

# Estimation of the Degree of Pollution and Sanitary and Bacteriological State of Underground and Surface Waters in Omulewski Aquifer Area after Liquidation of Large Cattle and Pig Farms

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## Abstract

Studies were carried out on the content of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$  and numbers of bacteria indicatory of water pollution (TVC 20°C, TVC 30°C) and its sanitary state (TC, FC, FS) in deep wells and shallow piezometric boreholes, as well as on bacteriological contamination of water in rivers Sawica and Omulew, in the area of water-bearing formations of Omulewski Aquifer (with no isolation from the surface), in 1995-1997 (after liquidation of the majority of large cattle and pig breeding farms in this area). The following were distinguished: 1. wells in afforested area in Sedansk and Narty, 2. wells located in farm lands of individual farmers in Jedwabno and Kot, 3. wells located in breeding farms of foxes, cattle and pigs in the villages Janowo, Dzierzki, Wesotowo, Wielbark, Przewdziek, Baranowo, Wyzegi, and 4. piezometric boreholes in the cattle farm at Wesotowo. Water of Sawica River (together with water from trout ponds fed by this river) and of Omulew River were analyzed at Janowo, Kot, Wesotowo and Wielbark, close to respective wells and boreholes. The degree of chemical and bacteriological contamination of well waters was diversified, depending on current and earlier use of land in the area of Omulewski Aquifer.  $\text{NH}_4\text{-N}$  content decreased in well and borehole waters located in the area of former cattle and pig farms at Dzierzki, Wesotowo, Przewdziek, Baranowo and Wyzegi compared to the levels found in 1989-1993. Notwithstanding this, its level in some wells exceeded 0.5 mg/l  $\text{NH}_4\text{-N}$ , i.e. the maximum level permissible in drinking water and water used for household purposes. As regards the sanitary state, only wells in Sedansk conformed to the standards for drinking and household water. Contrarily to what was expected, there was no decrease of indicatory bacteria numbers in water of wells and boreholes located in the area of former large cattle and pig farms. Water in deep wells at Kot, Wesotowo and Wielbark usually contained higher numbers of indicatory bacteria in the periods when their levels increased also in Sawica and Omulew rivers.

**Keywords:** underground waters, deep wells, piezometric boreholes, rivers, nitrogen compounds, indicatory bacteria

## Introduction

Complex physico-chemical and bacteriological studies [7, 8, 9, 13] carried out in 1989-1992 on the underground water-bearing formation of Omulewski Aquifer (having no

isolation from the surface), Mazuria, showed a noticeable effect of large cattle and pig farms upon the hygienic and sanitary states of these waters. This effect was due to faecal contamination originating from pigsties, cattle-sheds, manure storage pits, and usually permeable

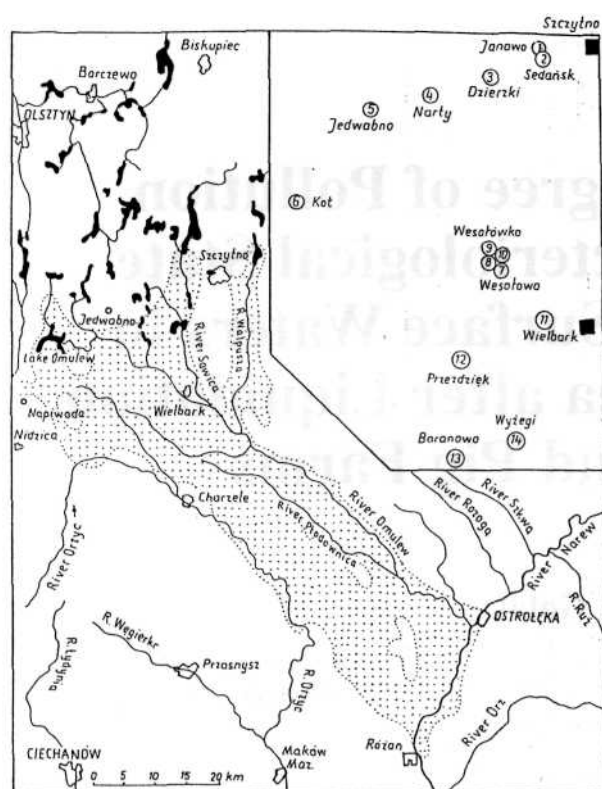


Fig. 1. Situation scheme of water-bearing formations of Omulewski Aquifer in Mazuria Region, after Szczepkowski [24].  
1, 2, 3 ... 11 - deep water wells  
12, 13, 14 - piezometric boreholes.

septic tanks and silage silos [7]. Water collected from shallow piezometric boreholes located in the area of a former cattle farm at Wesolowo was also affected by pollution leaking from animal runs and watering places. As regards nitrogen compounds, also improper storage of mineral fertilizers affected water quality, and at Jedwabno and Kot - irrational use of these fertilizers by private farmers cultivating plants on sandy soils. It was concluded [7, 8, 9, 13] that new septic tanks should be constructed well away from the depression crater around water-well, and in some cases - liquidation of cattle and pig farms was suggested, as well as subordination of agricultural practices to protect principles of the aquifer in question (propagation of ecological agriculture without use of mineral fertilizers and manure, ban on the use of herbicides and insecticides, afforestation of some areas etc.). Economic changes which had taken place in 1989 resulted in the rapid liquidation and disappearance of State Agricultural Farms together with large commercial animal breeding ones. This enabled a somewhat *in situ* possibility to check whether the suggested remedial measures and different land use have really decreased pollution and improved hygienic and bacteriological states of underground waters in the most sensitive areas of Omulewski Aquifer. This paper presents the results on the content of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , and numbers of bacteria indicator of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in water of deep wells and shallow piezometric boreholes located

within the area of Omulewski Aquifer, in 1995-1997 (when most animal farms had been already liquidated). Pollution and sanitary and bacteriological state was also estimated for two rivers flowing through this area, Sawica and Omulew, as well as of trout ponds at Janowo, supplied by Sawica River waters.

## Material and Methods

### Omulewski Aquifer

The Omulewski Aquifer (Fig. 1) is composed of water-bearing formations located in the western part of Mazuria-Kurpiowski sandr, between Omulew and Orzyc rivers, Narew River tributaries. The aquifer comprises a group of fossil fragments of the main valley, and parallel and side valleys. Middle valley parts contain the thickest sandy-gravel formations. The thickest water-bearing formations (120 m) are found in the middle part of the aquifer, near Wielbark, Przedzick and Baranowo, and become more and more shallow south-westward, in the direction of the Narew River [24]. Because aquifer surface is permeable, direct water infiltration is quite important. Surface level of underground water of the aquifer is at a depth of from 1 to several metres, depending on local morphology. It is also subject to vertical variations, usually of  $\pm 1.5$  m, depending on atmospheric precipitation. Underground water capacity is usually a few tens  $\text{m}^3\cdot\text{h}^{-1}$ , with depressions to a few over the area of hundreds  $\text{km}^2$ . Over half the aquifer area is located under forested lands (pine and spruce), and about 1/4 - under cultivated lands. They represent natural protection of the aquifer against infiltration of pollutants through rain water. Until 1992 the remaining part of the aquifer was located in places where large animal farms existed (cattle and pigs), which caused pollution of less deep underground waters of this area [7]. The aquifer area is drained by two major rivers, Sawica and Omulew, as also partly by Orzyc and Walpusza rivers. Sawica River begins in Szczepankowskie Lake, flows through Lake Sasek Wielki (close to the village Targowska Wola) which is intensively used for recreation. Omulew River is supplied with water from Lake Omulew as well as by Czarna River, the latter having its sources in Lake Dluzek. The two rivers (Sawica and Omulew) join at Wielbark, from which they flow to the Narew River (near Ostroleka). In Janowo village the Sawica River is dammed by a small weir to collect water for a nearby trout farm.

### Sampling Stations

Based on the data of the general geologist of the Regional Government in Olsztyn and of the Regional Inspectorate of Environment Protection in Olsztyn, 11 water wells and 3 piezometric boreholes were selected, all located in the Mazurian part of Omulewski Aquifer (Fig. 1), 4 stations along Sawica and Omulew rivers (Fig. 2A) and 2 stations in trout ponds of a fish farm in Janowo (Fig. 2B). A short characteristic of the stations from which

Table 1. Characteristics of wells and bore-holes of Omulewski Aquifer according to Niewolak [13] after Kochanska [7].

No.	Location	Utility	Depth of well (m)	Type of water
1.	Janowo	Fox farm (2 000)*	42.0	CO <sub>3</sub> /Ca/Mg <sup>1</sup>
2.	Sedańsk	Fox farm	38.0	CO <sub>3</sub> /Ca/Mg
3.	Dzierzki	Swine farm (2 500)	60.0	CO <sub>3</sub> /Ca/Mg
4.	Narty	Forester's lodge	40.0	CO <sub>3</sub> /Ca/Mg
5.	Jedwabno	Dairy	49.0	–
6.	Kot	Polythene processing plant	20.0	CO <sub>3</sub> /Ca <sup>2</sup>
7.	Wesołowo	Cattle farm (700)	38.0	CO <sub>3</sub> /Ca
8.	Wesołowo – bore-hole no. 1	Cattle farm	6.8	
9.	Wesołowo – bore-hole no. 2	Cattle farm	23.5	
10.	Wesołowo – bore-hole no. 3	Cattle farm	21.5	
11.	Wielbark	Swine farm (10 000)	60.0	CO <sub>3</sub> /Ca/Mg
12.	Przeździek	Cattle farm (500)	34.0	CO <sub>3</sub> /Ca
13.	Baranowo	Cattle farm (500)	64.0	CO <sub>3</sub> /Cl/Ca <sup>3</sup>
14.	Wyżegi	Cattle farm (1 000)	25.0	CO <sub>3</sub> /Ca/SO <sub>4</sub> <sup>4</sup>

\* - number of animals in brackets; <sup>1</sup> - carbonate-calcite-magnezite; <sup>2</sup> - carbonate-calcite; <sup>3</sup> - carbonate-chloride-calcite; <sup>4</sup> - carbon-ate-calcite-sulphate.

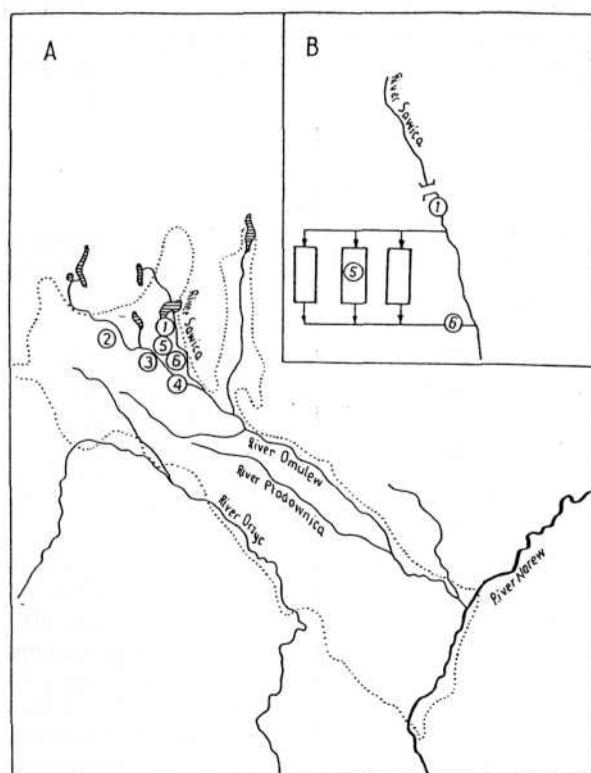


Fig. 2. Location of water sampling stations in Sawica and Omulew rivers (A) and in trout ponds of the Fish Farm in Janowo (B).

- 1- sampling station in Sawica River  
2, 3, 4 - sampling stations in Omulew River  
5, 6 - sampling stations in fish ponds.

underground water was collected is given in Table 1. Due to different development of particular areas and, thus, different degrees of possible pollution of well waters, 4 groups of wells were distinguished:

1. wells located on forested lands least exposed to anthropogenic pollution. These were wells in the villages Sedansk and Narty; they were treated as the control;

2. wells located in lands used by farmers in Jedwabno and Kot villages;

3. wells located in the area of animal farms: fox rearing farm (Janowo), cattle farms (Wesołowo, Przeździek, Baranowo, Wyżegi), and pig farms (Dzierzki, Wielbark).

4. piezometric boreholes located at Wesołowo, in the area of a former cattle farm:

No. 1 - close to cattle-sheds, in the quarter used as cattle-run as well as animal watering and additional feeding;

No. 2 - at a distance of 100 m, in a quarter formerly used (when there was a cattle farm there) to keep straw;

No. 3. - outside former farm buildings, several metres from the place where mineral fertilizers used to be stored, at the edge of a wood.

Sampling stations located in surface waters were as follows:

No. 1 - in Sawica River at Janowo, close to the bridge and below water weir damming the river for the fish farm;

No. 2 - in Omulew River at Kot, near the bridge;

No. 3 - in Omulew River at Wesołowo, near the bridge;

No. 4 - in Omulew River at Wielbark, near the bridge.

Sampling stations located in the Fish Farm at Janowo were as follows:

No. 1 - in the central trout pond;

No. 2 - at water outlet from the farm to Sawica River.

### Sampling Procedures

Water samples from water wells and boreholes used for chemical and bacteriological analyses were collected from March 1995 to December 1997, once every three months. Water from the wells in Janowo, Sedarisk, Dzierzki, Narty, Przewdziek, Baranowo and Wyzegi was collected directly from the water collecting pipes of the hydrophore. Well water in Janowo, Kot, Wesolowo and Wielbark, where there was no possibility to collect samples directly from water supply pipes, was collected from user taps. Before each sampling taps and valves were disinfected, and water samples collected after 10-min pumping. As regards piezometric boreholes at Wesolowo, samples were collected each time after pumping out 100 l of stagnating water, using a manual water pump.

Samples of river water were collected from the main stream of Sawica and Omulew rivers, from the depth of about 0.5 m. All samples of underground, river and pond water were collected to 300-500 ml sterile glass bottles (with ground glass stoppers). Water samples were then placed in containers with dry ice and transported to the laboratory in 4-6°C. Time lapse between sampling and chemical and bacteriological analyses never exceeded 12 hours. A total of 160 samples of well and borehole water were collected and analyzed, plus 48 samples of river water and 8 samples of water from fish ponds.

### Meteorological Observations

Meteorological observations comprised:

1. air temperature;
2. sum of atmospheric precipitation in the area of water-bearing formations of Omulewski aquifer. These data were collected from the Department of Agrometeorology of the Warmia and Mazury University in Olsztyn.

### Chemical Analyses

Chemical analyses comprised determination of the content of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  in all water samples. Analyses were performed by the Department of Chemistry and Water and Sewage Technology of the Warmia and Mazury University in Olsztyn. The methods used were those of Hermanowicz et al. [6] and as defined by Polish Standards [17, 18, 19]. The obtained levels of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  in water samples collected from water wells and piezometric boreholes were related to the quality criteria for underground water as stated in the Report on environment quality in Olsztyn Region, Annex No. 1 of 1997 [20], and described in the Directive of the Minister of Health and Social Security of 4 May 1990 pertaining to the quality of drinking water and water used for household purposes [22].

### Bacteriological Analyses

Bacteriological analyses comprised the following:

1. Total counts (CFU/1 ml) of psychrophilic bacteria

on broth agar after 72 h incubation at 20°C (TVC 20°C);

2. Total counts (CFU/1 ml) of mesophilic bacteria on broth agar after 24 h incubation at 37°C (TVC 37°C);

3. Total counts (MPN/100 ml) of coliforms (TC) on Eijkman medium after 48 h incubation at 37°C;

4. Total counts (MPN/100 ml) of faecal coliforms (FC) on Eijkman medium after 24 h incubation at 44.5°C;

5. Counts (MPN/100 ml) of faecal streptococci on Slanetz and Bartley medium after 72 h incubation at 37°C.

These determinations were made in 5 (well water and water from piezometric boreholes) or 3 (river and pond water) parallel repetitions. Physiological NaCl solution was used as a diluent. TVC 20°C and TVC 37°C were determined according to the standard procedures used for drinking water. The most probable number (MPN/100 ml) of TC, FC and FS was determined according to Standard Methods... [1] and the results were read from McCrady's tables for 5 or 3-test tube sets [12]. Determinations confirming presence of TC, FC and FS were the same as in the previous study [13] on bacteriological quality of underground waters of Omulewski Aquifer before liquidation of animal farms. The obtained results on the numbers of bacteria indicator of pollution (TVC 20°C and TVC 37°C) and sanitary state (TC, FC and FS) of samples collected from water wells and boreholes were related to the standards outlined in the Directive of the Minister of Health and Social Security of 4 May 1990 [21] and by the WHO [25]. As regards river water, the results were related to the standards given in literature [2, 3] related to the quality of surface waters and their suitability for recreation, as stated in the Directive of the Minister of Environment Protection, Natural Resources and Forestry of 5 November 1991 [21].

### Statistical Analyses

The results of chemical and bacteriological analyses of water collected from wells and piezometric boreholes located in Omulewski Aquifer was subject to statistical treatment performed in the Department of Applied Mathematics of the Warmia and Mazury University in Olsztyn [16]. The objectives of statistical analyses were:

1. to determine relationships between numbers of bacteria indicator of pollution (TVC 20°C and TVC 37°C) and sanitary state (TC, FC, FS) on the one hand, and content of  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  on the other, using the co-variance method, at significance level  $\alpha = 0.05$ ;

2. to determine the significance of differences between the mean numbers of bacteria indicator of water pollution (TVC 20°C, TVC 37°C) and its sanitary state (TC, FC, FS) in water samples collected from particular groups of water-wells (control wells at Sedansk and Narty, wells located in farmlands used by individual farmers at Jedwabno and Kot, wells in cattle farms at Wesolowo, Przewdziek, Baranowo and Wyzegi and in pig farms at Dzierzki and Wielbark, piezometric boreholes in Wesolowo) with the analysis of variance and Duncan's test, at significance level  $\alpha = 0.01$  and  $\alpha = 0.05$ .

Due to the fact that some indicator micro-organisms were often not found in the samples ( $n = 0$ ), statistical numbers of bacteria used in the analyses were calculated from the equation:  $y = \log(n+1)$ , where  $n$  is the actual

Table 2. Concentrations of some nitrogen compounds (N-NH<sub>4</sub>, N-NO<sub>2</sub>, N-NO<sub>3</sub>) in well water in Janowo, Sedańsk, Narty, Jedwabno and Kot, 1995-1997.

	Janowo			Sedańsk			Narty			Jedwabno			Kot		
	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>
	mg/dm <sup>3</sup>														
14 March 1995	0.273	0.000	0.103	–	–	–	0.000	0.000	0.228	0.000	0.022	6.070	0.649	0.093	4.820
19 June 1995	0.245	0.000	0.121	–	–	–	0.005	0.000	0.234	0.005	0.020	6.910	0.003	0.013	7.920
20 Sept. 1995	0.290	0.002	0.000	–	–	–	0.007	0.000	0.094	0.000	0.007	9.220	0.691	0.054	1.830
13 Dec. 1995	0.304	0.002	0.064	–	–	–	0.007	0.000	0.094	0.000	0.002	7.120	0.707	0.029	0.923
27 March 1996	0.352	0.000	0.076	–	–	–	0.003	0.000	0.126	0.003	0.005	7.540	0.000	0.051	0.449
18 June 1996	0.274	0.000	0.170	–	–	–	0.007	0.000	0.194	0.014	0.000	2.490	0.570	0.010	3.960
30 Sept. 1996	0.175	0.000	0.045	–	–	–	0.003	0.000	0.143	0.002	0.000	1.365	0.374	0.011	3.862
18 Dec. 1996	0.278	0.000	0.094	–	–	–	0.005	0.000	0.143	0.000	0.004	0.719	0.637	0.011	3.843
20 March 1997	0.030	0.000	0.042	0.000	0.000	0.122	0.003	0.000	0.085	0.000	0.000	2.610	0.009	0.000	0.042
24 June 1997	0.201	0.000	0.042	0.000	0.015	0.146	0.036	0.000	0.224	0.000	0.000	2.830	0.528	0.062	3.510
29 Sept. 1997	0.341	0.000	0.079	0.168	0.000	0.188	0.000	0.015	0.267	0.000	0.000	2.730	0.765	0.024	4.700
8 Dec. 1997	0.380	0.000	0.085	0.187	0.000	0.082	0.000	0.000	0.085	0.000	0.017	0.604	0.723	0.133	7.040

Table 3. Concentrations of some nitrogen compounds (N-NH<sub>4</sub>, N-NO<sub>2</sub>, N-NO<sub>3</sub>) in well water in Dzierżki, Wielbark, Przedzięk, Baranowo and Wyżęgi, 1995-1997.

	Dzierżki			Wielbark			Przedzięk			Baranowo			Wyżęgi		
	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>
	mg/dm <sup>3</sup>														
14 March 1995	0.023	0.000	0.121	0.402	0.000	0.137	0.275	0.000	0.282	1.190	0.000	0.185	5.890	0.013	0.304
19 June 1995	0.044	0.000	0.094	0.318	0.004	0.124	0.388	0.000	0.137	0.983	0.010	0.440	4.850	0.017	0.322
20 Sept. 1995	0.014	0.000	0.024	0.315	0.000	0.000	0.566	0.000	0.982	0.976	0.000	0.067	2.760	0.003	0.052
13 Dec. 1995	0.030	0.000	0.064	0.359	0.000	0.067	0.017	0.003	4.500	1.139	0.003	0.364	0.940	0.065	3.090
27 March 1996	0.009	0.000	0.103	0.411	0.000	0.109	0.371	0.000	0.170	1.060	0.003	0.410	4.060	0.019	0.300
18 June 1996	0.017	0.000	0.140	0.418	0.000	0.124	0.072	0.000	0.316	0.514	0.002	0.334	3.070	0.050	0.322
30 Sept. 1996	0.028	0.000	0.082	0.173	0.000	0.088	0.140	0.003	0.200	0.436	0.002	0.212	1.314	0.010	0.322
18 Dec. 1996	0.031	0.000	0.091	0.446	0.000	0.079	0.331	0.000	0.197	1.132	0.000	0.249	1.011	0.117	0.365
20 March 1997	0.000	0.000	0.115	0.271	0.000	0.070	0.381	0.000	0.073	0.835	0.000	0.100	4.200	0.019	0.370
24 June 1997	0.110	0.000	0.054	0.236	0.000	0.133	0.324	0.000	0.103	0.817	0.000	0.552	3.410	0.008	0.664
29 Sept. 1997	0.009	0.000	0.085	0.446	0.000	0.313	0.415	0.000	0.212	1.120	0.000	0.252	3.500	0.009	0.534
8 Dec. 1997	0.023	0.000	0.067	0.427	0.000	0.082	0.427	0.000	0.121	0.961	0.000	0.370	4.300	0.023	0.225

Table 4. Concentrations of some nitrogen compounds (N-NH<sub>4</sub>, N-NO<sub>2</sub>, N-NO<sub>3</sub>) in well water and 3 bore-holes in Wesotowo, 1995-1997.

	Well			Bore-hole no. 1			Bore-hole no. 2			Bore-hole no. 3		
	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>	N-NH <sub>4</sub>	N-NO <sub>2</sub>	N-NO <sub>3</sub>
	mg/dm <sup>3</sup>											
14 March 1995	1.600	0.000	0.410	0.199	0.000	0.228	0.000	0.000	0.085	0.145	0.000	0.170
19 June 1995	1.700	0.000	0.692	0.439	0.000	0.297	0.010	0.000	0.091	0.168	0.000	0.109
20 Sept. 1995	2.520	0.000	0.334	0.474	0.000	0.061	0.038	0.000	0.000	0.182	0.000	0.000
13 Dec. 1995	2.240	0.004	0.398	0.051	0.003	0.282	0.005	0.000	0.064	0.010	0.000	0.076
27 March 1996	2.100	0.000	0.437	0.376	0.000	0.449	0.000	0.000	0.140	0.000	0.000	0.115
18 June 1996	1.510	0.002	0.425	0.296	0.000	0.249	0.028	0.000	0.121	0.121	0.000	0.106
30 Sept. 1996	0.070	0.000	0.222	0.159	0.000	0.209	0.026	0.000	0.058	0.082	0.000	0.058
18 Dec. 1996	1.310	0.002	0.121	0.231	0.000	0.407	0.038	0.000	0.076	0.014	0.000	0.127
20 March 1997	2.670	0.000	0.061	0.135	0.000	0.188	0.000	0.000	0.045	0.000	0.000	0.064
24 June 1997	1.020	0.000	0.467	0.287	0.000	0.194	0.000	0.000	0.200	0.000	0.000	0.085
29 Sept. 1997	2.610	0.000	0.470	0.338	0.000	0.316	0.077	0.000	0.182	0.156	0.000	0.076
8 Dec. 1997	2.340	0.000	0.325	0.185	0.000	0.109	0.000	0.000	0.149	0.000	0.000	0.036

number of indicator micro-organisms. Statistical analyses of relationships between bacteria indicator of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) and nitrogen compounds did not comprise  $\text{NO}_2\text{-N}$  levels due to lack of nitrites in most of the samples, or their sporadic presence in trace amounts.

## Results

### Air Temperature and Sum of Atmospheric Precipitation during Studies

In 1995-1997 mean daily air temperatures ranged from -6.2°C in winter 1996 to 17.6°C in summer 1995. Sum of atmospheric precipitation in particular seasons ranged

from 68 mm in winter 1996 to 241 mm in summer 1997, and the annual mean was from 444 mm in 1996 to 637 mm in 1995 (Figs. 3 and 4).

### Content of Ammonia, Nitrites and Nitrates in Water Collected from Water-Wells and Piezometric Boreholes in the Area of Omulewski Aquifer

Contents of ammonia nitrogen, nitrites and nitrates in samples collected from water-wells and piezometric boreholes in the area of Omulewski Aquifer are presented in Tables 2-4. Ammonia nitrogen content ranged from undetectable levels ( $<0.001 \text{ mg/l NH}_4\text{-N}$ ) to  $5.89 \text{ mg/l NH}_4\text{-N}$ . Lower levels were usually found in well water at Sedahsk

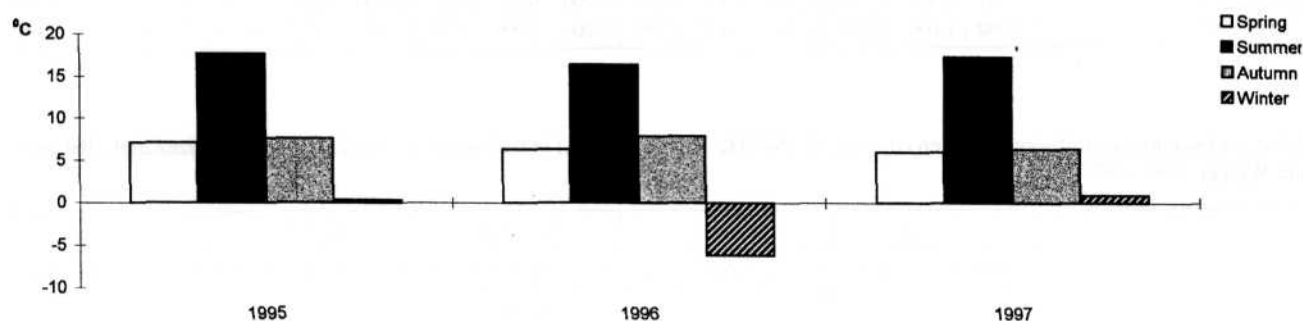


Fig. 3. Air temperature in the region of water-bearing formations of Omulewski Aquifer in 1995-1997.

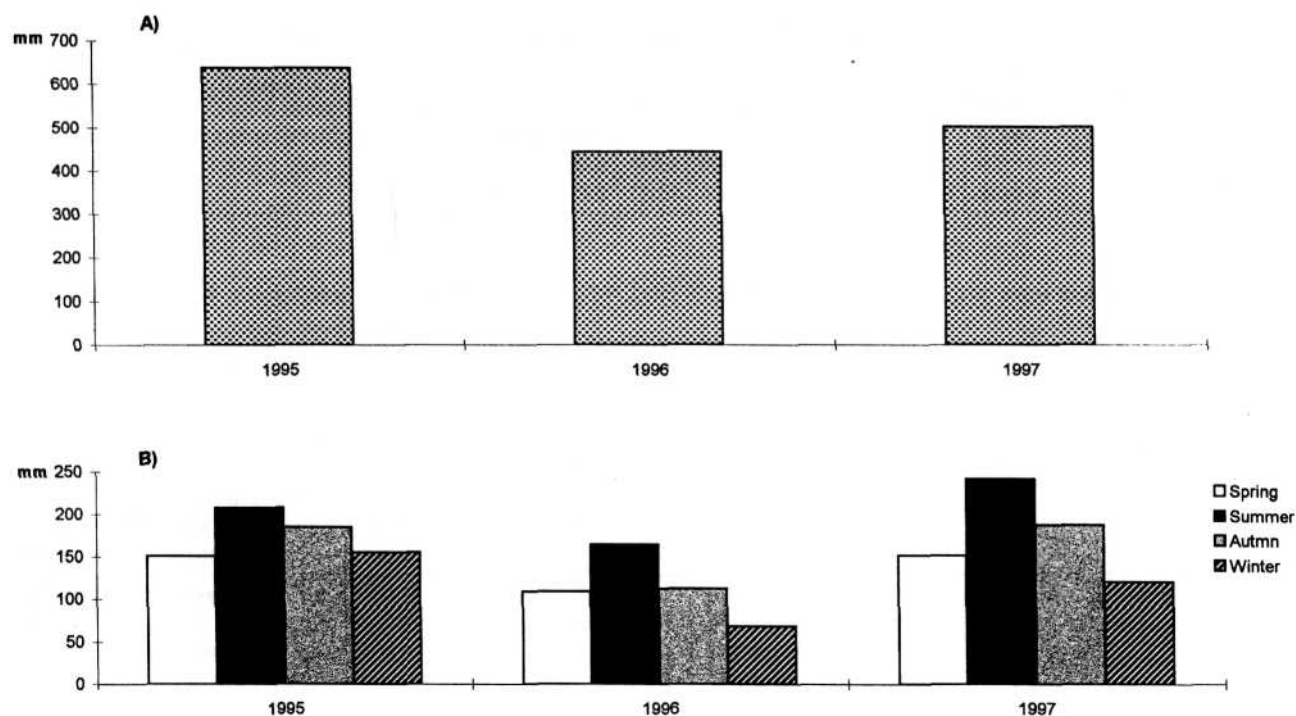


Fig. 4. Sum of atmospheric precipitation in the region of water-bearing formations of Omulewski Aquifer in 1995-1997; A - sum of atmospheric precipitation in calendar seasons, B - mean annual sum of precipitation.

and Narty (control wells), and in Jedwabno. Higher contents were recorded in wells located in the area of the former cattle and pig farms, especially in Baranowo and Wyzegi. Most wells and boreholes in the area of Omulewski Aquifer did not contain nitrites. Nominal concentrations found in wells in Kot, Baranowo and Wyzegi did not exceed 0.117 mg/l  $\text{NO}_2\text{-N}$ . Nitrate levels ranged from undetectable amounts ( $<0.001$  mg/l  $\text{NO}_3\text{-N}$ ) in water-wells in Janowo and Wielbark, and in piezometric boreholes No. 2 and 3 in Wesolowo, to 9.22 mg/l  $\text{NO}_3\text{-N}$  in the well in Jedwabno. Lower levels were usually found in wells at Sedansk and Narty (control wells), and in piezometric boreholes in Wesotowo, slightly higher in Przewdziek and Baranowo, the highest - in the area of farmed land, in the villages Jedwabno and Kot.

Compared to the data presented in Annex no. 1 (Report on environment state in Olsztyn Region in 1995-1996, 1997) [20], the majority of well-water samples in the area of Omulewski Aquifer fulfilled the standards of

the highest water quality (Ia) and/or high quality (Ib) with respect to nitrite and nitrate contents. Also contents of  $\text{NH}_4\text{-N}$  in most of the samples of group I (control wells in Sedansk and Narty), group II (wells located in farm lands used by individual farmers and group IV (piezometric boreholes in the region of the former cattle farm in Wesolowo) were low enough to qualify them into waters of the highest and high quality. Only samples collected from water-wells in Dzierzki, Wesolowo and Wyzegi contained ammonia levels regarded by the mentioned report as characterizing polluted waters, beyond any class of purity (Fig. 5). The same is concluded comparing maximal permissible concentrations of  $\text{NH}_4\text{-N}$  (0.5 mg/l) and  $\text{NO}_3\text{-N}$  (10 mg/l) for drinking water and water used for household purposes (Directive of the Minister of Health and Social Security of 4 May 1990 ... on the quality standards for drinking water and water used for household purposes; [22] (Fig. 6).

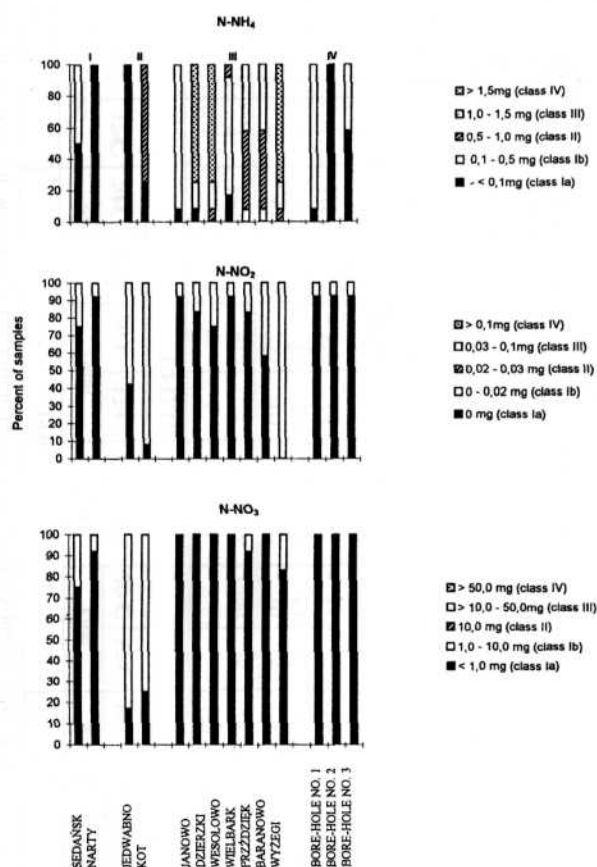


Fig. 5. Percentage of water samples conforming to the standards for the classification of normal underground waters with respect to nitrogen compounds (in mg/l) as given in Annex no. 1 of the Report on environment quality in Olsztyn District in 1995-1997  
I - wells in group I in forested land (control)  
II - wells in group II in farm lands used by individual fanners  
III - wells in group III in the area of commercial animal farms  
IV - piezometric boreholes in the area of cattle farm in Wesolowo.

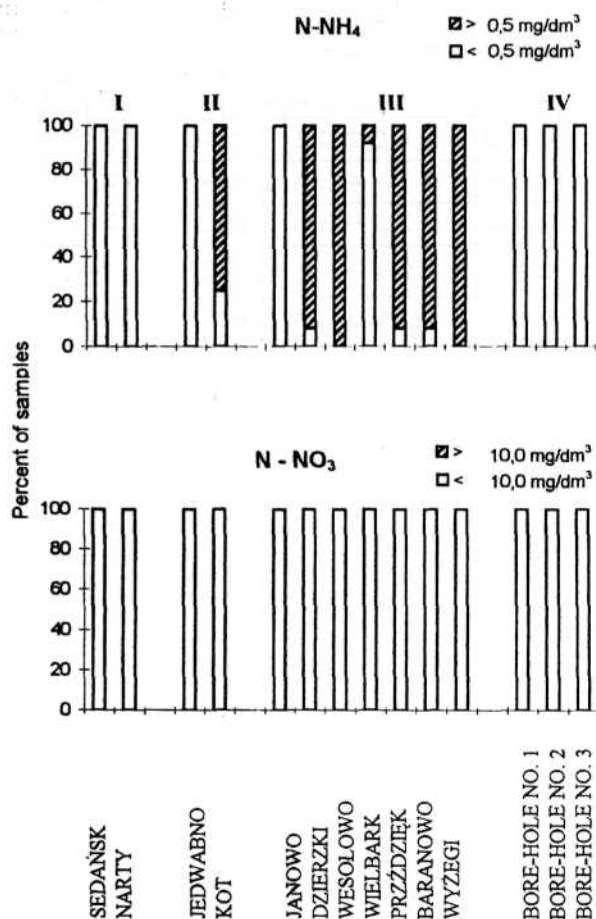


Fig. 6. Percentage of water samples conforming to the standards on  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  content (mg/l) in drinking water and water used for household purposes, as stated in the Directive of the Minister of Health and Social Security [22] in particular groups of wells (piezometric boreholes) located in the area of Omulewski Aquifer in 1995-1997. I, II, III and IV - well and borehole groups as in Fig. 5.



Table 5. Numbers of total viable counts at 20°C (TVC 20°C) and 37°C (TVC 37°C) in well water and boreholes of Omulewski Aquifer, 1995-1997.

Group of wells	Site*	1995						1996						1997												
		March		June		Sept.		Dec.		March		June		Sept.		Dec.		March		June		Sept.		Dec.		
		20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	20°C	37°C	
		CFU/1cm <sup>3</sup>																								
I	Sedańsk Nary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		16	9	5	4	7	7	10	7	196	10	413	3	8	2	1380	98	145	3	880	145	230	2	80	7	0
II	Jedwabno Kot	28	35	65	2	20	0	1	0	240	25	253	203	50	2	10	15	50	23	5	2	21	2	84	35	7
		43	5	100	18	35	1	14	1	70	1	73	10	12	1	53	22	2410	4160	157	170	4	1	5	1	1
III	Janowo Dzierżki Wesołowo Wielbark Przeździeń Baranowo Wyżęgi	9	8	8	3	1	1	1	1	115	3	320	55	65	20	43	15	235	7	13	3	16	5	1	3	3
		8	35	2	8	795	1	10	1	2	0	35	5	5	3	53	52	91	1	354	12	26	1	30	10	10
		4	10	215	90	55	0	2	0	4	4	11700	250	4350	4	145	0	36	50	13	3	13	1	11	2	2
		2	2	45	2	90	0	2	0	2	0	8	2	2	0	15	2	31	9	11	1	15	5	14	1	1
		13	32	270	75	310	0	1980	0	3	0	18	2	600	5	173	2	92	3	30	20	2	2	7	4	4
		6	2	653	50	185	1	2	1	38	1	1835	210	100	8	17	5	36	1	38	7	15	1	1	7	4
		10	10	17	0	173	0	255	0	2	2	38000	1350	455	52	303	2	114	660	354	4	1	1	200	4	4
IV	Bore-hole no.1 Bore-hole no.2 Bore-hole no.3	808	6	190	90	105	0	2720	0	400	2	315	110	465	5050	255	12	636	4720	90	3	8	4	266	2	2
		140	8	85	73	330	1	550	1	320	2	170	190	315	2	730	45	700	1	94	3	17	3	300	5	5
		3040	5	850	500	2045	0	810	0	300	1	2400	40	4550	685	21550	10	9760	108	5000	700	424	5	2790	2	2

\* - See Fig. 1

Table 6. Numbers of total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS) in well water and boreholes of Omulewski Aquifer, 1995-1997.

Group of wells	Site*	1995												1996												1997																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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\* - See Fig. 1



Table 7. Percentage of water samples conforming to the standards for drinking water and farm needs as recommended by the Act of Ministry of Health and Social Security [22]<sup>a</sup> and WHO [25].

Group of wells	Site	Number of samples	Indicatory microorganisms				
			TVC 20°C	TVC 37°C	TC		FC
			CFU/1 cm <sup>3</sup>		MPN/100 cm <sup>3</sup>		
			200 <sup>a</sup>	40 <sup>a</sup>	3 <sup>a</sup>	10 <sup>b</sup>	1 <sup>a</sup>
			Percent of samples				
I	Sedańsk Narty	4	100	75	75	75	100
		12	58	83	67	83	100
II	Jedwabno Kot	12	83	83	67	75	92
		12	92	83	75	83	92
III	Janowo	12	83	92	50	83	92
	Dzierzki	12	83	83	50	75	100
	Wesolowo	12	75	67	50	92	58
	Wielbark	12	100	92	67	100	100
	Przeździek	12	67	83	50	92	67
	Baranowo	12	83	75	17	42	92
	Wyzęgi	12	58	67	25	75	75
IV	Bore-hole no. 1	12	67	58	50	83	92
	Bore-hole no. 2	12	42	67	42	83	92
	Bore-hole no. 3	12	0	58	17	83	92

#### Numbers of Bacteria Indicatory of Pollution and Sanitary State Found in Well-Water and Water from Piezometric Boreholes in the Area of Omulewski Aquifer

Tables 5 and 6 present the results pertaining to the counts of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in water collected from wells and piezometric boreholes in the area of Omulewski Aquifer. Counts of TVC 20°C and TVC 37°C did not exceed, respectively, 38,000 CFU/1 ml of water from the well in Wyzęgi (in June 1996) and 5,050 CFU/1 ml of water from borehole No. 1 (in September 1996). The lowest numbers of these bacteria were found in spring and winter 1995 and 1996, in control wells in Sedańsk and Narty, and water from wells located in farm lands in Jedwabno, while the highest numbers were observed in summer and autumn, in wells located in the area of the former animal farms in Wesolowo and Wyzęgi, and in piezometric boreholes in the region of a former cattle farm in Wesolowo. Numbers of TC did not exceed 93 MPN/100 ml in the well in Jedwabno (in March 1995) and in the wells in Baranowo and Narty (respectively in September 1996 and 1997). Frequently these bacteria were not found at all. Their numbers in piezometric boreholes in Wesolowo did not exceed 18 MPN/100 ml (in autumn and winter 1995). FC counts reached maximally 24 MPN/100 ml in well water at Jedwabno (spring 1996), but most frequently these bacteria were not found at all. FS numbers did not exceed a few hundred MPN/100 ml; their lowest numbers were found in wells used by individual farmers in Jedwabno and Kot, the highest - in piezometric boreholes in the area of a former cattle farm in Wesolowo. Higher

contamination with these bacteria in wells and boreholes was usually observed in spring 1996 and 1997.

#### Numbers of Bacteria Indicatory of Pollution and Sanitary State Versus Sanitary and Bacteriological Standards for Drinking Water and Water Used for Household Purposes

According to the Directive of the Minister of Health and Social Security of 4 May 1990 [22] water from local water-pipes, public water-wells, enterprise wells (these were the control wells in forested area at Sedańsk and Narty, wells in farm lands in Jedwabno and Kot, and wells located in the areas of the former and still functioning animal farms: fox farm in Janowo, cattle farms in Wesolowo, Przeździek, Baranowo and Wyzęgi, pig farm in Dzierzki) should not contain any FC, while numbers of TC and TVC 37°C should not exceed, respectively, 3 MPN/100 ml and 40 CFU/1 ml. The mentioned Directive also states that water from public water-works which is not disinfected should not contain more than 200 CFU of TVC 20°C/1 ml. A rapid increase of these bacteria in drinking water and water used for household purposes reflects deterioration of water quality, which usually requires some remedial measures. WHO [24] has established the International Standards for Drinking Water, which state that TC numbers in non-disinfected water from individual wells used by small communities should not exceed 10 MPN/100 ml, and it should contain no FC (*Escherichia coli*) in 1 ml. Table 7 presents data showing to what extent the analyzed samples of well and borehole water in the area of Omulewski Aquifer con-

Table 8. Faecal coliform classification scheme applied to point source of water pollution of the Omulewski Aquifer in 1995-1997 and recommended remedial action according to the data published by Lloyd, Bartram [10].

Grade	Faecal coliform count in 100 cm <sup>3</sup>	Risk	Group of wells													Action			
			I			II		III						IV					
			Site*																
																	Bore-holes in Wesolowo		
			Sedańsk	Narty	Jedwabno	Kot	Janowo	Dzierżki	Wesołowo	Wielbark	Przeździeń	Baranowo	Wyżęgi	no. 1	no. 2		no. 3		
A	0	No risk; WHO guidelines	100.0	91.7	91.7	91.7	100.0	58.3	83.3	91.7	66.7	83.3	66.7	91.7	91.7	No action			
B	1 – 10	Low risk	0.0	8.3	8.3	8.3	0.0	41.6	16.7	8.3	33.3	16.7	33.3	8.3	8.3	Low priority			
C	11 – 100	Intermediate to high risk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Higher priority for improvement actions as soon as resources permit			
D	101 – 1000	Gross pollution. high risk	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Highest priority for urgent action			
E	> 1000	Gross pollution. very high risk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Highest priority for urgent action			

\* - see Fig. 1

Table 9. Product-moment correlation coefficients (R) between TVC 20°C, TVC 37°C (CFU/1 cm<sup>3</sup>), TC, FC and FS (MPN/100 cm<sup>3</sup>) and concentrations N-NH<sub>4</sub> and N-NO<sub>3</sub> (mg/dm<sup>3</sup>) in the underground waters of Omulewski Aquifer in 1995-1997 (at significance level  $\alpha = 0.05$ ).

Microorganisms	Years											
	1995						1996					
	1997						1997					
	14.03	19.06	20.09	13.12	27.03	18.06	30.09	18.12	20.03	24.06	29.09	8.12
TVC 20°C	Ns*	Ns	Ns	Ns	Ns	0.793**	Ns	Ns	Ns	Ns	Ns	Ns
TVC 37°C	Ns	Ns	Ns	Ns	0.823	0.779	Ns	Ns	Ns	Ns	Ns	Ns
TC	Ns	Ns	Ns	0.869	0.824	Ns	Ns	Ns	Ns	Ns	Ns	Ns
FC	Ns	Ns	Ns	Ns	0.994	0.901	Ns	Ns	Ns	Ns	Ns	Ns
FS	Ns	Ns	Ns	Ns	Ns	0.877	Ns	Ns	Ns	Ns	Ns	Ns

\* - Not significant,

\*\* - Significant at level  $\alpha = 0.05$

formed to the WHO standards. As regards control wells in Sedansk and Narty (I group of wells), standards related to FC (<1 MPN/100 ml), TC (<3 MPN/100 ml) and TVC 37°C (<40 CFU/1 ml) were met in respectively 100%, 67-75% and 75-83% of the samples. As regards wells located in farm lands used by individual farmers in Jedwabno and Kot (group II of wells), these standards were met by, respectively, 92%, 67-75% and 83% of samples. Samples collected from wells in the area of the former fox farm in Janowo, cattle farms in Wesofowo, Przewdziek, Baranowo and Wyzegi, and pig farm in Dzierzki, and still operating pig farm in Wielbark (group III of wells) met these standards in 58-100%, 17-67% and 67-92%, respectively. As regards piezometric boreholes in the area of the former cattle farm in Wesolowo (IV group of wells), these criteria were met by, respectively, 92%, 17-50% and 58-67% of the samples. WHO standards related to TC (<10 MPN/100 ml) were met by 75-83% of water samples collected from control wells in forested area in Sedansk and Narty (I group of wells), and in the area of farmed land in Jedwabno and Kot (II group of wells), by 42-100% of water samples collected in the area of animal farms (group III) and by 83% of the samples from piezometric boreholes in the region of the former cattle farm in Wesolowo (group IV).

According to Lloyd and Bartram [10], who classified contamination of underground waters based on faecal coliforms (FC), data obtained in the course of our study for well waters collected in the area of Omulewski Aquifer and presented in Table 8, only control wells in forested land (group I of wells) in Sedansk and Narty, and wells in the area of the fox farm in Janowo (group III of wells), can be regarded as totally safe from a bacteriological point of view. These wells did not require any remedial measures. Single water samples collected from the wells in Jedwabno (group II of wells), Wielbark (group III), from piezometric boreholes in the area of the former cattle farm in Wesolowo (group IV), 1/3 of the samples collected from the wells in Przewdziek, Baranowo and Wyzegi, and almost half of the samples collected in Dzierzki (group III of wells) could be regarded as slightly risky for human and animal health.

#### Statistical Analysis of the Data on the Numbers of Bacteria Indicatory of Pollution and Sanitary State and on Ammonia and Nitrate-Nitrogen Content in Well Waters and Water from Piezometric Boreholes in the Area of Omulewski Aquifer

Statistical analysis of the obtained data showed that there was no significant relationship between numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) and  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  content in the majority of samples collected in the region of Omulewski Aquifer (Table 9). A positive relationship ( $\alpha = 0.05$ ) was found only between TVC 20°C and TVC 37°C numbers and  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  levels, respectively, in June 1996, and March and June 1996 in water in each group of wells. The same relationship was found between TC, FC, and FS numbers and ammonia and nitrate levels, respectively, in December 1995 and March 1996, in March and June 1996, and in June 1996.

Based on Duncan's test, highly significant differences were discovered (at  $\alpha = 0.01$ ; Table 10):

1. as regards TVC 20°C numbers in water samples collected from piezometric boreholes (group IV of wells) and in water of the other three groups of wells in March 1995;
2. as regards TVC 20°C numbers in water collected from wells in group IV and III in March 1996 and 1997;
3. in TVC 37°C numbers in water samples from the I groups of wells (control) and those from the other three groups of wells in December 1995;
4. as regards TC numbers in water from the control wells (group I) and from group II wells (farm lands of individual farmers) in September 1997;
5. between FS numbers in water from group IV of wells and their numbers in water of the other three well groups in March 1995;
6. between FS numbers in water of group III wells and their numbers in group IV wells in December 1995;
7. as regards FS numbers in water of group I wells and their numbers in water of group II and III in December 1997.

In all other cases presented in Table 10 there were no statistically significant differences in the numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in water from particular wells, or the differences were of low significance (significance at the level  $\alpha = 0.05$ ).

#### Numbers of Bacteria Indicatory of Water Pollution and Sanitary State in Rivers Sawica and Omulew, Flowing in the Area of Omulewski Aquifer

Numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in water of the rivers Sawica and Omulew are presented in Tables II and 12. Water samples collected from Sawica River in Janowo (station 1) contained from 90 to 3620 CFU of TVC 20°C/ml and from 0 to 580 CFU of TVC 37°C/1 ml. The lowest counts of these bacteria were observed in September and December 1996. Total counts of TC ranged from 9 to 2400 MPN/100 ml. Numbers of faecal coliforms (FC) and faecal streptococci (FS) did not exceed 460 and 17,000 MPN/100 ml, respectively. Minimal and maximal contamination of river waters with these bacteria were recorded in different periods. FC:FS ratio was lower than 0.7 in over 50% of the samples, ranged from 0.7 to 4.0 in 35% of the samples, and was higher than 4.0 in 15% (Fig. 7).

Numbers of TVC 20°C in Omulew River water ranged from 50 CFU/1 ml at station 2 in Kot (March 1997) to 18,040 at station 3 in Wesotowo (March 1996). Usually these bacteria were less numerous at station 2 in Kot and station 3 in Wesolowo, and more numerous at station 4 in Wielbark. Numbers of TVC 37°C ranged from 5 CFU/1 ml at station 3 in Wesolowo (December 1995) to 14,400 CFU/1 ml at the same station in September 1996. TC numbers reached maximally 180,000 MPN/100 ml in the sample collected at station 2 in Kot in June 1997. Numbers of these bacteria in water samples collected at station 3 in Wesolowo and station 4 in Wielbark did not exceed 9,500 MPN/100 ml (September 1995) and 16,000 MPN/100 ml (June 1997), respectively. Numbers of faecal

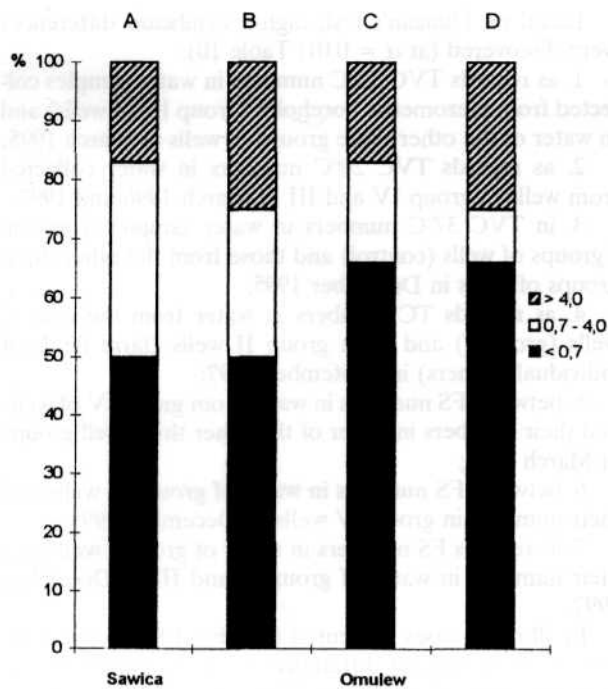


Fig. 7. Percentage of samples having FC:FS ratio in Sawica (A- in Janowo) and Omulew rivers (in: B- Kot, C - Wielbark and D- Wesołowo) in the area of water-bearing formations of Omulewski Aquifer in 1995-1997.

coliforms (FC) reached maximally 25,000 MPN/100 ml in water collected at station 2 in Kot, 220 MPN/100 ml in water collected at station 3 in Wesołowo, and 1600 MPN/100 ml in the sample collected at station 4 in Wielbark. These bacteria were often not found at all. The highest contamination of Omulew River with these bacteria was observed in June 1996 and 1997 at station 2 in Kot. FS numbers reached maximally 180,000 MPN/100 ml in water collected at station 2 in Kot (June 1997). Water collected at station 3 in Wesołowo and station 4 in Wielbark never contained more than respectively 14,000 MPN/100 ml (March 1996) and 21,000 MPN/100 ml (June 1996) of these bacteria. FC:FS ratio was less than 0.7 in 50-75 % of water samples, ranged from 0.7 to 4.0 in 10-25 % of the samples, and was higher than 4.0 in 15-25 %, depending on sampling date and station (Fig. 7).

#### Numbers of Indicatory Bacteria and Degree of Pollution and Suitability of Sawica and Omulew Rivers for Recreation

Comparison of the data on the numbers of TVC 20°C, TVC 37°C and FC in river water with the standards presented by Cabejszek et al. [2] and given in Table 13 points to slight contamination of the majority of water samples from Sawica River. The same is true of most samples collected in Omulew River. Only a few samples collected in latter river contained these bacteria in the amounts

Table 10. Significance of the differences between mean counts of bacteria indicatory of water pollution (TVC 20°C and TVC 37°C) and sanitary state (TC, FC, FS) in underground waters of particular well groups in the Omulewski Aquifer in 1995-1997, estimated using Duncan's test [16].

1, 2, 3, 4 - well group (piezometric bore-holes); a - highly significant differences at the level  $\alpha = 0.01$ ; b - significant differences at the level  $\alpha = 0.05$ ; c - differences not significant.

Group of indicatory microorganisms	Year	March	June	September	December
<sup>1</sup> TVC 20°C	1995	4/1, 2, 3 <sup>a</sup>	c	c	c
	1996	4/3 <sup>a</sup> ; 4/1 <sup>b</sup>	c	c	4/2, 3 <sup>b</sup>
	1997	4/3 <sup>a</sup> ; 4/1 <sup>b</sup>	c	c	c
<sup>2</sup> TVC 37°C	1995	c	c	c	1/2, 3, 4 <sup>a</sup>
	1996	c	c	c	c
	1997	c	c	c	c
<sup>3</sup> TC	1995	c	c	c	c
	1996	c	c	c	c
	1997	c	c	1/2 <sup>a</sup> ; 1/3, 4 <sup>b</sup>	c
<sup>4</sup> FC	1995	c	c	c	c
	1996	c	c	c	c
	1997	c	c	c	c
<sup>5</sup> FS	1995	4/1, 2, 3 <sup>a</sup>	c	c	3/4 <sup>a</sup> ; 4/1, 2 <sup>b</sup>
	1996	c	c	c	c
	1997	c	c	c	1/2, 3 <sup>a</sup>

<sup>1</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 20°C after 72 h incubation,

<sup>2</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 37°C after 24 h incubation,

<sup>3</sup> - the number of total coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 37°C after 48 h incubation,

<sup>4</sup> - the number of faecal coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 44.5°C after 24 h incubation,

<sup>5</sup> - the number of faecal streptococci (MPN/100 cm<sup>3</sup>) on the Slanetz and Bartley medium at 37°C after 72 h incubation

sufficient to suggest some pollution. On the other hand, data on FC numbers in the two rivers (see Table 11) compared to the standards given in the Directive of the Minister of Environment Protection, Natural Resources and Forestry of 5 November 1991 on water classification... [21]

suggest that 66.7% of the samples from Sawica River and 41.7-83.3% of those from Omulew River could be classified as class I water purity. As regards the latter river, the lowest percentage of samples classified into class I was collected in Wielbark, the highest - in Wesolowo. All

Table 11. The number of indicatory microorganisms (TVC 20°C and TVC 37°C) in waters of the Sawica River in Janowo and the Omulew River in Kot, Wesolowo and Wielbark in the area of Omulewski Aquifer in 1995-1997.

	Site*							
	River Sawica		River Omulew					
	Janowo		Kot		Wesolowo		Wielbark	
	TVC 20°C <sup>1</sup>	TVC 37°C <sup>2</sup>	TVC 20°C	TVC 37°C	TVC 20°C	TVC 37°C	TVC 20°C	TVC 37°C
	CFU/ 1 cm <sup>3</sup>							
14 March 1995	1 685	45	460	15	855	15	2 035	140
19 June 1995	500	220	1 960	4 600	1 000	350	9 600	3 220
20 Sept. 1995	90	15	170	65	1 040	225	1 990	650
13 Dec. 1995	1 500	15	2 380	15	3 080	5	7 100	1 770
27 March 1996	3 620	18	415	20	18 040	40	1 200	690
18 June 1996	830	550	2 175	1 850	1 400	230	3 075	2 000
30 Sept. 1996	1 550	580	5 000	572	4 000	14 400	5 300	435
18 Dec. 1996	1 900	105	1 370	70	1 700	82	12 000	545
20 March 1997	1 390	137	50	330	1 450	436	1 020	466
24 June 1997	262	95	2 680	520	2 180	237	3 540	728
29 Sept. 1997	400	126	800	305	670	88	1 110	760
8. Dec. 1997	740	97	1 120	45	1 460	84	1 600	170

\* - See Fig. 2 (A),

<sup>1</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 20°C after 72 h incubation,

<sup>2</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 37°C after 24 h incubation.

Table 12. The number microorganisms indicatory of sanitary state (TC, FC, FS) in waters of the Sawica River in Janowo and the Omulew River in Kot, Wesolowo and Wielbark in the area of Omulewski Aquifer in 1995-1997.

	Site*											
	River Sawica			River Omulew								
	Janowo			Kot			Wesolowo			Wielbark		
	TC <sup>1</sup>	FC <sup>2</sup>	FS <sup>3</sup>	TC	FC	FS	TC	FC	FS	TC	FC	FS
	MPN/100 cm <sup>3</sup>											
14 March 1995	460	3	43		4	4	150	39	4	460	43	2 400
19 June 1995	45	< 3	< 3		< 3	< 3	110	3	9	110	23	240
20 Sept. 1995	2 400	23	23	9 500	240	23	9 500	43	25	9 500	23	93
13 Dec. 1995	240	9	9	240	23	460	240	7	150	2 400	200	2 400
27 March 1996	9	460	4 500		43	3	460	93	14 000	460	93	240
18 June 1996	460	93	1 500	1 400	12 000	46 000	460	93	7 500	1 400	460	21 000
30 Sept. 1996	450	43	16	240	93	1 100	43	43	290	210	7	12 000
18 Dec. 1996	1 100	150	3	29	43	3	460	93	9	1 400	1 400	240
20 March 1997	90	20	120	140	20	170	140	70	120	170	170	120
24 June 1997	140	120	170	180 000	25 000	180 000	6 000	220	350	16 000	1 600	350
29 Sept. 1997	1 750	80	17 000	2 000	130	3 500	1 100	90	80	6 000	490	16 000
8 Dec. 1997	1 100	250	25	150	70	95	250	160	250	200	450	95

\* - See Fig. 2 (A),

<sup>1</sup> - the number of total coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 37°C after 48 h incubation,

<sup>2</sup> - the number of faecal coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 44.5°C after 24 h incubation,

<sup>3</sup> - the number of faecal streptococci (MPN/100 cm<sup>3</sup>) on the Slanetz and Bartley medium at 37°C after 72 h incubation.

Table 13. The analysis of bacteriological water quality of the rivers Sawica (in Janowo) and Omulew (in Kot, Wesotowo and Wielbark), using criteria given by Cabejszek et al. [2].

A - unpolluted, B - insignificantly polluted, C - distinctly polluted, D - heavily polluted. Percent distribution of samples relevant to the given class.

Bacteriological water quality criteria		Water quality	River				
Microorganisms	Number of cells (CFU/1 cm <sup>3</sup> )		Sawica	Omulew			
			Janowo	Kot 1	Wesołowo 2	Wielbark 3	1-3
Total viable count at 20°C	< 300	A	16.7	16.7	0.0	0.0	5.6
	300 – 5000	B	88.3	88.3	91.7	66.7	80.6
	5000 – 10,000	C	0.0	0.0	0.0	25.0	8.3
	> 10,000	D	0.0	0.0	8.3	8.3	5.5
			(12)* 100	(12) 100	(12) 100	(12) 100	(36) 100
Total viable count at 37°C	< 200	A	75.0	50.0	50.0	16.7	38.9
	200 – 1000	B	25.0	33.3	41.7	58.3	44.4
	1000 – 5000	C	0.0	16.7	0.0	25.0	13.9
	> 5000	D	0.0	0.0	8.3	0.0	2.8
			(12) 100	(12) 100	(12) 100	(12) 100	(36) 100
Coli titre	> 1	A	66.7	66.7	83.3	41.7	63.9
	1 – 0.1	B	33.3	16.7	16.7	41.7	25.1
	0.1 – 0.01	C	0.0	0.0	0.0	16.6	5.5
	> 0.01	D	0.0	16.6	0.0	0.0	5.5
			(12) 100	(12) 100	(12) 100	(12) 100	(36) 100

(\*) - Number of samples investigated.

other samples collected in Sawica River and in Omulew River in Wesolowo were classified as belonging to class II. All other samples collected in Kot and Wielbark belonged to class III.

According to the data of the European Commission on Water Quality for Swimming [3] total numbers of TC, FC and FS in surface waters used for swimming and recreation should not be higher than 500, 100 and 100 MPN/100 ml respectively (these are guide values). It is however permissible to swim in water containing no more than 10,000 MPN of TC/100 ml and 2000 MPN/100 ml of FS in at least 95% of the samples collected (mandatory values), at total lack of *Salmonella* in 1 l of water, and total lack of enteropathogenic viruses in 10 l of water. Examinations concentrated on the latter groups of pathogenic micro-organisms are necessary only in cases when there is a probability that they may occur in water. Mandatory values do not comprise examination of FS. Comparison of TC, FC and FS numbers in river water with the mentioned criteria for waters used for swimming reveals that only 58.3% of the samples collected from Sawica River in Janowo conformed to the guide values given by EEC [3]. As regards Omulew River, these standards were met by only 50% of the samples collected in Kot, 41% of those collected in Wesolowo, and 16.7% of those collected in Wielbark. On the other hand, however, all samples contained less than 10,000 MPN/100 ml of TC and less than

2000 MPN/100 ml of FC, i.e. than the maximal values permitted by this Commission for waters used for swimming (Table 14).

Table 14. Analysis of bacteriological water quality of the rivers Sawica (in Janowo) and Omulew (in Kot, Wesolowo and Wielbark), using criteria given by EEC [3]. Percentage of water samples relevant to the criteria for recreational water.

River	Site*	Number of samples investigated	TC <sup>1</sup>	FC <sup>2</sup>	FS <sup>3</sup>
			MPN/100 cm <sup>3</sup>		
			500	100	100
Sawica	Janowo	12	66.7	66.7	58.3
Omulew	Kot	12	66.7	66.7	50.0
	Wesolowo	12	75.0	83.3	41.7
	Wielbark	12	50.0	41.7	16.7
	Total	36	63.9	63.9	36.1

\* - see Fig. 2 (A),

<sup>1</sup> - number of total coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 37°C after 48 h incubation,

<sup>2</sup> - number of faecal coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 44.5°C after 24 h incubation,

<sup>3</sup> - number of faecal streptococci (MPN/100 cm<sup>3</sup>) on the Slanetz and Bartley medium at 37°C after 72 h incubation.



Table 15. Number of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in the waters of the Fishery Enterprise (water collected from fish ponds and their outflow to the Sawica River) in 1997 in Janowo; in the area of Omulewski Aquifer.

	Site*									
	Fish ponds in Janowo					Outflow from fish ponds				
	TVC 20°C <sup>1</sup>	TVC 37°C <sup>2</sup>	TC <sup>3</sup>	FC <sup>4</sup>	FS <sup>5</sup>	TVC 20°C	TVC 37°C	TC	FC	FS
	CFU/1 cm <sup>3</sup>		MPN/100 cm <sup>3</sup>			CFU/1 cm <sup>3</sup>		MPN/100 cm <sup>3</sup>		
20 March 1997	1 050	253	140	10	170	1 120	324	140	20	210
24 June 1997	1 160	408	350	110	63	5 140	480	1 000	120	180
29 Sept. 1997	1 100	720	400	20	6 000	3 100	800	2 000	49	18 000
8 Dec. 1997	900	11	1 100	150	45	1 170	47	1 450	150	45

\* - see Fig. 2 (B)

<sup>1</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 20°C after 72 h incubation,

<sup>2</sup> - the total viable counts (CFU/1 cm<sup>3</sup>) on broth-agar at 37°C after 24 h incubation,

<sup>3</sup> - the number of total coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 37°C after 48 h incubation,

<sup>4</sup> - the number of faecal coliforms (MPN/100 cm<sup>3</sup>) on the Eijkman medium at 44.5°C after 24 h incubation,

<sup>5</sup> - the number of faecal streptococci (MPN/100 cm<sup>3</sup>) on the Slanetz and Bartley medium at 37°C after 72 h incubation

#### Numbers of Bacteria Indicatory of Pollution and Sanitary State in Trout Ponds of the Fish Farm in Janowo

Water collected from trout ponds of the Fish Farm in Janowo, fed by Sawica River waters, at the inlet to the ponds contained from 900 to 1160 CFU/1 ml of TVC 20°C, and from 11 to 770 CFU/1 ml of TVC 37°C. Numbers of TC, FC and FS amounted, respectively, to: 140-1000 MPN/100ml, 10-150 MPN/100 ml and 45-6000 MPN/100ml. Effluent from trout ponds to Sawica River contained 1120-5140 CFU/1ml of TVC 20°C and 50-800 CFU/1 ml of TVC 37°C. Numbers of TC, FC and FS were respectively: 240-2000 MPN/100 ml, 20-150 MPN/100 ml and 45-18,000 MPN/100 ml. All samples collected in trout ponds conformed to the tentative guide values (no more than 10<sup>3</sup> MPN/100 ml FC) given by WHO [26] for fish ponds (Table 15).

#### Discussion

The same levels of ammonia, nitrites and nitrates in water collected from control wells (group I of wells) in Sedansk and Narty, and from wells located in farm lands used by individual farmers (group II of wells) in Jedwabno and Kot as those recorded in 1989-1993 are due to the fact that the wells in question are either situated in forested area (group I), or in areas where nothing changed as regards land use (group II) [8]. More or less pronounced decrease of ammonia levels in water of wells located in the area of the former cattle farms in Wesolowo, PrzeddzieX Baranowo and Wyzegi, and the former pig farm in Dzierzki (group III of wells) compared to its levels in 1989-1993 [8] can be related to an improvement of oxygen conditions, caused by the decrease of organic load in underground waters, which must have favoured nitrification processes. A decrease of ammonia levels in water collected from piezometric boreholes (group IV) compared to its levels found in 1989-1993 is probably related to the

liquidation of cattle farm in Wesolowo. There was also a noticeable change in organoleptic properties of water; it changed from dirty, muddy and yellowish to clear, with no noticeable odor. Lack of more pronounced differences in ammonia levels in well water in Wielbark might have been caused by the continuous operation of a commercial pig farm.

Water-bearing formations of Omulewski Aquifer are located fairly close to the land surface and are not isolated from it [24]. This, as well as intensive farming and animal breeding operations which used to dominate the area [7], still affect sanitary and bacteriological states of underground waters of this hydrological unit. Relatively higher numbers of TVC 20°C and TVC 37°C found in the control well in Narty in December 1996, June, September and December 1997 (in the last 2 months coupled with an increase of TC and FS) was probably due to a change (due to technical reasons) of sampling station location (water was collected from a user's tap instead of directly from the well, as had been done before). Re-opening of the fox farm in Janowo was probably the reason for an increase of TC numbers above the maximal limit permissible for drinking and household water, as well as for the increase of FS, an index of water pollution by animals, observed in well water in nearby Sedansk. The increase of TC and FS numbers in this well in autumn and winter 1997 was accompanied by an increase of ammonia nitrogen content. Higher levels of ammonia and nitrates were also coupled with higher numbers of TC and FS in water collected from the wells located in the area of the former animal farms in Wesolowo, Przeddziek, Baranowo and Wyzegi. Also Goselin et al. [5] observed an increase of faecal coliforms (FC) in the presence of NO<sub>3</sub>-N. Higher numbers of TVC 20°C, TVC 37°C and FS (but not FC) in the presence of higher ammonia levels were also observed in water collected from piezometric boreholes located in the area of the former cattle farm in Wesolowo. The hygienic and sanitary state of underground waters in the latter two groups of wells seems to reflect the former existence of large cattle and pig farms in this area, which operated until

1992/1993. According to Geldreich and Kenner [4] domination of FS and FC in water reflects pollution by animal faeces. On the other hand, however, the farms in question had been liquidated already 2-4 years previously, and this seems a too long period for these micro-organisms to be still present in underground waters of Omulewski Aquifer. It is known from literature [11] that enteric bacteria of humans and animals are unable to live long in a natural aquatic environment, and if they reach underground waters they can survive no more than several months [14].

Omulewski Aquifer is fed by infiltration. This, coupled with its geological structure and shallow level of water-bearing formations, with its isolation from the surface, as well as with the fact that maximal numbers of TVC 20°C, TVC 37°C, TC and FS were recorded in the periods when their numbers reached maximal levels also in Sawica and Omulew rivers suggest that the mentioned bacteria passed from surface to the nearest underground waters. Often, maximal numbers of these bacteria in Janowo well were also found in the same period in which they reached higher levels in Sawica River. Similar relations were observed also between numbers of these bacteria in wells in Kot, Wesotowo and Wielbark, and their numbers in Omulew River which flows from a few to at most a few hundred metres from these wells. Sometimes higher numbers of these bacteria in well waters were recorded a little later than in river waters, this being due to geological conditions in the area. The possibility of a horizontal transfer of pollution and accompanying bacteria reflecting sanitary state has also been suggested by Paul et al. [15] and Spandowska et al. [23]. Fortunately, both Sawica and Omulew carry waters of satisfactory quality; the most polluted stretch of Omulew River in Wielbark can be classified as slightly polluted, and only 1/6-1/4 of water samples collected at this station belonged to noticeably polluted. A direct effect of trout ponds in Janowo on the state of underground waters in this area is practically impossible as the ponds are made of concrete. Moreover, TC, FC and FS numbers in water discharged from these ponds to Sawica River, which reached maximal values in September 1997, were very similar to their numbers recorded at station No. 2, located some 100 m above the ponds, and it did not correlate with these numbers found in a nearby well at the fox farm in Janowo.

## Conclusions

1. Liquidation of commercial cattle farms in Wesoiowo, Przędzick, Baranowo and Wyzęgi, and of the commercial pig farm in Dzierzki was reflected in lower levels of ammonia in underground waters (water wells and piezometric boreholes), and higher content of nitrates, probably related to improved oxygen conditions and intensifying nitrification processes at decreased loads of organic matter. Nevertheless, this level was still higher than maximal permissible values for drinking water and water used for household purposes.

2. Contrary to underground waters located in the area of commercial animal farms, underground waters in wells located in forested regions (control wells) in Sedansk and Narty, and in farm lands used by individual farmers in

Jedwabno and Kot contained ammonia and nitrates in amounts classifying these waters as of high quality, permissible for drinking.

3. There was no noticeable improvement of bacteriological quality of underground waters in the area of Omulewski Aquifer after liquidation of commercial cattle and pig farms. This suggests that their "restoration" may take more time, and that it might be necessary to undertake some measures aimed at restoration of surface land in this area.

4. The facts that Omulewski Aquifer is fed by infiltration, has no isolation from the surface, and is characterized by shallow placing of water-bearing formations make it possible for river pollutants present to pass into the underground waters. This is suggested, among other things, by maximal numbers of the analyzed indicator bacteria found in wells located in Kot, Wesoiowo, and Wielbark in the same periods when their numbers increased also in Omulew River.

5. Numbers of bacteria indicator of water pollution (TVC 20°C, TVC 37°C) and its sanitary state (TC, FC, FS) in Sawica River were usually typical of slightly polluted waters (class II of purity); the discharge from trout ponds had no greater effect on water quality in this river, and it probably did not affect quality of underground waters either. Higher numbers of the mentioned indicator bacteria in Omulew River, especially in Wielbark, are due to pollution leaking from houses and farm buildings in Kot, Wesoiowo and Wielbark, as well as run-off from the arable-forest-pasture-meadow catchment basin.

6. The dominating position of faecal coliforms (FC) among the bacteria indicator of sanitary state in wells and piezometric boreholes, and in Sawica and Omulew rivers in the area of Omulewski Aquifer suggests the role of animal faeces on water quality. These bacteria may originate from faecal contamination accumulated during operation of the animal farms, as well as from wild animals and aerial run-offs from the arable-forest-pasture-meadow catchment basin.

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