple way of calculating river solute yield are rather small. Probably they are smaller than analytic errors of measurements of solute concentrations by evaporation — the method used in the Provincial Centres for Studies of the Environment and its Control.

Analysis of our map shows that the indices of river solute yield from the rural areas depend mainly on discharges of river waters. The influence of the geological structure and relief is most clear when variously leachable rocks occur in particular hydrological regions. For example, in the calcareous Western Tatra Mts we have indices over 150 t $km^{-2}y^{-1}$, and in the granitic Eastern Tatra Mts even below 20 t $km^{-2}y^{-1}$.

The discussed map presents indices of discharge of solutes coming from: 1) largely natural, chemical denudation of the lithosphere in the major part of the basin; 2) precipitation, which at present is already rather strongly polluted with different anthropogenic substances; 3) agricultural chemization, i.e. mainly fertilizers and different substances used in crop production; 4) farm sewage. This map constitutes a background against which we can present the sources of chemical pollution of river waters with municipal and industrial wastewater.

RIVER SOLUTE YIELD FROM SELECTED CATCHMENTS INCLUDING MUNICIPAL AND INDUSTRIAL WASTEWATER

The distribution of the main sources of chemical pollution of rivers with municipal and industrial wastewater is presented in Fig. 2. Wastewater volume and the degree and manner of their purification are presented as

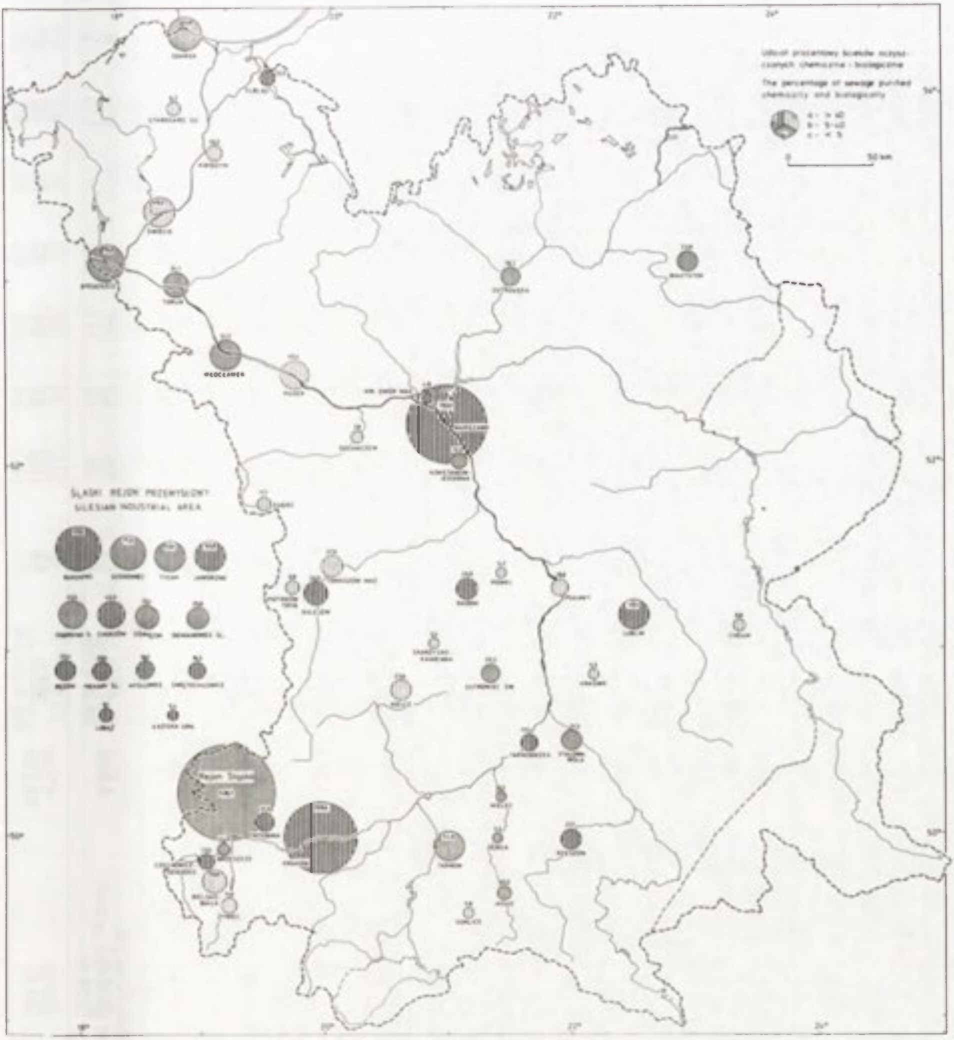

Fig. 2. Distribution of larger sources of municipal and industrial wastewater in the Vistula river basin according to statistical data of the Central Statistical Office from 1982; the size of a circle is proportional to the volume of wastewater in million m^3 denoted by numbers inside or outside the circles. Hachure inside the circles shows the percentage of wastewater treated chemically and biologically. Elaborated by H. Maruszczak and M. Wilgat, 1989

TABLE 1. Results of calculations of the river solute yield from selected larger catchments in the Vistula river basin, according to the measurement data from the years 1976–1985. A) Indices in brackets are calculated by interpolation due to a lack of solute concentration measurement, B) Data are compiled for calendar years because records of solute concentration made at Provincial Centres concern calendar years.

Catchment Q — point of discharge measurement (km of course) R — point of solute concentration measurement (km of course)	Catchment area km^2	Mean values from the years 1976–1985		Annual indices of solute yield^c $t\ km^{-2}\ y^{-1}$									
		discharge^a $m^3\ s^{-1}$	solute yield^b $t\ km^{-2}\ y^{-1}$	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
VISTULA upstream of Przemsza mouth (Little Vistula) Q — Nowy Bieruń ⎧3.7 km upstream R — Nowy Bieruń ⎩of Przemsza mouth	1,748	$\frac{20.2}{9.7\text{–}33.3}$	$\frac{622}{834}$	–	351 470	$\frac{303}{320}$	$\frac{247}{312}$	$\frac{339}{360}$	$\frac{830}{852}$	$\frac{772}{878}$	$\frac{838}{1009}$	935 943	$\frac{986}{1318}$
SOŁA : Q — Oświęcim (3.0) R — mouth (1.8)	1,386	$\frac{16.1}{6.0\text{–}22.4}$	$\frac{59}{60}$	$\frac{79}{80}$	$\frac{71}{71}$	$\frac{72}{74}$	$\frac{48}{47}$	$\frac{76}{77}$	$\frac{57}{58}$	$\frac{50}{50}$	$\frac{47}{48}$	$\frac{20}{21}$	$\frac{71}{74}$
RABA : Q — Proszówki (21.7) R — Proszówki (21.7)	1,470	$\frac{16.3}{8.5\text{–}22.9}$	$\frac{99}{107}$	$\frac{104}{105}$	$\frac{107}{107}$	$\frac{(113)}{(114)}$	$\frac{84}{88}$	$\frac{128}{133}$	$\frac{115}{121}$	$\frac{56}{55}$	$\frac{112}{150}$	$\frac{61}{66}$	$\frac{110}{119}$
DUNAJEC: Q — Żabno (17.4) R — Niedomice (22.0)	6,735	$\frac{86.8}{59.8\text{–}119.1}$	$\frac{109}{113'}$	109 114	$\frac{97}{103}$	$\frac{117}{123}$	$\frac{100}{102}$	$\frac{147}{152}$	$\frac{100}{101}$	$\frac{74}{77}$	$\frac{119}{114}$	$\frac{79}{83}$	$\frac{148}{159}$
WISŁOKA : Q — Mielec (19.1) R — Mielec (19.1)	3,915	$\frac{36.7}{19.3\text{–}66.7}$	$\frac{103}{100}$	94 92	$\frac{69}{73}$	$\frac{88}{92}$	$\frac{131}{118}$	$\frac{235}{227}$	$\frac{103}{102}$	$\frac{63}{66}$	$\frac{106}{105}$	$\frac{49}{52}$	$\frac{91}{96}$
SAN : Q — Radomyśl (10.3) R — Wrzawy (4.0)	16,824	$\frac{139.3}{78.2\text{–}250.1}$	$\frac{78}{80}$	$\frac{73}{75}$	$\frac{63}{67}$	$\frac{81}{84}$	$\frac{82}{87}$	$\frac{151}{149}$	$\frac{88}{87}$	$\frac{60}{62}$	$\frac{61}{64}$	$\frac{47}{48}$	$\frac{77}{80}$
WIEPRZ: Q — Kośmin (17.9) R — Dęblin (0.5)	10,231	$\frac{41.8}{23.0\text{–}64.0}$	$\frac{44}{45}$	$\frac{33}{34}$	$\frac{34}{34}$	$\frac{39}{40}$	$\frac{56}{60}$	$\frac{71}{70}$	$\frac{61}{62}$	$\frac{44}{45}$	$\frac{36}{38}$	$\frac{27}{26}$	$\frac{39}{40}$
UPPER BUG down to Huczwa Q — Strzyżów (536.6) R — Kryłów (579.0)	8,945	$\frac{44.0}{24.2\text{–}72.6}$	$\frac{82}{89}$	$\frac{84}{96}$	$\frac{67}{69}$	$\frac{102}{110}$	$\frac{78}{90}$	$\frac{136}{142}$	$\frac{100}{102}$	$\frac{66}{70}$	$\frac{53}{53}$	$\frac{58}{58}$	$\frac{81}{88}$
BUG: Q — Wyszków (33.8) R — Popowo	39,119	$\frac{182.8}{108.0\text{–}273.8}$	$\frac{52}{52}$	$\frac{(41)}{(41)}$	$\frac{44}{44}$	$\frac{68}{63}$	$\frac{62}{60}$	$\frac{78}{78}$	$\frac{68}{67}$	$\frac{47}{51}$	$\frac{39}{40}$	$\frac{30}{30}$	$\frac{45}{45}$

WKRA: Q — Cieksyn R — Pomiechówek	 (22.6) 	4,879	24.9/13.0–35.3	60/60	(32)/(31)	91/92	(64)/(65)	74/72	87/83	82/83	56/54	38/38	40/39	40/41
NAREW (excluding Bug and Wkra) Q — Zambski Kościelne R — Wierzbica	 (81.8) (41.1)	27,784	158.7/103.6–212.5	53/53	(40)/(40)	55/55	69/67	63/63	64/63	62/62	44/49	50/46	34/33	44/44
DRWĘCA: Q — Elgiszewo R — Elgiszewo	 (25.8) (25.8)	4,959	32.6/20.7–42.6	64/64	47/46	75/75	66/65	68/69	85/84	87/87	(72)/(72)	42/42	43/43	56/57
PRZEMSZA: Q — Jeleń R — Jeleń	 (12.8) (12.8)	1,996	21.2/15.2–26.0	418/426	(445)/(444)	461/472	(411)/(411)	427/430	(397)/(396)	480/482	409/419	420/429	349/350	379/384
NIDA: Q — Wiślica R — Nowy Korczyn	 (23.2) (6.1)	3,630	19.9/8.1–29.0	65/67	48/50	68/78	81/82	84/85	84/78	92/89	60/62	48/50	30/30	61/59
KAMIENNA: Q — Czekarzewice R — Pawłowice	 (14.6) 	1,878	9.7/5.4–14.2	47/48	39/40	69/68	49/50	62/67	64/65	57/56	36/39	33/34	26/26	41/37
RADOMKA: Q — Rogożek R — Rogożek	 (11.3) (11.3)	2,060	10.4/4.9–16.0	47/49	(37)/(37)	(77)/(79)	51/52	51/58	61/62	60/60	(42)/(42)	31/31	25/26	32/33
PILICA: Q — Białobrzegi R — Białobrzegi	 (45.3) (45.3)	8,664	47.3/27.2–63.8	48/49	(46)/(45)	75/76	49/49	41/45	49/52	60/61	(45)/(46)	39/40	31/31	42/42
BZURA: Q — Sochaczew R — Sochaczew	 (27.7) (27.7)	6,281	26.5/13.1–48.6	64/66	41/41	116/119	62/67	84/92	86/84	81/80	52/53	40/42	32/32	46/46
BRDA: Q — Smukała R — mouth	 (20.1) (0.5)	4,414	28.0/23.6–34.6	59/59	54/54	70/70	42/42	55/55	76/75	71/71	59/59	53/53	51/51	60/60
WDA: Q — Krąplewice R — mouth	 (21.3) (0.5)	2,022	12.6/10.0–16.7	51 51	41/42	–	–	–	61 60	–	–	–	–	52/52
WISŁA: Q — Tczew R — Leszkowy	 (908.6) (924)	194,376	1222/787–1780	82/87	61/65	82/85	77/79	96/101	111/115	103/102	78/84	73/80	65/67	78/80

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[a] Numerator — ten–year–mean discharge, denominator — extreme mean annual discharges. [b] Numerator — solute yield calculated by adding monthly values, denominator — solute yield calculated by multiplication of ten–year–mean discharge and solute concentration. [c] Numerator — solute yield calculated by adding monthly values, denominator — solute yield calculated by multiplication of mean annual discharge and solute concentration.

diagrams. These data only indirectly provide information about the potential content of municipal and industrial wastewater in river solute yield.

One can estimate the quantity of such wastewater comparing the data from our map of the solute yield from rural areas with the results of adequate calculations made for the catchments including urban and industrial centres. Volume calculations of the total river solute yield from such catchments were made using the simplified formula presented in the previous chapter. For calculations we chose twenty catchments of the Vistula river tributaries for which we could collect the results of measurements of the solute concentration and of discharges at gauging stations "closing" these catchments.

We managed to complete the aforementioned measurement data for the years 1976–1985 for almost all catchments. The results of calculations are presented in Table 1. Annual indices and mean values from ten years were calculated in two ways. Analysis of the results shows that the ten-year indices calculated by multiplication of mean solute concentration and mean discharge usually differ by about +8% to –2% from the sum of values calculated for particular months. Only in the case of strong pollution with mine wastewater in the Little Vistula river catchment (from its spring to the Przemsza river mouth) is this difference +15%. Of course, differences are bigger when such calculations are made for particular years of the analysed period. The indices calculated for one year by multiplication of mean values differ from the monthly sums by about +15% to –10%; only in the case of the Little Vistula river catchment is it +34%.

Thus, the most radical differences were found in the Little Vistula river catchment. At the point closing this catchment, water is very strongly polluted with industrial wastewater. However, the level of pollution varied greatly here. In the years 1976–1980 it was significantly lower, but it more than doubled in the years 1981–1985. Analysis of monthly indices of the solute concentration shows that in both periods it changed stepwise many times. These changes could be connected with building new mines in the Rybnik Coal Region. This assumption is supported by the fact that water of the Przemsza river — also very strongly polluted with mine wastewater — did not show greater changes in the solute concentration in the whole discussed period. The old mines in the Przemsza river catchment had a stabilized system of wastewater disposal. Therefore, two methods for calculations of annual indices of the solute yield from this catchment give only slightly different results (Table 1).

Therefore, for twenty selected catchments, calculations of the solute yield were made in two ways. However, the results obtained in the simplified way are usually overstated. So, in the balance calculations presented in this paper we took into account the results obtained from summing up monthly values of solute yield.

Then the results of calculations of total solute yield from selected catchments, including municipal and industrial wastewater, had to be compared with the results typical only for rural areas. This necessitated determination on our map (using a planimeter) of the ranges of the particular solute yield indices from rural areas; on this basis the mean indices of the solute yield from the analyzed catchments were calculated as "weighted mean". The differences between the indices of the total solute yield and those from rural areas can be considered as a quantitative measure of the solutes coming from municipal and industrial wastewater. In the case of little-polluted areas these differences are small, so in this way we probably obtain results with a big error (for example for the catchments of the Sola, Raba and Wieprz rivers). We have no adequate principles to determine this error.

Before making the final balance calculations of the percentages of municipal and industrial wastewater we should consider the representativeness of the measurement data from the years 1976–1985. The successive years of this period were characterized by a great variation in river discharges and thereby of the solute yield. In the discussed decade, in many catchments the mean discharges were higher than the average for the period 1951–1975 (or 1951–1970); a higher increase, about 46%, occurred in the Wkra river catchment. However, in two cases they were lower than the average ones for many years, namely, in the Sola river catchment even by about 31.5%, and in the Nida river catchment by about 7.5%. In seven cases the differences in relation to average values for many years did not exceed 5%.

In the calculations made while preparing the map of the solute yield from rural areas, we took the values of discharges determined empirically on the basis of meteorological measurement series from many years. Therefore, we decided to reduce — i.e. respectively decrease or increase — the ten–year–mean (1976–1985) discharges to mean values for many years. Accordingly, the indices of solute yield were also reduced for calculation of the balance. The percentage of municipal and industrial wastewater in total solute yield calculated in this way is presented in Table 2. This shows that the percentage varies from about 2 to 90%. The highest is of course in the catchments polluted by wastewater from the Upper Silesian Coal Basin (the Little Vistula and Przemsza rivers), while the lowest is in the Dunajec river catchment which is characterized by the highest index of natural chemical denudation.

BASIC DATA FOR ESTIMATION OF THE PERCENTAGE OF OTHER COMPONENTS OF SOLUTE YIELD

Now we can present the problem of component ratios of that part of the total solute yield which comes from rural areas and is shown on our map (Fig. 1).

Component coming from precipitation. In the previous paper (Maruszczak 1990), the percentage of this component in the solute yield from the Vistula river basin was estimated at 8 t $km^{-2}y^{-1}$, amounting to 16%. The results of measurements of the solute concentration in precipitation in the 60's

(Chojnacki 1967) and its later tendency to increase were taken into consideration. As the solute concentration was still increasing in the early 80's we assume that in the years 1976–1985 the mean value of the discussed component was 9 t $km^{-2}y^{-1}$. In particular catchments of the Vistula river basin this value varied in line with the degree of atmospheric pollution. As the measure of this pollution we took the quantity of atmospheric SO_2 "flux" on Poland's territory, shown by isolines after J. Juda et al. (see Więckowski 1989, p. 35). Thus, estimated quantities of the solutes coming from precipitation vary in the examined catchments in the range 4–23 t $km^{-2}y^{-1}$ (Table 2).

Component coming from agricultural chemization. This percentage was calculated identically as in the previous paper. Thus, we took into consideration the results of investigations of fertilizer losses (Wilamski and Śliwa 1978, Pondel and Terelak 1981, Pondel et al. 1978) due to leaching caused by rain-water. In this way it was estimated that the losses of NPK fertilizers amounted to 10–15%, and those of calcic fertilizers to about 50%. The total losses were calculated using statistical data for 1980, which illustrate the supply of fertilizers in the gminas within particular catchments. This varied in the range 3.2–10.0 t $km^{-2}y^{-1}$ (Table 2). Thus, the percentage of this component is considerably lower than of that coming from precipitation.

Component coming from farm sewage. In the previous paper this was not taken into consideration because of a lack of suitable data. It was assumed that the percentage of this component was very low due to the weak infrastructure of rural settlements. However, we took into consideration this component in this paper, noticing particularly its differentiation in the examined catchments. We assumed arbitrarily that the mean index for the percentage of such sewage for the whole Vistula river basin was 1.0 t $km^{-2}y^{-1}$, i.e. many times lower than in the case of the component coming from agricultural chemization. Differentiation of this index in particular catchments was calculated in regard to the population density of rural areas and the cultivation level, the measure of which was the quantity of used fertilizers. Thus the estimated index varied in the range 0.5–2.3 t $km^{-2}y^{-1}$ in the catchments examined (Table 2).

THE STRUCTURE OF THE RIVER SOLUTE YIELD IN THE EXAMINED CATCHMENTS

The calculated values of the particular components of the solute yield are presented in Table 2, and Fig. 3. Despite very different areas of the examined catchments (from 1400 to 39,100 km^2) we were able to define the regional differentiation of the solute yield structure.

The greatest differences are between strongly-industrialized and rural areas. The Little Vistula river catchment (wastewater constitutes here almost

90% of the solute yield!), and the Przemsza river catchment (75%) are the best examples of the solute yield structure dominated by municipal and industrial sewage. Less than half as great is the percentage of this component in the upper Bug and Bzura river catchments. However, it should be stressed that these catchments are many times larger than those of the Little Vistula and Przemsza rivers. Having data for the uppermost course of the Bug river (polluted by sewage from Lvov and the Volhynia Coal Basin) we may obtain

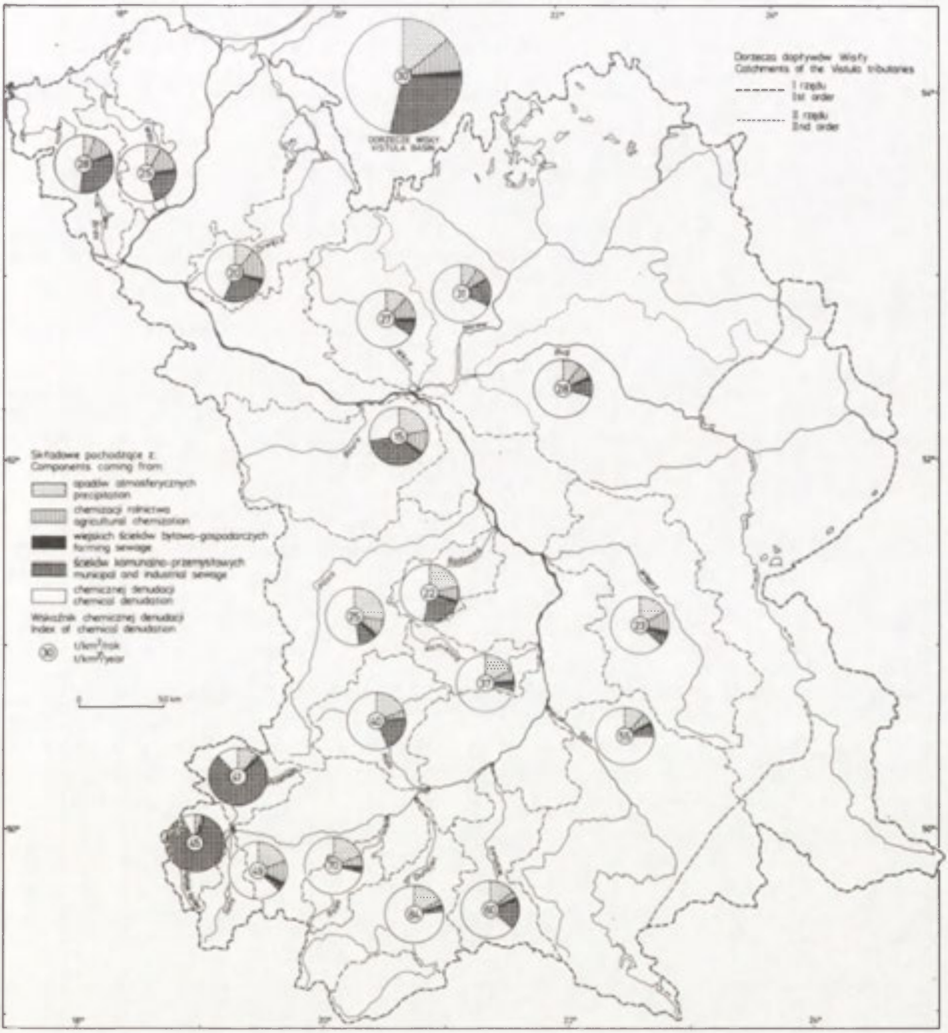

Fig. 3. Structure of river solute yield in the Vistula river basin; circles show the percentage of the particular components calculated on the basis of data from the years 1976–1985. Elaborated by H. Maruszczak and M. Wilgat, 1991

TABLE 2. Components of the solute yield from selected catchments in the Vistula river basin according to data from the years 1976–1985; numbering of the components (1–5) as in the text. The value of the discharge in t km^{-2}y^{-1} is expressed by the numerator, and the percentage of the particular components by the denominator

Catchment	Catchment area km^2	Components of the solute yield: numerator — in t km^{-2}y^{-1}, denominator-percentage (%)					
		from precipitation	from agricultural chemicals	from farm sewage	from municipal and industrial wastewater	from denudation of the lithosphere	Total Σ 1–5
		1	2	3	4	5	6
Vistula upstream of Przemsza mouth (Little Vistula)	1,748	$\frac{23}{3.7}$	$\frac{6.5}{1.0}$	$\frac{1.9}{0.3}$	$\frac{546}{87.8}$	$\frac{45}{7.2}$	$\frac{622}{100}$
Soła	1,386	$\frac{15}{19.2}$	$\frac{10.0}{12.8}$	$\frac{2.3}{2.9}$	$\frac{2.0}{2.6}$	$\frac{49}{62.8}$	$\frac{99}{100}$
Raba	1,470	$\frac{19}{19.2}$	$\frac{6.4}{6.5}$	$\frac{1.7}{1.7}$	$\frac{2.0}{2.0}$	$\frac{70}{10.7}$	$\frac{99}{100}$
Dunajec	6,735	$\frac{18}{16.5}$	$\frac{3.5}{3.2}$	$\frac{1.0}{0.9}$	$\frac{3.0}{2.8}$	$\frac{84}{77.1}$	$\frac{109}{100}$
Wisłoka	3,915	$\frac{13}{13.8}$	$\frac{3.6}{3.8}$	$\frac{1.2}{1.3}$	$\frac{16.0}{17.0}$	$\frac{60}{63.8}$	$\frac{94}{100}$
San	16,824	$\frac{8}{11.0}$	$\frac{4.0}{5.5}$	$\frac{1.1}{1.5}$	$\frac{5.0}{6.8}$	$\frac{55}{75.3}$	$\frac{73}{100}$
Wieprz	10,231	$\frac{6}{16.7}$	$\frac{4.3}{11.9}$	$\frac{1.1}{3.1}$	$\frac{2.0}{5.6}$	$\frac{23}{63.9}$	$\frac{36}{100}$
Upper Bug down to the Huczwa mouth	8,945	$\frac{9}{11.7}$	$\frac{4.0}{5.2}$	$\frac{1.2}{1.6}$	$\frac{29.0}{37.7}$	$\frac{34.4}{44.2}$	$\frac{77}{100}$
Bug	39,119	$\frac{4}{10.0}$	$\frac{3.2}{8.0}$	$\frac{0.6}{1.5}$	$\frac{4.0}{10.0}$	$\frac{28}{70.0}$	$\frac{40}{100}$
Wkra	4,879	$\frac{5}{12.2}$	$\frac{5.2}{12.7}$	$\frac{0.7}{1.7}$	$\frac{3.4}{8.3}$	$\frac{27}{65.8}$	$\frac{41}{100}$

Narew (excluding Bug and Wkra)	27,784	4 8.7	3.4 7.4	0.5 1.1	6.8 14.8	31 67.4	46 100
Drwęca	4,959	5 11.1	8.0 17.8	1.0 2.2	11.2 25.6	20 43.3	45 100
Przemsza	1,996	40 11.1	5.3 1.5	1.5 0.4	259.0 74.6	41 11.8	347 100
Nida	3,630	13 18.6	3.3 4.7	1.0 1.4	13.0 18.6	40 57.1	70 100
Kamienna	1,878	9 17.3	3.4 6.5	0.9 1.7	2.0 3.8	37 71.2	52 100
Radomka	2,060	10 21.3	3.8 8.1	0.8 1.7	10.6 22.6	22 46.8	47 100
Polica	8,664	13 27.1	4.3 9.0	1.0 2.1	4.4 9.2	25 52.1	48 100
Bzura	6,281	12 21.8	7.4 13.5	0.9 1.6	20.0 36.4	15 27.3	55 100
Brda	4,414	4 6.8	7.4 12.5	1.0 1.7	18.7 31.7	28 47.5	59 100
Wda	2,0322	4 8.7	6.7 14.6	1.0 2.2	9.5 20.7	25 54.3	46 100
Vistula upstream of Tczew	194,376	9 13.8	6.5 10.0	1.0 1.5	18.2 28.0	30 46.2	65 100

Comment: values of the solute yield components in columns 1 and 5 are rounded.
Percentages are calculated according to these rounded values, thus their sum is not exactly 100%.

an index considerably exceeding 50%. The lowest percentage of municipal and industrial wastewater is typical for the Sola, Raba and Dunajec river catchments; in these catchments the percentage of this component is many times lower than of that coming from precipitation. This is connected not only with their weak industrialization but also with forest cover, and above all probably with a very high chemical denudation of the lithosphere. In the Wieprz river catchment, with the absolute quantity of the solute yield coming from municipal and industrial wastewater similar to that in the Sola and Raba river catchments, the percentage of this component is distinctly higher in relation to a considerably lower index of chemical denudation, as well as lower total solute yield.

The differences between the physico-geographical regions are also distinct. If we disregard the strongly-industrialized regions, the following picture of the differentiation is obtained:

The regions of the Carpathians and their foothills are characterized by high indices of total solute yield, usually in the range 70–100 t $km^{-2}y^{-1}$. The component of chemical denudation prevails here, and even predominates in some places; in the Dunajec river catchment it is as high as 77%. The intensity of chemical denudation is here the highest in the whole Vistula river basin and amounts to 50–85 t $km^{-2}y^{-1}$; above all this is connected with very high indices for solute yield.

The regions of the Carpathian Foredeep basins. None of the catchments we examined represents this type; as a matter of fact there are no catchments of an area of 1000–2000 km^2 entirely situated within this belt. Therefore, only on the basis of our map of solute yield from rural areas can we assume that the indices for total solute yield here are in the interval 40–60 t $km^{-2}y^{-1}$. The percentage of the component coming from chemical denudation is lower than in the former belt, and over large areas it amounts to about 50%.

The regions of the Southern Polish Uplands are very differentiated in regard to the specific river discharges and geological structure (susceptibility of the bedrock to leaching). Of the analyzed catchments, those of the Nida and Kamienna rivers are typical for this belt. The indices for the total solute yield here are in the interval 40–100 t $km^{-2}y^{-1}$. The component coming from chemical denudation usually exceeds 50%.

The regions of the Central Polish Lowlands are less differentiated. Among the catchments analyzed only those of the Radomka and Bzura rivers are entirely situated within this belt, and the latter is strongly polluted by municipal and industrial wastewater. Indices for total solute yield here are the lowest in the whole Vistula river basin; in lowlands of the Polesiye type they even fall below 20 t $km^{-2}y^{-1}$, and on heights built of glacial sediments of the Middle-Polish glaciation they only slightly exceed 40 t $km^{-2}y^{-1}$. The component coming from chemical denudation falls distinctly below 50%; in the Bzura river catchment its percentage is slightly higher than that from precipitation, amounting to 27%. The intensity of chemical denudation is here the lowest in the whole Vistula river basin and amounts to between 10–12 and 20–25 t km^{-2}y^{-1}. It coresponds to low indices for solute yield, and also to flatland relief determining a limited thickness of leached layers composed mainly of sandy deposits (including glacial ones of older glaciations, i.e. intensely weathered).

The region of the North Polish Lake District is rather differentiated; among the analyzed catchments the most representative are those of the Brda, Wda and Drwęca rivers. They are characterized by considerably higher solute yield (in the interval 30–80 t km^{-2}y^{-1}) than those in the lowland belt. This is connected with greater indices of specific river discharges and with widely spread, unweathered, carbonate glacial sediments of the last glaciation. The intensity of chemical denudation is mostly in the interval 20–30 t km^{-2}y^{-1}, and it constitutes about 50% or more of the total solute yield.

From the review of regional differentiation, it appears that the structure of the solute yield from rural areas corresponds to the natural conditions of the particular catchments, i.e. hydroclimatic and geological-morphological ones. This problem was discussed in our previous papers (Maruszczak and Wilgat 1993, 1996), in which we stressed that the structure of river solute yield could be treated as an indirect differentiation index of geosystems.

BALANCE FOR RIVER SOLUTE YIELD IN THE VISTULA RIVER BASIN

The balance previously published (Maruszczak 1990) was calculated on the basis of few data relating to the second part of the 70's. The index of total solute yield was then calculated in a simplified way, multiplying the mean discharges of many years at Tczew and mean solute concentration measured in the years 1974–1977 at Kieżmark. This index amounted to 50.9 t km^{-2}y^{-1}. In this paper we calculated the quantities of solute yield by adding monthly values for transport. The thus-calculated index of the total solute yield from the Vistula river basin in the years 1976–1985 amounted to 65 t km^{-2}y^{-1}. So, the increase in comparison with the index calculated previously for the second part of the 70's is very high (20%). It can be explained by reference to increasing pollution of Poland's rivers in the 80's. Of great importance here was a very large increase in pollution of the Little Vistula river connected with the development of new mines in the Rybnik Coal Basin. In the second part of the 70's the mean index for solute yield from this catchment amounted to 310 t km^{-2}y^{-1}, and in the first part of the 80's to as much as 872 t km^{-2}y^{-1} (see Table 1).

The balance equation for solute yield from the Vistula river basin in the years 1976–1985 is as follows:

$$SYt = SYp + SYch + SYfs + SYmis + SYd$$

where:

SYt — total solute yield: 65.0 t $km^{-2}y^{-1}$ — 100%,
SYp — solute yield from precipitation: 9.0 t $km^{-2}y^{-1}$ — 13.8%,
SYch — solute yield from agricultural chemicals, i.e. mainly from fertilizers: 6.5 t $km^{-2}y^{-1}$ — 10.0%,
SYfs — solute yield from farm sewage: 1.0 t $km^{-2}y^{-1}$ — 1.5%,
SYmis — solute yield from municipal and industrial wastewater: 18.2 t $km^{-2}y^{-1}$ — 28.0%,
SYd — solute yield from chemical denudation of the lithosphere: 30.3 t $km^{-2}y^{-1}$ — 46.6%.

Our supplementary explanation of the symbols is as follows: The component SYp now mainly contains "synthetic" substances produced by man; the index for these substances should be estimated at least 6 t $km^{-2}y^{-1}$. The component SYmis contains not only "synthetic" substances, but also natural ones (pumped with groundwaters used by man). In the previous paper it was assumed that these natural substances accounted for almost half of the solutes coming from municipal and industrial wastewater. The data concerning upland areas were the basis for this estimation. Probably it was overestimated because solute concentration of groundwaters in other landscape belts of the Vistula river basin is not so high. Therefore, we assume now that in 18.2 t $km^{-2}y^{-1}$ of the solutes coming from municipal and industrial wastewater "synthetic" substances account for at least 10 t $km^{-2}y^{-1}$.

So, the amount of "synthetic" substances representing environmental pollutants can be estimated at about 23.5 t $km^{-2}y^{-1}$ in the discussed period, that makes 36% of the total quantity of solutes transported by the Vistula river to the sea.

Between the two World Wars, the percentage of "synthetic" substances was many times lower with a considerably lower total solute yield. We can deduce the index of the total solute yield from the Vistula river basin in the 30's from a few data published by M. Stangenberg (1958). Unfortunately, no information about the level of solute concentration in the Vistula river mouth has been given in this paper. We can estimate this value only on the basis of the series of solute concentration measurements on the Vistula river at Puławy in 1952; the average amounted to 256 mg dm^{-3} at that time. In the 30's, this index was probably even lower; such a conclusion can be drawn unequivocally on the basis of comparison of the content of chlorides in the Vistula river water at Warsaw. In 1934 it was 14.4 mg dm^{-3}, in 1948 — 16.5, and in 1952 — about 29 mg dm^{-3} (Stangenberg 1958). Therefore, we can assume that before World War II the average solute concentration of the Vistula river water at Warsaw did not exceed 24 mg dm^{-3}.(2) Downstream of Warsaw

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[2] The deduced index of solute concentration at the mouth of the Vistula river in 1934 (240 mg dm^{-3}) falls in the range of the measurement data of solute concentrations near the Warsaw Water Works, obtained ten years earlier and eleven years later. Analyses carried out by T. Kirkor in 1924 gave 215 mg dm^{-3} on average, with extreme values of 136 and 283 mg dm^{-3}, and analyses from 1945 — 258 mg dm^{-3}, with extreme values of 172 and 358 mg dm^{-3} (see Dojlido and Woyciechowska 1985, p. 43).

it decreased rather than increased, because the downstream tributaries of the Vistula river drained weakly–industrialized areas. So, to calculate the balance for the 30's we assumed that the mean index of solute concentration in the Vistula river mouth was 240 mg dm^{-3}. In the years 1976–1985 this index was 440 mg dm^{-3} on average, i.e. higher by 83%. Assuming that the mean discharge of the Vistula river in the 30's was like that of many years that we accepted in our work, we calculated the total solute yield in 1934 at 35.5 t km^{-2} y^{-1}. In it, chemical denudation probably constituted about 27–28 t km^{-2}y^{-1}, the component from precipitation — 2–3 t km^{-2}y^{-1}, and all other components — about 5 t km^{-2}y^{-1}.(3). The component from precipitation was then almost entirely of natural origin, and other components were partially also natural (from groundwaters pumped by man). Therefore, "synthetic" substances probably constituted 3–4 t km^{-2}y^{-1}, i.e. about 10% of the total solute yield.

The estimated balance of the total solute yield for the 30's presented in this paper allows us to suggest that the chemical denudation of the lithosphere was at that time lower than now. The index for the present chemical denudation is about 10% higher. This difference may result from insufficient data for deductive determination of the indices for 1934. However, it seems quite logical that it is the consequence of "acid rain", which have resulted in a considerable increase in the aggressiveness of waters infiltrating the lithosphere.

FINAL REMARKS

1. The structure of river solute yield from rural areas can be used as a numerical index of the natural characteristics of geosystems typical for the particular landscape belts in the Vistula river basin. It is differentiated in relation to hydroclimatic conditions, geological structure and relief.
2. At present the indices for the total solute yield in the Vistula river basin are not a good measure of the intensity of chemical denudation of the lithosphere, even in typical rural areas. In a large part of this basin, in more industrialized areas, these indices are rather a measure of degradation and pollution of the environment.
3. As a more direct measure of environmental pollution we can assume that part of the total solute yield which consists of "synthetic" substances.

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[3] The component coming from precipitation can be estimated on the basis of the results of analyses from the 60's (Chojnacki 1967). They reveal that the total solute concentration of precipitation in unpolluted rural areas was about 15 mg dm^{-3}. Accepting this value as average for the whole basin of the Vistula river in the 30's, we calculate that this component amounts to 2.2 t km^{-2} y^{-1}. The percentage of the component coming from municipal and industrial wastewater can also be estimated only indirectly on the basis of very scarce data illustrating the content of Cl^- and SO_4^{2-} in river waters in the Vistula river basin, compiled by M. Stangenberg (1958). The content of Cl^- in unpolluted rivers in the 30's was below 10 mg dm^{-3}, and in the middle part of the Vistula river about 15 mg dm^{-3}. The contents of SO_4^{2-} were below 20 mg dm^{-3} and about 30 mg dm^{-3}, respectively. Therefore, about 7 mg Cl^- in 1 dm^3 and about 15 mg SO_4^{2-} in 1 dm^3 can be attributed to pollution. Together with other components it constituted about 10% of the total solute yield, i.e. 3–4 t km^{-2} y^{-1}. The component coming from agricultural chemicals (largely soil liming) can be estimated at 1–2 t km^{-2} y^{-1}.

In the years 1976–1985 they constituted as much as 36% of the total solute yield, which on average amounted to 65 t km^{-2}y^{-1} in the Vistula river basin in that period. Fifty years before, i.e. in the 30's, the percentage of "synthetic" substances was many times lower; it most likely did not exceed 10% of the total solute yield which was estimated at about 35 t km^{-2}y^{-1}.

4. A great increase in environment pollution, especially that of the atmosphere, in the last decade probably also contributed to the increase in the chemical denudation of the lithosphere, because "acid rain" causes increased aggressiveness of waters percolating soils and their bedrocks. Estimated calculations allow us to suggest that in the 30's the index of chemical denudation in the Vistula river basin was 27–28 t km^{-2}y^{-1}. An analogous index calculated for the years 1976–1985 was 30 t km^{-2}y^{-1}. It can, therefore, be suggested that it is now a measure of not completely natural, chemical denudation of the lithosphere.

REFERENCES

Aurada K. D., 1982, *Ionenabfluss und chemische Denudation* (*Regionale Differenzierung und Steuerungsmechanismen*), Petermanns Geogr. Mitt. 126, 1, 23–36.

Chojnacki A., 1967, *Wyniki badań składu chemicznego wód opadowych w Polsce* (*Results of investigations on chemical composition of atmospheric precipitations in Poland*), Pam. Puł. 24, 287–298; 29, 163–187.

Dojlido J. R., Woyciechowska J., 1985, *Zmiany jakości wód powierzchniowych w Polsce w ciągu pół wieku* (*Alteration of surface water quality in Poland at the time of last half century*), Gosp. Wodna 45, 1–2, 39–44.

Maruszczak H., 1986, *Próba bilansu odpływu chemicznego z dorzecza Wisły* (*An attempt at balancing the solution yield from the Vistula river basin*), II Zjazd Geografów Polskich, Streszcz. Referatów, Łódź, 115–118.

Maruszczak H., 1990, *Denudacja chemiczna* (*Chemical denudation*), [in:] *Współczesne przemiany rzeźby Polski południowowschodniej*, Prace Geogr. IGiPZ PAN 153, 23–41.

Maruszczak H., Wilgat M., 1993, *Struktura rzecznego odpływu roztworów jako wskaźnik przewodnich cech geosystemów zlewni nizinnych w dorzeczu Wisły (Structure of river solution yield as indicator of principle features of geosystems in lowland catchments of the Wisła river basin), [in:] Geoekosystem obszarów nizinnych*, Ossolineum, 131–136.

Maruszczak H., Wilgat M., 1996, *An attempt at balancing the solute yield from the Bug river catchment with a special consideration of anthropogenic components*, Wyd. Międzynarod. Asoc. Region. Probl. Ekol., Uniw. Lwowski (in press).

Pondel H., Terelak H., 1981, *Skład chemiczny wód drenarskich jako podstawa oceny strat składników mineralnych wymywanych do wód gruntowych* (*Chemical composition of drainage waters as a basis for evaluation of mineral element losses by leading out to the ground waters*), Pam. Puł. 75, 149–167.

Pondel H., Terelak H., Sadurska K., 1978, *Skład chemiczny wód w dorzeczu Bystrej, Wyżyna Lubelska* (*Chemical composition of waters in Bystra drainage basin, Upland of Lublin*), Pam. Puł. 70, 7–22.

Stachy J., 1966, *Rozmieszczenie odpływu średniego na obszarze Polski* (*Distribution of mean discharge in Poland area*), Prace PIHM 88, 3–42.

Stachy J., Biernat B., Dobrzyńska J., 1977, *Odpływ rzek polskich w latach 1951–1970* (*Outflow from Polish rivers in the years 1951–1970*), Gosp. Wodna 37, 3, 71–78.

Stangenberg M., 1958, *Ogólny pogląd na skład chemiczny wód rzecznych Polski* (*A general *outlook on the chemical composition of river waters in Poland*), Pol. Arch. Hydrobiol. 4(17), 289–359.

Świeca A., 1984, *Wpływ ścieków komunalnych i przemysłowych miasta Chełma na wielkość transportu roztworów i zawiesin w rzece Uherce* (*The effect of municipal sewage and industrial wastes of Chełm town on the size of carriage of solutions and suspensions in the Uherka river*), Folia Soc. Sc. Lubl., 26, Geogr. 1/2, 23–28.

Więckowski S. K., 1989, *Wybrane zagadnienia ochrony i kształtowania środowiska przyrodniczego człowieka* (*Selected problems of preservation and modelling of man natural environment*), PWN, Warszawa.

Wilamski J., Śliwa Z., 1978, *Spływ składników nawozowych roślin ze zlewni rzek Przymorza Zachodniego* (*Outflow of fertilizer elements of plants from catchment areas of rivers of the Przymorze Zachodnie region*), Mat. Bad. IMiGW, Ser.: Gosp. Wod. Ochr. Wód.

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THE INFLUENCE OF WATERS FROM HARD-COAL MINES ON THE HYDROCHEMICAL RELATIONS OF UPPER SILESIAN COAL BASIN (USCB) RIVERS

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ABSTRACT: Surface waters of the Upper Silesian Coal Basin (USCB) are highly transformed in quality as a consequence of salty minewater discharge to the hydrographic net. These waters drain coal beds which are extracted to a depth of 1000 m. The amount of minewater, discharging directly or indirectly to the river net of the USCB reaches 8–9 m^3/s with a variability in particular years of 1–1.5 m^3/s, which depends on hydrological conditions of the levels extracted. In 1994, the salt load introduced together with these waters to the Vistula and the Oder reached 6793 tons per 24 hours of chloride ions and 1351 tons per 24 hours of sulphate ions. This accounted for over 50% of the chlorides and about 35% of the sulphates discharged to surface waters in the country. Furthermore, a part of the minewater also contains radioactive elements ($radium^{226}$). The chance to improve the quality of the Oder and Vistula waters in the nearest future is meagre.

KEY WORDS: minewaters, hydrochemistry, water quality, salinity of river waters, Upper Silesian Coal Basin.

INTRODUCTION

In urbanized and industrialized areas where intensive mining in the shape of the exploitation of underground and open-cast-resources takes place there is indirect and direct discharge of minewaters to the surface water net.

These waters originate from: 1) the draining of underground mining levels which under normal conditions play little or no part, in the local water circuit, 2) the draining of excavations for open-cast exploitation mineral resources.

Draining work is carried according to a program for the development of exploitation works as well as considering safety after the finishing of mining. Because mines exploit deposits in different geological structures characterized by variability in hydrochemical conditions, the minewaters which are pumped out differ in chemical composition and are very often considerably mineralized

(Różkowski 1995; Sawicki Gutry-Korycka 1993; Wilk, Adamczyk, Nałęcki 1990). Therefore minewater discharges disturb the natural water regime of streams and cause an increase in river pollution. A. Różkowski (1995) states that the general mineralization of underground waters in the area of the Upper Silesian Coal Basin (USCB) is very variable and fluctuates within the range 0.5–372 g/dm^3 and there is an increase in mineralization with the depth as well as simultaneous variability of its hydrochemical type from multiionic to bi- or triionic-brines.

Thus mines which exploit coal deposits up to the depth of 600–700 m (maximum 1000 m) drain water-bearing horizons characterized by differing water mineralization. In the 80s it was estimated that indirect or direct minewaters draining from coal mines in the Upper Silesia area amounted to 8–9 m^3/s with variability in particular years within the range 1–1.5 m^3/s, depending on the hydrochemical situation of the exploited horizons. Waters of total mineralization up to 1.5 g/dm^3 were introduced into the surface hydrographical system in the amount of 3.5–4.0 m^3/s, but above 1.5 g/dm^3 – 5.0 m^3/s. Strongly mineralized brines of salt concentrations above 70 g/dm^3 were drained only at 0.08–0.1 m^3/s. Recently there has been a "sweetening" of underground waters which are within the range of mine activity, especially in areas where coal exploitation has been carried on for more than 100 years (Gajowiec, Różkowski 1988).

This paper is an attempt to estimate the influence of minewater discharge from the hard coal mines of USCB on the shaping of the hydrochemical conditions of river waters, considering mostly salinity and the salt load removed from this area by the Vistula and Oder rivers.

THE AMOUNT OF MINEWATERS PUMPED OUT

In the period 1980–1987, the amount of minewater pumped out in Poland was kept at a near constant level, with a decreasing trend after 1987 (Table 1). In 1980 the amount of water pumped out was 1273 M m^3, and in 1993 1042 M m^3, which converted to a flow of 40.37 m^3/s in 1980 and 33.06 m^3/s in 1993 (*Ochrona środowiska...* 1981, 1991, 1994).

The majority of minewater is pumped out in the province of Katowice which is the most industrialized in the country. Their share in the total amount of minewater pumped out in the country is about 50% but there has been a slightly decreasing trend in the last few years (from 54.03% in 1980 to 48.4% in 1993). The amount of minewater pumped out in the province of Katowice and the two following ones (Piotrków and Konin) is above 80% of the total pumped out in Poland, and all provinces mentioned in the Table 1 account for 90%. The remaining provinces, where drainage work connected with resource exploitation took place, discharge only from 9.5% (1980) to 5.2% (1993).

TABLE 1. The amount of minewater pumped out in Poland in the years 1980–1993

Provinces (country)	The amount of minewater pumped out (in dam^3) in:				
	1980	1985	1987	1990	1993
POLAND	1,273,102	1,273,031	1,264,693	1,207,086	1,042,507
Katowice	688,026	644,001	659,108	596,401	504,532
Piotrków Tryb.	228,654	261,377	201,002	219,289	208,340
Konin	153,145	160,363	169,509	187,664	160,312
Legnica	31,852	51,836	56,747	51,626	48,877
Tarnobrzeg	22,392	45,610	48,408	45,394	17,728
Opole	1800	36,870	44,709	35,871	33,973
Wałbrzych	26,259	20,445	20,904	16,521	14,707
Others	120,974	52,529	64,304	54,320	54,041

Source: *Ochrona Środowiska...* 1981, 1991, 1994.

Fluctuations in amounts of drained minewater were connected with both hydrogeological conditions and intensity of exploitation. A significant part of the minewater is used for municipal and industrial purposes. The remainder, considering significant pollution, is discharged directly to the surface water network or temporarily retained in special reservoirs which are called dosing ones and discharge to rivers in amounts proportional to actual capacity. In the area of USCB, the thermal-chemical method is applied to utilize minewaters which are strongly saline. This entails evaporating water in a multistage system of evaporators, and crystallization of sodium chloride and calcium sulphate (Węgrzynowska 1993). The "Dębieńsko" hard coal mine in Czerwionka has Poland's only desalinating plant which processes about 2000 m^3 brine per day and simultaneously produces 129 tons per day of sodium chloride and 1000 m^3 per day of demineralized water. This plant utilizes only 2% of the salt load discharged to rivers by mining (*Raport...* 1995).

THE ORIGIN OF MINEWATERS IN THE AREA OF USCB

The minewaters originate from the draining of three geological formations (Rogoż, Staszewski, Wilk 1987; Różkowski, Przewłocki 1987): 1) Quaternary formations, from the opencast exploitation of stowing sands, 2) Triassic formations, from the underground exploitation of zinc and lead ores, 3) Carboniferous formations, from the underground exploitation of hard coal carried on at different depths — maximally at 1000 m.

The amounts of waters pumped out in the Upper Silesia area in the years 1970–1987 was within the range 20–21 m^3/s (Czaja, Jankowski 1992; Jankowski 1987) and after 1994 it decreased to about 16 m^3/s (Table 2).

TABLE 2. The amount of minewater pumped out from the mines of the Upper Silesian Coal Basin (USCB) in the years 1967–1994

Mines	Amount of water pumped out in m^3/s						
	1967–1976	1980	1985	1987	1990	1992	1994
Stowing sand	4.08	4.08	3.70	3.16	3.05	2.61	2.96
Zinc and lead ores	6.35	6.38	5.85	5.36	3.23	3.14	3.08
Hard coal	10.45	10.41	11.00	11.90	10.15	10.51	9.94
All	20.88	20.85	20.65	20.42	16.43	16.21	15.98

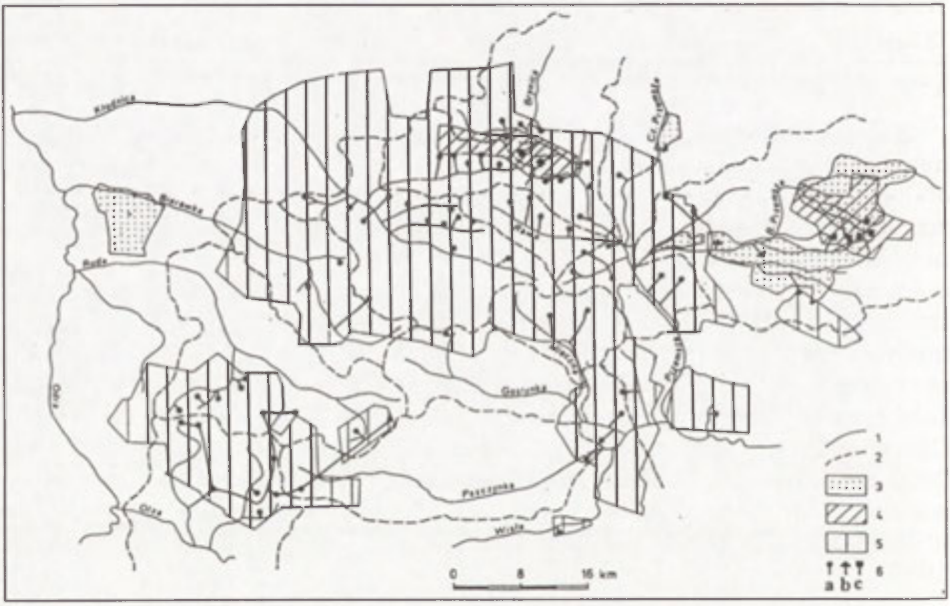

Fig. 1. Places of minewater discharges to the surface water network of Katowice province (after Czaja & Jankowski 1992)
1 — rivers, 2 — watersheds, 3 — areas of stowing sand exploitation, 4 — areas of zinc and lead ore exploitation, 5 — areas of hard coal exploitation, 6 — directions of drainage and places of the minewater discharge: a — from hard coal mines, b — from stowing sand mines, c — from zinc and lead mines

Half of the minewater pumped out, above all waters from mines of stowing sand and zinc and lead ores, is used as drinking or industrial water and after use is discharged to the sewerage system in the shape of wastewater. The remaining minewaters — mostly strongly-mineralized ones — are discharged directly to the surface hydrographic net (Czaja, Jankowski 1992), *vide* Fig. 1.

MINERALIZATION OF MINEWATERS

The mineralization of natural minewaters ranges from 0.2 to 372.6 g/m^3 (Różkowski 1995; Różkowski, Rudzińska, 1983). M. Rogoż, M. Staszewski and Z. Wilk (1987) estimate that at the beginning of the 80s the amount of minewater from hard coal mine drainage amounted on average to 960,000 m^3 per day which made 11.1 m^3/s in four minewater quality classes which differed in the content of Cl^- and SO_4^{2-} ions (Table 3).

TABLE 3. Amount of water pumped out from mines of hard coal in the area of the Upper Silesian Coal Basin, in particular classes of water quality (after Rogoż, Staszewski and Wilk 1987)

Class	Content of Cl^- and SO_4^- ions kg/m^3	Amount of waters pumped out thousand m^3 per day	Percentage share
I	< 0.6	427	45
II	0.6–1.8	232	24
III	1.8–42.0	278	29
IV	> 42.0	23	2
Total		960	100

Waters of low mineralization which belong to the first class originate from upper exploitation horizons (depths to 400 m) and are drinkable but those from the second class can be used only for industrial purposes. Waters of the third class (weakly saline) which originate from excavations located lower down are only useful to a limited degree so are discharged to the surface hydrographic net. Part of them is utilized at the new station for desalination, located at the existing plant desalinating the "Dębieńsko" hard coal mine. A connected method of desalination is used here which consists in the increase in concentration of weakly saline waters by reverse osmosis. This way about 13,300 m^3 water per day can be utilized. Water of the fourth class (brine), where concentrations of chlorine-sulphate ions exceed 42 g/dm^3, cannot be used for economic purposes and is also discharged to the hydrographical net. This brine can only undergo utilization at 2000 m^3 per day by way of the thermal-chemical method at the "Dębieńsko" desalination plant in Czerwionka.

On the base of a prognosis for water inflow to the coal mines of the USCB up to 2005, worked out by Main Mining Institute (GIG) in Katowice, I. Węgrzynowska (1993) states that the amount of waters of III and IV classes will increase by 57%, while in class I it decreases by 11% and in II by 23%; the overall salt load discharged to rivers will increase by 28%.

So large an amount of minewater discharged to the surface and especially waters of increased mineralization, is not without influence on river water quality. The load of salt which is discharged from the mines to rivers of the

Vistula and the Oder basins was estimated in the mid-80s by M. Rogoż, A. Różkowski and Z. Wilk (1987) at 6900 tons per day, but in 1993 W. Szczepański and others (1995) evaluate it at 4834 tons per day including 4453 tons of chloride ions (Cl^-) per day and 381 tons of sulphate ions (SO_4^{2-}) per day. In 1994 the salt load discharged by the Vistula and the Oder rivers from the mines of USCB, calculated by the author on the base of data from the Centre of Research and Monitoring on Environment (OBiKS) (*Monitoring...* 1995), amounted to 6793 tons of chloride ions per day (for the Vistula — 6442.2 and for the Oder 1351.0 tons per day) and 1062.5 tons of sulphate ions per day (Table 7).

An estimation of Visula river pollution in the region of the Przemsza confluence, caused by the discharge of minewaters, was made by A. Różkowski and others (1986) and by B. Gajowiec and J. Różkowski (1988) on the basis of hydrochemical analyses of river waters realized in 1985 (Table 4). Hydrochemical research was performed then in the winter, spring, summer and autumn seasons in some sections (Fig. 2A).

Differences in chemical composition and overall mineralization between sections investigated on the Vistula are presented in hydrochemical profiles (Fig. 2B). Mean mineralization of the Vistula waters in 1985, specified for mean low and mean flows, increased from 0.2 g/dm^3 in the section of Goczałkowice to the maximum value of 3.1 g/dm^3 in Czernuchowice, where minewaters from three coal mines are discharged to the Przemsza above its confluence. The salt load of the Little Vistula waters from the USCB area minewaters caused multiple and overstandard increase in the pollution indicators as follows: dissolved compounds 1400–2550%, chlorides 1500–2750% and sulphates 1550–3900%. It conforms to the following absolute values: dissolved compounds 7400–9300 tons per day, chlorides 3600–4650 tons per day and sulphates 640–800 tons per day (Gajowiec, Różkowski 1988). The mineralization in the Dwory section amounts to 2.7 g/dm^3 in consequence of the inflow of the more-badly mineralized waters of the Przemsza and the Soła rivers (Różkowski et al. 1986).

TABLE 4. Concentration of ions and salt loads in waters of the Vistula and its tributaries in 1985 (after A. Różkowski et al. 1986)

Stream	Profile	Concentration in g/m^3			Load in tons per day $Cl^- + SO_4^{2-}$
		Cl^-	SO_4^{2-}	mineralization	
Vistula	Jawiszowice (1)*	386.0	55.75	826.7	242.0
Vistula	Nowy Bieruń (2)	1740.0	146.30	3169.3	2098.0
Vistula	Dwory (3)	1371.0	234.00	2786.5	5034.0
Gostynia	Bojszowy (4)	6037.5	406.50	10 498.5	1779.1
Potok Goławiecki	Czarnuchowice (5)	16 912.2	1009.20	29 229.0	919.6
Przemsza	Jeleń (6)	456.5	274.20	1492.0	1011.6

* numbers of profiles are as in Figure 2.

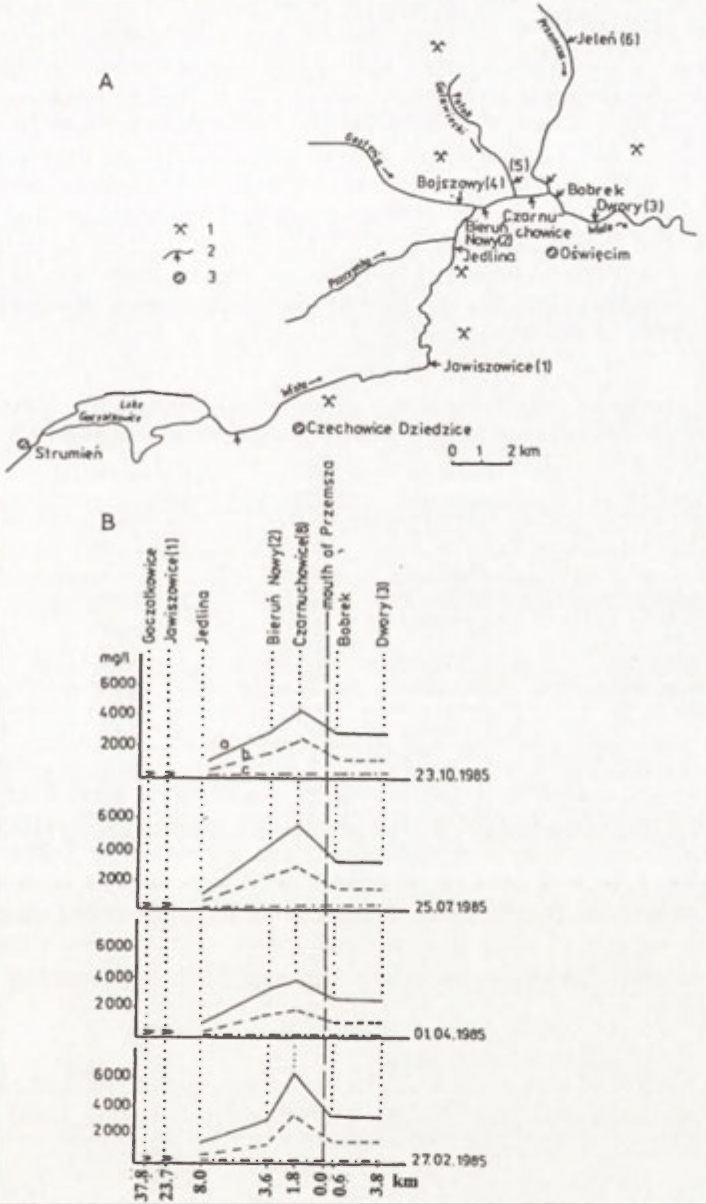

Fig. 2. Sketch of the hydrological net in the region of the Przemsza confluence with the Vistula (after Rozkowski et al. 1986):
A — location of hydrochemical profiles: 1 — hard coal mines which drain saline minewater, 2 — places of water sampling for hydrochemical analyses (numbers in brackets comply with the profiles in Table 4), 3 — localities, B — hydrochemical profiles of the Vistula:
a — overall mineralization, b — content of Cl^- ion, c — content of SO_4^{2-}

On the basis of archival materials from the 1980 analysis, verified by measurements in 1985, A. Różkowski and others (1986) state that the amount of minewater discharged to the Vistula catchment closed by the profiles Jawiszowice and Dwory (Fig. 2) amounted to 8.49 m^3/s. These waters contained a total load of both chlorides and sulphates of 4027 tons per day. In the profile of Dwory the salt load discharged by minewaters made 78% of the river pollution total load. In 1993 — 388.1 thousand m^3 per day of minewaters (4.49 m^3/s) containing 3382.4 tons per day of chlorides and 270.7 tons per day sulphates were discharged to the Vistula. 79% of this load was discharged to the Vistula by its tributaries: the Gostynia (57%) and the Potok Golawiecki (22.6%). The amount of minewater, as well as the salt load, which were discharged to the Vistula in 1993 are presented in Table 5.

TABLE 5. Amount of minewater and salt load discharged to the Vistula and its tributaries in 1993 from the area of the USCB (after Szczepański et al. 1995)

River	Amount of minewater m^3 per day	Load in tons per day		
		Cl^-	SO_4^{2-}	$Cl^- + SO_4^{2-}$
Gostynka	71,261	1931.18	91.55	2022.73
Potok Goławiecki	35,693	878.99	50.63	929.62
Przemsza	251,418	268.75	123.40	392.15
Little Vistula	14,006	271.88	1.42	273.30
Vistula (Gromiec profile)	15,842	31.61	3.75	35.36
Total	388,220	3382.41	270.75	3653.16

In 1993 — 126.7 m^3 per day of minewaters with a total load of 1181.7 tons per day were discharged to the Oder. The quantity of waters and salt load introduced into the Oder tributaries are presented in Table 6.

Excessive pollution of the Vistula and Oder waters caused by the discharge of minewaters from coal mines has been observed since the 70s (comparison of salt load in the water of the Vistula between the profiles Jawiszowice and Dwory in the years 1976 and 1985 is presented in Figure 3).

TABLE 6. Amount of minewater and salt load discharged in 1993 to rivers of the Oder catchment from the area of the USCB (after Szczepański et al. 1995)

River	Amount of minewater m^3 per day	Load in tons per day		
		Cl^-	SO_4^{2-}	$Cl^- + SO_4^{2-}$
Klodnica	74,735	315.37	83.92	399.29
Olza	28,886	555.51	7.94	563.45
Bierawka	13,868	164.34	8.47	172.81
Ruda–Nacyna	9228	35.74	10.37	46.11
Total	126,717	1070.96	110.70	1181.66

The course of reliable concentrations of chlorides and sulphates in three profiles on the Vistula is presented above. In Jawiszowice, with mean annual low flow (MLQ) in the period 1976–1985 a more than 3-fold increase in chlorides concentration took place (from 520 mg/ dm^3 to 1750 mg/dm^3) but the concentration of sulphates increased insignificantly. In the profile of Bieruń Nowy a sixfold increase in the concentration of the Cl^- ions (from 850 mg/dm^3 to 5000 mg/dm^3) took place and the concentration of sulphates increased by 170 mg/dm^3, which means that it almost doubled. In the third profile — Dwory, a small increase in concentration was noted (chlorides by 650 mg/dm^3 and sulphates by 70 mg/dm^3 — Fig. 3). The comparison of the salt load in the waters of the Vistula and the Oder and its tributaries in the years: 1980, 1985, 1989 and 1994 is presented in Table 7.

TABLE 7. Mean annual salt load in waters of the Vistula and the Oder and their tributaries

River — measuring section	Indicator of salinity	Mean annual salt load in tons per day in the years			
		1980	1985	1989	1994
		The Vistula river and its tributaries			
Little Vistula —	chlorides	183.2	186.6	189.2	217.4
Jawiszowice	sulphates	31.1	23.3	19.0	16.8
Little Vistula —	chlorides	336.1	1308.1	2218.7	2643.3
Bieruń Nowy	sulphates	89.0	99.4	139.9	182.3
Gostynia —	chlorides	99.1	1076.1	2027.5	1715.5
mouth to Vistula	sulphates	45.4	73.7	124.1	114.6
Potok Golawiecki —	chlorides	953.5	876.4	1022.4	877.1
mouth to Vistula	sulphates	52.3	43.2	48.1	47.8
Przemsza —	chlorides	604.4	732.9	1012.9	730.6
mouth to Vistula	sulphates	459.0	595.2	465.2	418.6
Vistula —	chlorides	2043.3	3250.5	5158.3	5442.2
Bobrek	sulphates	659.8	544.7	621.5	659.5
		The Oder river and its tributaries			
Oder —	chlorides	205.2	213.2	269.5	217.1
Chałupki	sulphates	155.2	266.1	337.7	207.7
Olza —	chlorides	200.1	148.8	357.4	419.0
mouth to Oder	sulphates	37.3	50.3	40.1	47.8
Ruda —	chlorides	74.7	90.1	142.9	281.3
Ruda Kozielska	sulphates	31.1	36.7	39.9	50.2
Bierawka —	chlorides	389.7	287.4	829.8	313.9
Tworóg Mały	sulphates	37.0	35.5	55.5	45.8
Kłodnica —	chlorides	45.6	112.9	164.1	119.9
Łany Małe	sulphates	50.8	47.1	51.4	51.5

From the data presented in Table 7 it results that in 1980 the largest salt load was discharged to the Vistula by: the Potok Golawiecki and the Przemsza and since 1985 by the Gostynia and the Potok Golawiecki.

In the Oder basin located within the range of influence of the USCB, i.e. its left-bank tributaries (the Olza, Ruda, Bierawka and Klodnica) the largest amount of salt is discharged by the Olza and therefore by the Bierawka, Ruda and Klodnica. In the case of the Klodnica the role of "specific" settling tank in the years 1965–1994 was fullfilled by the Dzierżno Duże reservoir, which was finished in 1964. In the measuring section above the inflow of the Klodnica to the reservoir, the mean annual concentrations of chlorides in the years 1969–1975 amounted to from 835 to 1740 mg/dm^3. In 1977 the concentration of chlorides in this section amounted to 1635 mg/dm^3 and in 1994 — 1458 mg/dm^3. In the years 1969–1975 water in the reservoir contained significantly fewer chloride ions in relation to the water which flowed to it because the concentration of these ranged from 750 to 990 mg/dm^3. At the outflow from the Dzierżno Duże reservoir the concentration of chloride ions in 1977 amounted to 941 mg/dm^3 and in 1994 — 1368 mg/dm^3 (Rzętała, Wach 1995). It betokens the general increase in the salinity of the reservoir waters. The content of chlorides in water which outflowed from the reservoir conforms to its concentration in the water which inflowed. This situation now has a permanent (stabilized) character because the mean concentration of chloride ion in the period 04. 1994 — 04. 1995 in the reservoir water was still at the level of 1300 mg/dm^3 (Jankowski 1995).

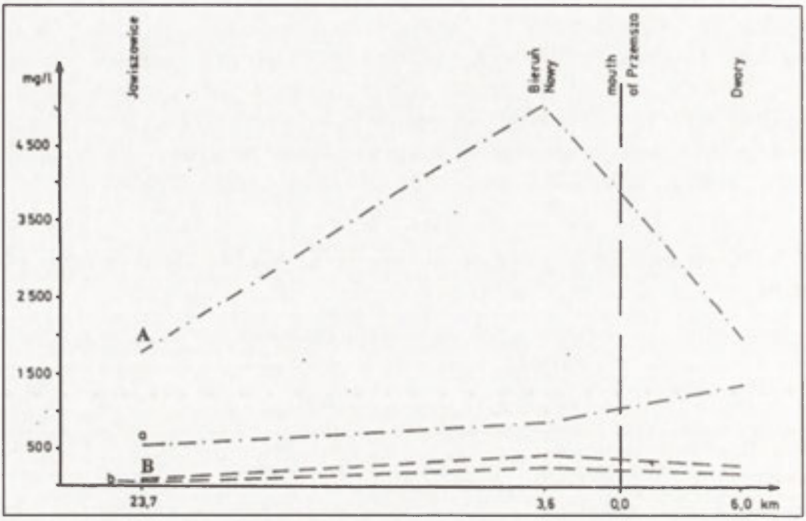

Fig. 3. Reliable concentrations of chlorides (a) and sulphates (b) for mean low flow (MLQ) of Vistula waters in 1976 (a and b) and 1985 (A and B)

It is very odd that the values given in Tables 5, 6 and 7, which confirm salt load discharged to the Vistula and the Oder and their tributaries are very different. It is rather unlikely that the load was bigger and bigger by so a big degree year by year. Values given by W. Szczepański and others (1995) base themselves on values for minewater discharges which were obtained from mines (Table 5 and 6). Calculations of the author from 1994 (Table 7) base themselves on the hydrochemical measurements of waters made by the Centre of Research and Monitoring on the Environment (OBiKS) in Katowice. Which values are more correct? In the opinion of the author the data from 1994 are right because they relate to really measured indicators of water pollution in the river. But these values of loads are polluted by the amount of chlorides and sulphates which are discharged in industrial wastewaters from the plants of other branches. OBiKS does not do precise research on wastewaters discharged in particular plants. It is sure that the chloride and sulphate ion load is not smaller than that estimated by W. Szczepański and others (1995). It is possible to think that these amounts are rather lowered. There is also the fact that in the overall load of pollutants discharged together with industrial and municipal wastewaters to the surface waters of Katowice province in 1993, chlorides and sulphates predominated. They accounted for over 50% of the total load of chlorides and about 35% of the sulphates which were discharged to surface waters in the country. Considering this, the share of minewaters from the USCB mines is unquestionable.

J. Krokowski and M. Karnas (1994) state that in the years 1989–1990 the mean percentage share of chlorides from minewater discharge in relation to the total chloride load in the Vistula above Cracow amounted to 83% and in the section of Warsaw — about 62% but in Kieżmark — the profile at the mouth of the Vistula to the Baltic Sea — about 38%. It is estimated that the excessive salinity of the Vistula waters is kept to the Wieprz confluence but in the case of the Oder remains along 277 km of its length, counting from the Olza confluence (Korol and others 1994).

In connection with the decrease in coal exploitation after 1985 the decrease in amount of minewater discharged to rivers as well as the decrease in the introduced chlorides and sulphates load followed. The decrease in introduced salt load is not as important as the decrease in the amount of minewater (Fig. 4).

Minewaters of some mines contain radioactive elements occuring in the formation, eg. radium (Ra^{226}) whose amount exceeds the values of the natural background. I. Węgrzynowska (1993) informs us that the concentration of radium Ra^{226} in minewaters of some mines amounts to: 17.3 kBq/m^3 — "Krupiński", 16.9 kBq/m^3— "1 Maja", 1.10 kBq/m^3—"Jankowice", 4–6 kBq/m^3 — "Piast"and "Czeczott" (but the maximum value is 20 kBq/m^3), 6.3 kBq/m^3 — "Silesia". The concentration for the natural background reaches 0.1 kBq/m^3; the standard for drinking water in Poland is determined as 0.11 kBq/m^3 (Węgrzynowska 1993). Research from the Main Mining Institute (GIG) in Katowice indicates that the minewaters do not put the inhabitants of the region at hazard radioactively but are not neutral for the natural environment. For this reason these mines undertake activities to remove radium from the minewaters. These exertions reduce the concentration of radium Ra^{226} to 0.4 kBq/m^3 in the case of the "Krupiński" mine.

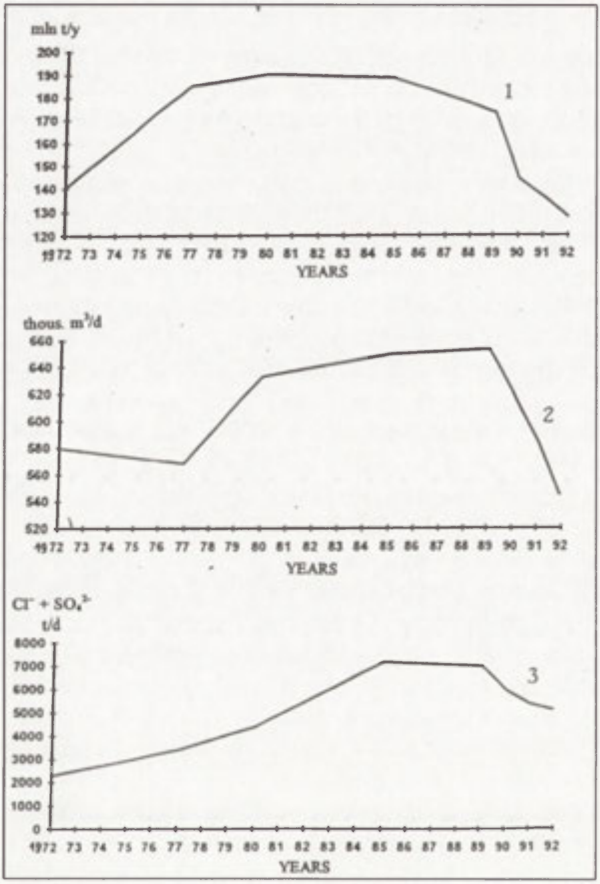

Fig. 4. Output of hard coal (1), amount of minewaters pumped out (2) and salt load (3) discharged to the rivers of Katowice province in 1972, 1977, 1980, 1985, 1989–1992 (after W. Szczepański — archival materials of IMGW — Katowice)

FINAL REMARKS

The above-presented data reveal that the influence of minewaters on the mineralization of river waters of the USCB area is very big and determines the salinity of rivers including the Vistula and the Oder. The excessive salinity of both rivers' waters is observed on rather long sections of their courses. As the years go by one should estimate that the excessive salinity of the Vistula and the Oder will move to the upper courses. The total salt load which is discharged to both rivers from the USCB reaches 5 thousand tones per day and thus accounts for over 50% of the overall chloride load and about 35% of the sulphates introduced into surface waters in the country.

The process of river water quality degradation in the area of Upper Silesia is also revealed as decrease in the dynamics of changes in the size of the transported salt load. This fact indicates that seasonal changes in water flow in the rivers have a smaller and smaller influence on the load size. It betokens important disturbance of their natural regimes. In some streams the amount of minewaters is greater than 50% of the total runoff. This has economic consequences as a result of the limitation of possibilities for use and the appearance of losses caused by accelerated disturbing of machineries which draw saline river waters for technological needs, e.g. in the ironworks of T. Sendzimir in Cracow. Prognoses made indicate that by about 2005, the amount of water pumped out by mines will have decreased by 14% but the concentrations of chlorides and sulphates ions will have increased by about 67% (Rogoż 1994) It will be caused by an increase in the mean depth of mine workings. Therefore the problem of salt water utilization will still be relevant and will be rather more sharpened. Although restructuring of the mine industry is being undertaken, the exploitation of coal (on a limited scale) is retained in the worked-out scenarios of spatial policy for the country's management (*Poland 2000 plus* 1995). Therefore a decided improvement of both Vistula and Oder water quality in near future is not a real possibility.

REFERENCES

Czaja S., Jankowski A. T., 1992, *The contribution of mine waters to the discharge and salinity of rivers in Katowice province*, Arch. Ochr. Środ. 2, 181–194.

Gajowiec B., Różkowski J., 1988, *Charakterystyka stopnia zasolenia zlewni Górnej Wisły*, Kwart. Geolog. 32, 3–4, 715–728.

Jankowski A. T., 1987, *Wpływ urbanizacji i uprzemysłowienia na zmiany stosunków wodnych w regionie śląskim w świetle dotychczasowych badań*, Geographia, Studia et Diss. 10, 62–99.

Jankowski A. T., 1995, *Z badań nad antropogenicznymi zbiornikami wodnymi na obszarze górnośląskim*, [in:] *Wybrane zagadnienia geograficzne*, Sosnowiec, 12–18.

Korol R., Jaśniewicz E., Bożek A., Szyjkowska U., Zelent B., Czapliński M., 1994, *Atlas zanieczyszczeń rzek w Polsce — lata 1990–1992*, Biblioteka Monitoringu Środowiska, Warszawa.

Krokowski J., Karnasa M., 1994, *Pomiar zasolenia wody w rzece Wiśle w przekroju powyżej Krakowa*, [in:] *Zasolenie rzeki Wisły*, Kraków.

Monitoring powierzchniowych wód płynących w województwie katowickim w 1994 roku, 1995, Aneks "A", *Obróbka statystyczna danych monitoringu rzek za okres 1.01.1994 do 31.12.1994*, Ośrodek Badań i Kontroli Środowiska, Katowice.

Ochrona środowiska i gospodarka wodna, Rocznik GUS z lat 1981, 1986, 1987, 1991.

Ochrona środowiska, 1994, GUS Warszawa.

Ochrona środowiska w województwie katowickim w latach 1990–1993, 1995, WUS Katowice.

Polska 2000 plus — Wstępna koncepcja polityki przestrzennego zagospodarowania kraju 1995, CUP, Warszawa.

Raport o stanie środowiska w województwie katowickim w 1994 roku, 1995, Biblioteka Monitoringu Środowiska, PIOŚ-WIOŚ Katowice.

Rogoż M., 1994, *Słone wody kopalniane w GZW i próby ograniczenia ich zrzutu do Wisły*, [in:] *Zasolenie rzek Wisły*, Kraków, 17–32.

Rogoż M., Staszewski M., Wilk Z., 1987, *Impact of mining activities upon the aquatic environment within the Upper Silesian Coal Basin (USCB)*, [in:] *Hydrogeology of Coal Basin*, IAH Kraków, 553–566.

Rogoż M., Różkowski A., Wilk Z., 1987, *Hydrogeologic problems in the Upper Silesian Coal Basin,* [in:] *Hydrogeology of Coal Basin,* IAH Kraków, 365–382.

Różkowski A., 1987, *Wpływ górnictwa na środowisko wodne GZW,* [in:] *Ochrona i zanieczyszczenie wód podziemnych,* Materiały IV polsko-czechosłowackiego sympozjum, Bierutowice, 127–137.

Różkowski A., 1995, *Factors controlling the groundwater conditions of the Carboniferous strata in the Upper Silesian Coal Basin, Poland,* Ann. Soc. Geol. Pol. 64, 53–66.

Różkowski A., Chmura A., Gajowiec B., Różkowski J., Stachura A., 1986, *Zasolenie wód Małej Wisły odprowadzanymi wodami kopalń węgla kamiennego,* [in:] *Problemy hydrologiczne południowo-zachodniej Polski,* Prace Nauk. Inst. Geotech. PWr, 237–244.

Różkowski A., Przewłocki K., 1987, *The origin of groundwater in the Upper Silesian Coal Basin,* [in:] *Hydrogeology of Coal Basin,* IAH Kraków, 155–170

Różkowski A., Rudzińska T., 1983, *Pochodzenie wód podziemnych w Górnośląskim i Lubelskim Zagłębiu Węglowym,* Przegl. Geol. 6, 370–377.

Rzętała M., Wach J., 1995, *Zmiany zasolenia wody zbiornika antropogenicznego Dzierżno Duże,* [in:] Jankowski A.T., Szczypek T. (eds) *Przeobrażenia środowiska geograficznego w przygranicznej strefie górnośląsko-ostrawskiego regionu przemysłowego,* Sosnowiec, 112–116.

Sawicki J., Gutry-Korycka M., 1993, *Wpływ kopalnictwa,* [in:] Dynowska I (ed.) *Przemiany stosunków wodnych w Polsce w wyniku procesów naturalnych i antropogenicznych,* Wyd. UJ, Kraków, 354–371.

Szczepański W., Sokołowska E., Pniak G., Korol R., Godlewski B., 1995, *Wpływ słonych wód dołowych z kopalń węgla kamiennego na jakość wód Wisły i Odry,* [in:] *Zagrożenia i szanse gospodarki wodnej* 2, Katowice, 371–380.

Węgrzynowska I., 1993, *Kierunki działań w zakresie utylizacji i zagospodarowania wód słonych z kopalń węgla kamiennego,* [in:] *Program działań ekologicznych zmierzających do poprawy warunków życia mieszkańców Górnego Śląska,* Katowice, 43–54.

Wilk Z., Adamczyk A. F., Nałęcki T., 1990, *Wpływ działalności górnictwa na środowisko wodne w Polsce* SGGW-AR 27, Warszawa.

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THE INFLUENCE OF ANTHROPOPRESSURE ON WATER RELATIONS IN THE WIELKOPOLSKA LOWLAND

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ABSTRACT: This contribution describes the influence of anthropopressure on water conditions in the Wielkopolska Lowland. In particular this is connected with gaining new areas for agriculture: firstly through deforestation and then through drainage of marshy areas. As an effect of this hydro-economic activity of man the natural cycle and balance of hydrological processes have often been interrupted. This is particularly visible in the modification of the hydrographic network; e.g. changes in river routes, the elimination of some rivers and lakes, the loss of marsh areas and the regulation of outflow conditions in rivers. Dewatering of the Wielkopolska Lowland has progressed for around 1000 years and is manifested in the form of increasing water shortages.

KEY WORDS: anthropopressure on water conditions, water management, drainage work, Wielkopolska Lowland, Central Poland.

In the last millennium, the natural environment of the Wielkopolska Lowland has undergone intensive changes primarily related to man's economic activity. The changes have affected the vegetation cover, soil and water relations and, in some areas, also their hydrographic pattern. In general, the process of change was very slow and as such could not be perceived by the inhabitants, especially since their average life span up to the 19th century did not exceed 30 years. Changes of this type can only be observed in retrospect, after they have become consolidated and have assumed certain features of stability.

The changes in the natural environment related to man's economic activities and natural climatic changes have overlapped and we cannot clearly determine or separate these effects. For instance, increased climatic humidification has made river valleys more marshy, but a similar change could also result from dividing a valley with a road embankment stopping or limiting the drainage of water from its upper regions. On the other hand, the cleaning-out of a river bed to enable the work of water mills, could have the contrary effect. The inhabitants of the Wielkopolska Lowland built embankments and exerted an influence on the shape of rivers as far back as in the early Middle Ages.

Due to the lack of a chronological compilation of archaeological findings and a lack of studies on the history of settlement in the Wielkopolska Lowland, a detailed reconstruction of changes in water relations in earlier centuries is still impossible. Even the results of the research on the changes in water level in Goplo Lake in the early Middle Ages do not allow for generalisations, since they could be caused by both natural factors of local character as well as by human activity. One should also take into account local effects of neotectonic movements, for example uplifting movements in the Kruszwica region resulting from the tectonic structure of Goplo Lake, or downward movements in the region of Poznań. Although in the scale of one year the intensity of these movements is small, in a millennium they could bring about changes influencing the hydrographic system and humidity relations. So far we have not discovered the mechanism of such transformations of water relations. In consequence we are not able to explain why the settlements located by lakes, dated back to the early Middle Ages are placed in some areas high above the present water level and in others below that level.

Up to the 10th century, man's economic activity had a relatively small influence on environmental changes and covered as little as 10–20% of the Wielkopolska Lowland, with only 5–6% of the area affected by intensive exploitation (Kurnatowski 1975). At that time, settlement and agricultural activity concentrated mainly in river valleys and in lake gullies. Early settlers were attracted by the ease of farming on alluvial soils, formed predominantly on the layers of sand covering the bottoms of river valleys which were additionally fertilised by annual flood waters. At the end of the last millennium the level of underground waters in river valleys was at least 1 metre below the present level, a situation which can be inferred from the fact that most settlements were then located at the upper levels of the flood terrace. Moreover, archaeological research conducted in the Obra river valley revealed that lower parts of dug-outs and fortifications were situated 1 to 2 metres below the present level of groundwaters (Kurnatowski 1968).

Due to the increasing humidification of climate entailing a rise of underground as well as surface waters, the process of settlement moved from valleys to upland regions which were adapted for agricultural purposes, mainly through deforestation. After the 13th century the process was facilitated by the introduction of improved agricultural tools by German settlers, which helped put heavier soils under cultivation. The decrease in the area overgrown with forests was often accompanied by the self-renewal of forests on the land abandoned by farmers. However, the new forests were considerably poorer in species. People still did not know how to adapt wetlands for farming. At the end of the 13th century, river valleys were used mainly for pastures. According to H. Błaszczyk (1974), at the end of the 14th century, that is under near-natural landscape conditions, the area of plough-land constituted only 18% of the historical region of Wielkopolska, while forests covered 50.5% of the area (Fig. 1). Till the end of the 18th century the plough-land area was enlarged, primarily through deforestation, especially in the regions with fertile soils. Initially, deforestation was only a way to obtain arable land. However, from the 15th century, its intensity in the Wielkopolska region increased considerably. Wood and wooden products became attractive export commodities and in the 16th century the boom in corn exports to Western Europe started. Also at that time industry and crafts requiring large supplies of wood developed. According to K. Hładyłowicz (1932), at the close of the 16th century forests occupied 40.9% and at the end of the 18th century only 30.8% of Wielkopolska. By the beginning of the 20th century the area had decreased to as little as 20.7% (Miklaszewski 1928). The process of the shrinking of the area covered by forests and swamps was presented by K. Hładyłowicz (1932). See Table 1.

TABLE 1. The process of shrinking of the area occupied by forests and swamps in Wielkopolska from the end of the 14th century till the 19th century (Hładyłowicz 1932)

Administrative district	Total area in km^2	% of the total area			
		14th century (1370–1400)	16th century 1523 and (1580–1600)	18th century (1780–1800)	20th century
Gniezno	3121	38.4	28.4	19.4	7.9
Kcynia	2192	43.0	30.5	27.1	12.7
Kruszwica	327	39.4	33.6	27.2	16.3
Pyzdry	3221	37.3	28.1	20.5	10.3
Kościan	5079	44.8	37.1	27.3	20.2
Wschowa	532	62.4	53.4	28.4	22.3
Poznań	8780	57.7	49.9	38.6	33.1
Kalisz	3301	45.0	35.2	29.2	17.4
Ostrzeszów	1073	64.4	56.1	38.9	28.2
Bydgoszcz	1702	63.4	55.9	45.4	35.3
Nakło	3137	63.7	46.1	30.1	17.9
Total	32,393	50.5	40.9	30.7	20.7

Source: after Hładyłowicz 1932.

Intensive deforestation of upland areas brought about changes in the whole natural environment, since forests fulfil the role of natural regulators of the water cycle. Apart from reducing evapotranspiration, deforestation affected the infiltration capacity of soils, which in turn resulted in increased surface run-off of precipitation waters and thus reduced the supply of underground waters. As a result the water table was lowered. The increase in the amount of water flowing into river valleys and depressions with a small

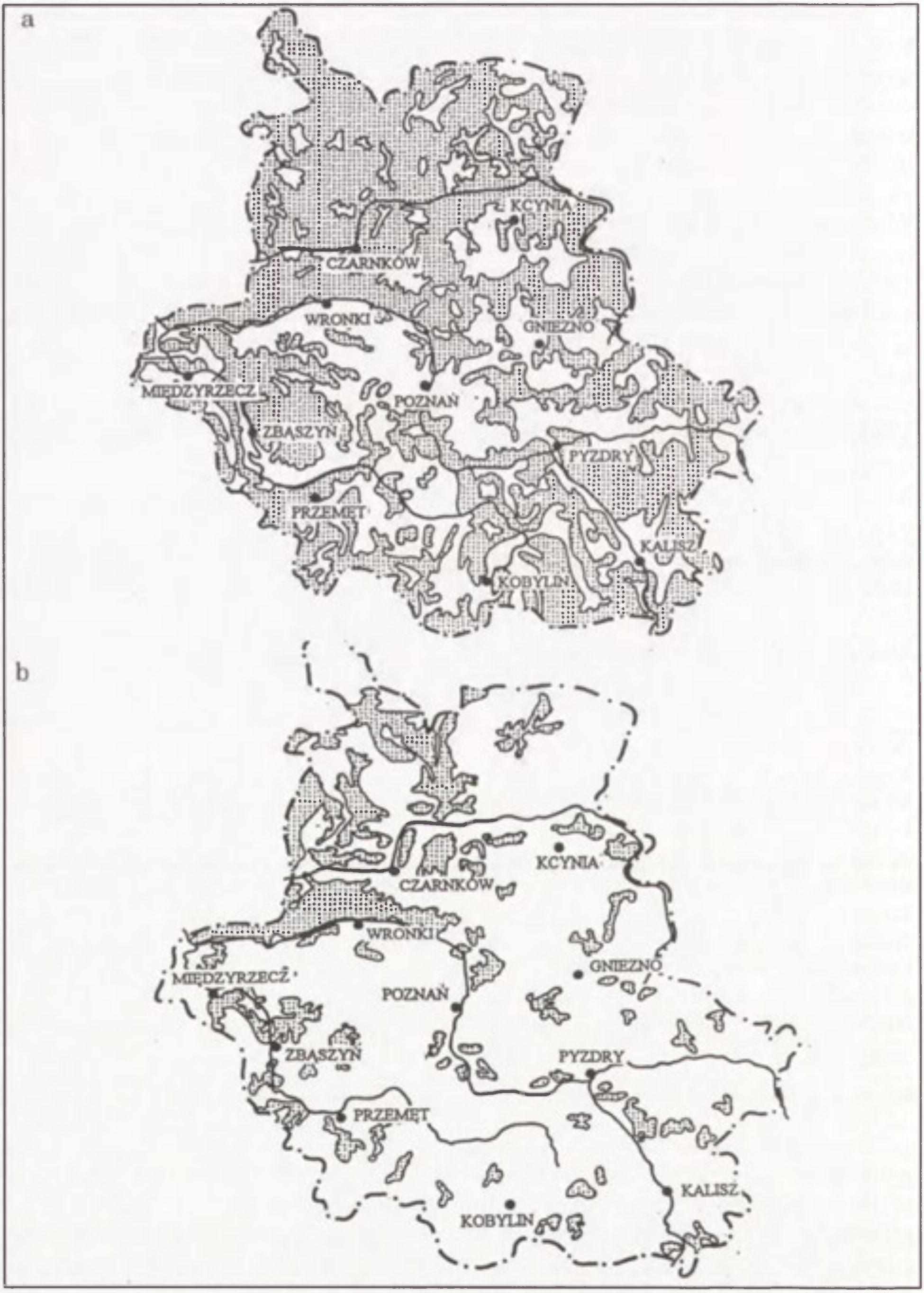

Fig. 1. Distribution of forests in Wielkopolska at the close of the 14th century (a) (H. Błaszczyk 1974) and nowadays (b)

elevational drop in lowland areas resulted in a rise in water levels and turned their lowest parts into marshes. The increased irregularity of river flows was another consequence of the phenomenon.

Freshets were increasingly high, while the duration of low stages lengthened with a simultaneous decrease in water level. Increased surface run-off contributed to intensified erosion of soil resulting in the increased presence of rubble which in turn accelerated the process of reversion of rivers to their virgin state. This is by no means a complete list of the consequences of deforestation in Wielkopolska.

According to rough estimates, in the 10th century, forests, swamps and surface waters occupied between 70% and 80% of the total area of Poland (Kaniecki 1993). The oldest chronicles and accounts present the Wielkopolska Lowland not only as a land of forests, but also as a region of marshes, difficult to travel across. In order to determine the size of the ancient wetlands, the surface areas of hydrogenic soils were calculated on the basis of the existing soil maps at the scale of 1:100,000 (Kuczyńska 1995). The types of soils formed on wetlands were taken into account. These included: black-earth, silt-peat soil, peat and muck-peat, muck-mineral and fen soils. One can assume that in the Middle Ages the area of wetlands slightly exceeded the present area of hydrogenic soils, since as a result of dewatering carried out in the 19th and 20th centuries, soils in some areas were transformed and dried out to such an extent that now it is difficult to find traces of their marshy origin. In the six provinces under study the total area of the above listed types of soil amounts to 6040 km^2, that is slightly more than 22% of their area.

Adding the area of surface waters, i.e. rivers and lakes, which in the Middle Ages was much larger than nowadays (the present area of lakes in the Wielkopolska–Kujawy Lake District is 1.23% of the total area; see Choiński 1995), to the wetlands area, one can assume that they together occupied around 25% of the area of the Wielkopolska Lowland.

Numerous town names, frequently originating in the early Middle Ages, refer to the past marshy character of the area (e.g. Kalisz, Babiebloto, Trzęsawiska, Bielawy, Błotno, Mokrzec, Bagienko, etc.). The vastness of the wetlands created the need for the construction of dikes, roads embankments and bridges to maintain communication between towns and settlements. Numerous mentions referring to that fact can be found in source materials. Probably the earliest piece of information about a "bridge" over the marshes comes from Ibrahim ibn Jacob's relation from the journey to Slavic countries in the year 996, translated by Al-Bekri. The author described a one mile long platform or road made of logs and round timber laid across a marsh in the land of prince Nakon, south of the present town of Perleberg (*The Ibrahim* ... 1946).

Archaeological research has revealed numerous traces of such medieval fords. Inhabitants of towns or villages adjacent to such crossings over rivers and swamps were obliged to repair them. In the Middle Ages the construction of bridges was regulated by laws issued by the prince of the land (Gloger 1972).

The development of trade, both domestic and between different nations, depended to a large degree upon the condition of roads and bridges. That is why the authorities took care to maintain them in a good state.

While in the early days the passages through wetlands were paved only with wood, they later took the form of dikes filled with sand, reinforced and interlaid with wood and, still later, were paved with stones ("...A like between the lakes paved with cobble-stones, further with fascines, ditched, bordered with trees ..." — Góralski 1959). Some of them, even in the Middle Ages, were constructions of impressive sizes. A 25 km road embankment running from Głuszyna near Poznań along the Kórnik–Zaniemyśl Lakes gully up to the Warta could serve as an example. In 1331 a battle with troops of the Teutonic Order, recorded by Jan Długosz (1961–1985), was fought in its vicinity.

Crossing of wetlands required the preparation of a "bridge", a dike or a paved ford. Names of towns, such as Brodnica, Brody, Brodek, Bródno, Biały Brod, etc. indicate the past existence of nearby fords, most often paved with wood.

Apart from wooden platforms one can distinguish:

— communication dikes in the form of embankments, built across river valleys, ranging from less than 100 m to over 4000 m in length, e.g. the dike in Międzyrzecz or dikes crossing the Noteć river valley, 6–7 metres wide,

— flood protection dikes in Poznań and Skwierzyna ("... the dam along the river is 260 metres long and 6.5 m wide" — Góralski 1959),

— dikes leading to water mills, usually short structures, running across marshes,

— dikes located by ponds,

— dams impounding river waters in order to extend the operating capacity of water mills.

Along with the development of trade, the problem of maintaining the main routes in good condition acquired increasing significance. As early as in 1569, the Polish Parliament (Sejm) appointed special officers responsible for inspecting roads and passages. At that time the first survey of all the roads and highways in Poland was carried out and bridge and dike toll rates were inspected.

The inspection carried out in 1767 showed that practically all river valleys had been provided with communication dikes, i.e. with road embankments, in order to maintain the continuity of traffic (ibidem). Sometimes even small valleys e.g. the Samica river valley (near Stęszew) were crossed with at least three communication dikes. They hindered the outflow of water from the valley and thus made them more marshy. One can assume that such dikes already existed in the Middle Ages. Through the centuries they were maintained in a good state in order to preserve the continuity of traffic along the main communication routes.

At the close of the 16th century, the so-called "Dutch colonisation" ("kolonizacja holenderska"), aiming at bringing wetlands under cultivation, started in the Wielkopolska Lowland. The area of plough-land was increased by the drainage of the excess water from the boggy or partly-flooded areas. Dutchmen indeed were the first colonists who brought under cultivation vast areas of wetlands, often overgrown with black alder bog forests and shrubs. They were equipped with many centuries of experience in that field. Later on the "Dutch colonisation", which in the 15th century started in the region of Żuławy Gdańskie, and subsequently spread over Prusy Królewskie and Prusy Książęce and progressed towards the south along the Vistula valley, was continued mainly by German immigrants. In the region of the present Ciechocinek on the Vistula, "Dutch" settlements extended in a wide belt across the Kujawy, especially in the vicinity of larger lakes, and entered the Warta river valley where their number reached several tens between Kolo and Oborniki Wielkopolskie (Baranowski 1915). The oldest preserved location privilege from the historical region of Poznań province refers to Olędry Ujskie. The village was established in the year 1597. Other settlements of this type were built in the areas adjacent to the Noteć and Warta estuaries (Rusiński 1947).

The "Dutch colonisation" developed on a particularly large scale at the close of the 17th century and lasted up to the partitions of Poland. For instance, in the Kościan administrative district, all "Dutch settlements" are dated to the 18th century. The highest concentrations of settlements of this type came in to existence in the Noteć river valley between Czarnków and Wieleń, on the Warta river in the vicinity of Międzychód and to the east of the Obra river, on the Warta between Śrem and Pyzdry, and in a wide belt extending along the Czerniejewo–Murowana Goślina–Rogoźno–Chodzież line. All these settlements were located in the former Kościan and Poznań administrative districts, while none of them were established in the Walcz administrative district and in the district of Wschowa. In 1789, the number of unquestionably "Dutch" settlements amounted to 156 in Poznań administrative district and to 111 in Kościan administrative district (Rusiński 1947). Apart from being located in the valleys of big rivers and on shores of all types of inland waters, "Dutch" settlements were sometimes built on flat, outwash wetlands, for instance near Nowy Tomyśl, and in higher, dry areas where the land for farming was gained by way of tree logging. However, the building of settlements in wet areas and their dewatering prevailed.

Within the wet areas water was directed to rivers or lakes by means of ditches or was accumulated in deep ditches and pits. In spite of the high intensity of "Dutch" colonisation, the process of the dewatering of wetlands was relatively slow and covered relatively small areas. Vast areas of marshes remained untouched.

River engineering entailing in the straightening of the courses of rivers, moving river-beds, clearing and protection of their banks, initially for defence reasons, and then impounding of their waters enabling the work of plants driven by water wheels, also affected water relations in the adjacent areas and the intensity of river-bed processes (Fig. 2). The processes were particularly clearly evident in the areas adjacent to larger towns, where water mills were most frequent (Fig. 3). The adaptation of watercourses for the needs of water mills involved first of all dredging of their beds and damming-up of their waters. As far as the change of water relations is concerned the consequences of these activities varied. Damming-up of watercourse waters resulted in the rise of the underground water level in adjacent areas, while the dredging of river-beds and the digging of drainage ditches in wetlands were responsible for lowering of the water table.

Within lowlands, where only a slight elevational drop occurred and where in summer, due to low flow, water- courses frequently lost their waters in boggy segments of valleys, their resources were increased by supplying water from lakes, other watercourses or bogs by means of canals and ditches. In the course of time changes of this type, initially taking place in areas adjacent to towns, spread over increasingly large

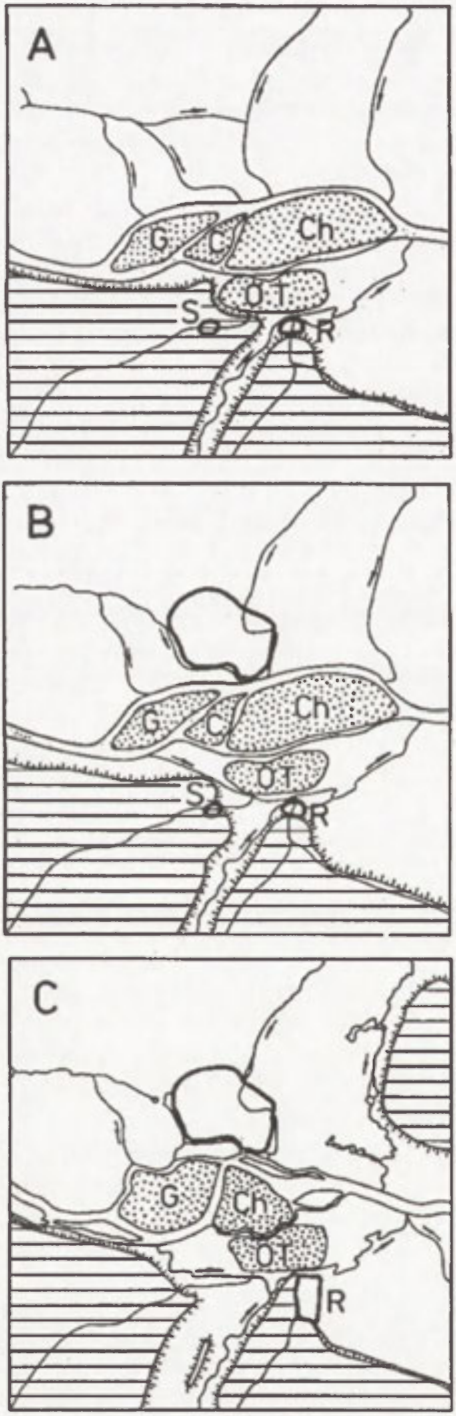

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Fig. 2. Changes in the relief and watercourse network in the vicinity of Poznań
A — around the middle of the 13th century, B — in the 14th century, C — in the 18th century, G — Grobla; C — Czartoria, OT — Ostrów Tumski, S — Spytkowo, R — Śródka, 1 — boulder clays of the upper terrace level, 2 — alluvial sands on river islands (Kaniecki 1993), 3 — the boundary of cities

areas, as is exemplified by the adaptation of the Bogdanka river for the needs of water mills in Poznań (Kaniecki 1993).

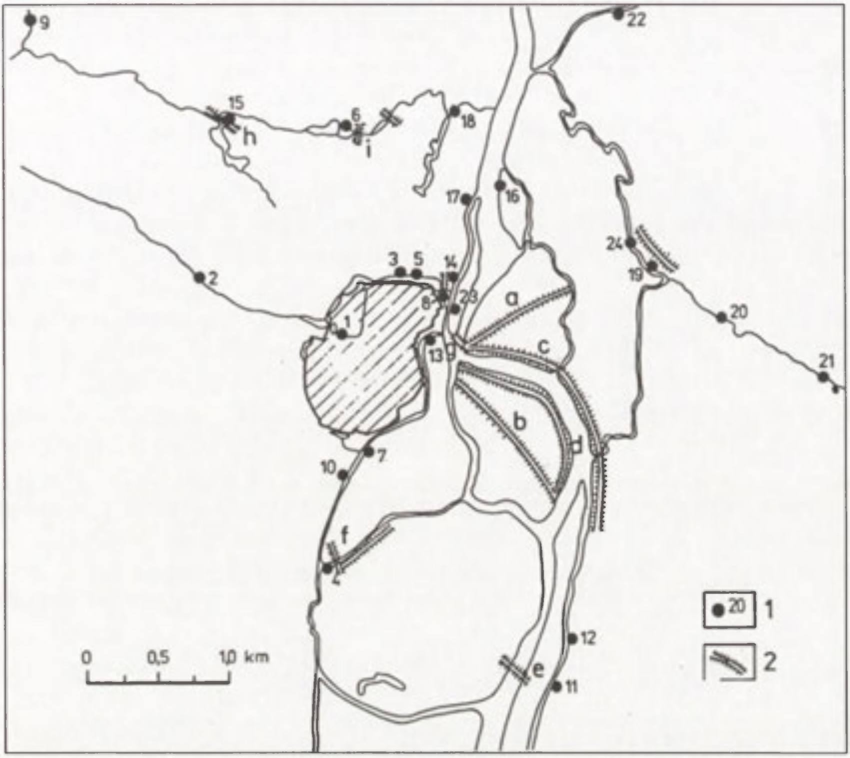

Fig. 3. Location of water mills (1) and dikes (2) in the vicinity of Poznań in the 15th and 16th centuries (Kaniecki 1993):
water mills: 1 — Bogdanka, 2 — Folusz, 3 — Folusik, 4 — Śluza, 5 — Piła, 6 — Podgórnik, 7 — Czapnicki, 8 — Wielki, 9 — Wierzbak, 10 — Ungrów, 11 — Górków, 12 — Topolny, 13 — Faffków (hospital św. Krzyża), 14 — hospotal św. Ducha, 15 — Przepadek, 16 — Kapitulny, 17 — Groffowy (Dominikański), 18 — Podolny, 19 — Środka, 20 — św. Jana, 21 — Łączny, 22 — Nadolnik, 23 — Garbuz, 24 — Szklany; dikes: a — Chwaliszewo, b — Nowa Grobla, c — Czartoria, d — Łacina, e — Kamienna, f — Spustna, g — near Dominikanie, h — near mill Przepadek, i — near mill Podgórnik

In the second half of the 16th century, extensive river regulation works, covering longer river segments, were initiated. River-beds, often blocked with wood and boulders, dammed with dikes and weirs, separated into arms and branches. The Warta and the Noteć rivers in their lower courses created a real water labyrinth covering the entire proglacial stream valley. Only short segments of their main beds were clearly marked. In spring, during thaws and after torrential rains, huge marginal lakes covering vast areas of land formed. The process was facilitated by a very low elevational drop of most of the rivers and of the bottom of the valley, lower than 0.2‰.

The Warta and Noteć river beds in their lower courses, that is within the borders of the Prussian state, were regulated first, under Frederick II's rule. Straightening of the bed of the lower Noteć and cutting the obstructing bushes away "...doubled the outflow, lowered the water level in the river and dewatered the areas of previously-flooded banks" (Surowiecki 1811). Straightening of the river-bed was accompanied by the digging of canals and ditches draining water from wetlands (Piasecka 1974). At that time cuttings were dug, arms of the river regulated, banks protected and the elimination of the redundant network of river arms begun.

In the bed of the Warta, along its middle and upper course, work aiming at improving navigation was undertaken before the beginning of the 19th century. The regulation of the Warta by the Prussian government involved removing weirs and objects obstructing navigation, planting extensive sand outwashes with shrubs, digging cuttings and stabilising banks.

Intensification of drainage work within the Wielkopolska Lowland took place after the annexation of the region by the Prussian state. In 1773, when as a result of the first partition of Poland a part of the Bydgoszcz region was annexed, the construction of the Bydgoszcz Canal connecting the Wisła with the Noteć commenced, and the eastern areas of the Noteć river valley were drained. Within one year of the annexation of Poznań province, in 1793, preparation of drainage system plans for the Obra river valley had started. However, extensive marshy areas existed in this region even up to the beginning of the 19th century. These were: in the north — the Noteć river marshes, and towards the west — the Oder and Obra Skwierzyńska river valley, towards the south the Warta and Obra valley and the Barycz river valley, towards the east — the upper Noteć valley. In addition, the valleys of the tributaries of the above mentioned rivers formed continuous tracts of swamps and marshes. Other larger marshy areas were: the Bachorskie, Dzimońskie, Buczkowskie and Oniczkowskie marshes and the valleys of the Orla, Gąsawka and Wełna rivers. According to historical records over 40 large marshy areas existed within the Wielkopolska Lowland at that time. According to F. Stryjewski (1980), in 1815 there were 1,175,000 ha of plough-lands and 1 million ha of grassland, including 587,500 ha of meadows and 412,500 ha of pastures. Marshlands covered 50,200 ha and forests 605,800 ha. Land melioration was undertaken on the largest scale in the Obra river valley; it commenced in 1799 and continued up till 1806. At that time canals within the area of Wielki Łęg (Great Ash–Alder Forest) were dug: the 53.9 km Southern Canal, 57.6 km Northern Canal, 8.2 km Kościan Canal, 25.7 km Mosina Canal, 6.8 km Wincentów Canal and the 6.3 km Dźwina Canal. The total length of the canals built at that period amounted to around 158.5 km. They contributed towards improving the run-off of waters from the Obra river Great Ash–Alder Forest.

In the years 1810–1812 the first thorough maintenance work along the canals, entailing the removal of aggradate muds, was carried out. With the use of technical means available at that time maintenance of canals was very difficult due to the limited access to the areas as well as the incompleteness of maps and drawings.

The partial drainage of the upper Obra valley, carried out in 1820–1823, enabled work to commence on new land surveys, and in consequence further development of the basic land melioration system. Major land melioration work was undertaken in 1825. This involved extending the Kościan Canal from Kościan to Krzywiń and building a canal starting in Wonieść lake. In 1830 the canal between Krzywiń and Goworek was completed, and later, in the years 1830–1831, the Central Canal running through the middle of the Obra river Great Ash–Alder Forest was dug.

The main network of ditches was completed and the correction of existing canals was carried out following the institution of Towarzystwo Melioracji Obrzańskich (the Obra River Land Melioration Society) in 1842. The statutes of the Society were signed by the Prussian king Frederick William on 16th August in his Sanssouci residence. In the following years further water companies were established. Using government loans they drained particular wetlands or lowered the water level in lakes in order to reclaim new lands. The companies were formed in order to lower the water level in: Slesińskie Lake near Bydgoszcz (1844), and the Powidzkie, Budzisławskie and Wójcińskie Lakes (1874). Valleys of smaller rivers were meliorated in the years 1855–1864 and the beds of rivers, such as the Samica Stęszewska (1853), Orla, Dąbroczna, Barycz, Ołobok and the tributaries of the Ciemna, Samica, Flinta, Sredzka Struga, Miłosławka and Lutynia were cleaned out.

In the second part of the 19th century, following the great flood of 1855, work began on the regulation of the upper Noteć river between Goplo Lake and the Nakło and Bachorskie and Parchańskie Marshes. The biggest land melioration company (the Obra River Land Melioration Society) covered an area of around 25 thousand ha, and the smallest — 7.31 ha.

The increase in the number of these companies was very slow. In the first 30 years (1842–1872), 1 to 2 companies per year were established. In each of the years 1842, 1851, 1852, 1855 the establishment of only one company took place, two companies were set up in the year 1856 and so on. Only in 1876 — 4 and in 1869 — 5 were larger numbers of companies established. The sizes of the areas covered ranged between 62 and 6000 ha (with the exception of the Obra River company covering 24 900 ha). In the next 28 years (1872–1890), from 2 to 8 new companies appeared every year. The year 1891 began the prime time for their development.

The following data present a general picture of the development of land melioration companies (Łukomski 1935):

Period	Number of companies established	Area covered in ha
1842–1870	24	48,509
1871–1890	57	39,546
1891–1914	420	162,542
1915–1922	52	16,605
1923–1930	144	40,882
Total	697	308,024

On the other hand, drainage companies only started to appear around the year 1885. The first such company to be registered was a drainage company from Lipownica (Śrem administrative district) established in 1886. According to B. Łukomski (1935), 711 land melioration companies were officially registered before the year 1935. Łukomski distinguished three types of land melioration:

1. Regulation of rivers, ditches and canals (24 companies),
2. Dewatering, mostly of meadows, sometimes combined with irrigation (128 companies, including 15 also dealing with irrigation),
3. Drainage companies.

After 1848 the size of subsidies allocated yearly to river regulation increased. Systematic regulation of the Warta river bed, upstream from Poznań, only started in 1873 (Jaśkowiak 1995). Carried out definitely much more vigorously was the work conducted in the Warta river bed downstream from Poznań, where apart from being regulated the bed was also cleaned of stones. First of all, the meandering sections of the river bed were straightened, then remnants of old hydraulic engineering structures (bridges, water mills and such like) were removed. The bed was dredged and flood dikes were erected from Poznań up to the estuary. After the year 1876 relatively safe navigation was possible along the lower and middle courses of the Warta

Regulation work in the Warta river bed, carried out several times and consisting primarily in the straightening of its course, facilitated water runoff and the floating of goods and resulted in dewatering of vast wetlands. The course of the river was shortened considerably; by 30.5% from the Prosna estuary up to Śrem, and by 27% between Śrem and Rogalinek (Ingarden 1921). Subsequently the regulation of smaller watercourses started. The regulation of the Prosna primarily involved the erection of embankments in its lower course, while in its upper course numerous weirs damming up the water were built. As a result of regulation, the lower course of the Noteć was shortened by 16.1% (Stryjewski 1980).

Deepening of the river bed is one of the common results of the regulation. In the case of the Warta, however, lowering of its bed was insignificantly small, and the opposite process took place in its certain sections. Within the 408 km section of the river between Koło and the place the Warta flows into the Oder the free surface of water was only lowered within a span of 110 km, while it was raised along a 150 km section and remained unchanged along a 148 km section (Lambor 1951).

Attempts to achieve maximal increase in the size of the areas under cultivation through deforestation or through dewatering of marshy areas or open water reservoirs had an adverse effect on the water cycle. Similarly, regulation of rivers consisting mainly in the straightening of the naturally meandering river beds resulted in an increase of elevational drop and of the speed of water runoff. It caused deepening of river beds and, in consequence, lowering of the level of underground waters. Soon, often as early as in the next generation's lifetime, newly-reclaimed cultivated land turned out to be excessively dry. For instance, as a result of the land melioration in Kujawy the underground water level fell by several meters. In wide, previously marshy, river valleys the underground water level in summer months often falls below 2 m (Kaniecki 1991).

Low stages of watercourses are a reflection of the underground water supply. Z. Pasławski states (1964) that according to the water level indicator in Skwierzyna on the Warta river in the years 1870–1962 the average level of low stages fell by 18 cm. At the same time the average duration of low stages increased from 75 days at the beginning of the studied period to 192 days at its end, that is almost three times. Minimal water levels were shifted from July to September. Moreover, some of the minor rivers disappeared. These were: the Goplenica, starting at Gopło Lake and mentioned by Jan Długosz, the Elsse near Świebodzin, the Oder's tributary and the Zielona Struga starting in the peat-bogs in the Dziemionna valley in the vicinity of Inowrocław (Falkowski, Karłowska 1961).

A particularly intensive process of reduction of the river network is evident in urban areas. At the turn of the 19th and 20th centuries the following watercourses ceased to exist: the Zgniła Warta, Struga Karmelicka and Struga Rybacka as well as the lower courses of the Wierzbak and Bogdanka rivers (Kaniecki 1993). This tendency is still evident — in the 20th century the following watercourses disappeared: the Bystry Rów, Obrzyca, Piaśnica and its tributaries: the Pokrzywka, Zegrzynka and Chartynia, directed to the underground sewage system (Kowalik 1995). In the rural areas, for instance in the vicinity of Poznań or Gniezno, "piping" of minor watercourses, making agricultural work difficult, is practised. The majority of the rivers (as evidenced on the basis of hydrographic charting carried out currently in the Wielkopolska Lowland) run waters periodically. In the summer months even rivers draining areas of several hundred square kilometres run water only from the middle of their courses.

Intensive dewatering of both uplands and valleys resulted in lowering of the water level in lakes and frequently in their complete disappearance. The survey of the 18th century maps drawn by Zanoni, Gilly and Fan, that is from the period preceding intensive land melioration, proves that around 30 lakes disappeared completely from the Wielkopolska Lowland. At the same time, the surface areas of the remaining lakes decreased considerably. This is especially true of the lakes with artificially lowered water levels, for example: Goplo Lake whose water level decreased by 270 cm, Sadlogoszcz Lake — by 130 cm, Ptureckie Lake — by 50 cm, Mielno Lake — by 116 cm, Pakoskie Lake — by 76 cm and Bronislawskie Lake — by 66 cm (Schulemann 1865).

In order to determine the changes in the surface area of lakes within the Wielkopolska Lowland a comparison of the surface areas of 326 lakes was made using: a) Prussian maps from the years 1890–1894 (150 sheets) and b) the corresponding contemporary Polish maps from the 1980s, on the scale of 1:25,000. The average rate of lake disappearance for this period is 13% (Jutrzenka 1989). While, according to A Choiński (1992), in this century, up to 1975 in the Wielkopolska–Kujawy Lake District the total surface area of lakes decreased by 15.21%. It is true to an even greater extent of small water reservoirs with surface areas below 1 ha. To evaluate the rate of their disappearance during the last 100 years their numbers were calculated on 56 topographic sheets on the scale of 1:25,000 from the years 1890–1894 and on the corresponding photographic maps from 1941 and on the maps from the 1960s on the same scale (Stasiak 1991). On the maps from 1890–1894 11,068 of such small bodies of water were recorded, on the photo maps from the year 1941 — 4,483 (44%), and on the maps from the 1960s — 2490 (22%). One should remember, however, that the 1890s witnessed the final stages of the implementation of big dewatering projects in the Wielkopolska Lowland.

The same comparative materials proved that the most significant changes in the numbers of small bodies of water took place in the regions of Jarocin and Dobrzyca — around 80% of such reservoirs disappeared (ibidem).

On the other hand, in the two decades between 1942 and 1963, significantly greater than average decreases in the number of small lakes took place in the area of Dąbrowa Biskupia, Duszniki, Konojad and Jutrosin where it exceeded 40%. During the entire studied period (1890–1963) a particularly high number of formerly-existing lakes was recorded in the southern part of the Wielkopolska Lowland, in the region of Dobrzyca, Borzacin, Rozdrażewo, Krotoszyn, Ostrów, and in watershed zones.

The decreasing surface area of lakes and their disappearance can be associated with land melioration and drainage, regulation of rivers, or eutrophication of lakes as a result of a considerable inflow of biogenic substances. As a result of dewatering low areas, low grasslands dried out and they were turned into arable land, as a consequence of which the share of meadows and pastures gradually decreased. While at the close of the 18th century the areas of meadows and pastures still equalled the surface area of arable land (a 1:1 rate), by 1815 the rate had changed to 1:1.2 (Stryjewski 1980), and by the middle of the previous century it had changed to 1:3.7 (Falkowski, Skolimowski 1969), and currently it is around 1:5.

Dewatering of the Wielkopolska Lowland has progressed for around 1000 years now. At present it is a stable process caused exclusively by man's activity; initially unintended and for around the last 200–300 years an intentional one. It manifests itself in the form of disturbances occurring in the water cycle and in river bed processes, and also in the form of increasing water deficiency in this area due to continuous dewatering work carried out in present times also.

REFERENCES

Baranowsk T., 1915, *Wsie holenderskie na ziemiach polskich*, Przegl. Hist. 19, Warszawa.

Błaszyk H. 1974, *Rozwój lesistości Wielkopolski*, Kronika Wielkopolska 3–4, Poznań.

Bobrowicz J.N., 1846, *Opisanie historyczno-statystyczne Wielkiego Księstwa Poznańskiego*, Leipzig

Choiński A., 1992, *Katalog jezior Polski*, Part 3, Pojezierze Wielkopolsko-Kujawskie, UAM Publishing House, Poznań.

Choiński A, 1995, *Zarys limnologii fizycznej Polski*, UAM Publishing House, Poznań.

Długosz J.,1961–1985, *Roczniki, czyli kroniki sławnego Królestwa Polskiego*, PWN, Warszawa.

Falkowski M., Karłowska G., 1961, *Rozwój łąkarstwa w Wielkopolsce*, PTPN, The studies of the Committee for Agricultural and Forest Sciences 9, 2, Poznań.

Falkowski M., Skolimowski L., 1969, *Gospodarka łąkowa w Wielkopolsce*, PWRiL, Warszawa.

Gloger Z., 1972, *Encyklopedia staropolska*, 3, Wiedza Powszechna, Warszawa.

Góralski Z. 1959, *Taryfy mostowego i grobelnego Wielkopolski z 1769 roku. Województwo poznańskie i kaliskie*, Studies and materials for the History of Wielkopolska and Pomerania 5, 1, Poznań

Hładyłowicz K., 1932, *Zmiany krajobrazu i rozwój osadnictwa w Wielkopolsce od XIV do XIX wieku*, Lvov.

Ingarden R, 1921, *Rzeki i kanały żeglowne w byłych trzech zaborach i znaczenie ich gospodarcze dla Polski*, Kraków.

Jaśkowiak H., 1985, *Wpływ XIX-wiecznych melioracji na odwodnienie Niziny Wielkopolskiej*, Typescript, the archives of the Institute of Hydrology and Water Management, Physical Geography Department UAM, Poznań.

Jutrzenka K., 1989, *Zmiany powierzchni jezior na Nizinie Wielkopolskiej*, Typescript, the archives of the Institute of Hydrology and Water Management, UAM Poznań.

Kaniecki A. 1991, *Problem odwadniania Niziny Wielkopolskiej w ciągu ostatnich 200 lat*, [in:] A. Kosturkiewicz (ed.), *Ochrona i racjonalne wykorzystanie zasobów wodnych na obszarach rolniczych w regionie Wielkopolski*, Conference materials, Urząd Wojewódzki, Poznań, 73–80.

Kaniecki A. 1993, *Poznań — The History of the City Written with Water*, Part I, Transformations of the relief and water network, Aquarius, Poznań.

Kowalik A. 1995, *Zmiany sieci wodnej w Poznaniu w latach 1954–1994* [in:] *Wody powierzchniowe Poznania. Problemy wodne obszarów miejskich*, Conference materials, A. Kaniecki, J. Rotnicka (ed.), Sorus Publishing House, 65–77, Poznań.

Kuczyńska A.. 1995, *Próba odtworzenia zasięgu terenów podmokłych na Nizinie Wielkopolskiej w poprednich wiekach*, Typescript, the archives of the Institute of Hydrology and Water Management, Physical Geography Department UAM, Poznań.

Kurnatowski S., 1968, *Osadnictwo i jego rola w kształtowaniu krajobrazu*, Folia Quatern. 29, PAN Kraków.

Kurnatowski S., 1975, *Wczesnośredniowieczny przełom gospodarczy w Wielkopolsce oraz jego konsekwencje krajobrazowe i demograficzne*, Archeologia Polski 20, 1, Wrocław.

Lambor J.,1951, *Zmiany dna rzeki warty po wykonaniu regulacji*, Wiadomości Służby Hydrologicznej i Meteorologicznej, 2, 4–5, Warszawa.

Łukomski B., 1935, *Spółki melioracyjne na terenie województwa poznańskiego*, Roczniki nauk rolniczych i leśnych 35, Poznań.

Miklaszewski J., 1928, *Lasy i leśnictwo w Polsce*, Warszawa.

Pasławski Z., 1964, *Stany niżówkowe w rzekach Wielkopolski w ostatnim stuleciu*, Zesz. Nauk. UAM, Geografia 5, Poznań.

Piasecka D., 1974, *Zmiany hydrograficzne doliny Warty w okresie ostatnich 200 lat*, Czas. Geogr. 45, 2, Wrocław.

Rusiński W., 1947, *Osady tzw. "Olędrów" w dawnym województwie poznańskim*, Polska Akademia Umiejętności, prace Komisji Atlasu Historycznego Polski 5, Kraków.

Schulemann ?, 1865, *Die Pakosch — Labischiner Netzwiesen — Melioration*, Bromberg.

Stasiak P., 1991, *Zanik małych zbiorników wodnych na obszarze niziny Wielkopolskiej w świetle materiałów kartograficznych*, Typescript, the archives of the Institute of Hydrology and Water Management, Physical Geography Department UAM, Poznań.

Stryjewski F., 1980, *Melioracje użytków zielonych*, PWRiL, Poznań.

Surowiecki W., 1811, *O rzekach i spławach krajów Księstwa Warszawskiego*, Warszawa.

The Ibrahim Ibn Jacob's relation from the journej to Slavic countries in 996, translated by Al-Bekri?, Pomniki dziejowe Polski, 1946, 2, 1, Kraków.

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ANTHROPOGENIC CHANGES IN WATER CONDITIONS IN THE LUBLIN AREA

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ABSTRACT: The development of the city of Lublin has been closely associated with the exploitation of water resources in the Bystrzyca river basin. The extension of this city distinctly affects the water conditions of the middle part of this basin. Lublin is supplied with water almost solely from underground resources, a situation which has been dictated by excellent-quality and easily-available underground waters and small resources of surface water. A high level of exploitation of the underground waters has led to considerable changes in water circulation. Its character and grade have been changing over the centuries with the development of the city and an increase in water needs.

KEY WORDS: water circulation, water resources, changes in water conditions, Bystrzyca river basin, Eastern Poland.

INTRODUCTION

Lublin, 147.5 km^2 in size, is a large economic, cultural and administrative centre. The number of inhabitants in 1993 was 350,000 (making it the biggest city in eastern Poland). It is situated on the Bystrzyca river, a left tributary of the Wieprz river flowing into the Vistula (Fig. 1). This city has for centuries been strongly connected with the Bystrzyca river and the estuarial regions of its tributaries — the Czechówka and the Czerniejówka, and its further development has distinctly affected the water conditions in the middle part of the Bystrzyca river basin.

Before intensive changes in water circulation the average flow of the three rivers in the Lublin area used to be: 3.1 m^3/s for the Bystrzyca, 0.7 m^3/s for the Czerniejówka and 0.2 m^3/s for the Czechówka. South of Lublin, the

Krężniczanka tributary flows on average at about 0.8 m^3/s into the Bystrzyca river, and down the Ciemięga tributary carrying about 0.55 m^3/s in its lower course. The average outflow from the whole Bystrzyca river basin 1316 km^2 in area is 5.2 m^3/s. Thus, these rivers are of small water resources and very vulnerable to anthropological actions concentrated in the Lublin area. The development of this city has long influenced water conditions of the rivers mentioned, and this has been very strong in the last decade because of low precipitation and a high consumption of water.

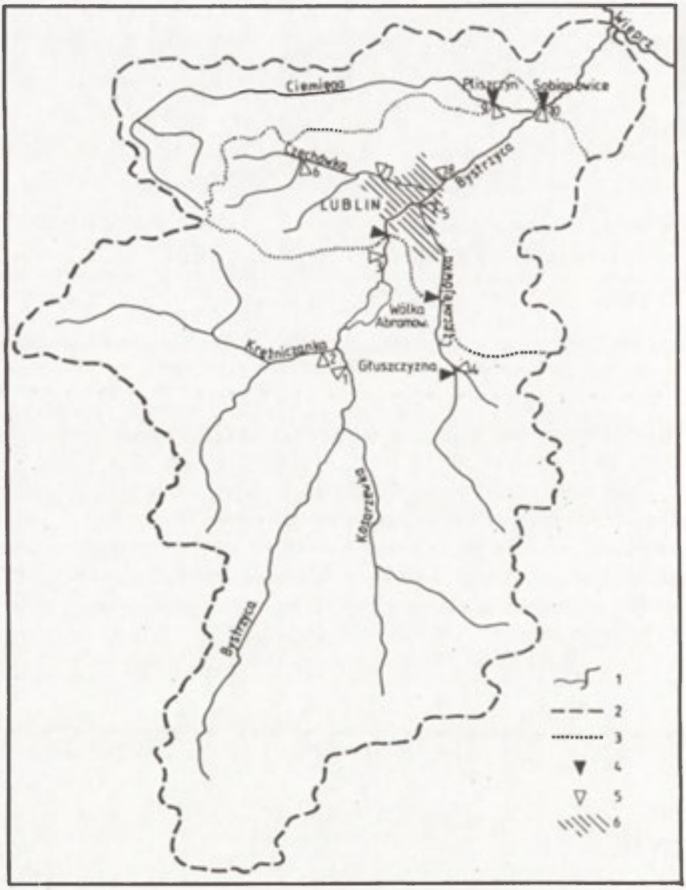

Fig. 1. Location of Lublin in the Bystrzyca river basin
1 — rivers, 2 — watersheds, 3 — boundaries of the distinguished differential basin of Lublin, 4 — water-gauges, 5 — localities of flow measurements (Table 1), 6 — area of dense municipal buildings in 1992

An increasing number of inhabitants, as well as the development of industry and various services, cause a rapid increase in water consumption in Lublin. In recent years about 50 million m^3 of water have been pumped annually from underground resources, which corresponds to 1/3 of the flow of the Bystrzyca river in its lower course. Intensified consumption of underground waters is stimulated by their easy availability and excellent quality and a relative shortage of top waters. Progressing house-building considerably limits the possibilities of reconditioning underground water resources in the area of the city, 23.7% of which is occupied by buildings, streets and roads (according to a report of 1993). In the remaining city area water infiltration has decreased considerably due to land compaction. To satisfy the increasing water demand for communal and industrial needs, the finding of new water sources is indispensable as are actions to protect the water resources of the Bystrzyca river basin.

AN OUTLINE OF WATER CONDITIONS IN THE LUBLIN AREA

A decisive role in the accumulation of underground waters is played here by Upper Cretaceous and Pleistocene carbonate rocks formed as opokas, limestones, marls and gezas. On the eastern side of the Bystrzyca river these rocks are found under a thin sand layer, whereas on its western side loesses several meters in depth occur. They are deposited on elevated carbonate rocks or on quaternary boulder loams locally constituting an impermeable layer on which underground waters are retained. Separating the two different areas the Bystrzyca river valley cuts 40–50 m into Upper Cretaceous rocks. It is filled with sandy deposits with gravels at the bottom and silts and peats at the top (Harasimiuk, Henkiel 1982). On both sides of the valley the surface formations are characterized by good permeability, which is connected with low river net density. The high water permeability of rocks of the aeration zone makes favourable conditions for supplementing underground water resources.

The Lublin area is characterized by the occurence of gap-layer waters circulating in strongly-fissured carbonate rocks of the Upper Cretaceous and Pleistocene. The waters are in rock pores and fissures and they flow largely by way of expansion gaps. Vertical and horizontal lithological differentiation of rock layers, as well as varying patency of the gaps cause considerable variation in hydrogeological conditions. Layer waters occur only in Quaternary deposits filling rills of the Bystrzyca river valley and its tributaries. Underground waters of the Cretaceous-Pleistocene and Quaternary stage form one reservoir hydraulically connected with top waters. One water surface inclined towards the Bystrzyca river valley and its tributaries occurs in the greater part of the Lublin area. Higher aquiferous layers poorer in water, used to supply farms, occur locally only in the zone of watersheds.

The depth of underground waters is very differentiated and is generally related to relief. In natural conditions, underground water occurs close to the surface of the river valley bottoms. On lower parts of slopes the dry layer is several meters thick, and it reaches 30–50 m in watershed areas. Gap systems existing in tectonic zones play an important role in the drainage of underground waters, which are joined to a network of river valleys. These are one-river areas in which hydrogeological conditions are most favourable for underground water intake. The high output of wells of over 150 m^3/h which is obtained in small depressions confirms suitable hydrogeological conditions for building reservoirs in tectonic zones.

The available waters of the Bystrzyca river basin are 55 million m^3/year in a moderately-dry year and 88 million m^3/year in a moderately-humid one (Michalczyk 1986, Michalczyk et al. 1983). Similar calculation results for available waters were given by Wilgat (1980), and distinctly higher ones by Krajewski and Hassa (1973). The resources of the Bystrzyca river basin were approved for exploitation at 220 thousand m^3/day, i.e. about 80 million m^3/year (Jałowiec 1989).

The supply conditions of the rivers are satisfactory, owing to large resources of underground waters. Nevertheless, the total unitary outflow was 4.0 l/s km^2 in the years 1951–1990 (Michalczyk, Turczyński 1992). The average share of the underground supply in the outflow is estimated at 75%; in 1951–1990 it varied from 60% to over 90%. Of significance are considerable differences in the water availability of the rivers in dry and moist periods (Wilgat 1980, Michalczyk 1986). In dry years, average unitary outflows decrease to 2 l/s km^2, and minimal temporal ones do not even reach 1 l/s km^2.

THE EXPLOITATION OF WATER RESOURCES IN OLD LUBLIN

Lublin was located in the fork of the Bystrzyca and Czechówka rivers; the waterlogged valley bottoms of these rivers warranted good defence conditions. As early as in the 14th century both rivers appeared to be of great economic importance besides having defence advantages. In the 16th and 17th century 45 water mills were working in the Bystrzyca river basin, thus 29.2 km^2 were served by one mill (Łoś 1986). Special attention is deserved by the 'big' royal mill on the Bystrzyca river, which used ac. 4 m high fall of water collected in a pond of about 130 ha. Two other mills can be mentioned: one in Wrotków on the Bystrzyca with a pond of 120 ha dammed up about 2.5 m, the other — a 'small' royal mill built on the Czechówka river at Lublin Castle. In the 16th and 17th c. there were 8 ponds and 10 mills, a paper-mill, a fullery and an ironworks in the neighbourhood of Lublin (Sierpiński 1843; Gawarecki 1974; Łoś 1986). The mechanisms damming up water (Fig. 2) were destroyed during catastrophic water rising or wars. They were usually reconstructed in their original places.

In 1506 a contract was signed for the building of a water supply system in Lublin (Szczygieł 1986). For this purpose the Bystrzyca river bed was destroyed in Wrotków and a part of the water was directed into a canal about 4 km (Łoś 1986). This water was utilized to set going an appliance called 'rurmus' which pumped spring-water, conveying it from Wrotków through wooden pipes to a water-tower. After reaching a height of about 25 m it was distributed in the city. The discharge is estimated at 4–5 m^3/h.

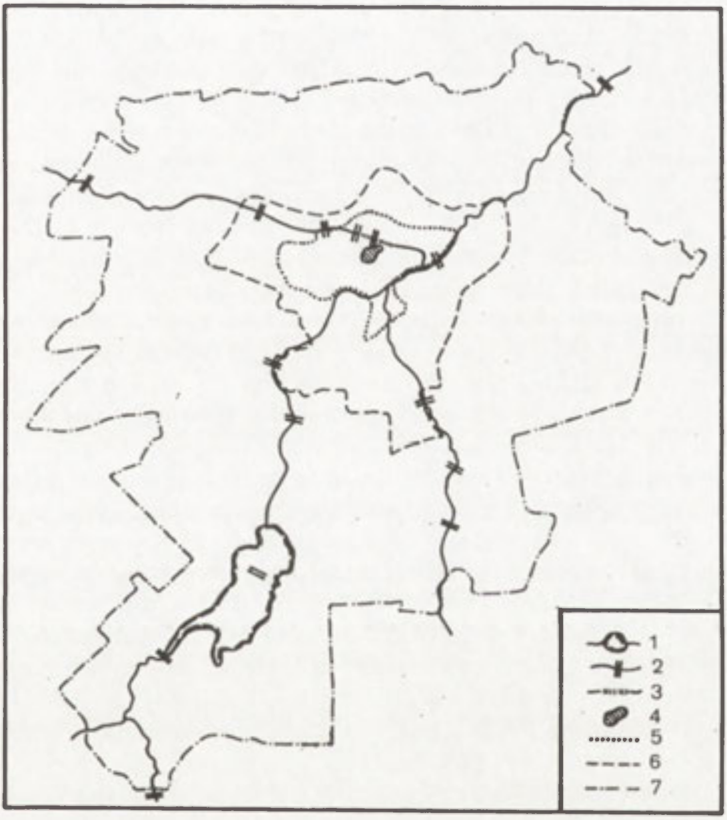

Fig. 2. Spatial development of Lublin from the 16th c.
1 — rivers, water reservoirs (according to the present state), 2 — liquidated mill dams, 3 — covered river bed, 4 — city boundaries in 1317, 5 — in 1875, 6 — in 1931, 7 — in 1992

At the beginning of the 16th c., Lublin had about 3000 inhabitants, Thus the diurnal water consumption was about 30 l/person (Mazurek 1986). These waterworks were functioning till the middle of the 17th c.

The damming-up facilities, canals conveying water and ponds, changed the character of the valley bottoms, generally increasing top water resources. It can be concluded that after the building of a number of such facilities the ground water table was also raised. Accumulation of peats and alluvia (alluvial soils) in the river valleys was accelerated, resulting in the filling-out of ponds and, in consequence, their becomming shallow. Drainage carried out locally was to bring the reverse effect. However, it was not of great importance because it did not change the water table in the Bystrzyca river valley which remained a natural drainage ground of underground and top waters.

By the 19th c., the economic significance of the water installations built earlier on the Bystrzyca and Czechówka rivers was decreasing. The silted-up ponds brought small profits, and the river valley bottoms hampered spatial development of the city because it was difficult to get them under control. The rivers and their valleys served as natural reservoirs for municipal sewage, constituting a big threat to the inhabitants. Therefore, some of the ponds were liquidated in the 19th c., and in the others the amounts of water damming up was reduced. Due to this, local lowering of the underground water table occurred by about 1–2 m in the areas adjacent to the ponds. Further lowering of the table, probably considerable, was caused by sinking wells to get water to satisfy communal und industrial demands.

In the second half of the 19th c. a fast demographic development of Lublin occurred; the population increased from 21,300 in 1870 to 80,100 in 1914. In the years 1875–1916, the area of the city was 8.7 km^2 (Kierek 1965). The city compounds extended beyond the Bystrzyca and Czechówka river valleys (Fig. 2). The central part of Lublin is situated in the fork area of the two valleys, and then residential and industrial suburbs developed. To supply the city with water, more and more wells were sunk. In the 19th c. there were about 90 wells in Lublin, sunk most often in quaternary deposits in river valleys and interfluves (Brunner et al. 1893). Because of relatively limited exploitation of underground waters and bad sanitary conditions of top waters epidemics of infectious diseases occurred. To improve the sanitary state of the city three deep wells were sunk (the 'Central' source) for the second waterworks in the history of the city. In the years 1898–1914 the waterworks supplying the central part of the city was developed. The building of a sewer system was also started.

In 1916, neighbouring villages were incorporated into Lublin, whereby its area increased to 30.1 km^2 (Fig. 2). The number of inhabitants increased from 86,700 in 1920 to 120,000 in 1939 (Kierek 1975). The building of a modern waterworks, which came into operation in 1929, was indispensable. Water was taken from Upper Cretaceous rocks by means of 8 wells in Wrotków suburb in the Bystrzyca river valley. In 1930, about one million m^3 of water were obtained from both sources (the old 'Central' and the new 'Wrotków'), and in 1938 1,300,000 m^3 (Marczuk 1978). In addition, underground water was exploited at an amount reaching 0.3 million m^3/year from the wells of industrial plants. The sewer system was developed in parallel reaching a length of 55.7 km in 1938. The communal treatment plant received 0.8 million m^3 of wastewater and about 0.9 million m^3 of rain water (Kierek

1975). Significant changes also occurred in the river valleys. Water damming of the 'big' mill on the Bystrzyca river was lowered by about 1.2 m in 1933, and in the following year a pond on the Czechówka river was liquidated. In the years 1934–1939, the valleys of both rivers were meliorated. In 1937, a section of the Czerniejówka near the castle was arched, thereby liquidating the natural element of the hydrographic network and including it into the sewer system (Gawarecki 1975). Municipal building started to encroach upon the river valley bottoms. However, until 1950 the transformation rate of the water conditions in the city area was relatively small. In many sections, wetness and meandering as well as weakly-cut in river beds were preserved, which overflowed during inundation. Numerous springs were also preserved, e.g. in Wrotków, Bronowice and Slawinek.

PRESENT CHANGES IN THE WATER CONDITIONS

In the second half of the 20th century, the demographic development of Lublin has been accelerated; the number of inhabitants increased from 99,000 in 1946 to 242,000 in 1970, and 350,000 in 1992. The city area extended from 30 km^2 to 40 km^2 in 1955, to 93 km^2 in 1959, and to 147.5 km^2 in 1992. The developing city consumed more and more water, largely underground. New waterworks intakes were succesively put into operation in the river valleys of the Czerniejówka-'Dziesiąta', Czechówka-'Slawinek' and Bystrzyca-'Prawiedniki'. Intensified water exploitation resulted in lowering of the underground water table in the water intake regions and the city, forming a regional depression funnel. This has led to accelerated drainage of the primary waterlogged valley bottoms. All mill dams have disappeared. The regulated and partially-embanked rivers carry waters from the upper parts of the basin through the city. In the Lublin area they are not supplied with underground water, but only receive waters from storm sewers. In the area of the depression funnel, water losses are found in the rivers which cause seasonal disappearance of water in the lower course of the Czechówka river. Municipal house building has encroached upon the dried river valley bottoms; the valley meadows have also changed to allotments, city parks, sport grounds and communication routes.

In the 50's the city was supplied with water from two intakes (Fig. 3) and sunk wells, the number of which was about one thousand in that period. In 1950 about 4 million m^3 of water were taken from underground resources, and as many as 8.4 million m^3 in 1955. The underground water table of 1955 presented in Fig. 3. can still be considered similar to the natural one. The system of hydroisohypses then indicated a general lowering of the water table towards the Bystrzyca river as well as the strongly-drained Czerniejówka and Czechówka river valleys. Within the valley bottoms the water table was found not to be deep; there still existed waterlogged areas, and water came up from springs on the slopes of the Bystrzyca, Czerniejówka and Czechówka river valleys.

In the following years the amount of exploited water was increasing. New waterworks intakes were built in the Czerniejówka, Czechówka and Bystrzyca river valleys. After setting them to work, water dissipation was recorded in the neighbouring springs and sunk wells, as well as drying of waterlogged land. The region of the anthropologically-lowered underground water table was 120 km^2 in size in 1971. The range and development of

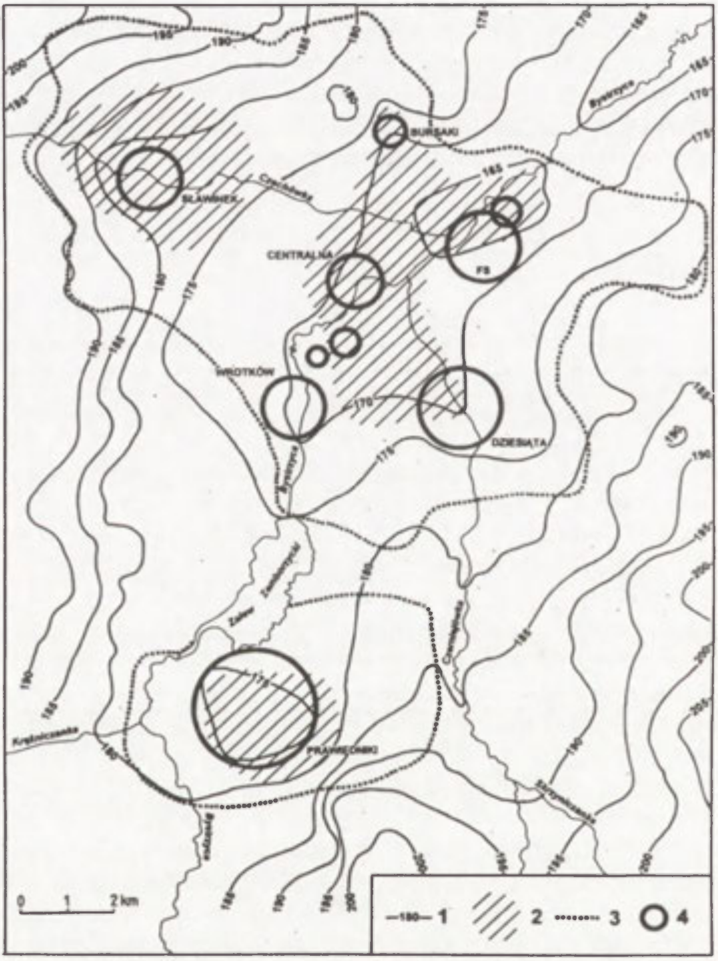

Fig. 3. Water table form in July 1955 in Lublin and its environs
1 — hydroisohypses, 2 — main intakes of underground water (the marked area corresponds to water exploitation at 2000 m^3/day)

this regional depression depended on atmospheric precipitation, which, when they were high, decreased considerably (Michalczyk et al. 1983).

A distinct improvement in water conditions occurred in the southern part of the city after the building in 1974 of the Zemborzyce Reservoir (Fig. 4), in which 6.8 million m^3 of Bystrzyca river waters were dammed up. This reservoir, 2.82 km^2 in size, constitutes not only the largest recreation facility for Lublin inhabitants but also supplements underground water resources. Surface water infiltration of the subterrain, and unusually high atmospheric preciptation in the years 1978–1981, caused the depression funnel to be

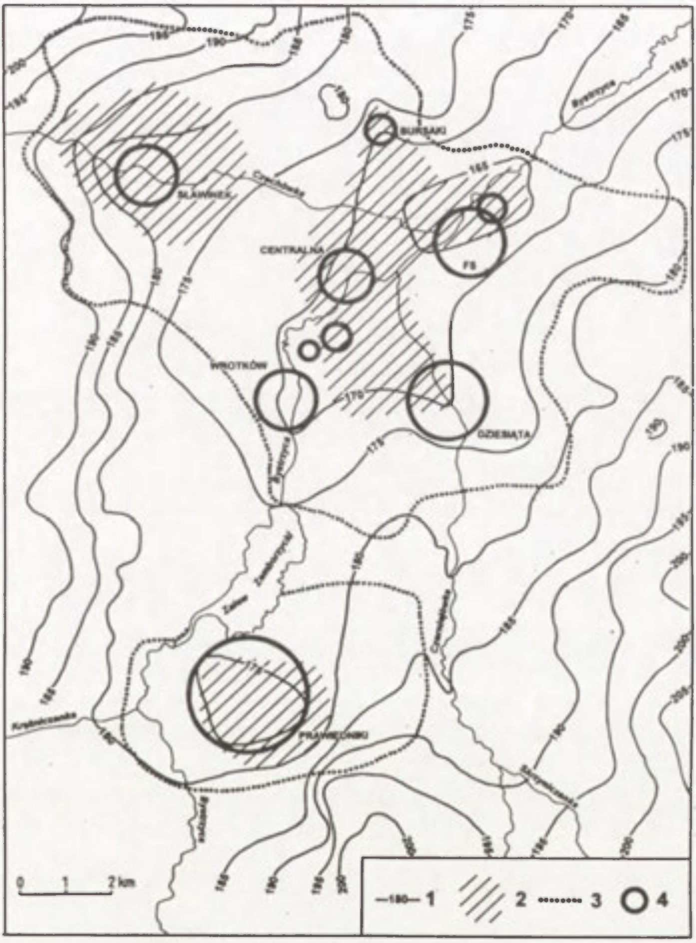

Fig. 4. Water table form in June 1981 in Lublin and its environs
1 —hydroisohypses, 2 — areas of underground water table lowered more than 4 m in the years 1955–1981, 3 — range of influence of underground water intakes, 4 — main underground water intake

filled up partially. Its area in 1981 was 120 km^2, similar to that in 1972 despite a double water exploitation which increased to 58 million m^3/year. The biggest water table lowering exceeding 4 m occurred in the centre of the city and in the neighbourhood of big water intakes (Fig. 4).

Further excess exploitation of underground waters caused water table lowering not only in the city area but also in the adjacent regions. In 1992 the depression funnel was about 200 km^2 in size (Fig. 5) with underground water exploitation of about 50 million m^3/year. The biggest lowering of the water table, exceeding 4 m as determined from comparison of hydroisohypsic

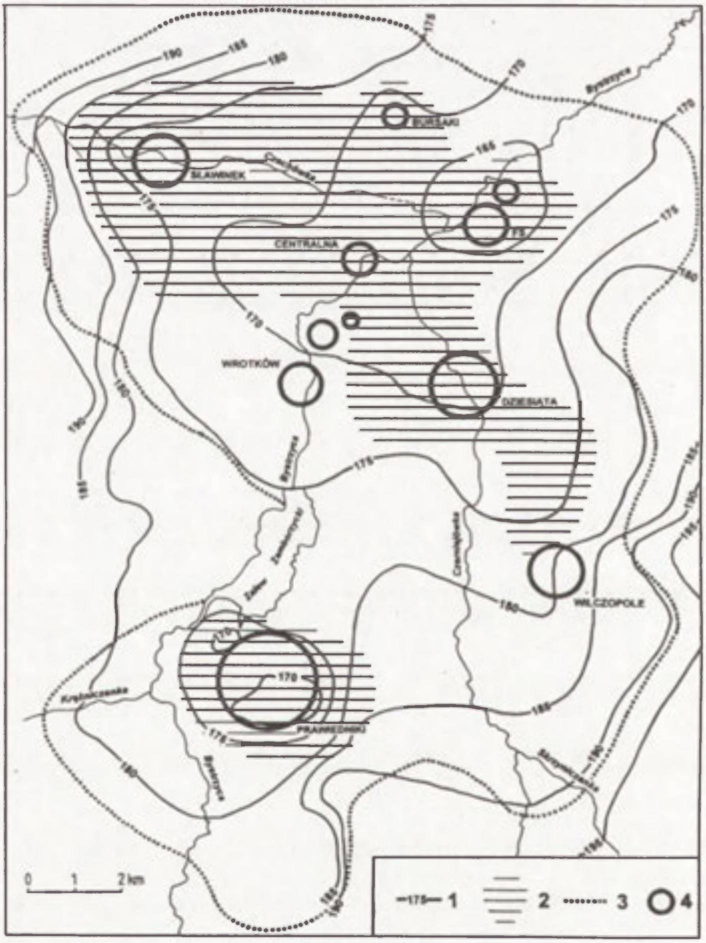

Fig. 5. Underground water table form in June 1992 in Lublin and its environs
1 — hydroisohypses, 2 — areas of underground water table lowered more than 4 m in the years 1955–1992, 3 — range of influence of underground water intakes, 4 — main underground water intake

maps of 1955 and 1992, occurred in an area of about 68 km^2 i.e. $^1/_3$ of its surface. In the city centre that lowering was about 5 m, and in the neighbourhood of the water intakes built after 1960 ('Sławinek', 'Prawiedniki') it exceeded 8 m. Water table lowering in the river valleys disturbed the hydraulic equilibrium between underground and top waters. In the areas of lowered underground water table waterlogging and springs of the Czechowka and Czerniejowka river valleys disappeared. Conditions for top waters to escape underground thus emerged.

QUANTITATIVE EVALUATION OF WATER CIRCULATION CHANGES

The evaluation of changes in river flows was made on the basis of hydrometric data for the years 1951–1991. The river flows in the Lublin region are checked by two water-gauge stations of the Institute of Meteorology and Water Management (IMiGW) on the Bystrzyca river (Fig. 1); a) in Lublin above dense municipal construction; b) in Sobianowice below the city. In the years 1978–1989, at the commission of the Directorate of Municipal Investments, IMiGW monitored Czerniejowka river flows in Wólka Abramowicka and Gluszczyzna. In the years 1981–1991 the Ciemięga river flows were registered in Pliszczyn by the Department of Hydrography of the Maria Curie-Sklodowska University, Lublin. Thus in the last decade 5 water-gauges operated in the Lublin region. After taking off from the Bystrzyca basin area to Sobianowice its area to Lublin, that of the Czerniejowka to Wólka Abramowicka and of the Ciemięga river basin to Pliszczyn, we obtain a differential basin of Lublin; it is 261 km^2 in area including the whole area of dense municipal construction and the Czechówka river basin. In its area, wastewaters and rainwater from storm sewers are discharged into the rivers. After taking off from the amount of water flowing at Sobianowice the amount of discharged wastewaters and the flows in the three remaining control profiles, we obtain the outflow from the differential basin of Lublin. In the years 1983–1987, negative values for this outflow were recorded, indicating top water escape underground. Since 1988 a limited underground supply of the rivers in this region has been observed. In the years 1982–1991 the unitary outflow from the differential basin was only 0.11 l/s km^2, with an average of 3.95 l/s km^2 for the whole Bystrzyca river basin.

From a forty-year-series of flows the hydrometric data of 1977–1991 recorded an influence of intensive underground water exploitation on river flows in the Lublin region. In the years 1977–1980 the atmospheric supply was higher than normal. Accordingly, river flows were then higher. In the period 1987–1982 the mean annual Bystrzyca river flow at Sobianowice exceeded the long-term mean value for 1951–1990 (amounting to 5.02 m^3/s), and in 1981 it reached 9.63 m^3/s (Fig. 6). After 1981 the annual amount of precipitation did not reach the normal value. The result was that the mean annual flow of this river was much lower than the mean of many years, and in 1991 it decreased to 3.02 m^3/s. In the last 15 years a decrease in the amount of the exploited underground water was also recorded, as well as one in the amount of discharged wastewater, which determined the amount of Bystrzyca river flow in its lower course. Most water was exploited in 1981 — 58.3 million m^3. In the following years the consumption decreased systematically to a level of 50 million m^3 in 1991. Despite decreased underground water consumption, big changes in water circulation were found after 1982, being particularly noticeable in periods of a low flow.

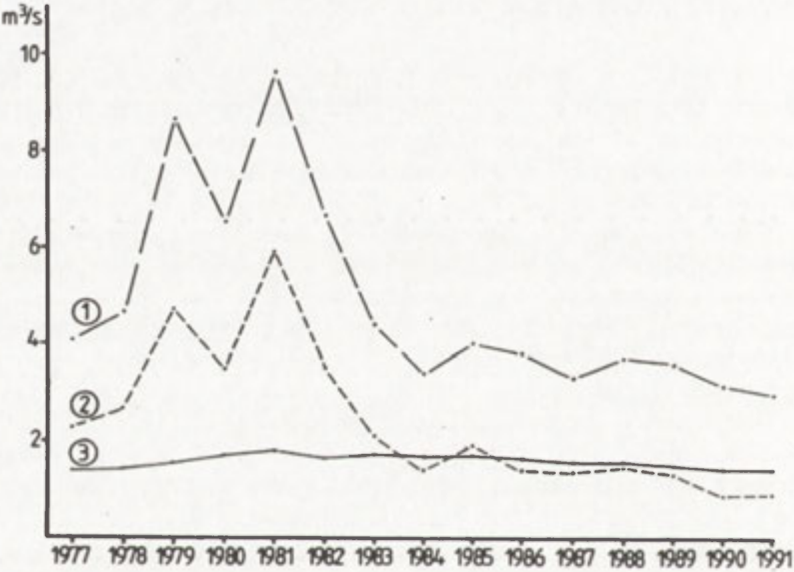

Fig. 6. Changes in the years 1977–1991 in annual mean flows of the Bystrzyca river at Sobianowice (1), in Lublin (2), and water exploitation in Lublin (3)

Big transformations in water circulation are well documented from the Lublin water-gauge records. It closes the Bystrzyca river basin, 748 km^2 in area, which constitutes 59.1% of the whole collecting area. The mean flows in the Lublin hydrometric section were in the range 54.4–64.9% of the flows at Sobianowice in the years 1977–1981; thus, they were proportional to the catchment basin area. In the following years a considerable decrease in the outflow from the upper Bystrzyca river was noticed. In 1990 the amount of conveyed water in the Lublin profile was only 28.6% of the flow at Sobianowice. In the period 1990–1991, at the Lublin water-gauge profile the mean annual flow was 0.92 and 0.96 m^3/s. These are much smaller values than the unimpaired (biological) flow estimated at 1.17 m^3/s according to the hydrobiological criteria (Kostrzewa 1977).

To document long-term trends for flow changes, a curve of total annual Bystrzyca river flows in Lublin was plotted in comparison to those at Sobianowice (Fig. 7). It shows the flow relationships between these water-gauges. On this curve a trend for flows to decrease in Lublin is found from 1982. For the period 1982–1991 the total 'deficit' of flows in this section was almost 182 million m^3 in all. This value corresponds to almost a four-year exploitaton of underground water to satisfy the needs of the city. A trend for flows to decrease was also found in the Wólka Abramowicka profile on the Czerniejówka river.

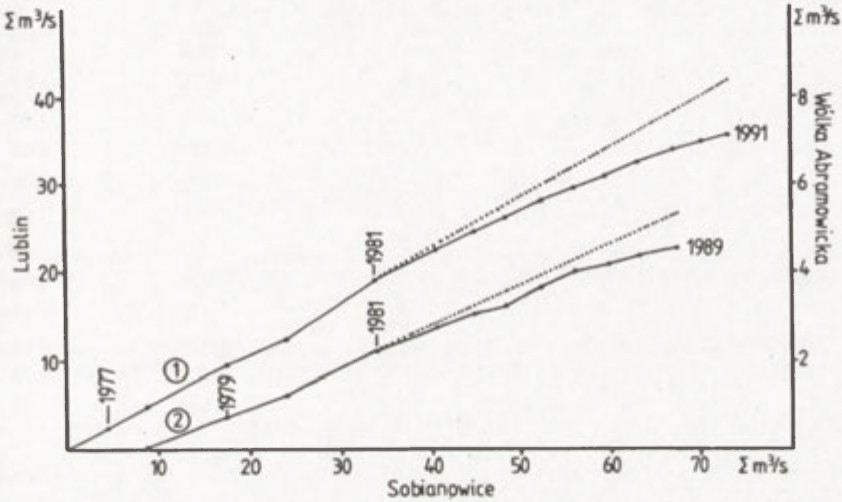

Fig. 7. Totals of annual mean flows of the Bystrzyca river in the years 1977–1991 in Lublin (1), and in the years 1979–1989 at Wólka Abramowicka (2) (calculated in relation to those at Sobianowice). Dotted line shows the trend till 1981; continuous line — real sums of flows

Losses of river flows in the area of the Lublin depression funnel are caused by decreasing underground supply and escaping top waters (Loś, Michalczyk 1984, 1989). Series of flow measurements made at low flows of 1990–1992 in 10 hydrometric sections point to non-natural changes in the amount of flowing water (Fig. 1). Five measurement series were carried out in rainless periods by workers of the Department of Hydrography, Maria Curie-Sklodowska University and the Municipal Company for Water Supply and Treatment in Lublin (Table 1). Despite the basin enlargement of the Bystrzyca river and its supply by the Kręzniczanka river, a decrease in its flow is found. A similar situation is in the river basins of the Czerniejówka and Czechówka rivers, where flows are decreasing in their lower courses. The Bystrzyca river below the city is supplied with wastewaters on average of 1.51 m^3/s, thus regaining its normal flow. Unitary outflows calculated from the given mean flows also indicate the escape of top waters underground.

Its value was 1.80 l/s km^2 for the basin above the city, 0.91 l/s km^2 in the centre of Lublin, and 1.93 l/s km^2 in Sobianowice, i.e. a little more than in the upper part of the basin. From the measurements mentioned a shortage of river supplies can be found, and even a decrement at an amount of 0.42 m^3/s of flowing waters.

TABLE 1. Mean unitary flows and outflows calculated from five flow measurement series carried out by the Department of Hydrography, Maria Curie-Skłodowska University, and the Municipal Company for Water Supply and Treatment in Lublin in rainless periods of 1990–1992 (measurements were made on the days: 9.05.1990, 12.07.1990, 19.05.1991, 23.07.1992 and 18.08.1992)

No	River	Measurement locality	Basin area [km^2]	Flow [m3/s]	Unitary outflow [l/s km^2]
1	Bystrzyca	Nowiny	480	0.865	1.80
2	Krężniczanka	Krężnica	225	0.330	1.48
3	Bystrzyca	Wrotków	718	0.768	1.07
4	Czerniejówka	Głuszczyzna	56	0.089	1.60
5	Czerniejówka	Lublin	172	0.023	0.13
6	Czechówka	Dąbrowica	29	0.018	0.61
7	Czechówka	Sławinek	67	0.001	0.01
8	Bystrzyca	Tatary	1046	0.875	0.84
9	Ciemięga	Pliszczyn	152	0.263	1.73
10	Bystrzyca	Sobianowice	1265	2.440	1.93

On the basis of hydrometric materials for 1982–1991 the magnitude of the outflow from the particular parts of the Bystrzyca river basin and Lublin differential collecting area was estimated (Table 2). Hydrometric data from the Pliszczyn water-gauge on the Cimięga river, closing its basin with relatively small transformation of water conditions, were taken as the basis for calculations. The mean outflow from this basin was 3.22 l/s km^2. In the years 1982–1991 the average area of the Lublin depression funnel was 178 km^2. Assuming the mean outflow at 3.22 l/s km^2, the supply in this funnel was only 0.57 m^3/s. This is a decided small amount to compensate for the exploitation of underground water in the Lublin region, estimated on average at 1.6 m^3/s. The remaining part of the water exploited from communal and industrial intakes (1.03 m^3/s), reaching water-bearing layers, comes from top waters in the city area. Underground supply from the upper part of the Bystrzyca river basin and its tributaries may also have a positive influence. Of 1.60 m^3 water exploited an amount of 1.51 m^3/s returns as wastewater to the Bystrzyca river, which is discharged within the Lublin differential collecting area, and 0.09 m^3/s constitutes non-returnable loss.

In recent years, very advantageous changes in water management have taken place in Lublin. Economizing on water and reduced industrial production have considerably reduced water consumption in the city. The amount of wastewater discharged into rivers has also decreased by about 50 million m^3 in 1983 to 42 million m^3 in 1992. In recent years, all wastewaters have been treated mechanically and biologically, which has considerably improved the quality of the Bystrzyca river water in its lower course. The chemical composition of water in the upper course of the rivers is approximate to the natural. In the city area, wastewater and water from rain canalization, which cause quality changes of top waters, are discharged into the rivers. The polluted Bystrzyca river is a substantial threat to the quality of underground water in the area of lowered water table.

TABLE 2. Mean unitary flows and outflows in the years 1982–1991 according to data from the Institute of Meteorology and Water Management, Warsaw Division, and the Department of Hydrography, Maria Curie-Sklodowska University in Lublin

River basin	Water-gauge	A [km^2]	Q [m^3/s]	q [$l/s\ km^2$]
Bystrzyca	Sobianowice	1265	3.95	3.12
Bystrzyca	Lublin	748	1.67	2.23
Czerniejówka	Wólka Abram.	104	0.25	2.40
Ciemięga	Pliszczyn	152	0.49	3.22
Differential basin of Lublin		261	0.03	0.11

A — area, Q — flow, q — unitary outflow.

CONCLUSIONS

Lublin has, since its establishment in 1317, influenced the water conditions of the Bystrzyca river significantly. The character of the influence and its range have changed over the centuries with the development of the city and economic utilization of waters.

The first period lasting from the 14th to 17th c. was characterized by exploiting the Bystrzyca river and its tributaries to obtain energy. In that time many dammed-up mill reservoirs of various sizes were built. The rivers lost their natural character and looked like a series of flux reservoirs. This affected rubble movement significantly, accumulation processes in the valleys and the state of top and underground waters. Water exploitation for communal and craft needs was limited and did not influence water balance.

The second period lasted from the end of the 18th to the middle of the 20th c. In that time the energetic significance of the rivers declined, a situation connected with the introduction of steam engines and then combustion and electric motors. The particular dammed-up ponds were successively liquidated or their height was reduced. The ponds which were primarily of large economic importance to the city then became barriers to its development and a sanitary threat. Thus subsequent liquidation of the ponds, regulation of the rivers and melioration of their valleys followed. As a result, the local drainage base and water surface were lowered, as a consequence of which rubble movement in the river beds was facilitated.

The third period referring to the second half of the 20th c. is characterized by the very fast demographic and spatial development of Lublin. All dammed-up mill ponds have ultimately been liquidated and regulation and partial embanking of rivers and melioration of their valleys completed. A considerable part of them has been designated for parks, sport facilities, allotments and communication routes. The exploitation of underground water is increasing very rapidly, as is the amount of discharged wastewater and the length of storm sewers and sanitation canals in the city. Due to pumping underground water at an amount of 50–58 million m^3/year the table is being lowered over an area of about 200 km^2. Exploitation of underground water substantially impacts upon the water balance of the Bystrzyca river. Its magnitude has exceeded the Bystrzyca flows in Lublin in recent years. A significant role in the determination of water conditions is played by the Zemborzyce Reservoir feeding underground water and thereby deepening shallow flows in the city area.

Water management in Lublin has led to significant changes in water relations in the city area. At present the rivers do not drain the underground water resources, but there are conditions for river waters to escape underground. Human activity is a virtual threat to the amount and quality of water resources in the Lublin region. There are numerous pollution foci in the area of the city struggling with a big water deficit, the liquidation of which requires great costs. At the beginning of the 70's, Lublin was in danger of being unable to supply the water needed for consumption from the Bystrzyca river resources. However, limited industrial production and economized water management in the last decade have averted this danger but have not erased it. At the beginning of the 21st c. water problems will become one of the most important barriers to the development of Lublin. In the farther perspective a significant increase in water consumption will be possible by conveying it from outside the Bystrzyca river basin.

REFERENCES

Brunner I., Mierzyński Z., Zawadzki A., 1893, *Wyniki badań wody studziennej w mieście Lublinie*, Pamiętnik Towarzystwa Lekarskiego Warszawskiego 99, 3, Warszawa, 625–655.

Gawarecki H., 1974, *O dawnym Lublinie*, Wyd. Lubelskie, Lublin.

Gawarecki H., 1975, *Rozwój urbanistyczny i architektoniczny miasta w latach 1918–1939,* [in:] *Dzieje Lublina* 2, Wyd. Lubelskie, Lublin, 249–265.

Harasimiuk M., Henkiel A., 1982, *Objaśnienia do Szczegółowej Mapy Geologicznej Polski, Lublin.* Wyd. Geol., Warszawa.

Jałowiec L., 1979, *Dokumentacja hydrogeologiczna zasobów wód podziemnych zlewni Bystrzycy*, PG, Warszawa (typescript).

Kierek A., 1965, *Rozwój Lublina w latach 1864–1914*, [in:] *Dzieje Lublina* 1, Wyd. Lubelskie, Lublin, 257–300.

Kierek A., 1975, *Rozwój gospodarczy Lublina w latach 1918–1939*, [in:] *Dzieje Lublina* 2, Wyd. Lubelskie, Lublin, 33–114.

Kostrzewa H., 1977, *Weryfikacja kryteriów i wielkości przepływu nienaruszalnego dla rzek Polski*, IMiGW, Warszawa, 207.

Krajewski S., Hassa B., 1973, *Studium zaopatrzenia w wodę miasta Lublina*, Zakł. Prac .Geol. UW, Warszawa (typescript).

Krisztafowicz N.I., 1902, *Gidro-geologiczeskoje opisanie teritorii goroda Lublina i jego okresnostiej* (Hydrogeologische Beschreibung des Territoriums der Stadt Lublin und ihrer Umgegenden), Warszawa.

Łoś M., 1986, *Wykorzystanie zasobów wodnych Bystrzycy w XVI i XVII w.*, Mat. konf. nt. Wodociąg Lublina okresu staropolskiego, Wyd. PZIiTS O. Lubelski, Lublin–Warszawa, 58–77.

Łoś M. J., Michalczyk Z., 1984, *Wpływ gospodarki wodnej Lublina na przepływ Bystrzycy*, Gosp. Wodna 1, 12–14.

Łoś M. J., Michalczyk Z., 1989, *Antropogeniczne zmiany przepływu Bystrzycy w rejonie Lublina*, Gosp. Wodna 7/8, 151–154.

Marczuk J., 1978, *Wodociągi i kanalizacja miasta Lublina w latach 1918–1939*, Gaz Woda i Techn. Sanitarna 6, 170–171.

Mazurek Z., 1986, *Technologia wodociągu staropolskiego miasta Lublina w XVI*, Mat. konf. nt. Wodociąg Lublina okresu staropolskiego, Wyd. PZIiTS O. Lubelski, Lublin–Warszawa, 93–100.

Michalczyk Z., 1986, *Warunki występowania i krążenia wód na obszarze Wyżyny Lubelskiej i Roztocza*, Wyd. UMCS, Lublin.

Michalczyk Z., Łoś M.J., Sawicka-Ner Z., 1983, *Zasięg oddziaływania ujęć wód podziemnych miasta Lublina*, Prace Hydrogeol. IG. 16, Wyd. Geol., Warszawa.

Michalczyk Z., Turczyński T., 1992, *Charakterystyka hydrologiczna okolic Turki pod Lublinem*, Annales UMCS s. B. 44/45, 187–209.

Raport o stanie środowiska miasta Lublina, 1993, J. Stochlak (ed.), Lublin.

Sierpiński S., 1843, *Historyczny obraz miasta Lublina*, Wyd. powtórne, Warszawa.

Szczygieł R., 1986, *Dokumenty królewskie i decyzje władz miasta Lublina związane z funkcjonowaniem wodociągu miejskiego w XV.i pierwszej połowie XVI wieku*, Mat. konf. nt. Wodociąg staropolski miasta Lublina. Wyd. PZIiTS O. Lubelski, Lublin–Warszawa, 23–35.

Wilgat T., 1980, *Zasoby wodne Lublina*, Biuletyn LTN. Geogr. 22, 1, 27–31.

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CHANGES IN THE CHEMISM OF THE WATERS OF THE ŁABUŃKA RIVER CATCHMENT UNDER THE INFLUENCE OF MUNICIPAL AND INDUSTRIAL WASTEWATER

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ABSTRACT: In the years 1989–1992, river water samples for physicochemical analyses were taken at 9 points of the Łabuńka river catchment up-stream of the gauging station of the Institute of Meteorology and Water Management (IMWM) in Krzak. These show differentiation in hydrochemical features controlled by the lithology of the bedrock. Particular consideration was given to changes caused by municipal wastewater from Zamośc. An attempt was made to determine the content of solutes coming from sewage.

KEY WORDS: water chemism, hydrochemical background, municipal and industrial wastewater, chemical denudation, solute yield, anthropopressure, Zamość Basin, Eastern Poland.

INTRODUCTION

The Łabuńka river catchment is situated in the upper part of the Wieprz river basin. According to the State project for spatial development till 1995, this part of the Wieprz river basin is among areas requiring special protection of water quality (Kozłowski 1991). From the latest data of the Provincial Inspectorates of Environment Protection in Lublin, Zamość and Chełm, it appears that the Łabuńka river catchment, besides that of the Bystrzyca, is distinguished by the highest discharge of municipal and industrial wastewater in the Wieprz basin. This is discharged into surface waters, which evidently changes their chemism. For quantitative evaluation of the role of wastewater, studies were undertaken to differentiate the physicochemical features of river waters with regard to geological structure.

Studies of the chemism of surface waters were undertaken in the Łabuńka river catchment up-stream of the gauging station of the IMWM at Krzak in the years 1989–1992. Four measurement points were located on the Łabuńka river and another 5 on its tributaries — the Czarny Potok and

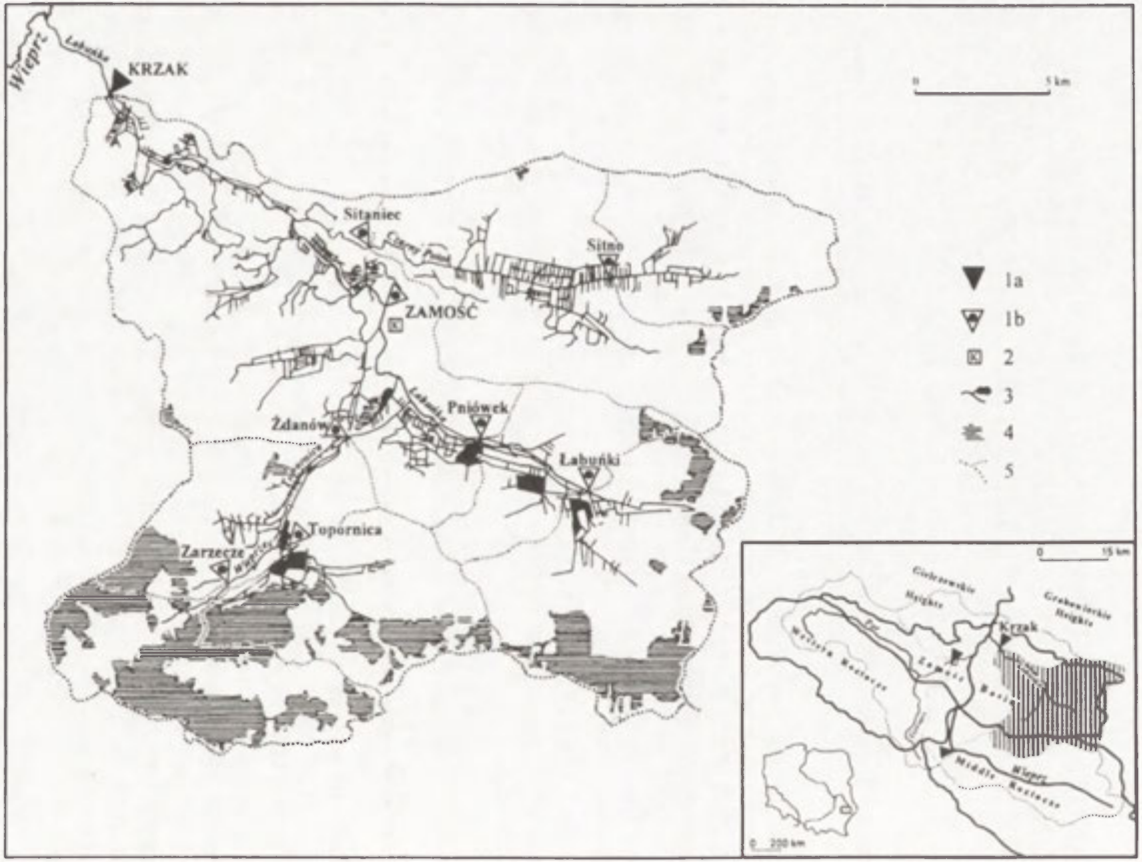

Fig. 1. Location of measurement points in the Łabunka river catchment up-stream of the gauging station at Krzak
1 — point of river water sampling: a — in the gauging station, b — at remaining points; 2 — climatic station, 3 — river network, 4 — forests, 5 — watersheds

the Topornica (Fig. 1), water samples for laboratory analyses were taken every 2 weeks. Among other things, I determined total solute concentration conductometrically, pH value potentiometrically, and the concentration of macrocomponents by the standard methods according to M. Markowicz and M. Pulina (1979). I also took into consideration the results of sample analyses of river waters made once a month from 1980–1992 at 3 measurement points of the Provincial Inspectorate of Environment Protection in Zamość (on the Łabuńka river in Krzak, its tributary the Czarny Potok in Sitaniec and the Topornica in Zamość). For these points the concentration of dissolved oxygen, phosphates and ammonium nitrogen were also taken into consideration, as well as the content of organic substances (BOD_5 index). From this Inspectorate, I also obtained data on the amount of sewage discharged into surface waters in the years 1989–1992.

From these data a relatively detailed picture of the different hydrochemical conditions of the discussed catchment, and changes caused by wastewater, was obtained.

HYDROLOGICAL CHARACTERISTICS OF THE ŁABUŃKA RIVER CATCHMENT

The Łabuńka river is the biggest right tributary of the upper Wieprz river, with a length of 34.4 km, and a catchment area of 513.5 km^2. Its two bigger tributaries are: on the left — the Topornica on the 22.5 km of its course, and on the right — the Czarny Potok on the 13 km of its course. The studied catchment up-stream of the gauging station at Krzak (the 4.2 km of its course) is 416 km^2 in size, which constitutes 81% of the Łabuńka river catchment.

The Łabuńka river catchment up-stream of the gauging station at Krzak largely comprises the area of the Zamość Basin, partially the Middle Roztocze and the Grabowieckie Heights (Fig. 1). Upper Cretaceous marls predominate in the substratum; marly and typical opokas occur in places. Of Quaternary formations, mineral-organic ones lining the valley bottom of the Łabuńka river and its tributaries, are the most widely-distributed. Loesses occur on the Grabowieckie Heights and in Roztocze as well as in watershed zones in the Zamość Basin.

My studies were carried out in much warmer and drier years than average, i.e. at much lower flows. The mean annual air temperature was 8.2°C in Zamość in the years 1989–1992 and was almost one degree higher than the average of the years 1951–1980 (7.2°C). The mean annual precipitation was 567 mm in Zamość in those years and was lower by 3.1% than that of 1951–1980 (585 mm). The Łabuńka river discharges were also low; at Krzak the mean annual discharge in the years 1989–1992 was 1.16 m^{3}s^{-1}, thus as lower as 40% of the average for the years 1951–1980.

The river waters of the area studied largely come from underground supply. According to Z. Michalczyk (1986), the underground supply of the Łabuńka river amounts to 72% at the gauging station in Krzak.

DIFFERENCES IN CHEMISM OF THE RIVER WATERS

On average about 6.5 million m^3 of municipal and industrial wastewater coming largely from Zamość (63.1 thousand inhabitants in 1991) were discharged annually into surface waters in the Łabuńka river catchment up-stream of the gauging station at Krzak in the years 1989–1992. This constituted 18% of the mean annual river discharge of those years. Only the Topornica river waters were not polluted with wastewater; a small amount of wastewater (0.2% of the mean annual discharge) got into the Czarny Potok river waters; as much as 99.8% of wastewater was discharged directly into the Łabuńka river, of which 98.4% came from the Company for Water Supply and Treatment in Zamość. The degree of sewage purification was unsatisfactory; 98.1% was treated only mechanically, i.e. by removing largely insoluble impurities. Only 0.9% of wastewater, was treated in a biological-mechanical system better reducing impurities; 1.0% was carried away in crude form.

The results of the studies allowed the author to follow chemism changes in Łabuńka river waters and the degree of pollution at the distance from the Łabuńki section (0.1 km of its course) to Krzak (4.2 km), i.e. along a distance of 25.9 km (75.2% of the river length), as well as for its two tributaries (Topornica and Czarny Potok). Histograms of the distribution of physico-chemical indices (Fig. 2), characteristic values (Table 1 and 2) and selected oxygen and biogenic indices of river waters (Table 3) allowed me to determine not only the differentiation of the studied catchment with regard to its bedrock lithology, but also the changes caused by economic actions.

On the basis of the results it can be seen that surface waters in the Łabuńka river catchment are characterized by a relatively high concentration of solutes. The mean annual solute concentration, however, varies considerably from 322 to 473 mg dm^{-3} (Table 1). "Pure" waters, i.e. unpolluted with municipal and industrial wastewater, show a differentiation controlled by lithology of the bedrock. Higher indices for solute concentration (419–443 mg dm^{-3}) were found in waters drained off from bogs. According to the results of analyses in river sections at Łabuńki and Sitno (Table 1) the waters can be qualified as hard and weak-alkaline; they are distinguished by the highest concentration of Ca^{2+} ions, and relatively high Mg^{2+} and SO_4^{2-} concentrations (Table 2). A lower solute concentration (322–337 mg dm^{-3}) was recorded in catchments with a loess cover. The waters in the sections at Zarzecze, Topornica and Żdanów showed much lower hardness (Table 1) characteristic for medium hard ones; they also belong to the weak-alkaline group but with slightly higher indices;

TABŁE 1. Characteristic indices of total solute concentration, hardness and pH of waters of the Łabuńka and its tributaries — the Topornica and the Czarny Potok, in the years 1989–1992; from the author's measurements

River	Locality	Solute concentration				Hardness				pH			
		max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V
			mg dm^{-3}		%		mval dm^{-3}		%				%
Topornica	Zarzecze	336 303	322	5.9	1.8	5.85 5.20	5.52	0.14	2.6	7.91 7.46	7.72	0.10	1.3
	Topornica	408 208	330	43.9	13.3	7.05 3.50	5.62	0.76	13.5	8.37 7.32	7.70	0.17	2.2
	Zdanów	402 221	337	29.8	8.9	6.80 3.85	5.74	0.49	8.5	8.23 7.68	7.92	0.13	1.7
Czarny Potok	Sitno	567 310	443	64.8	14.6	10.00 5.35	7.65	1.16	15.2	8.22 7.13	7.83	0.24	3.1
	Sitaniec	562 303	440	53.9	12.3	9.65 4.95	7.36	0.93	12.6	8.29 7.37	7.93	0.20	2.5
Łabuńka	Łabuńska	609 347	419	50.2	12.0	10.10 5.40	7.10	0.94	13.2	8.59 7.52	7.95	0.17	2.1
	Pniówek	595 337	456	58.2	12.8	10.40 5.60	7.63	1.02	13.4	8.35 7.26	7.69	0.19	2.4
	Zamość	558 267	379	43.5	11.5	7.70 4.40	6.25	0.64	10.2	8.55 7.49	7.98	0.20	2.6
	Krzak	681 329	473	56.4	11.9	8.30 5.15	6.99	0.60	8.7	8.21 6.91	7.49	0.20	2.6

$\bar{X}$ — arithmetic mean,
σ — deviation from arithmetic mean,
V — variation coefficient.

TABLE 2. Characteristic indices for the main ions in waters of the Łabuńka river and its tributaries — the Topornica and the Czarny Potok, in the years 1989–1992; from the author's measurements

River	Locality	Anions											
		HCO_3^-				SO_4^{2-}				Cl^-			
		max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V
		mg dm^{-3}			%	mg dm^{-3}			%	mg dm–3			%
Topornica	Zarzecze	347.8 295.9	316.0	6.0	1.9	36.0 9.6	19.5	5.4	27.7	18.4 10.6	14.1	1.7	11.8
	Topornica	378.3 192.2	318.4	40.5	12.7	55.2 7.2	25.4	9.4	37.0	21.3 10.3	13.8	2.2	16.1
	Zdanów	338.7 204.4	312.9	23.5	7.5	60.1 9.6	27.9	9.6	34.4	19.5 11.3	15.6	1.9	12.2
Czarny Potok	Sitno	524.8 308.2	431.7	55.5	12.9	55.2 4.8	21.9	11.7	53.4	29.1 11.7	20.7	4.4	21.2
	Sitaniec	485.1 265.4	401.7	46.5	11.6	69.7 7.2	31.2	13.5	43.2	32.6 19.5	25.2	2.6	10.3
Łabuńka	Łabuńka	454.6 286.8	377.2	30.7	8.1	91.3 4.8	33.7	18.8	55.7	34.4 16.0	21.5	3.1	14.5
	Pniówek	494.3 302.0	412.3	42.3	10.3	84.1 4.8	28.9	17.2	59.5	90.1 18.8	27.0	8.0	29.8
	Zamość	393.6 241.0	338.6	28.9	8.5	69.7 4.8	30.0	12.0	39.9	106.4 15.6	23.5	11.1	47.3
	Krzak	509.5 277.6	402.8	41.6	10.3	67.3 4.8	34.2	12.4	36.5	105.3 21.3	37.1	12.7	34.2

River	Locality	Cations											
		Ca^{2+}				Mg^{2+}				$Na^{+} + K^{+}$			
		max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V	max min	$\bar{X}$	σ	V
		mg dm^{-3}			%	mg dm^{-3}			%	mg dm–3			%
Topornica	Zarzecze	105.2 89.2	98.5	2.9	3.0	10.3 3.6	7.4	1.3	18.0	23.5 4.0	11.5	3.5	30.3
	Topornica	123.2 57.1	95.3	14.9	15.6	13.4 5.5	10.6	1.4	13.2	27.5 3.5	12.8	4.4	34.5
	Zdanów	126.3 61.1	101.7	10.2	10.0	10.3 3.6	8.0	1.4	17.9	24.0 2.5	10.3	4.0	39.2
Czarny Potok	Sitno	179.4 90.2	136.2	21.8	16.0	18.8 4.3	10.4	2.8	26.6	30.0 2.0	11.5	7.2	63.2
	Sitaniec	166.3 76.2	124.0	17.5	14.1	22.5 6.7	14.2	3.1	21.9	33.3 3.8	14.7	6.0	40.5
Łabuńka	Łabuńka	181.4 95.2	125.5	18.1	14.4	17.0 3.0	10.2	2.3	22.8	30.0 1.3	9.7	5.2	53.5
	Pniówek	185.4 89.2	133.1	21.0	15.8	17.0 6.7	12.1	1.8	15.3	47.3 2.0	12.2	7.3	60.3
	Zamość	139.3 76.2	109.6	13.3	12.1	15.2 3.0	9.5	2.2	23.1	71.3 2.5	14.5	9.8	67.7
	Krzak	142.3 83.2	117.9	11.5	9.8	17.6 7.3	13.4	1.9	14.2	106.8 7.5	34.3	15.2	44.3

$\bar{X}$ — arithmetic mean,
σ — deviation from arithmetic mean,
V — variation coefficient.

TABLE 3. Quality of the Łabuńka river waters and those its tributaries — the Czarny Potok and the Topornica, on the basis of data from the Provincial Inspectorate of Environment Protection in Zamość; data for the years 1989–1992 (A) and the decade 1981–1990 (B)

River	Locality	Period of studies	O_2							BOD_5						
			Number of measurements	Typical values		Classes of water quality*				Number of measurements	Typical values		Classes of water quality**			
				max min	$\overline{X}$	I	II	III	pkz		max min	$\overline{X}$	I	II	III	pkz
				mg dm^{-3}		%					mg O_2 dm^{-3}		%			
Czarny Potok	Sitaniec	A	46	14.0 5.2	8.6	91.3	8.7	–	–	46	7.6 0.4	2.7	82.6	17.4	–	–
		B	86	15.0 4.0	8.0	80.2	15.1	4.7	–	86	48.4 0.6	2.8	87.2	9.3	–	3.5
Topornica	Zamość	A	24	11.8 6.6	9.0	100.0	–	–	–	36	7.8 0.4	2.9	77.8	22.2	–	–
		B	45	12.8 6.2	9.2	100.0	–	–	–	57	7.2 0.2	2.4	87.7	12.3	–	–
Łabuńka	Krzak	A	43	9.2 0.0	2.7	9.3	4.6	11.6	74.5	48	112.2 1.8	20.3	8.3	22.9	18.8	50.0
		B	112	8.8 0.0	2.0	14.3	5.4	5.4	74.9	112	208.6 1.2	30.1	12.5	10.7	11.6	65.2

River	Locality	Period of studies	Number of measurements	PO_4^{3-}						N-NH$_4^+$						
				Typical values		Classes of water quality***				Number of measurements	Typical values		Classes of water quality****			
				max min	$\overline{X}$	I	II	III	pkz		max min	$\overline{X}$	I	II	III	pkz
				mg dm^{-3}		%					mg O$_2$ dm^{-3}		%			
Czarny Potok	Sitaniec	A	46	0.55 0.05	0.18	73.9	26.1	–	–	45	3.94 0.0	0.93	64.4	31.1	4.5	–
		B	87	2.13 0.07	0.30	47.1	48.3	1.2	3.4	86	4.18 0.0	0.87	63.9	32.6	3.5	–
Topornica	Zamość	A	35	0.45 0.05	0.25	7.1	62.9	–	–	36	3.94 0.09	0.94	61.1	36.1	2.8	–
		B	60	0.67 0.05	0.30	23.3	76.7	–	–	59	6.52 0.0	1.00	39.0	39.0	3.3	1.7
Łabuńka	Krzak	A	48	15.80 0.20	3.11	2.1	2.1	10.4	85.4	47	21.0 0.17	6.30	4.3	14.9	42.5	38.3
		B	113	22.50 0.10	2.50	3.5	11.5	8.0	77.0	114	21.0 0.07	4.54	20.2	20.2	33.3	26.3

$\overline{X}$ — arithmetic mean, pzk — waters beyond classification

Classification standards of waters on the basis of The Decree of the Minister of Environment Protection, Natural Resources and Forestry of 5 Nov. 1991

*		**		***		****	
I	6.0 mg dm^{-3} and above	I	4.0 mg O$_2$ dm^{-3} below	I	0.2 mg dm^{-3} and below	I	1.0 mg dm^{-3} and below
II	5.0–5.9	II	4.1–8.0	II	0.21–0.60	II	1.1–3.0
III	4.0–4.9	III	8.1–12.0	III	0.61–1.00	III	3.1–6.0
pzk	below 4.0	pzk	above 12.0	pzk	above 1.0	pzk	above 6.0

TABLE 4. Selected chemism features of river waters unpolluted (R_1) and polluted with municipal — industrial wastewaters (R_2) in the Łabunka river catchment in the years 1989—1992

Tributary and measurement point	Anions														
	HCO_3^-					SO_4^{2-}					Cl^-				
	min max	X	n	Most numerous class interval		min max	X	n	Most numerous class interval		min max	X	n	Most numerous class interval	
	mg dm^{-3}			Interval	Measurement %	mg dm^{-3}			Interval	Measurement %	mg dm^{-3}			Interval	Measurement %
Łabunka R_1	524.8 192.2	342.4	384	281–360	61.2	91.3 4.8	27.9	384	10.1–30.0	65.3	34.4 10.3	17.0	384	10.1–20.0	76.13
Łabunka R_2 — Krzak	509.5 277.6	402.8	79	361–440	71.8	67.3 4.8	34.2	78	30.1–50.0	56.5	105.3 21.3	37.1	78	20.1–40.0	69.2

Tributary and measurement point	Cations														
	Ca^{2+}					Mg^{2+}					$Na^+ + K^+$				
	min max	X	n	Most numerous class interval		min max	X	n	Most numerous class interval		min max	X	n	Most numerous class interval	
	mg dm^{-3}			Interval	Measurement %	mg dm^{-3}			Interval	Measurement %	mg dm^{-3}			Interval	Measurement %
Łabunka R_1	181.4 57.1	109.5	384	81–120	70.1	18.8 3.0	9.0	384	5.1–10.0	61.7	30.0 1.3	10.8	384	0.0–20.0	94.5
Łabunka R_2 — Krzak	142.3 83.2	117.9	78	101–140	92.3	17.6 7.3	13.4	78	10.1–15.0	71.8	106.8 7.5	34.3	78	20.1–40.0	52.7

Tributary and measurement point	Solute concentration					Hardness					pH				
	min max	$\bar{X}$	n	Most numerous class interval		min max	$\bar{X}$	n	Most numerous class interval		min max	$\bar{X}$	n	Most numerous class interval	
	mg dm^{-3}			Interval	Measurement %	mval dm^{-3}			Interval	Measurement %				Interval	Measurement %
Łabuńka R_1	609 208	364	384	301–400	68.0	10.1 3.50	6.22	384	5.01–6.20	53.6	8.59 7.13	7.86	375	7.61–8.00	70.9
Łabuńka R_2 — Krzak	681 329	473	78	401–500	62.6	8.30 5.15	6.99	78	6.21–7.40	66.6	8.21 6.91	7.49	76	7.21–7.60	72.4

$\bar{X}$ — arithmetic mean,
n — number of analyses,
R_1 — weighted means for the catchment of the Topornica, upper Czarny Potok and upper Łabuńka rivers.

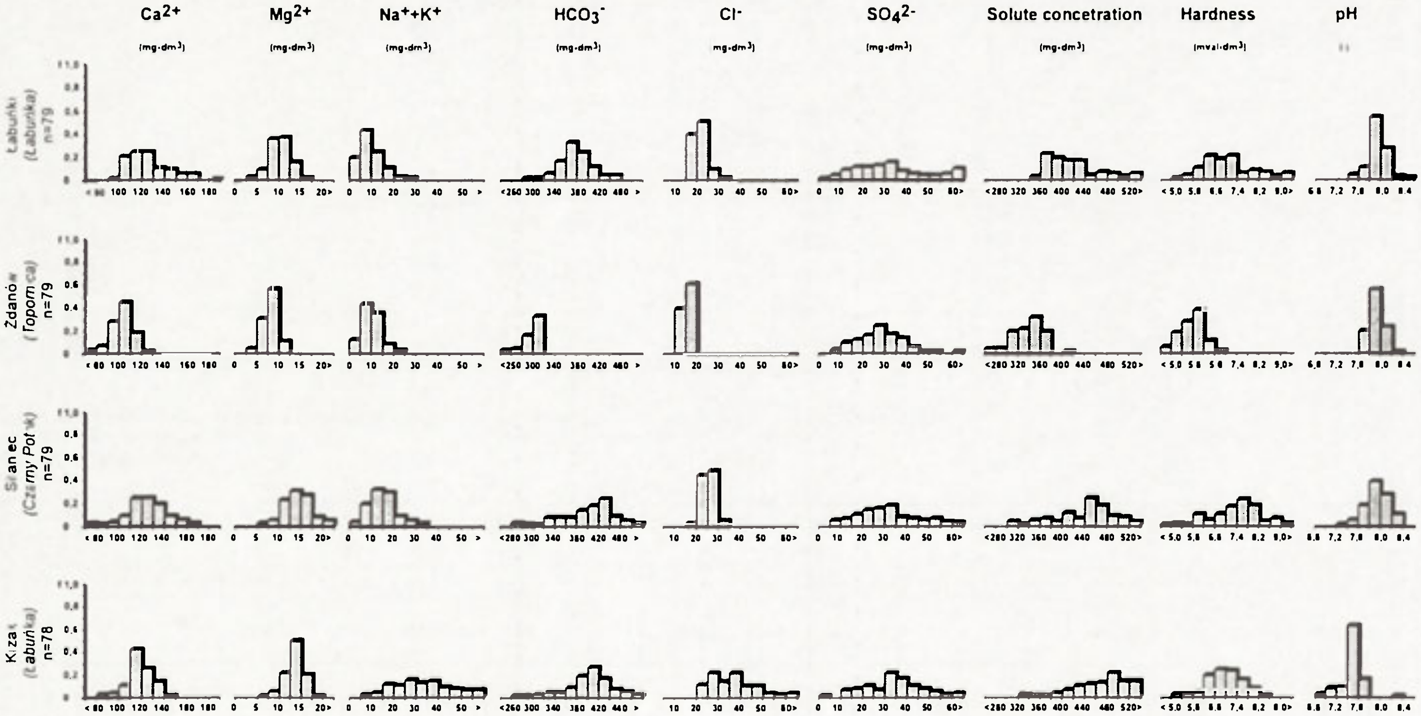

Fig. 2. Distribution histograms for selected physicochemical indices of waters of the Łabuńka river and its tributaries —the Czarny Potok and the Topornica. On the basis of author's data for the years 1989–1992

n — number of measurements taken for calculations they contain fewer Ca^{2+} ions and are characterized by the lowest concentrations of Cl^- and SO_4^{2-} ions (Table 2).

The results obtained for the upper Łabuńka river in the section at Łabuńki, for the Topornica river in the sections at Zarzecze, Topornica and Zdanów, and for the Czarny Potok river at Sitno were the basis to determine mean indices for waters unpolluted with wastewater, being representative for the present hydrochemical background (Table 4). It should be noted that the sections close partial catchments (206 km^2 in all), in which surface waters are influenced by farming; 71.8% of the area is farmland (Table 5). On the basis of the results of studies in the years 1989–1991, waters recognized as hydrochemical background were characterized by an average solute concentration of 364 mg dm^{-3}; they were hard waters (6.22 mval dm^{-3}) of weak-alkaline reaction (pH — 7.86). An analysis of the lowest values for dissolved oxygen in Czarny Potok and Topornica waters unpolluted by sewage (Table 3) indicates that they were not in critical situations as regards their oxygenation. This attests to their limited pollution with organic substances and relatively good reaeration. Mean oxygen content in waters of the hydrochemical background was about 9.0 mg dm^{-3}, and the BOD_5 index — 2.8 mg O_2 dm^{-3}; both oxygen concentration and the BOD_5 index were most often recorded in intervals specific for class I water quality (Table 3). Also relatively low were the concentrations of phosphates and ammonium nitrogen — 0.20 and 0.94 mg dm^{-3}, respectively.

TABLE 5. Land use in the Labuńka river catchment according to the author's measurements

Catchment		Total	Arable land	Meadows	Forests	Others
Catchments unpolluted by wastewater*	km^2	205.8	128.0	19.7	49.6	8.5
	%	100.0	62.2	9.6	24.1	4.1
Łabuńka river catchment up-stream of the gauging station at Krzak **	km^2	416.0	262.5	67.4	51.2	34.9
	%	100.0	63.1	16.2	12.3	8.4

* Summarized values for the river catchments: Topornica up-stream of Żdanów, upper Łabuńka up-stream of Łabuńki village and Czarny Potok up-stream of Sitno.

** Catchment including the city area of Zamość with municipal- industrial wastewater sources.

In relation to the thus-determined indices characterizing the hydrochemical background of the catchment studied, the Łabuńka river waters at Krzak show symptoms of considerable degradation. In the years 1989–1992, their solute concentration was higher by 29.9%, hardness higher by 12.4%, and pH lower by 4.7%. In waters polluted with wastewater a higher concentration of the analysed macrocomponents was also found (Table 4); being highest in the case of the following ions: Mg^{2+} (by 48.8%), Cl^- (by 118%) and $Na^+ + K^+$ (by 217.6%). The oxygen and biogenic indices differed much more (Table 3). The Łabuńka river waters at Krzak contained three times less oxygen and seven times more organic substance; the values recorded most often did not meet the standards. In the Łabuńka river waters at Krzak, the mean concentration of ammonium nitrogen (6.30 mg dm^{-3}) was 7 times higher than that characterizing the hydrochemical background, and that of phosphates (3.11 mg dm^{-3}) even 12 times higher.

The oxygen and biogenic indices and ion concentrations of chloride, magnesium, sulphate, sodium and potassium account for the distinctly different character of the Łabuńka river waters at Krzak, affected by wastewater.

THE CONTRIBUTION OF WASTEWATER TO THE RUNOFF OF SOLUTES FROM THE ŁABUŃKA RIVER CATCHMENT

An attempt was made to determine the content of solutes from wastewater in a way similar to that presented by H. Maruszczak (1990). Calculations were performed for the gauging station section at Krzak from data for the years 1990–1991.

It was assumed that the difference in total solute concentrations of waters polluted with wastewater down-stream of Zamość and unpolluted up-stream of this city is an indirect measure of the wastewater content in the outflow of solutes. In the catchment 416 km^2 in size up-stream of the gauging station at Krzak, the mean annual index of specific discharge was 2.4 $dm^3\ s^{-1}\ km^{-2}$ in the years 1990–1991. The mean solute concentration of Łabuńka river waters polluted with wastewater was 474 mg dm^{-3}; the solute yield from this catchment was thus 35.9 tons km^{-2} $year^{-1}$. About 15,000 tons of solutes flowed away through the gauging station at Krzak. The mean solute concentration of waters unpolluted with wastewater in 1990–1991, determined from the data for the Łabuńka river up-stream of Zamość and its tributaries, was 361 mg dm^{-3}. Accepting such a solute concentration as natural, representing the hydrochemical background for the whole Łabuńka river catchment, we can calculate the solute yield at 27 t km^{-2} $year^{-1}$ for the gauging station at Krzak, and the volume index of solutes at 11,400 tons. The difference in the volume of solutes from the catchment polluted with wastewater and estimated for the hydrochemical background is an indirect measure of the transport of solutes from wastewater. In the years 1990–1991 this value was 3600 tons, which constituted 24% of the total outflow of solutes.

For comparison, the results of similar calculations made for other catchments can be given. For the Uherka river catchment (98.5 km^2) polluted with wastewater from Chełm, a city of similar size (67,000 inhabitants in 1990), the content of solutes supplied with sewage was estimated at 18.3% from data for 1989–1990 (H. Maruszczak et al. 1993). The wastewater from Łublin, a much bigger city than Zamość (304,000 inhabitants in 1980, and 351,000 in 1990), constituted a considerably greater part of the total outflow of solutes in the Bystrzyca river catchment. Calculations made by H. Maruszczak (1990) from the data of 1975–1980 for waters of the Bystrzyca (a basin of 1025 km^2) up-stream and down-stream of Lublin showed that about 29% of the total solute outflow came from municipal and industrial wastewater. Corresponding data for the years 1981–1990 showed advancing degradation of the Bystrzyca river waters down-stream of Lublin; on average as much as 41% of the total outflow of solutes came from wastewater in that decade (H. Maruszczak et al. 1993).

The component coming from wastewater includes natural substances drawn from the lithosphere with groundwaters exploited for municipal and industrial needs, and "artificial" substances connected with economic actions. In the Łabuńka river catchment, water demands for municipal and economic needs are wholly satisfied by exploitation of Upper Cretaceous groundwaters. Due to that, the above component can be estimated from the volume indices of water carried away in the form of wastewater and from the average solute concentration of tap waters. In the years 1990–1991, the mean annual water volume discharged as wastewater into the Łabuńka river was 6.25 million m^3, and the average solute concentration of tap waters was 380 mg dm^{-3} in the 80's. Thus about 2400 tons of dissolved substances came annually from groundwaters exploited by waterworks. The mean annual amount of solutes supplied by wastewater (3600 tons) reduced by the amount drawn from the lithosphere by means of wells (2400 tons) gives an "artificial" component (1200 tons). In the Łabuńka river catchment this magnitude constituted 8% of the total solute yields in 1990–1991. For the Bystrzyca river basin an analogous component was determined by H. Maruszczak (1990) at 12%, from data for the years 1975–1980.

The estimated index of the amount of municipal-industrial wastewater from Zamość is appropriate for the last years. Pollution of the Łabuńka river waters, particularly with sewage from Zamość, has changed with the development of this city. This can be illustrated by measurement data from 1959 published by K. Czyż et al. (1963); the number of inhabitants of Zamość was 29,000 in that year, and 63,100 in 1991. In 1959, the mean solute concentration of the Łabuńka waters in the village of Krzak (354 mg dm^{-3}), polluted with wastewater from Zamość, was on the level of today's hydrochemical background. Also on that level was the concentration of oxygen (9.2 mg dm^{-3}), ammonium nitrogen (0.80 mg dm^{-3}) and phosphates (0.22 mg dm^{-3}). However, the concentration of chlorides (14 mg dm^{-3}) and sulphates (18 mg dm^{-3}) was much lower than that characterizing the present hydrochemical background.

During the last few decades a big increase of symptoms of surface water degradation has occurred in the Łabuńka river catchment. This has been most distinctly documented by indices of chloride and sulphate ion concentrations, oxygen conditions and the pollution of waters with organic and biogenic compounds.

CONCLUSIONS AND DISCUSSION

1. In the years 1989–1992 about 6.5 million m^3 of wastewater was discharged annually into surface waters of the Łabuńka river catchment up-stream of the gauging station at Krzak; this constituted 18% of the mean annual river outflow. Waters of the upper Łabuńka river and its left tributary — the Topornica were not polluted with wastewater; a small amount of wastewater (0.2% of the mean annual volume) was received by the Czarny Potok river waters; as much as 99.8% of wastewater was discharged into the Łabuńka river. It is polluted with wastewater coming largely from Zamość (as much as 98.4% of the mean annual volume of wastewater is delivered by the Company for Water Supply and Treatment in Zamość).

2. On the basis of the author's measurements and the data from the Provincial Inspectorate of Environment Protection in Zamość for the years 1989–1992 it has been found that the Łabuńka river waters at Krzak are most polluted largely with municipal-industrial wastewater from Zamość. They are characterized by the highest concentration of solutes (473 mg dm^{-3}); increased amounts of ions: Cl^- — 37 mg dm^{-3}, SO_4^{2-} — 34, $Na^+ + K^+$ — 34, and biogenic components: $N\text{–}NH_4^+$ — 6.3 and PO_4^{3-} — 3.11 mg dm^{-3}; bad oxygen conditions (2.7 mg dm^{-3}) and considerable pollution with organic compounds (BOD_5 — 20.3 mg $O_2\,dm^{-3}$).

3. In the Łabuńka river catchment the chemism of waters unpolluted with wastewater shows a differentiation controlled by lithology of the bedrock. Higher solute concentration indices (419–443 mg dm^{-3}) were found in waters drained off from bogs; they are distinguished by the highest content of Ca^{2+} ions (126–136 mg dm^{-3}) and a relatively high concentration of SO_4^{2-} ions (22–34 mg dm^{-3}). Waters with lower solute concentration (322–333 mg dm^{-3}) were found in partial catchments with loess cover; they contain fewer Ca^{2+} ions (95–102 mg dm^{-3}) and fewest Cl^- ions (14–16 mg dm^{-3}).

4. The results of studies of the upper Łabuńka river and its tributaries — the Topornica and the Czarny Potok, allowed the author to determine indices characteristic for the present hydrochemical background of the river water in the Łabuńka river catchment. This background is characterized by: a solute concentration of 364 mg dm^{-3}, concentration of ions: Ca^{2+} — 110 mg dm^{-3}, Mg^{2+} — 9, $Na^+ + K^+$ — 11, SO_4^{2-} — 28 and Cl^- — 17 mg dm^{-3}, good oxygen conditions (about 9 mg dm^{-3}) and a low content of organic compounds (BOD_5 — about 2.9 mg $O_2\,dm^{-3}$) and biogenic ones (PO_4^{3-} — 0.20 mg dm^{-3} and $N\text{–}NH_4^+$ — 0.94 mg dm^{-3}).

5. In the years 1989–1992 the Łabuńka river waters at Krzak showed solute concentrations higher by about 30% in relation to the hydrochemical background. They were characterized by a considerably higher concentration of all macrocomponents (in the case of Cl^- ions about two times higher and $Na^+ + K^+$ about three times higher); 3 times lower oxygen concentration, 7 times greater concentrations of organic compounds and ammonium nitrogen and 12 times greater concentration of phosphates.

6. From comparison of indices determined for catchments unpolluted with wastewater and the catchment including Zamość an attempt was made to define the amounts of solutes derived from municipal-industrial wastewater. In the years 1990–1991 the mean annual transport of solutes supplied with Zamość wastewater amounted to 3600 tons, which constituted 24% of the total outflow of solutes from the Łabuńka river catchment up-stream of Krzak. Substances dissolved in wastewater are largely of natural origin. From the data concerning the wastewater volume and solute concentration of river and groundwaters exploited by the Zamość Water Works it can be estimated that the "artificial" component constitutes about 33% of substances dissloved in sewage.

7. Over the 33 years 1959–1992 considerable changes in the chemism of waters in the Łabuńka river catchment occurred. On the basis of the data published by K. Czyż et al. (1963) it can be seen that today's hydrochemical background is on the level of waters with wastewater of 1959. The scale of changes in the background level can be estimated approximately from the measurement results of chloride ion concentrations in river waters from the 40's. According to M. Stangenberg (1958), chlorides occurred at that time at 5–10 mg dm^{-3} in river waters unpolluted with wastewater in Poland's territory. The present values determined for the hydrochemical background are almost twice as high.

REFERENCES

Czyż K., Koziorowski B., Moraczewski J., 1963, *Charakterystyka zanieczyszczenia rzeki Wieprz*, Prace Inst. Gosp. Wodnej 1(3), 75–173.

Kozłowski S., 1991, *Gospodarka a środowisko przyrodnicze*, PWN, Warszawa.

Markowicz M., Pulina M., 1979, *Ilościowa półmikroanaliza chemiczna wód w obszarach krasu węglanowego*, USl., Katowice.

Maruszczak H., 1990, *Denudacja chemiczna (Chemical denudation)*, [in:] *Współczesne przemiany rzeźby Polski południowowschodniej*, Prace Geogr. IGiPZ PAN 153, 23–41.

Maruszczak H., Świeca A., Wilgat M., Siewiereniuk K., 1993, *Udział ścieków komunalno-przemysłowych w odpływie roztworów z wybranych zlewni we wschodniej Polsce jako wskaźnik stopnia degradacji środowiska (The share of communal and industrial sewage in the solution runoff from selected east-Polish catchments as an index of the enviromental degradation level)*. Zintegrowany Monitoring Środowiska Przyrodniczego, Biblioteka Monitoringu Środowiska, Warszawa, 169–184.

Michalczyk Z., 1986, *Warunki występowania i krążenia wód na obszarze Wyżyny Lubelskiej i Roztocza*, Rozpr. Habil. 30, UMCS, Lublin.

Stangenberg M., 1958, *Ogólny pogląd na skład chemiczny wód rzecznych Polski (A general outlook on the chemical composition of river waters in Poland)*, Polskie Archiwum Hydrobiologiczne 4(17), 289–359.

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HYDROLOGICAL CONSEQUENCES OF HUMAN ACTION IN THE ŁĘCZNA–WŁODAWA LAKE REGION

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ABSTRACT: An attempt was made to define the character and dynamics of hydrographical changes in the Łęczna–Włodawa Lake Region. They have been influenced not only by agricultural land use, but also by the building of the Wieprza–Krzna canal and the drainage system connected with it, by rapid development of tourism, and by coal mining. Cartographic materials, hydrometric data, and field work carried out from the beginning of the 50's by research workers of the Department of Hydrography, Maria Curie-Sklodowska University, were a basis for these studies.

KEY WORDS: anthropopressure, water management, water quality, environmental protection, Polesie Lubelskie region, Eastern Poland.

NATURAL WATER CONDITIONS

The Łęczna–Włodawa Lake Region is located in the European lowland belt, close to the elevated Lublin Plateau. It is a subregion of Polesie, which is considered to belong to Eastern Europe (Fig. 1). This region extends latitudinally over 50 km but its meridional extent does not reach 30 km. The lakes are a peculiar feature of this region, and are the only group in Poland situated beyond the maximum extent of the Vistulian ice sheet.

The climate determines water deficiency in this area. The mean annual precipitation is 560 mm, and evapotranspiration 450 mm. The runoff amounts 110 mm, which gives a runoff coefficient below 20%. Even if error correction of precipitation measurements is taken into account, the resulting value is not equal to the potential evaporation, the magnitude of which exceeds 600 mm only in the summer half-year period. Thus water deficit characterizes this region, a fact to which attention was drawn by K. Wojciechowski (1965). Periodic water deficiency resulting from precipitation and evaporation distribution over the year occurs most frequently in summer, despite the fact that rainfalls are most abundant in this season.

Although the amount of circulating water is small, there are numerous lakes — natural and changed to reservoirs, small ponds, wetlands of various types, streams and ditches periodically discharging water. The secret of the apparent abundance of water lies in the relief and geological structure. This morphological flat depression is open eastwards and surrounded by higher terrain on three sides. The altitudes vary from 180–200 m a. s.l. on its southern and northern peripheries, to 160 m by the river Bug and 140 m in the north–west. Plains inclined below 2° are the main element. But the origin of the monotonous plains differs. Two denudation and two accumulation surfaces can be distinguished here (Wilgat 1957). The accumulation plains, differing slightly in their heights, contrast with their moisture-conditioned vegetation. The lower ones have mire vegetation, whereas the higher sandy ones are cultivated or used as pasture, or partially covered with forest.

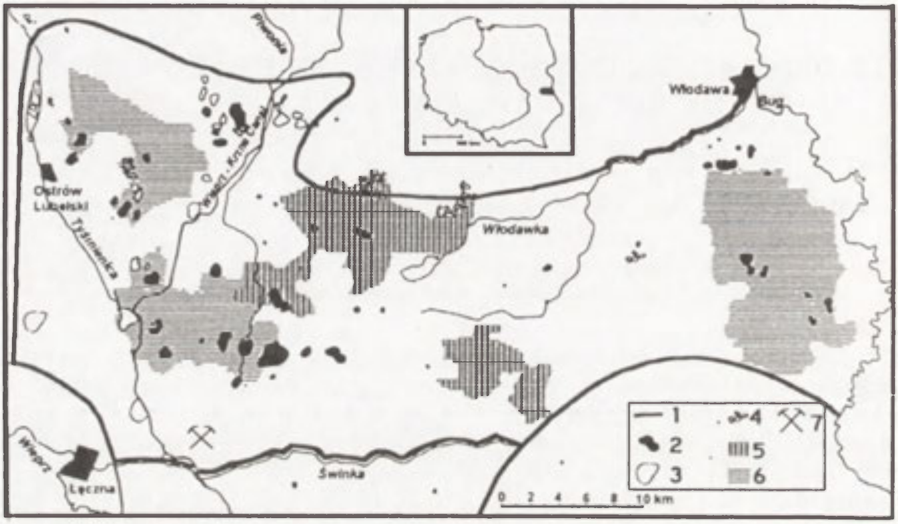

Fig. 1. Łęczna–Włodawa Lake Region
1 — region boundaries, 2 — lakes, 3 — lakes turned into retention reservoirs, 4 — ponds, 5 — Polesie National Park, 6 — Landscape Parks, 7 — colliery

The sandy plain was formed in the period of the Middle-Polish glaciation, by the accumulation of stagnant and flowing waters. In the last glaciation it was overlain with sands. Numerous depressions in its surface were filled with organic sediments in the Holocene, and they now form a large — discontinuous — lower accumulation plain.

The denudation plains, common in the northern part of Polesie, occupy small areas in the Lake Region. They were formed on ground moraine or Upper Cretaceous outcrops. They are a little higher than the accumulation plains and have a diversified microrelief.

The thickness of Quaternary formations in the Łęczna–Włodawa Lake Region fluctuates from less than 1 to 80 m (Buraczyński 1983; Henkiel 1983). Cretaceous beds emerge on the surface in the form of gently-shaped elevations, which do not exceed 20 m. Where Cretaceous rock is exposed from overlying deposits, numerous karst dolines are found on its surface. The Łęczna–Włodawa Lake Region and the neighbouring Dorohusk Depression differ from subregions of western Polesie in such karst forms as funnel-shaped and flat-bottomed dolines occurring densely in Cretaceous hills and denudation plains.

Fine-grained deposits — silty sands, muds and clays — play a large part in the structure of accumulation plains. Their shallow occurrence strongly reduces water infiltration into deeper layers and favours the formation of swamps and wetlands.

Within the lower accumulation plain, the groundwater table occurs just below or at the land surface. In the area of the higher accumulation plain precipitation waters easily percolate through the layer of sands and are intercepted by less permeable deposits at a depth of several metres. The table of these waters occurs mainly at a depth of 2–5 m. Groundwaters of both accumulation plains form one table accordant with the lake levels. It also extends to the area of denudation plains and Cretaceous hills, where groundwater depths even exceed 10 m.

Thus in the whole Lake Region the depth of the groundwater table fluctuates from zero to about 8–10 m. High permeability of sands facilitates considerable seasonal oscillations of the groundwater table, which is reflected by the varying range of wetland areas. A few decades ago many areas were still inaccessible during spring thaw and some villages were isolated.

Older Pleistocene deposits of various lithology and permeability have been preserved under muddy-sandy deposits on which waters of the first Quaternary horizon are intercepted. Waters occurring in the former formations are most often associated with water-bearing Cretaceous horizon.

Quaternary deposits cover a series of Upper Cretaceous rocks, the thickness of which is from 300 m in the Bug river region to 550 m on the western peripheries in the Tyśmienica river valley (Krassowska, Niemczycka 1984). Marly chalk of the Lower Maestrichtian occurs along the eastern Bug river region; in the remaining area rocks of the Upper Maestrichtian are found, largely chalk and marls with interbeddings of harder opokas.

In the top part, Upper Cretaceous rocks are shattered, forming a dense network of weathering fissures, whereas joint fissures occur deeper. Fissures conducting water easily are found only in opokas and harder marls. In soft marls and chalk the fissures are easily constricted and stopped, which makes groundwater movement difficult; its rates are only a few metres per 24 hrs. With increasing depth, the number of open fissures decreases; at a depth of 120–170 m Cretaceous rocks are practically impermeable (Różkowski, Rudzińska 1982; *Conditions...* 1989).

The zone of free water exchange thus comprises Quaternary formations, locally-preserved residues of Tertiary formations of no hydrological significance, as well as an upper part of Cretaceous rocks. This zone does not reach a depth of 200 m (Różkowski, Rudzińska 1982).

Geological and geomorphological conditions effect the character of water circulation. The extensiveness of water and very moist areas, as well as a very shallow position of the groundwater-table favour a high evapotranspiration. From the balance calculations made by Michalczyk (Wilgat et al. 1991) it results that over 80% of precipitation water returns to the atmosphere. The remaining runoff consists of almost of equal parts of overland (48%) and subsurface flow (52%). The equilibrium results from land flatness making water runoff difficult, and limited absorbance of ground which cannot store a large excess of water, particularly in spring.

The runoff rhythm typical for rivers with rain-snow supply in this part of Europe distinguishes by the Polesie rivers from those flowing in the neighbouring regions. A strongly marked maximum runoff in March is followed by a minimum in July unlike that of other Polish rivers in the summer–autumn months. This is a consequence of weak underground supply, the reserves of which are readily exhausted. Most water runs off in spring (III–V) — 41%, much less in summer (VI–VIII) — 18% and still less in autumn (IX– XI) — 16% when underground reserves are exhausted and the atmosphere supply is very small. In winter, runoff increases to 25%, as a result of irregularly occurring thaw.

The specific discharge is small, on average a little below 3.5 l/s km^2, and even below 0.5 l/s km^2 during long-standing droughts. The small amount of discharged water does not favour the formation of a well-developed stream network. There are few rivers flowing in distinct valleys. All streams carry little water. The biggest, the Wlodawka river, discharges an average of over 2 m^3/s of water into the Bug river. None of the remaining rivers in the Lake district carries 1 m^3/s.

The rivers flow E into the Bug, and W and NW into the Wieprz. The watershed dividing the two catchments runs across the middle of the Lake Region. Distinct on Cretaceous hills, it disappears in flat soaked depressions, where artifical ditches form water 'gates' in it.

River sections near the watershed, which at present cannot be distinguished from artificial ditches, have no developed valleys and their channel slopes are small. Farther from the watershed the channel slopes are bigger and the valleys more distinct. This accounts for the immaturity of the hydrographic system; the rivers have not yet reached the central part of the region. Accordingly, a part of the lakes have not been included in the drainage network.

Lakes are the main element of the Lake Region's hydrosphere. Cataloguing performed at the beginning of the 50's showed the existence of 68 lakes of over 1 ha in area (Wilgat 1954). They are small bodies — the largest is 284 ha — of non-diversified shapes, often close to a circle or an oval. The lake depths are differentiated; shallow and very shallow ones predominate. The deepest exceed 30 m, which with the small surface areas gives big mean depths and considerable slope inclinations. Most lakes are overgrown heavily by plants, and numerous depressions filled with peat and gythia at present point to advanced process of lake disappearance. There are, however, lakes in which a mineral bottom and the scantiness of shore vegetation indicate their physiologically young age. It has not been determined whether this is the effect of conditions unfavourable for eutrophication or of the later formation of these lakes. Opinions about the genesis of the lakes differ. Some researchers associate their formation with karst processes in Cretaceous bedrock (Wilgat 1954,1963; Wilgat et al. 1991), others with Pleistocene permafrost (Buraczyński, Wojtanowicz 1974; Wojtanowicz 1993). However, after examining the sediments in several lakes it is known that they were formed not earlier than by the end of Pleistocene about 11,000 years ago (Więckowski, Wojciechowski 1971; Bałaga 1982).

In the environment of the Łęczna–Włodawa Lake Region water is of great importance. Hydrological features of the terrain — the scantiness of water reserves, the shallow occurrence of groundwaters, the poorly-organized drainage network, the extensiveness of wetlands, the shallowness of lakes and their strong overgrowth — all cause the component to be characterized by exceptionally limited resistance to transformations (Wilgat 1954, 1963; Wilgat et al. 1991; Michalczyk, Bartoszewski et al. 1993; Michalczyk, Dawidek et al. 1993).

FACTORS OF HYDROGRAPHIC CHANGE

It is difficult to estimate the transformation of the Lake Region hydrosphere due to human action, the history of which is long and cannot be reconstructed because of lack of, or inaccurate, documentation. Changes in the hydrosphere are not only caused by direct human interference in it, but also by farming in the environment, which makes it dificult to determine the role of the particular factors of change. Numerous and complicated are the ways of action on the hydrosphere (Wilgat 1979, 1983), and the effects cannot always be associated with the causes. Actions in various directions constitute a factor modifying natural development of the environment. The interlacing of natural and anthropogenic processes can result in unidirectional or antagonistic action on the hydrosphere of variable intensity in the course of time. It is therefore a problematic undertaking to find a point of reference for the determination of the effects of anthropopressure.

The difficulty scale in studies of anthropopressure is of course differentiated. This is largely determined by features of the natural environment, which condition its susceptibility to transformation. When environment resistance to changes becomes small, anthropopressure is increased and the effects of human action more evident. However, an attempt at reading direct and indirect effects on the hydrosphere can be more troublesome.

The hydrosphere of the Łęczna–Wlodawa Lake Region is, as has been stressed, very liable to transformations. However, this region was thinly populated for ages, and primitive farming did not cause significant changes in the environment. Simple hydrotechnical measures were taken here for a very long time, but till the 1960's they did not effect the character of water relationships. Since that time more and more conspicuous changes have occurred, as a result of intensified farming and increasing use of the lakes for recreation. Coal mining has become another new factor appearing here. Its role cannot be compared with those of the others because its influence on the hydrosphere is not confined to the zone of active water exchange, but also effects deeper water-bearing horizons.

CHANGES IN LAND USE AND THEIR HYDROLOGICAL CONSEQUENCES

Chronologically, the first transformation factor in the hydrosphere was the extirpation of forests and their changing to arable land. No data are available to determine the exact time when the process started. Therefore, attempts to reconstruct the changes of the primary environment are undertaken on the basis of the results of studies of settlement and farming. For the Lublin district in its historical bundaries — neighbouring from the East with the Łęczna–Wlodawa Lake Region — changes of land use in several periods of time were presented by Maruszczak (1987). According to this study, 83–88% of its area was covered with forest in the year 1000 — the dawn of Poland's history; by 1340 this index had decreased to 73–77%, by 1580 to 44–48%, and by 1824 to 36%. In 1980 its woodland was only 20.5%. Arable land increased in parallel, exceeding 50% at the beginning of the 19th century, and constituting 71% in 1980. From the data it appears that the deforestation rate varied. It was low in the early Middle Ages, increased considerably in the late Middle Ages with increasing population density and changes in the cultivation system and land holding (feudal farming). It decreased again in the 17th c., when Poland entered a period of long economic stagnation and devastating wars. Population increase in the 19th c. and growing land hunger became the cause of a repeated, considerable intensification of deforestation.

In the Łęczna–Włodawa Lake Region the primary forest cover was lower than in the Lublin district, because open waters, swamps and wetland scrub constituted a bigger percantage area. Higher land stretches were deforested, but poor soils and a sparse population did not favour the development of agriculture. A Topographical Chart of the Polish Kingdom at 1:126,000 (issued in 1839) gave a relatively credible first image of land use in the Lake Region area, reproducing the state existing there in about 1830. The Lake Region is presented as a mosaic of arable land, forests, shrub patches, meadows and swamps with lakes scattered all over its area. Forests occupy less than 50% of its area but predominate over other natural or almost natural terrain in the landscape in which cultivated fields form smaller or larger enclaves.

Later years brought considerable changes to forest cover. According to Maruszczak (1952), the woodland area decreased by over 50% in the central part of the Lake Region between 1830 and 1930. The forest cover of three time periods was compared for this fragment of the Region comprising 3500 ha (Fig. 2 and 3). A German 1:25,000 map issued in 1915, a copy of a Russian map for which the topographical picture was made in 1887, presents the situation from the end of the 19th c. The forest area was then only 29.0% and that of cultivated fields together with farm buildings — 39.5%. According to the 1:25,000 topographical map issued by Główny Urząd Geodezji i Kartografii (The Central Office of Survey and Cartography) the arable land area in 1976 had increased to 52.4%, and that of forests had decreased to 27.7%. In an aerial photograph in August 1992 the area of arable land was 47.4%, and that of forests 33.6%.

Besides cutting, afforestation was conducted in the 19th and 20th c., but its scale was much smaller. Moreover, pine monocultures were introduced in place of natural forest communities, and the role of a forest depends not only on its area and its location in the catchment but also on its species composition and the age structure of the stand of trees.

The consequences of changes in land-use cannot be determined precisely. The influence of forest on water circulation and relationships, despite studies carried out for a long time and abundant literature, have not been fully elucidated. It depends on climate, particularly snow percentage

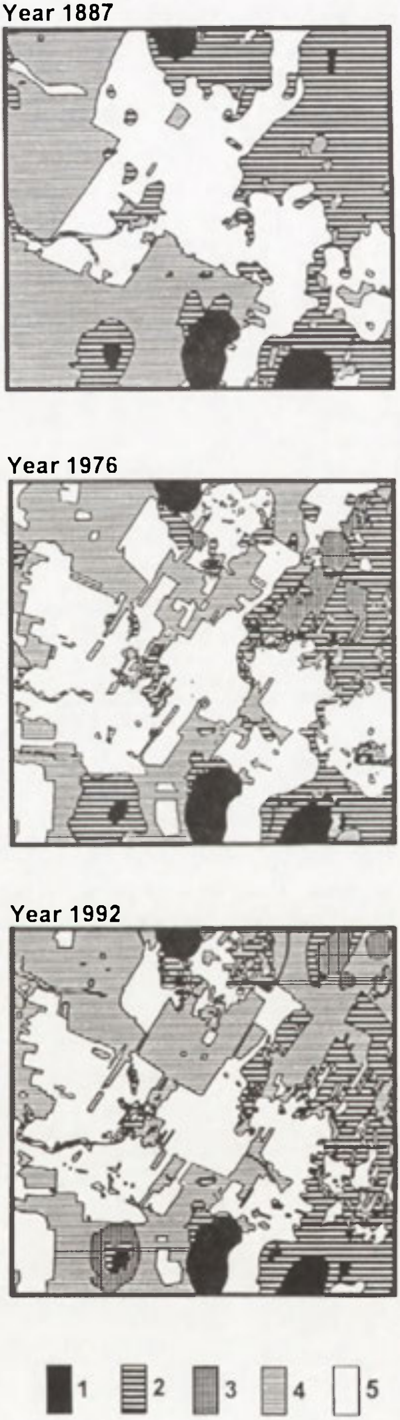

Fig. 2. Land use in the central part of the Lake Region
1 — waters, 2 —wet meadows, mires,
3 — forests in wetland, 4 — other forests,
5 — arable land and farm buildings

in total precipitation, and on the course of temperature as well as land conditions such as: slope, soil type land, subsoil character. Thus, it is not well known to what extent forest effects the incoming amount in a water balance, though in Poland its role is rather positive[1].

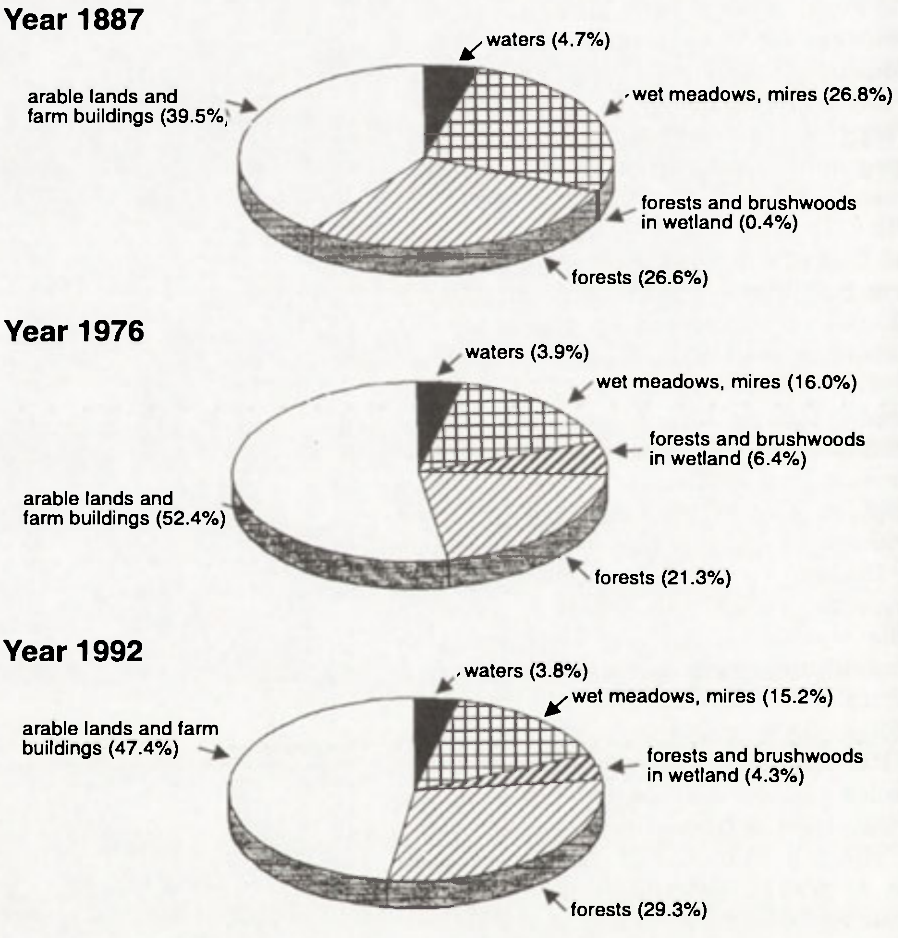

Fig. 3. Land use in the central part of the Lake Region

It has not been determined, either, how forest areas influence the water balance's outgoing amount, i.e. evaporation and runoff. Unequivocal conclusions are confined to those concerning runoff dynamics regulated by forest. Snow cover lying longer and thawing more slowly, and big moisture retention in forest litter and soil frozen a little or not at all increase water

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[1] A review of studies on forest influences on water circulation carried out in Poland was presented recently by Gutry-Korycka, 1993.

infiltration into soil and restrict overland flow. Runoff in periods with excess water, particularly in spring, is delayed or reduced, which attenuates floods. In dry periods, however, supply from underground reserves restricts the formation of low water. This regulating role of the forest also depends on local conditions.

It is more dificult to determine the influence of farming on water relationships. A big role is played by the character of farming:

— the method of soil cultivation conditioning evaporation, infiltration, overland flow and soil retention,

— the kind of cultivated plants differing strongly with regard to water requirements, i.e. affecting the magnitude of evapotranspiration and very differently protecting soil from overland flow,

— the intensity of soil cultivation on which the amount of used fertilizers depends, which effects the magnitude of soil moisture storage.

In the conditions of the Łęczna–Wlodawa Lake Region changes in landuse must have affected above all the magnitude of evapotranspiration. With shallow groundwater occurrence evapotranspiration in forests could be maximum in the given thermal conditions. Replacing forests with cultivated fields or pastures decreased ground evaporation, which resulted in a rise in the groundwater-table, and thus in the extended range of wetlands.

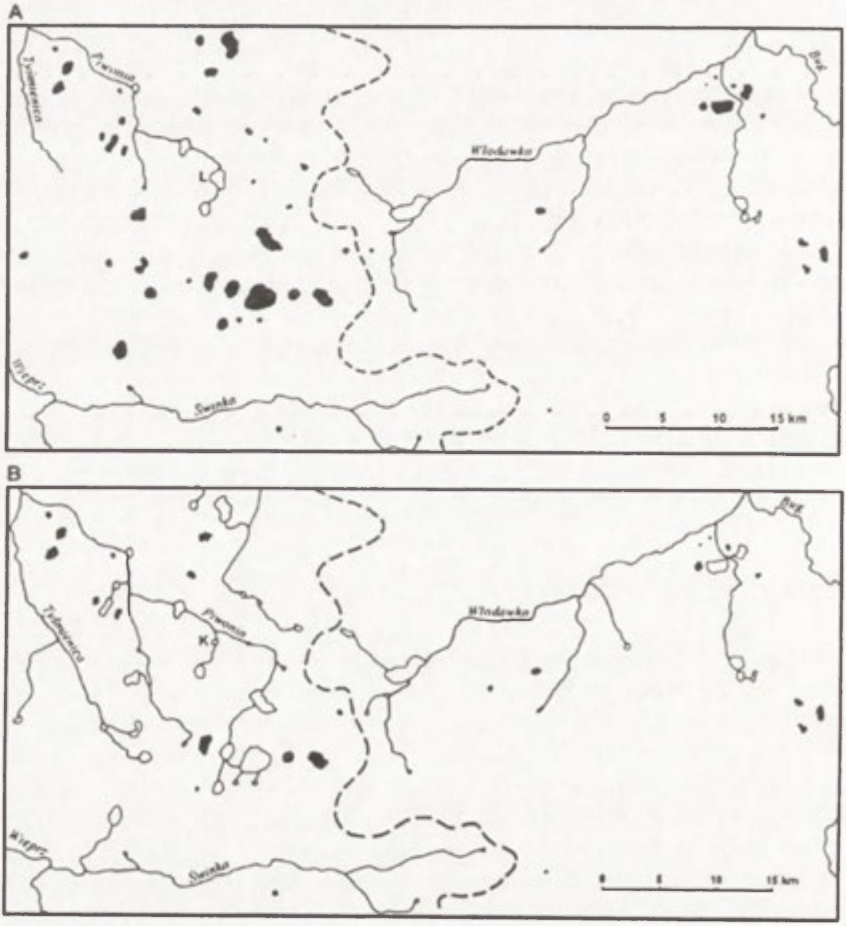
Runoff conditions also changed. In spring, waters retained in snow cover are released faster on cultivated areas. On the flat land of the Lake Region large areas were covered with water, the runoff of which was impeded due to a poorly-developed river network. Thus we can assume that a forest landscape changed to forest-agricultural caused an increase in wetlands, particularly in the spring season. There was also a bigger contrast between the amount of water running off in spring and that in the period of small autumn supply when river flow is sustained only by poor, easily-exhaustible underground reserves.

These changes cannot be expressed quantitatively because hydrotechnical work was conducted in parallel to changes in land use, and these also modify retention and runoff conditions.

HYDROTECHNICAL WORKS

The digging of drainage ditches to get rid of excess spring water was practised in the Lęczna–Wlodawa Lake Region a very long time ago. No documentation of these primitive hydrotechnical works is available, but it can be supposed that they consisted in facilitating runoff by deepening and straightening the natural, poorly-developed drainage system and connecting depressions without outflow with ditches. The natural character has been preserved only by the lower and middle courses of the rivers: Wlodawka with tributaries, Tarasinka and Krzemianka in the Bug river basin, and on the west side, those of the Tyśmienica river with the two Piwonia rivers and that of the Świnka on the south–west border of the Lake Region. The primary sources of these rivers cannot be determind. Their upper courses have been transformed and elongated, in some sections considerably. For example, the Northern Piwonia river, whose springs were most likely north of the Region, begins at present in the region of Nadrybie Lake, over 20 km southwards.

Despite the imperfection of the old cartographic materials, the problem of the lack of outflow from lakes has been addressed as far as possible. On the Topographical Chart of the Polish Kingdom few lakes were included in the outflow network, some of which have an evident artificial outflow (Fig. 4a). It is possible that only the lakes situated in the upper course of the river Wlodawka (Wytyckie Lake) originally and Southern Piwonia (Ściegienne Lake) originally had natural outflows, but they too could give off their waters through waterlogged ground, or only in the period of spring thaw. The lakes were included into the outflow network largely in the 19th c. as is presented



on the map. Most lakes were already connected by rivers (Fig. 4b) by the end of the 19th c.

The connection of the lakes with rivers accelerated spring runoff, reduced the range of stable wetlands and facilitated lake overgrowth by plants. However, radical changes were exceptional and were recorded in the central part of the Lake Region. Lejno Lake, a big body among the largest in the whole Region (L in Fig. 4a), is marked on the Topographical Chart of the

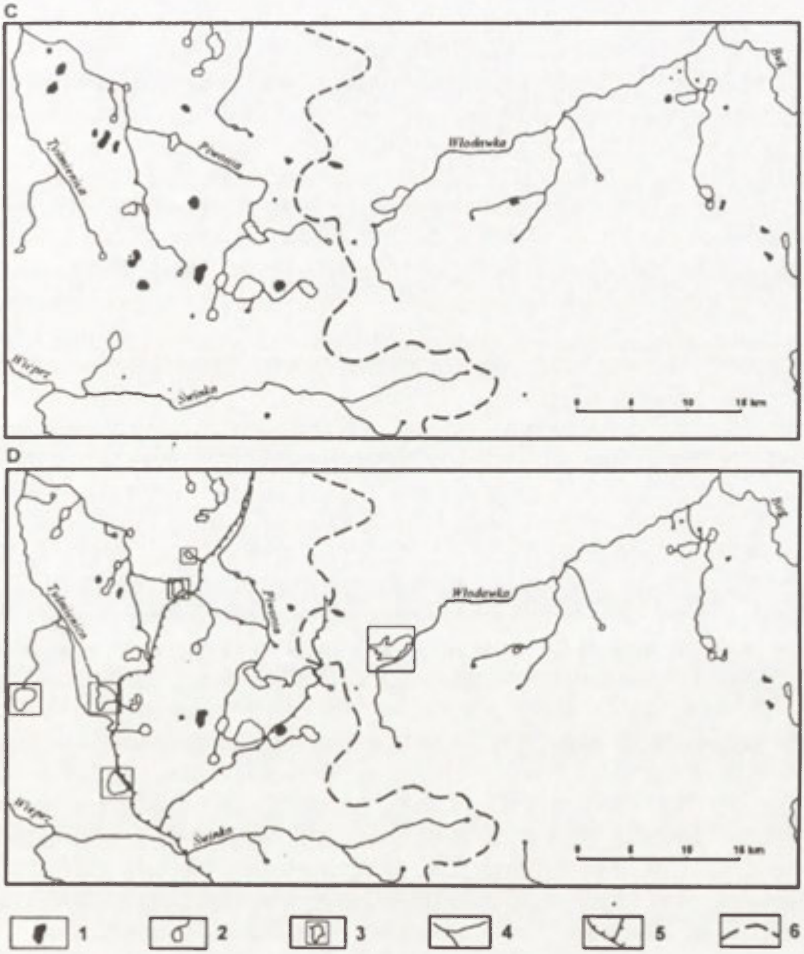


Fig. 4. Lakes with and without outflow
1 — lakes without outflow, 2 —lakes with outflow, 3 — lakes turned into retention reservoirs, 4 — lines of natural and artificial outflow, 5 — canals, 6 — watersheds
A — situation at the beginning of the 19th c. (on the basis of *Carte Topographique du Royaume de Pologne 1:126,000*), B — situation at the end of the 19th c. (on the basis of *Karte des Westlichen Russlands 1:25,000*), C — situation at the beginning of the 50's (on the basis of the *Topographical Map WIG* and field studies), D — present situation (from autopsy)

Polish Kingdom. This lake was so shallow that after digging a ditch it ran off, leaving a small pool of water then called Kałuża (the Puddle) (K in Fig. 4b). This small reservoir existed till the middle of this century and then disappeared.

At the beginning of the 50's detailed studies of lakes were carried out in the Lake Region (Wilgat 1954). Those lakes which are not included into the outflow network (Fig. 4c) were then registered. Changes of a non-unidirectional nature occurred in comparison with the situation over half a century ago. Lakes with outflow had increased in number, but there were also some that had lost their connection with rivers. The reason is that in boggy flat land areas, hydrotechnical intervention easily changes the existing hydrographical system. Moreover, non-conserved drainage ditches are readily overgrown and the relationship of a lake with the outflow network can be disrupted.

Studies carried out in the Lake Region by workers of the Hydrography Department, Maria Curie-Skłodowska University, Lublin, show an increasing number of lakes with outlets (Fig. 4d). However, it should be stressed that outflow is episodic, because some of the dug ditches do not convey water at all or quite sporadically. They ceased to function as outflow lines when the groundwater table and water level in lakes declined. Old ditches could function as before after being deepened.

Thus, it can be seen that no radical changes in water relationships occurred in the Łęczna–Włodawa Lake Region between the end of the 19th c. and the first half of the 20th c. despite the undertaken drainage works. Two world wars, the difficult economic situation in postwar Poland and the depopulation of the Lake Region after World War II did not promote hydrotechnical investment. An undertaking of great importance was the building of a 140 km long canal connecting the middle Wieprz river with the Krzna, a tributary of the Bug river. This biggest investment of its kind in Poland was started in 1954. The role of this canal was to supply an area with water from the Wieprz river to intensify farming. The idea of building the canal was opposed by naturalists. Being unable to prevent it, they suggested that the Łęczna–Włodawa Lake Region, exceptionally valuable from the natural point of view, should not influenced by the canal system (*Polesie*... 1963), and that the land area north of the Lake Region be supplied with Wieprz river water. Unfortunately, hydrotechnicians developed most intensively the irrigation-drainage system just in the Lake Region, with water ducts from the main canal, retention reservoirs and a network of drainage ditches. One of the ducts went across the less-changed and naturally most-valuable swamps in the region of Lakes Moszne and Długie — an area planned for protection, in which a National Park was established in 1990. Six lakes were turned into retention reservoirs (Fig. 4d), and several others are supplied with Wieprz river water, which differs considerably in its chemical composition from that of the local waters. The drainage system, although not fully completed, changed the rate and character of water circulation in a large part of the Lake Region.

In areas with water conditions so liable to transformations as the Łęczna–Wlodawa Lake Region, the regulation of water supply and drainage requires

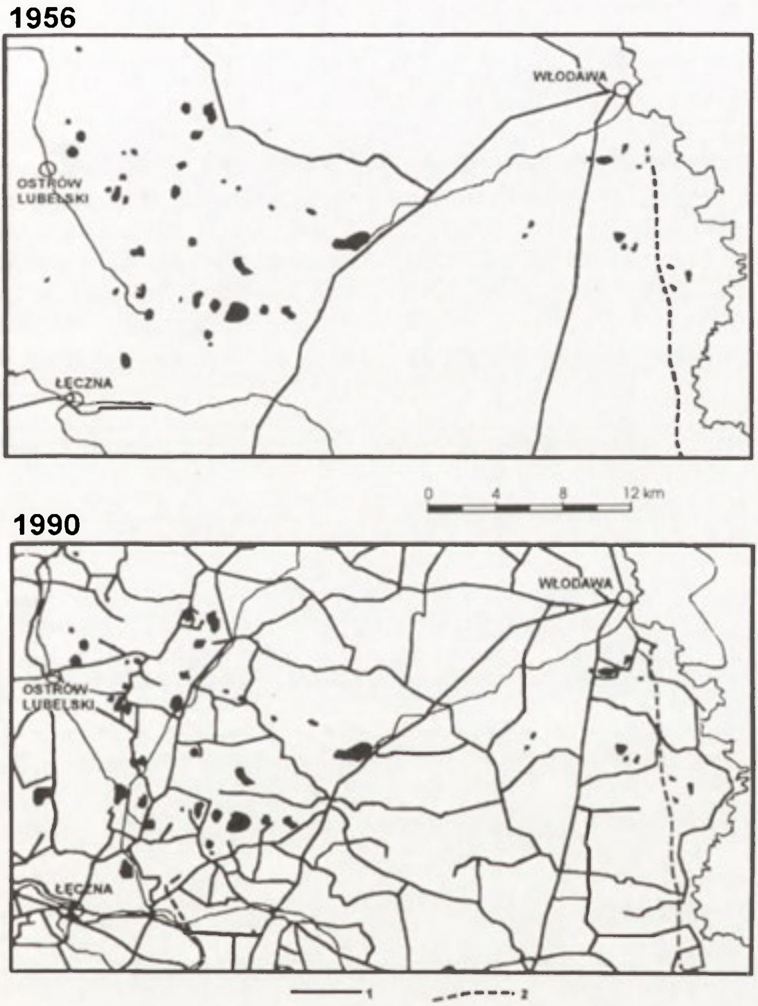


Fig. 5. Communication lines in the Łęczna–Wlodawa Lake Region
1 — roads, 2 — railway

great precision. If it is neglected the effects of the undertaken proceedings can be a failure. Such is the case with the Wieprz–Krzna canal. The melioration measures taken have resulted in the appearance of numerous overdraining symptoms. The direction of hydrosphere transformations caused by hydrotechnical works is thus the same as that induced by changes of soil management. The overlapping of these causes makes it difficult to assess them separately. However, the fact that after building the drainage system of the Wieprz–Krzna canal, symptoms of land drying were commonly manifested and relatively fast, allows us to conclude that hydrotechnical work played a predominating role.

RECREATIONAL UTILIZATION OF LAKES

The Łęczna–Włodawa Lake Region was a neglected region to the middle of the 1950's. Poorly-developed communication networks (Fig. 5) practically hindered entry to its interior. Its natural and landscape attributes were described for the first time in 1956 (Wilgat 1956), promoting this region for geographical excursions. The earliest tourism started on Biale–Wlodawa Lake, situated in the eastern part of the Region, which tourists began to visit after 1958. The land around it was sold to state institutions for recreational purposes in 1961.

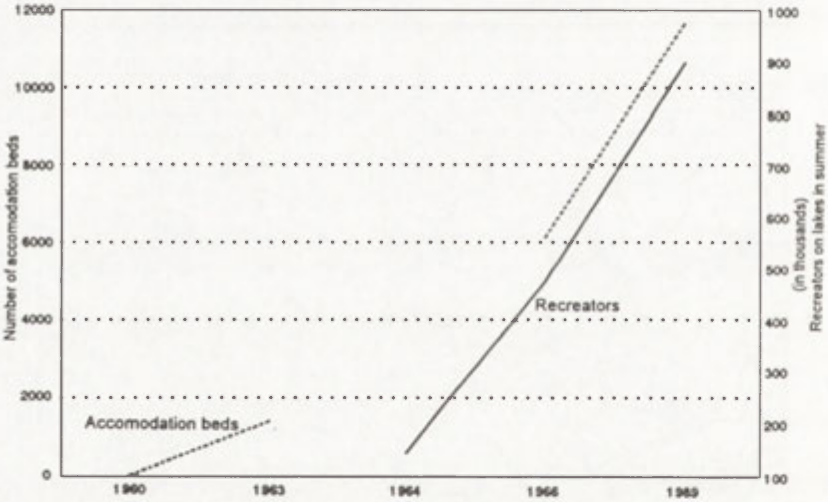
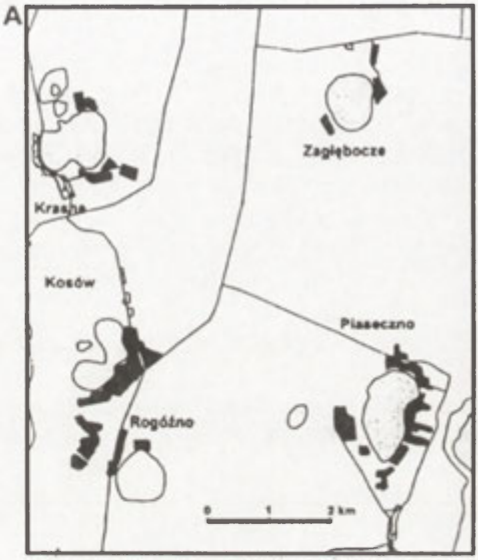


Fig. 6. Recreators on lakes and accommodation facilities in the Lake Region

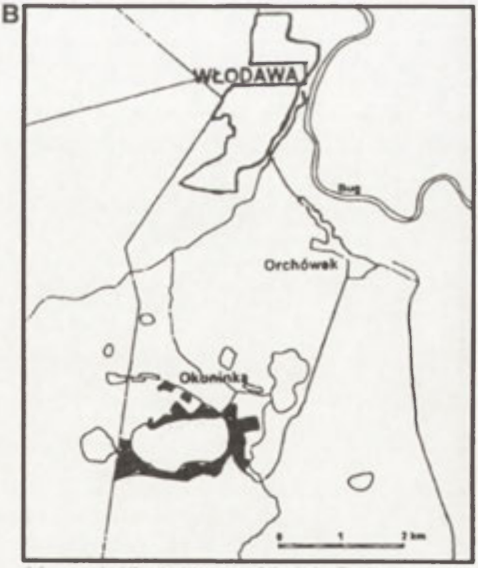
That year was the beginning of building permanent facilities in the Lake Region area. As building the Wieprz–Krzna canal required the construction of new roads, the late 50's and early 60's saw new communication tracks built, facilitating penetration of the western and central part of the Region. By 1963 further permanent recreational facilities had been established on Rogóźno and Bialka lakes so that at that time 1400 tourists or visitors could be accommodated for the night, and weekend recreation predominated. In 1964, 145,000 persons enjoyed recreation in the summer season (July, August) on the lakes. In 1965 Piaseczno Lake was provided with recreational facilities. A year later 6158 beds were offered on all lakes, over half on Lakes: Biale–Wlodawa and Bialka. In that year 475,000 persons visited the Lake Region, 284,000 of whom spent their weekends and feasts. On one sunny July Sunday 13,000 visitors arrived at Włodawa–Biale Lake, 5000 at Piaseczno Lake, 1500 at Bialka Lake, and 200 at Rogózno and Lukcze lakes[2].

The beginning of the 70's was a period of intensified building of private rest-bungalows. In 1989, the number of beds increased to 11,730 (Fig. 6), and bases for night accommodation were organized on 13 lakes. The greatest intensification of building private rest-bungalows was observed at the beginning of the 90's. It was developing spontaneously, particularly on the most attractive lakes with overcrowded recreation facilities existing earlier. Many lakes are surrounded by recreational houses (Fig. 7), which considerably reduce their natural attributes. In extreme cases, recreational bulding has entered swamps adjacent to lakes (lakes Piaseczno and Wlodawa–Biale). Spontaneous recreational management and utilization of the Lake Region in recent years has resulted in a lack of current statistical data about the dynamics of these processes.

According to the authors' estimations about a million people relax in the Lake Region over the summer season. Overcrowding of some places insufficiently prepared to receive a large number of people causes degradation of the environment. Only a few owners of recreational objects are prepared to render proper services to tourists. Sewage stored in nogroundwatermetic



A fragment of the western part of the Lake Region



A fragment of the eastern part of the Lake Region

Fig. 7. Areas with recreation facilities

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[2] Data from unpublished Master's theses.

cesspools and primitive toilets are a threat to groundwaters and the lakes. There is a lack of sanitary arrangements largely near intensively-utilized lakes. Other pollution sources are 'wild' garbage dump encountered most often in forests near camping areas.

THE INFLUENCE OF COAL-MINING

The coal deposits of Lublin District were discovered in 1964–1971 on the basis of studies conducted according to the results of Samsonowicz's investigations (Porzycki 1984). Their presence was noted in an area of 4000 km^2 extending NW–SE from Parczew to Hrubieszów — 180 km in length and 18–37 km in width, which is called the Lublin Coal Basin. Three regions of coal exploitation have been established: northern of 450 km^2, central — 240 km^2 and southern — 320 km^2. The central region was exploited first. This area constitues a wide transitional zone between the Lublin Upland and Polesie. The shafts of the first coal-mine were built in close proximity to the south–west part of the Lake Region at Bogdanka and Nadrybie (Fig. 8). They were located 3 and 2 km south of Nadrybie Lake, respectively, despite the protests of naturalists, who pointed to threats to the environment resulting

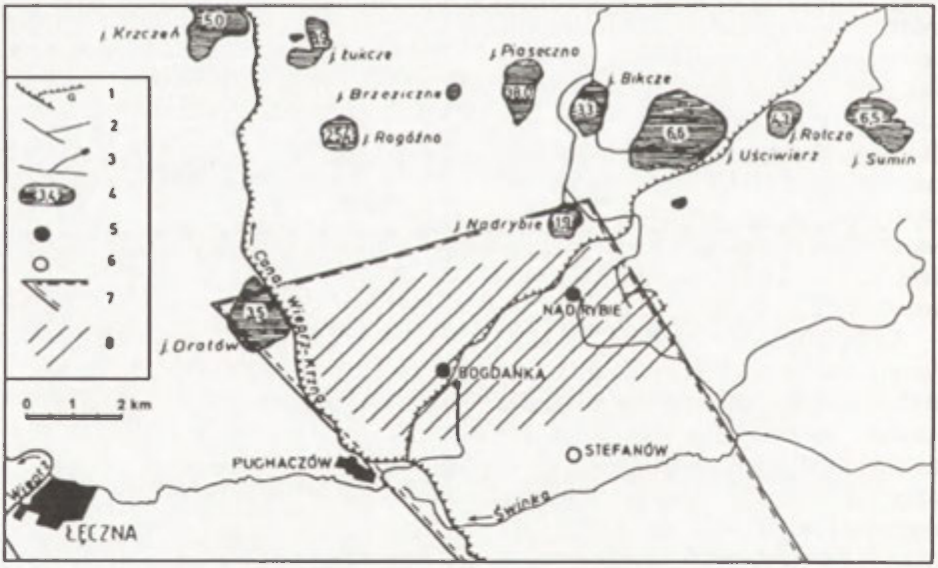

Fig. 8. Situation of lakes and location of the 'Bogdanka' colliery
1 — Wieprz-Krzna canal, Puchaczów — Wola Wereszczyńska conveyer, 2 — rivers, 3 — settling tanks for minewaters and sites of their discharge into the Swinka river, 4 — lakes and their maximal depths, 5 — shafts of the 'Bogdanka' colliery, 6 — a shaft of the 'Stefanów' colliery (building stopped), 7 — range of the coal field, 8 — area of found land subsidence

from coal exploitation near a region of small resistance to anthropopressure (Wilgat 1973, 1975; Wilgat and Fijałkowski 1974).

The coal deposits occur in a Carboniferous formation which is covered by Jurassic and Cretaceous carbonate sediments of varying resistance and plasticity. Hydrological studies have shown 4 water-bearing horizons associated with formations of: a) the Quaternary and Upper Cretaceous, b) the Lower Cretaceous (Albium) and Upper Jurassic, c) the Jurassic, and d) the Carboniferous periods. Besides the first horizon, waters of the others are confined. Since the beginning of coal-mine building, waters of the Jurassic and Carboniferous formations have been pumped intensively to protect it from flooding. As a result, separate cones of depression transgressing the central coal region have been formed in both formations. A pressure decrease in Jurassic and Carboniferous waters changing the conditions of their circulation and feeding. Do these changes effect the surface water relationships? This problem is approached from two points of view. Some are of the opinion that poorly-permeable Cretaceous rocks constitute a good barrier for waters of the Quaternary-Cretaceous upper water horizon, which should protect the hydrographic conditions of the Lake Region against the consequences of pumping waters from Jurassic and Carboniferous beds. Others think that the intensification of water percolation from the upper horizon will be possible due to the opening of fissures during rock subsidence. At present there is not enough evidence to confirm the reality of such threats.

As a result of mining work in the Lublin Coal Basin, there is land subsidence caused by decreasing confined waters of the Jurassic and Carboniferous formation and coal exploitation by the 'fall' method. At present surface subsidence exceeding 0.2 m has been found in an area of about 20 km^2 in a mining field in the neighbourhood of the shafts, largely over the coal deposits exploited since 1982. Coal beds 2.5–3.3 m thick are mined at a depth of 815–920 m. Local depressions of the land surface in the exploitation region near Bogdanka and Nadrybie have already exceeded 1.5 m. They will deepen and widen with developing coal exploitation.

Depressions up to 2.8 m are expected to have been formed by 2010 after the exploitation of two coal beds. In the further future land deformations will be still bigger. Land subsidence results in changes of water occurrence and circulation, largely in the first horizon, but slow changes of deeper waters are not excluded.

Land deformations in areas of shallow groundwater lead to the formation of depressions filled with water or excessively moistured. From the natural point of view it would be most advisable to leave such depressions and not attempt to dry them. However, naturalists' suggestions are difficult to realize, largely because of private ownership and agricultural utilization of the land. Thus earlier drainage works are planned consisting in regulating and deepening the Świnka river channel and other rivers even by 5 m (*Drainage study...* 1986). This would cause a considerable increase of the draining role of rivers, followed by a decrease of the undergroud water table, local ground drying, a change in hydraulic gradients and a shift of ground-watersheds. The zone of Nadrybie Lake would be included into the Świnka river basin, which at present is drained by the upper Piwonia river. The Usciwierz Depression and lakes with big natural and recreational advantages would then be in the range of the Świnka river drainage (Wilgat et al. 1987; Janiec et al. 1988; Michalczyk 1985).

A considerable threat to the environment is the discharge of mine waters and sewage exceeding admissible standards into surface reservoirs.

Another threat to the hydrosphere comes from the penetration of precipitation waters through heaps of Carboniferous waste-rocks. These waste-rocks are also distributed in the region to fill depressions without run-off and peat excavations. In the neighbourhood of Piaseczno Lake the specific conductivity of waters percolating these waste-rocks is ten times higher than that of lake waters.

AN ATTEMPT AT DETERMINING CHANGES IN THE OCCURRENCE AND CIRCULATION OF WATER

Hydrographic changes can be determined by various methods:

a) One of them is comparing maps issued in different periods. Thus — determined changes to the drainage network were presented in chapter *Hydrological works* (p. 125). Maps allow us to find most lakes included into the drainage network. It is much more difficult to determine differences in the surface area of lakes, because the shore contours are not distinct due to a vegetation belt occurring around them. However, the decline of some of the lakes can be found (besides the described Lejno Lake, Blizny Lake, which was shown on map at the end of the 19th c., has already disappeared), as well as the shrinking of the surface area of others. There are two reasons for the latter: water surface lowering after digging runoff ditches and plant overgrowth of lakes. Field studies, however, give more data about disappearence of lakes than the comparing of maps.

Maps show a big increase of runoff network density. No attempt has been made to present this problem in numbers because of the inadequate accuracy of maps showing ditch courses. Nevertheless, it can be seen that all areas of the low accumulation plain have been cut by ditches connected with the river network. The building of the Wieprz–Krzna canal with all its waterducts caused the biggest change in the water system of this region.

The range of wetlands is an important problem in the evaluation of hydrographical changes. An analysis of the land character and its utilization was made for three time periods in the central part of the Lake Region, which was mentioned in chapter *Changes in landuse...* (p. 122). Its results are presented in Table 1 and Fig. 3. Despite some reservations as to the exactness of distinguishing various kinds of land on maps, the changes can be recognized distinctly. The area of wet meadows and mires decreased from 26.8% in 1887 to 16% in 1976 and 15.2% in 1992.

Comparison of the total area of waters, meadows, mires and forests on wetland leads to the same conclusion. The percentage of these areas is also decreasing systematically from 31.9% via 26.3% to 23.3%. Even if we take into consideration the facts that maps do not show accurately enough forest wetlands, and that has a bearing on the given percentages, the process of decrease in wetland areas is quite conspicuous.

TABLE 1. Character and utilization of land areas in the central part of the Łęczna–Wlodawa Lake Region (3525 ha)

Kind of land utilization	Period (year)					
	1887		1976		1992	
	ha	%	ha	%	ha	%
Waters	167.2	4.7	139.1	3.9	134.4	3.8
Wet meadows and mires	943.8	26.8	562.5	16.0	536.9	15.2
Wet forests and scrub in wetland	14.1	0.4	226.6	6.4	150.0	4.3
Forests	1007.8	28.6	789.1	21.3	1032.8	29.3
Arable land	1392.1	39.5	1846.8	52.4	1671.9	47.4

b) A method widely used in hydrology is analysis of continuous observations of water phenomena. In the case of the Lake Region it is to little avail because of deficient data.

There are only four stations registering the level of groundwaters and only one of them has done so continuously since 1951. They show (like the stations in neighbouring regions) a similar rhythm — seasonally and over many years — of water table oscillations (Wilgat et al. 1984), which point to rain — and thaw water supply being of decisive importance (Fig. 9).

At three stations a tendency for groundwater table lowering occurs, but this is statistically significant only in Ludwin. For the 43-year observation series of this station the regression coefficient is 2.03 cm/year.

Data concerning river runoff are also scarce. Mean annual river discharges show big oscillations from year to year (Fig. 10), and on their basis it cannot be shown whether a unidirectional tendency to runoff changes exists.

To find out whether water runoff had been modified by farming, a graphical analysis was performed. Curves of summed-up annual mean values for river discharges were plotted not in relation to the time marked on the X-axis but in relation to analogous sums for the Krzna river discharge at Malowa Gora, which were recognized as reference values. In the diagram (Fig. 11), in which the Tysmienica river is presented in two profiles, a change in the curve inclination occurred in about 1967. This means that after that year the discharge ratio of the Tysmienica and Krzna rivers changed. After 1967 the Tysmienica has been

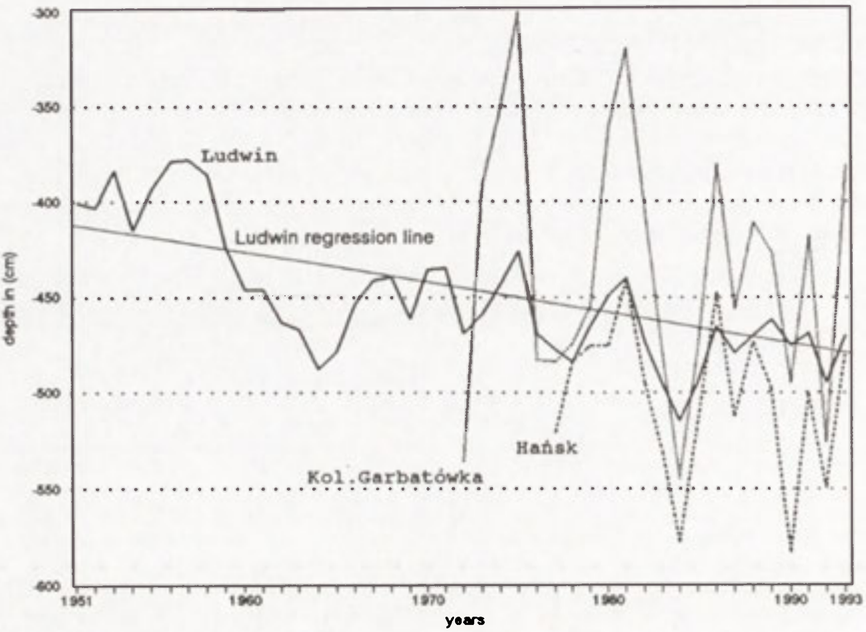

Fig. 9. Annual mean levels of groundwater at stations of IMiGW (The Institute of Meteorology and Water Management)

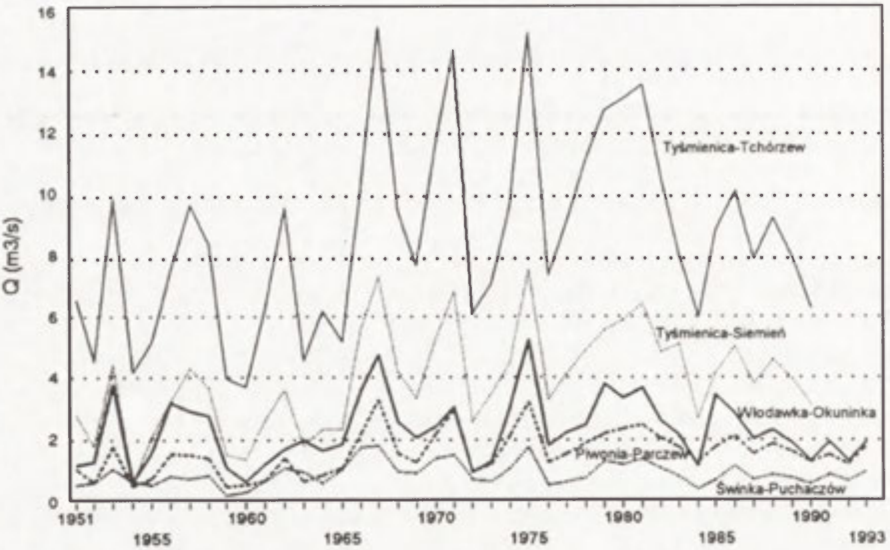

Fig. 10. Annual mean runoff of rivers

carrying relatively more water than before. It cannot be determined from the available data whether this results from the supply from the upper Wieprz river, from which most waters are conveyed to the Tyśmienica basin, or whether a role is also played by increased runoff from its own basin due to hydrotechnical action.

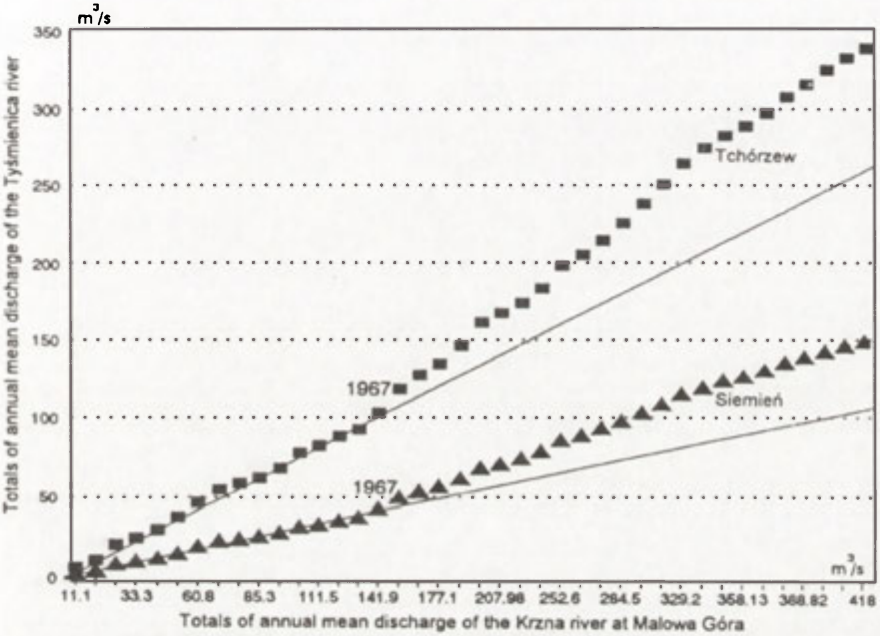

Fig. 11. Totals of annual mean discharge of the Tyśmienica river at Tchórzew and Siemień (1951–1990). In relation to totals of annual mean discharge of the Krzna river at Malowa Góra

Lake water levels have been observed for only a short time. Piaseczno Lake has the longest observation series, from September 1971[3]. The diagram of monthly water levels (Fig. 12) shows that there were two periods of high levels — 1975–1976 and 1981–1982 — over 22 years. In the last decade, a decrease in annual maxima and minima has been observed. The lowest level recorded in 1992 was over 70 cm lower than the minima recorded in the first observation period. Mean water level lowering was 0.35 cm/month in the whole period, and since 1982 it has increased to 1.1 cm/month. The results of both periods are statistically significant.

c) Hydrographical changes can be recorded directly in the field. The first studies in which attention was drawn to changes were carried out by the end of the 40's and the beginning of the 50's (Wilgat 1950, 1954). Most

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[3] In the years 1971–1982 readings of water levels were performed by the state service. In the following years observations were organized by the Department of Hydrography, Maria Curie-Skłodowska University, Lublin.

attention was given to the decline of lakes. Many forms indicating shrinking of the shore line have remained and their short-lived existence allows us to conclude that the changes occurred relatively recently, largely by the end of the 19th c. and at the beginning of the 20th c. The disappearance time of some of them can be defined from few data in the literature (Roztworowski 1882) and interviews with people.

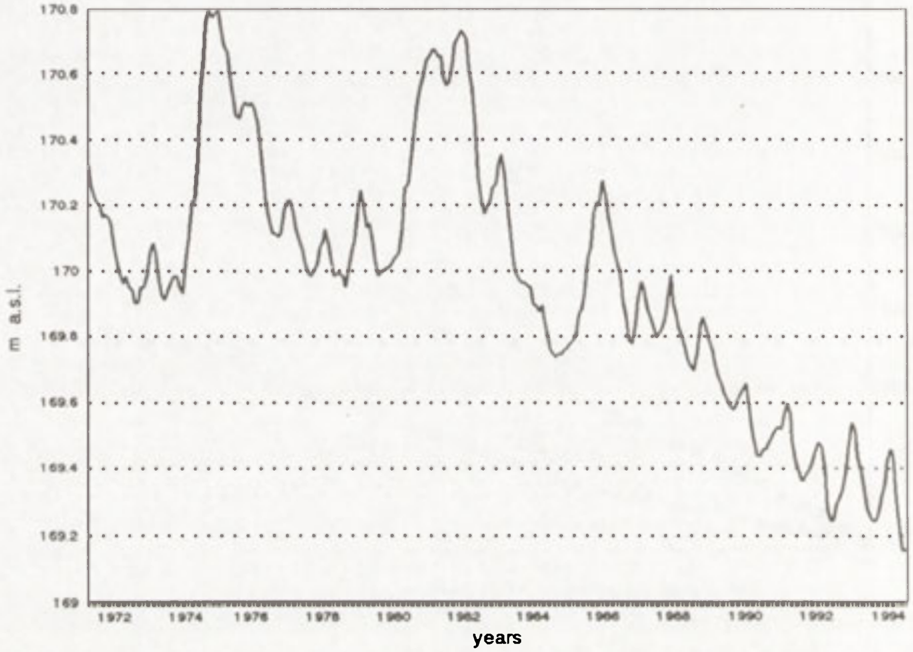

Fig. 12. Water level of Piaseczno Lake

The Department of Hydrography, Maria Curie-Skłodowska University, Lublin, has carried out field studies on a large scale since the 50's. To obtain an extensive knowledge of water conditions the method of hydrographical survey according to the instruction of Polish geographers was used (*Instrukcja...* 1954, II ed. 1959, III ed. 1964). In 1964, a 1:100,000 hydrographical map was made by T. Wilgat for a large part of the Lake Region. Censorship did not allow its printing. The one proof-sheet saved is a document of the region's water conditions at that time preceding the changes connected with the building and functioning of the Wieprz–Krzna canal (Fig. 13 and 14). In the following years a hydrographical survey was repeated for large fragments of the Lake Region (Wilgat et al. 1984; Michalczyk, Bartoszewski et al. 1993). From successive maps presenting the state of the groundwater table it results that from the early 60's no change occurred in the course of the main watershed of groundwaters and runoff directions, but the depth of the water table and the range of wetlands changed. On comparing maps of the thickness of the aeration zone made in different periods, great caution must be used because of the seasonal character of water phenomena. Nonetheless, they allow us to determine that in the last 25 years the Lake Region has undoubtedly been drained. Convincing proof has been given by comparing the results of charting in the central part of the Region in autumn 1977 and July 1985. Despite a high level of groundwater in 1985 and that close to the mean value in 1977, water table decreases in seven land fragments and a considerable decrease in groundwater range were found. A precise determination of undergroundwater table decrease in the Lake Region conditions is impossible, therefore the numbers given in the literature: 1–2 m (Różycka et al. 1983), or 0.5–1.5 m (Chmielewski, Radwan 1993) cannot be considered as referring to the whole region.

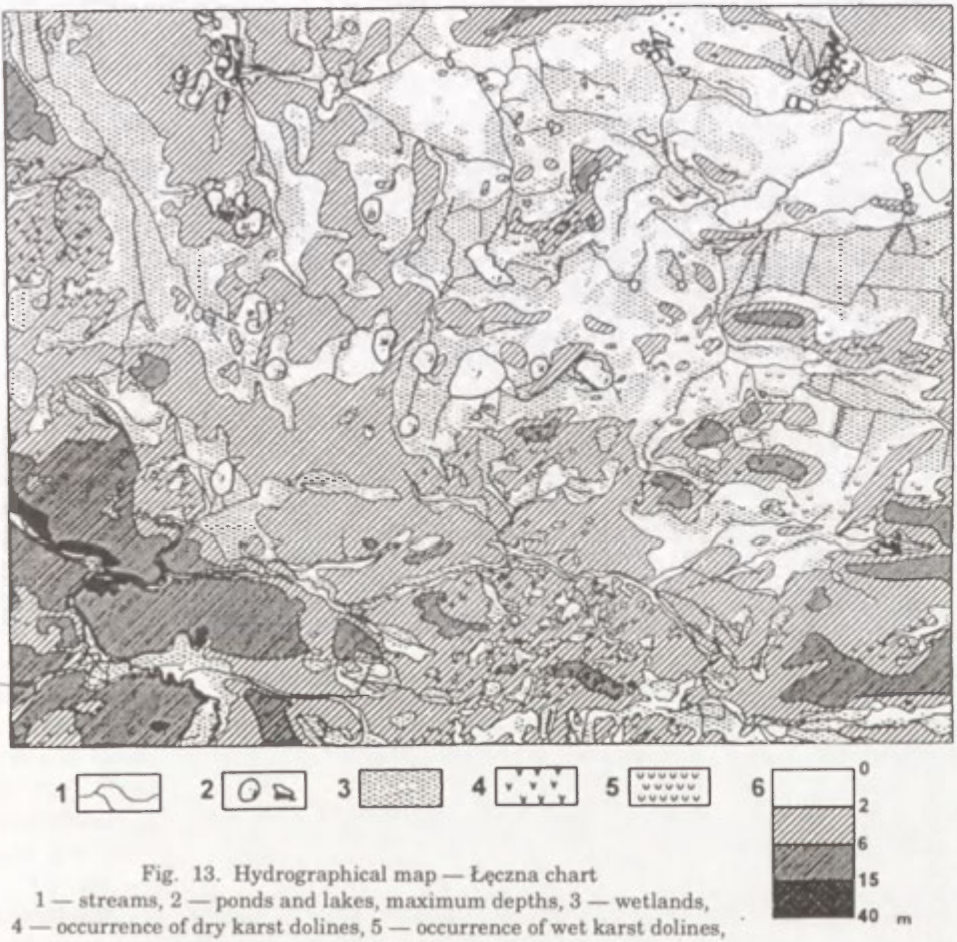

Fig. 13. Hydrographical map — Łęczna chart
1 — streams, 2 — ponds and lakes, maximum depths, 3 — wetlands, 4 — occurrence of dry karst dolines, 5 — occurrence of wet karst dolines, 6 — depths of groundwater table occurrence

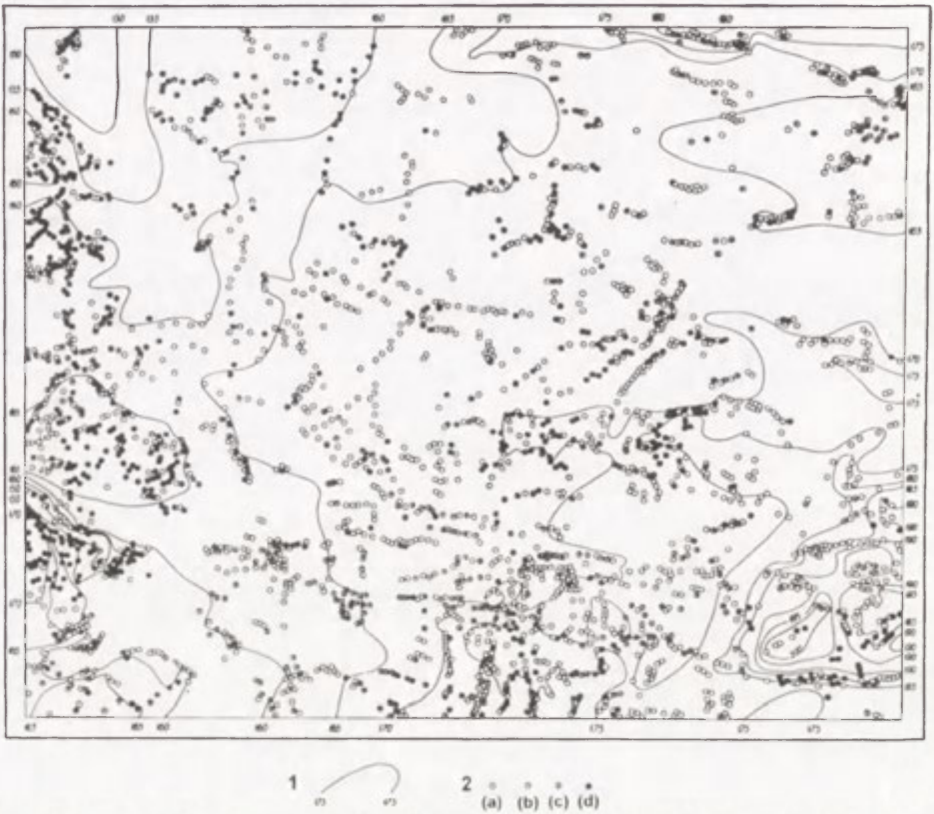

Fig. 14. Situation of groundwater table — Łęczna chart
1 — hydroisobaths, 2 — measured sunk wells; rock material on well bottom: a — sands and gravels, b — silty sands, muds, c — Cretaceous opokas and marls, d — other rocks not defined

CHANGES IN HYDROSPHERE QUALITY

In the area of the Łęczna–Włodawa Lake Region, waters of very different concentrations of dissolved constituents occur: from hyperfresh (50–100 mg/l) to fresh waters of the upper limit (≈500 mg/l). Natural differentiation of solute concentration in the lake or river catchments determines their liability to anthropogenic transformations. The sensititvity to quality changes results from the hydrogeological conditions and geochemical features of the catchment. In some lake catchments a relative deficiency of carbonates alkalizing the water habitat is found, whereas silica, aluminium compounds and peat occur commonly. Sparingly-soluble minerals and rocks are the reason that waters contain few macroelements, and in consequence have limited resistance to degradation (Janiec 1987, 1993).

In the western part of the Lake Region such waters occur in 7 lakes (Table 2); they are fewer in the central and eastern part of this region. These are ecosystems with differently-developed efficiency of matter exchange between organic and inorganic components; from mesotrophic (Piaseczno Lake), through eutrophic (Maśluchowskie, Miejskie, Kleszczów lakes) to dystrophic (Brzeziczno, Łukietek, Czarne Gościnieckie lakes). Because of low solute concentration, the waters in the Lake Region are generally considered to be least-transformed anthropologically (Janiec 1984, 1987). This opinion should be verified.

An analysis of the geochemical medium of the basins of these lakes leads to the conclusion that in their initial stage their waters were simple, of type HCO_3–Ca and strongly fresh. Mires were formed as a result of partial transformation of these lakes' littoral. Energetic transformations in the lake-mire ecosystems conditioned the evolution of their natural waters of the HCO_3–SO_4–Ca type. Then anthropopressure resulted in the formation of tetra- and pentaionic waters (Table 2). Weighted means of macrocomponents in 7 studied lakes qualify the thus-formed water as pentaionic of the type SO_4–HCO_3–Cl–Ca–Na (in the Shtchukariev-Priklonskiy classification). Multiionic waters of such a type do not occur as natural in the phreatic zone. Then from the natural point of view they are waters strongly transformed anthropogenetically. The percentage of carbonate hardness in the total hardness (on average about 62%) and a high value of the Mg/Ca coefficient (0.338) also account for advanced anthropogenization of the water of the 7 lakes studied.

Thus the measure of anthropogenic transformation of waters need not be their increased solute concentration nor the decrease of the so-called water quality class. However, a change in the hydrochemical type of water always indicates human action. Waters of other lakes of a solute load over 150–200 mg/l are more resistant to changes and are qualified as diionic or triionic types (HCO_3–Ca, HCO_3–SO_4–Ca). Such lakes include: Zagłębocze, Rotcze, Sumin, Białe Włodawskie. Accordingly, the conclusion is that hyperfresh waters of the 7 lakes studied are among those most changed and are not the "purest" in the Region.

In the middle part of the Lake Region, on elevations built of marly limestones of the Upper Cretaceous, the quality of waters is different, and their solute load several times higher. These are simple waters, bicarbonate-calcium (HCO_3–Ca), less liable to anthropogenetic transformations.

In the eastern part of the Lake Region, the lake waters are of similar solute load to those in the western part (70–150 mg/l) and are equally sensitive to pollution.

In the ion composition of most lakes the Ca–HCO_3 ion pair predominates. This gives evidence of the significance of carbonates in the chemical composition of water even in an environment characterized by a deficiency of carbonate minerals. Calcium and magnesium contents in the waters of

TABLE 2. Hydrochemical characteristics of waters of selected lakes in the western part of the Łęczna–Włodawa Lake Region

Lake	pH	Hardness		Ions [mg/l]						K*	Solute load [mg/l]	Hydrochemical type of water**
		Total	Carbonate	Ca	Mg	Na+K	HCO_3	Cl	SO_4			
Piaseczno	7.53	0.58	0.32	8.4	1.9	9.2	19.5	7.1	22.1	65.0	71.0	SO_4–HCO_3–Ca–Na
Brzeziczno	5.30	0.43	0.20	5.0	2.2	6.9	12.2	6.7	16.3	46.0	50.0	SO_4–HCO_3–Na–Ca
Łukietek	6.62	0.70	0.45	12.2	1.2	12.0	27.5	8.9	21.1	76.0	83.0	HCO_3–SO_4–Cl–Ca–Na
Maśluchowskie	7.97	0.64	0.57	8.0	2.9	18.0	34.8	12.4	24.5	93.0	102.5	HCO_3–SO_4–Cl–Na–Ca
Miejskie	7.56	0.83	0.78	12.4	2.6	13.6	47.6	15.6	9.6	94.0	103.0	HCO_3–Cl–Ca–Na
Kleszczów	7.50	0.80	0.65	12.0	2.4	4.0	39.7	7.1	6.2	74.0	81.0	HCO_3–Cl–Ca–Mg
Czarne Gościenieckie	6.43	0.62	0.40	8.8	2.2	7.1	24.4	8.2	14.4	61.0	66.0	HCO_3–SO_4–Cl–Ca–Na
Global weighted mean values of 7 lakes		0.61	0.38	8.7	2.0	9.9	23.2	8.0	20.8	69.0	76.0	

[*] specific conductivity of water at 10°C [µS/cm]

[**] hydrochemical types of waters were determined according to the classification proposed by Shtchukariev-Priklouskiy (see: Macioszczyk, 1987, *Hydrogeochemia*, Wyd. Geol.).

all lakes is on average 1.43 and 0.47 meq/l, with extreme values 0.18–3.48 meq Ca/l and 0.18–0.9 meq Mg/l, respectively. The big differentiation in calcium and magnesium contents may result from geochemical variability of the environment and anthropogenetic influences, among other things, foreign water transfers. The Mg/Ca coefficient, exceeding an average of 0.33, is in natural conditions characteristic for waters in contact with dolomite limestones or carbonate loesses.

The functioning of lake ecosystems is influenced significantly by the content of biotic components in water, largely phosphorus and nitrogen compounds, and the oxygen indices connected with them. They determine to a considerable extent the eutrophication intensity. Studies of PO_4, N_x and O_2 content were carried out selectively in the Łęczna–Włodawa lakes (Cydzik, Soszka 1988). Phosphorus is considered an eutrophication index, although its amount in waters depends also on the development intensity of macrophytes in the body of water and the total primary production. In lakes thermally stratified it occurred from trace amounts to 0.12 mg PO_4/l (total phosphorus) in the epilimnion to 1.25 mg PO_4/l in the ground hypolimnion; whereas in polymictic lakes it reaches 0.16 mg PO_4/l. In lake waters various nitrogen forms were studied (NH_4, NO_3, N_{org} and N_{total}); they occur at amounts from 0.01 mg/l to 3.0 mg/l, but organic nitrogen predominates.

One of the main factors changing the hydrosphere quality in the Lake Region is the Wieprz–Krzna canal leading fertile carbonate waters from the upper Wieprz river basin. The inflow of these waters into some lakes (among others: Łukie, Zaglębocze and Uścimowskie) has caused alkalization and changes of water-mire ecosystems. The scale of these transformations cannot be determined because of a lack of studies in the period preceding strong human interference. Particularly big changes took place in lakes turned into retention reservoirs filled every year with allochthonous waters and successively emptied.

To date the influence of the Wieprz–Krzna canal has caused: a) considerable changes in water quality in the lakes included into the systems of artificial distribution of foreign waters, b) accelerated eutrophication, e.g. in Krzczeń, Krasne, Biale, Sosnowickie and Bialskie lakes, c) a distinct retreat of advanced dystrophication in Czarne Sosnowickie Lake, d) the initiation of dystrophization in lakes strongly eutrophicated (Bikcze Lake) as a result of radical hydrological changes.

CONCLUSIONS

Man's influence on the hydrosphere is a process occurring stepwise, particularly in cases of big water investments, and at the same time of a continuous character. In general it is increasing with the increasing population and developing technology. In the long history of this influence periods can be distinguished which differ in the character and intensity of anthropopressure. In the case of the Lęczna–Wlodawa Lake Region three periods can be distinguished. The beginning of the first goes back into prehistorical time, and was finished at the beginning of the 18th c. This long period was characterized by a very small direct human influence on the hydrosphere and a very slowly-increasing indirect influence through clearing of forests.

In the second period comprising about 150 years a considerable increase in direct human influence on the water network occurred. Many stretches of river channels were straightened, and their upper courses were elongated by artificial ditches. The whole area was cut by ditches, and most lakes were included into the runoff network. Although drainage operations were primitive, their influence on water conditions was not indifferent as they became common. At the same time further changes in land use occurred which effected a slow transformation in water circulation. Although the changes occurring in it affected the whole region, bringing distinct results, they did not effect the water relationships, and consequently living nature significantly. The region preserved its 'Polesie' character — largely marshiness. With its poor population, inaccessible communication, low agricultural level and lack of industrial objects, this region was economically underdeveloped and constituted an area of interst largely for researchers appreciating its great natural richness.

The third period started only in the 1960's, but it has brought the biggest changes. Their main cause was the building of the drainage system — the Wieprz–Krzna canal. Another factor in the changes is developing recreation, and a third one — coal mining. The consequences of these phenomena are changes in the quantity and circulation of water and its quality, as well as landscape changes. Water from the Wieprz river conveyed by the canal to the Lake Region area increases local reserves. Collected in retention reservoirs it serves in irrigation of meadows and supplies lakes as well as fish ponds. It is difficult to estimate to what extent its increased quantity effects the magnitude of runoff and evaporation. However, both circulation components have increased.

The drainage operations, accomplished on a large scale, particularly in the western and central part of the Lake Region, have affected the circulation dynamics. Runoff has increased, surface runoff has been accelerated, surface and ground retention have decreased, and the percentage of underground runoff in relation to the total has increased. Another consequence is lowering of the first groundwater table. The scale of this lowering is differentiated, locally it exceeds 1.5 m, a big value in the Lake Region conditions.

Water surface lowering in lakes is also recorded, particularly in the south–west region. This process is supposed to be associated with the coal mining in this area because neither a climatological nor drainage factor can play a role here; coal has not been exploited long to fully support this assumption. However, an evident effect of mining is ground subsidence over the exploited coal and the formation of wetlands in the appearing land depressions.

The conveying of Wieprz river waters to the Lake Region area, including most lakes into the runoff system, the changing dynamics of water circulation, the discharging of coal-mine waters and the recreational utilization of lakes and their neighbourhood have all contributed to quality changes in surface and groundwaters. Solute load in surface waters has generally increased. The hydrochemical types of lake waters, characteristic for natural waters, changed to those encountered only in conditions of anthropopressure. The eutrophication process has been accelerated in most lakes. In some lakes natural evolution has been disturbed due to the fact that a dystrophic reservoir changes into an eutrophic one or vice versa.

The specified changes in the hydrosphere are followed by numerous natural consequences, to which specialists draw more and more attention. Peat soils undergo degradation, rare plant species disappear, particularly on mires and in water reservoirs, changes in the fauna are also observed. The valuable natural and landscape qualities of this region decrease; and this process will proceed if counter measures are not taken. The present attempts at recultivation of the degraded areas do not promise success because of their limited range, an in properly chosen area near a coal-mine, and controversial methods of action.

In the Łęczna–Wlodawa Lake Region, water is the decisive element determining the specificity of the environment and its capacity for self-regulation. In order to preserve the water conditions in a state enabling protection of the whole environment from unfavourable natural changes, it is necessary to subordinate farming, coal-mining and recreation to the primary goal — the preservation of the natural and landscape qualities of this exceptional region. The most important postulates include: a) prevention of encroaching coal exploitation in the Lake Region area; b) changing the distribution of waters taken from the Wieprz river and conveying them to the Wieprz–Krzna canal, thus not letting them enter oligotrophic and dystrophic lakes or bogs and transition mires; c) development of plans concerning the utilization of areas adjacent to the lakes to guarantee the quality of surface and groundwaters.

REFERENCES

Bałaga K., 1982, *Vegetational History of the Lake Łukcze Environment (Lublin Polesie, E Poland) during the Lake-glacial on Holocene,* Acta Paleobot. 22, 1, 7–22.

Bałaga K., Buraczyński J., Wojtanowicz J., 1983, *Budowa geologiczna i rozwój torfowiska Krowie Bagno–Polesie Lubelskie (Geological structure and development of the Krowie Bagno peatland),* Ann. UMCS, s. B., 35/36, 37–62.

Buraczyński J., 1983, *Rzeźba powierzchni podczwartorzędowej,* [in:] *Kenozoik Lubelskiego Zagłębia Węglowego,* Wyd. UMCS, Lublin, 65–72.

Buraczyński J., Wojtanowicz J., 1974, *Geneza jezior uściwierskich (Pojezierze Łęczyńsko-Włodawskie),* Mat. Krajowego Symp. Paleolimnologicznego, Warszawa (manuscript).

Chmielewski T. J., Radwan S., 1993, *Zmiany stosunków ekologicznych w rejonie Poleskiego Parku Narodowego w ostatnich 75 latach,* [in:] *Ekosystemy wodne i torfowiskowe w obszarach chronionych,* PTH, TWWP, AR, PPN, Lublin, 13–25.

Cydzik D., Soszka H., 1988, *Atlas stanu czystości jezior Polski badanych w latach 1979–1983*, Wyd. Geol., Warszawa.

Ekosystemy wodne i torfowiskowe w obszarach chronionych, S. Radwan, Z. Karbowski, M. Sołtys (eds.), PTH, TWWP, AR, PPN, Lublin.

Henkiel A., 1983, *Regionalne zróżnicowanie facjalne czwartorzędu,* [in:] *Kenozoik Lubelskiego Zagłębia Węglowego*, Wyd. UMCS, Lublin, 92–107.

Instrukcja opracowania Mapy Hydrograficznej Polski 1:50,000, 1954, 2nd ed. 1959, 3rd ed. 1964, PAN Warszawa.

Janiec B., 1984, *Naturalna i antropogeniczna ewolucja właściwości wód jezior w zachodniej części Pojezierza Łęczyńsko-Włodawskiego*, Przewodnik Ogólnopolskiego Zjazdu PTG, cz. I, Lublin, 191–194.

Janiec B., 1987, *Wybrane problemy jakości wód powierzchniowych Centralnego Rejonu Lubelskiego Zagłębia Węglowego*, Prace Nauk. Politechniki Lubelskiej, Lublin, 212–222.

Janiec B., 1988, *Obliczone i stwierdzone wartości pH w przypowierzchniowych warstwach wody najsgłębszych jezior Pojezierza Łęczyńsko-Włodawskiego*, Mat. Kom. Hydrograf. PTG, Toruń, 140–146.

Janiec B., 1993, *Przyrodnicza ocena wpływu kanału Wieprz–Krzna na jakość hydrosfery Pojezierza Łęczyńsko-Włodawskiego*, Gosp. Wodna 2, 36–42.

Janiec B., Michalczyk Z., Wojciechowski K., 1988, *Stan i zagrożenia stosunków wodnych centralnego rejonu Lubelskiego Zagłębia Węglowego* (*State and Dangerous Changes of Water Relations of the Central Lublin Coal Basin*), Ann. UMCS s. B, 39, 173–206.

Krassowska A., Niemczycka T., 1984, *Pokrywa mezozoiczna Lubelskiego Zagłębia Węglowego*, Przewodnik LVI Zjazdu PTGeol., Wyd. Geol., Warszawa, 36–55.

Łoś M. J., 1983, *Zagrożenie stosunków wodnych na Pojezierzu Łęczyńsko-Włodawskim*, [in:] *Zagrożenie Pojezierza Łęczyńsko-Włodawskiego na skutek eksploatacji węgla kamiennego w Lubelskim Zagłębiu Węglowym*, GIG, Katowice, 67–89.

Maruszczak H., 1952, *Stan i zmiany lesistości województwa lubelskiego w latach 1830–1930*, Ann. UMCS, s. B. V, 109–178.

Maruszczak H., 1987, *Zmiany środowiska przyrodniczego kraju w czasach historycznych*, [in:] *Przemiany środowiska geograficznego*, Ossolineum, Wrocław, 109–135.

Michalczyk Z., 1985, *Hydrologiczne konsekwencje antropopresji w obszarze LZW*, [in:] *Problemy gospodarki wodnej makroregionu środkowo-wschodniego i ochrony Pojezierza Łęczyńsko-Włodawskiego*, NOT, Lublin, 165–169.

Michalczyk Z., Bartoszewski S., Głowacki S., Turczyński M., 1993, *Wody Poleskiego Parku Narodowego*, Ekobios 1, TWWP, Lublin.

Michalczyk Z., Dawidek J., Głowacki S., Sobolewski W., Turczyński M., 1993, *Stosunki wodne Parku Krajobrazowego Pojezierze Łęczyńskie*, Ekobios 10, TWWP, Lublin.

Mojski J. E., 1972, *Polesie Lubelskie*, [in:] *Geomorfologia Polski*, PWN, Warszawa, 363–373.

Naturalne i antropogeniczne zmiany obiegu wody (pod kier. M. Gutry-Koryckiej) 1993, [in:] *Przemiany stosunków wodnych w Polsce w wyniku procesów naturalnych i antropogenicznych*, Kraków, 273–390.

Paczos S., 1988, *Ogólne warunki meteorologiczne obszaru LZW*, [in:] *Stan badań obszaru LZW ze szczególnym uwzględnieniem CRW*, Wyd. Polit. Lubelska, Lublin, 223–263.

Polesie Lubelskie, 1963, T. Wilgat (ed.), Wyd. Lubelskie, Lublin.

Porzycki J., 1984, *Zarys geologii Lubelskiego Zagłębia Węglowego*, Przewodnik LVI Zjazdu PTGeol. Wyd. Geol., Warszawa, 7–21.

Przemiany stosunków wodnych w Polsce w wyniku procesów naturalnych i antropogenicznych, 1993, I. Dynowska (ed.), Kraków.

Roztworowski J., 1882, *Jeziora Łęczyńsko-Włodawskie* (Le groupe des lacs situes entre Łęczna et Włodawa), Pam. Fizjogr. 2, Warszawa, 76–78.

Różkowski A., Rudzińska T., 1982, *Odnawialność zasobów wód podziemnych w Lubelskim Zagłębiu Węglowym*, Kwart. Geol. 26, 3/4, 703–704.

Różycka W., Jaroszewski T., Zemła J., 1983, *Przyrodnicze uwarunkowania jako podstawa kształtowania środowiska w Lubelskim Zagłębiu Węglowym*, [in:] *Zagrożenie Pojezierza Łęczyńsko-Włodawskiego na skutek eksploatacji węgla kamiennego w Lubelskim Zagłębiu Węglowym*, GIG, Katowice, 3–17.

Studium melioracji doliny Świnki i regulacji rzeki z uwzględnieniem skutków eksploatacji górniczej, 1982, BPWM (manuscript).

Turczyński M., 1988, *Wstępne rozpoznanie stosunków termicznych jezior Pojezierza Łęczyńsko-Włodawskiego*, Mat. Konf. Hydrogr. PTG, Toruń, 120–124.

Warunki hydrogeologiczne Lubelskiego Zagłębia Węglowego, A. Różkowski, Z. Wilk. (eds), Wyd. Geol., Warszawa.

Więckowski K., Wojciechowski I., 1971, *Zmiany charakteru linmologicznego jezior sosnowickich* (Variations in the limnological character of lakes in the Sosnowica District), Wiad. Ekolog. 17, 3, 239–246.

Wilgat T., 1950, *Kras okolic Cycowa*, Ann. UMCS, s. B, 4, 227–256.

Wilgat T., 1954, *Jeziora Łęczyńsko-Włodawskie (Lakes between Łęczna and Włodawa)*, Ann. UMCS, s. B, 8, 37–122.

Wilgat T., 1956, *Pojezierze Łęczyńsko-Włodawskie jako teren wycieczek geograficznych*, Czas. Geogr. 27, 1, 99–118.

Wilgat T., 1957, *Stosunki geomorfologiczne i hydrograficzne w strefie kanału Wieprz–Krzna* (*Geomorphological and hydrographic conditions in the Wieprz–Krzna canal zone*), Przegl. Geogr. 29, 2, 259–285.

Wilgat T., 1963, *Budowa geologiczna, rzeźba i wody Polesia Lubelskiego*, [in:] *Polesie Lubelskie*, Wyd. Lubelskie, Lublin, 9–30.

Wilgat T., 1975, *Zagadnienie ochrony środowiska w Lubelskim Zagłębiu Węglowym*, Sylwan 12, 25–34.

Wilgat T., 1979, *Zmiany struktury obiegu wody pod wpływem działalności gospodarczej*, [in:] *Antropogeniczne zmiany stosunków wodnych*, Wyd. UMCS, Lublin, 7–34.

Wilgat T., 1980, *Możliwości zmian stosunków wodnych pod wpływem robót górniczych w Centralnym Rejonie Węglowym Lubelskiego Zagłębia Węglowego*, 88 Sesja Naukowa Inst. Geol. Wyd. Geol., Warszawa, 75–82.

Wilgat T., 1983, *Influence of human activity on water circulation*, Geogr. Polonica 45, 71–81.

Wilgat T., 1991, *Zmiany stosunków wodnych pod wpływem gospodarki*, [in:] *Geografia Polski — środowisko przyrodnicze*, Warszawa, 205–223.

Wilgat T., Fijałkowski D., 1974, *Projekt ochrony krajobrazu w przyszłym Lubelskim Zagłębiu Węglowym*, Ochrona Przyrody 40, 11–44.

Wilgat T., Janiec B., Michalczyk Z., Wojciechowski K., 1987, *Wpływ górnictwa na stosunki wodne w Lubelskim Zagłębiu Węglowym*, [in:] *Ekologiczno-gospodarcze problemy rozwoju górnictwa Lubelskiego Zagłębia Węglowego*, NOT, Lublin, 37–61.

Wilgat T., Michalczyk Z., Paszczyk J., 1984, *Płytkie wody podziemne w obszarze związanym z centralnym rejonem Lubelskiego Zagłębia Węglowego*, Wyd. UMCS, Lublin.

Wilgat T., Michalczyk Z., Turczyński M., Wojciechowski K., 1991, *Jeziora Łęczyńsko-Włodawskie*, Studia Ośrodka Dokumentacji Fizjograficznej 19, PAN. O. Kraków, 23–140.

Wojciechowski K., 1965, *Niedobory i nadwyżki wodne w województwie lubelskim, Ann. UMCS*, s. B, 18, 249–263.

Wojtanowicz J., 1993, *O termokrasowej genezie jezior Łęczyńsko-Włodawskich*, streszczenie referatu na II Zjeździe Geomorfologów Polskich, Lądek Zdrój, 33–34.

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