WELCOME

WATER, ENVIRONMENT, LANDSCAPE MANAGEMENT AT CONTAMINATED MEGASITES

DEVELOPMENT OF INTEGRATED MANAGEMENT SYSTEM (IMS) FOR PREVENTION AND REDUCTION OF POLLUTION OF WATERBODIES AT CONTAMINATED INDUSTRIAL MEGASITES

WP4.1 GIS DESCRIPTION

PART III

Chemistry and quality of groundwater in the area of the Tarnowskie Góry town

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WORKPACKAGE 4

TASK 4.1 – GIS DESCRIPTION

PART III – CHEMISTRY AND GROUNDWATER QUALITY IN REGION OF TARNOWSKIE GÓRY TOWN

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1 RECOGNITION OF THE PRESENT STATE OF GROUNDWATER CHEMISTRY

Studies of groundwater chemistry in the area of the Tarnowskie Góry have been relatively intensive. Beside systematic investigations carried out within the groundwater quality monitoring programme (in national, regional and local monitoring networks), the chemistry of groundwater was investigated as part of a number of projects, records and scientific and research studies which comprised Tarnowskie Góry area in the sections of data interpretation [Aniszczyk M., et al., 1997; Hordejuk T., 1994, 1996, 1998; Kowalczyk a. et al., 2000; Kowalczyk a. et al., 2001; Różkowski A. et al. (ed.), Różkowski A., Siwek P., 1996; Kropka J. et al., 1994; Rubin H., 1997, 1999; Rubin K. et al., 1997; 1999; Witkowski A.J., 1997, 2000]. The most extensive source of data are studies concerning the monitoring of groundwaters carried out since 1999 in the area of the landfills in the Tarnowskie Góry Chemical Plant in liquidation [GIG Katowice, 1999-2002]. A systematic local monitoring of the groundwater quality is performed also for a municipal landfill site at Tarnowskie Góry – Rybna. The concept of the regional groundwater monitoring network for the Tarnowskie Góry Poviat (poviat=county) developed in 2002 is an important source of the most up-to-date information [PIG, ZBU INTERGEO, 2002].

1.1 GROUNDWATER MONITORING

Presently, there are 42 groundwater monitoring points located in the town (Fig. 1), in that: 2 points of national network, 2 points of regional Silesian Voivodeship network (1 point belongs to both: national and regional network), and 39 points of local network (Table 1). The studies are performed by various organisational units and cover a differentiated scope of investigations.

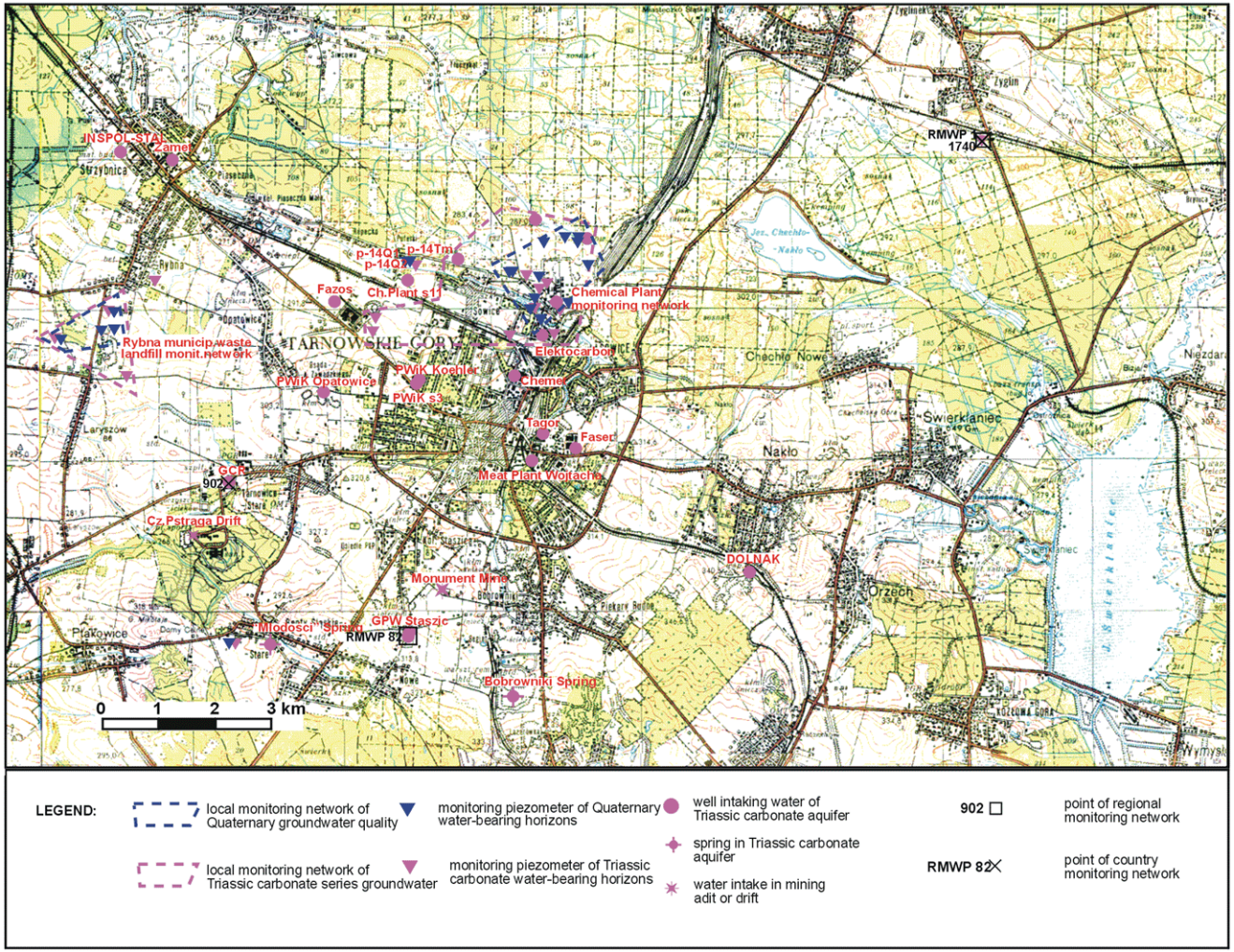

INSPOL-STAL
Zamet
Szczybnica
Rybna
Opatowice
Fazos
Ch.Plant s1
p-14Q
p-14Tm
p-14Q
Chemical Plant monitoring network
Rybna municip.waste landfill monit.network
TARNOWSKIE GÓRY
Elektrocarbon
PWiK Koehler
PWiK Opatowice
PWiK s3
Chemer
Tagos
Faser
Meat Plant Wojtachy
GCP
902
Cz.Pstrąga Drift
Monument Mine
Młodości Spring
GPW Staszic
RMWP 82
Bobrowniki Spring
Piekary Bytkowskie
Piekary Bytkowskie
Piekary Bytkowskie

Table 1 Number and structure of monitoring points of individual monitoring networks in the area of Tarnowskie Góry

Monitoring network	Piezometers	Wells		Stratygraphy
		Active	Closed	
National	1	1	-	T
Regional	1		1	T
Local of the Tarnowskie Góry Chemical Plant	14			Q
	14*	1	3	T
Local of the Rybna Landfill	4			Q
	3			T

*Note: One piezometer T2 is presently closed.

1.1.1 National network

There are 2 points of national groundwater monitoring network located in the area of Tarnowskie Góry: S-1a in Repty Sląskie (no. 902) and in Tarnowskie Góry-Żyglin (no. 1704).

The S-1a Repty Śląskie well of 130 m depth monitors Triassic aquifer (horizon of Muschelkalk) and is used by the Upper Silesian Rehabilitation Centre (GCR). Groundwater from this well is sampled on a regular basis since 1992. The piezometer located in Żyglin (no.1704) monitors Triassic aquifer (horizon of Muschelkalk). The depth of this piezometer is 70 m and it has been used for sampling since 1997.

Samples from the national groundwater network monitoring points are collected once a year, usually in autumn (September). The scope of the performed analytical determinations is very broad and comprises a maximum of 39 indicators: pH, electric conductivity, suspended matter, dissolved substances, total alkalinity, total hardness, Na, K, Ca, Mg, N-NH_4, Fe $_{tot.}$, Mn, Al, Cr, Zn, Cd, Pb, Ni, Cu, Li, Co, As, Br, B, Ba, Ti, V, Mo, Sr, N-NO_2, N-NO_3, Cl, SO_4, F, SiO_2, PO_4, free cyanides, dissolved organic carbon.

Investigations are performed within the national monitoring since 1991 by the State Geological Institute (PIG) (T. Hordejuk, 1994, 1996, 1998). Chemical analyses are performed by the PIG Central Chemical Laboratory in Warsaw.

1.1.2 Silesian Voievodeship regional network

There are 2 points of the regional groundwater monitoring network (RMWP) of the Silesian Voivodeship located in the area of Tarnowskie Góry: RMWP1 – piezometer in Żyglin and RMWP82 – "Staszic" intake point of the Upper Silesian Waterworks (GPW). The network, in its present shape, has been functioning since 2000 and is co-ordinated by the Environmental Protection Inspection of the Silesian Voivodeship in Katowice. The network has been created as a result of combining the networks of the regional network of the former Częstochowa Voivodeship with the network of the former Regional Water Management Board in Katowice. The Żyglin piezometer (RMWP1) monitors groundwater since 1993, while the "Staszic" intake point has been incorporated into the monitoring network in 2000.

Sampling campaigns in the presently existing Silesian Voivodeship regional groundwater monitoring network are performed on a yearly basis. Determinations comprise the following scope of analysis:

a) basic analysis:

- 15 indicators: pH, total alkalinity, dissolved substances (incl. mineral and volatile), carbonate hardness, oxidizability (COD_{Mn}), nitrogen compounds: $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$, chlorides, sulphates, sodium, potassium, calcium, magnesium, iron, manganese (2001 exclusive)

b) extended analysis:

- 19 indicators: barium, boron, chromium^{+6}, zinc, fluorides, phosphates, aluminium, cadmium, silica, lead, strontium, cyanides, volatile phenols, total dissolved organic carbon (DOC), anionic surface-active substances, total aliphatic hydrocarbons, trichloroethane ($C_2H_3Cl_3$), tetrachloroethane ($C_2H_2Cl_4$).

  Tricholoroethane and tetrachloroethane determinations were made in 8 selected samples from: RMWP1 (Żyglin), RMWP 82 (Tarnowskie Góry), RMWP 83 (Miedary), RMWP 84 (Tworóg), T-203 (Kalety), T-204 (Bibiela, well 10bis), T-205 (Bibiela, well 1bis).

In the years 1991-1993 and 1995-1996, the Chair of Hydrogeology and Geology Engineering of the Silesian University performed a goal oriented project for the Department of Environmental Protection of the Voivodeship Office in Katowice. The project concerned

groundwater quality studies within the regional monitoring of groundwater quality of selected fissured-carstic Main Groundwater Reservoirs (GZWP) of Silesian Triassic. This network comprised three wells located in the area of Tarnowskie Góry:

- S VII well of the Tarnowskie Góry Chemical Plant – in the years 1991-1993;
- S1 GCR well in Repty Śl. – in the years 1991 – 1993 and 1995 – 1996;
- Well in the Tarnowskie Góry Meat Processing Plant (presently 'Wojtacha" Meat Processing Plant) – in the years 1991 – 1993.

A final report from the performed studies was developed in 1996 (A. Różkowski, P. Siwek, 1996). Since 1996, monitoring of wells in this network has not been continued.

Summarising, it should be stressed that the Żyglin monitoring point has been investigated very intensively. Currently, this point has been incorporated into both networks: national (since 1997) and regional (since 1993).

1.1.3 Local networks

Groundwater quality in the area of Tarnowskie Góry has been also investigated within a local monitoring system. This monitoring comprises landfills of industrial wastes of the Tarnowskie Góry Chemical Plant in liquidation and a municipal landfill site in Rybna (Fig. 1).

Local monitoring of groundwater quality at the industrial waste landfills of Tarnowskie Góry Chemical Plant in liquidation.

First network of a local groundwater quality monitoring network at the Tarnowskie Góry Chemical Plant landfill site was established in the period of September – October 1990 by Geoprojekt Śląsk. A total of 27 piezometers were installed, marked with symbols of P1 - P20. The network comprised 26 piezometers monitoring Quaternary water-bearing horizons, in that 6 piezometers comprising 2-3 strata in a cross section of a water bearing horizon (P12/1, P12/2, P13/1, P13/2, P13/3, P15/1, P15/2, P16/1, P16/2, P17/1, P17/2, P18/1, P18/2). One piezometer (P14) was installed for monitoring carbonate Triassic aquifer. It intakes the roof part (rock-waste) of the carbonate formations. Also, within this monitoring of this water bearing complex, samples were taken from a shaft well and wells operated by the Chemical Plant (wells symbols according to hydrogeological records of wells: SI, SIII, SV, SVII, S1, S9).

Some of the points of the original network: P1, P4, P12, P13, P19 have been destroyed by third persons, while some others have been abandoned: P2, P3, P7, P8, P11, P15, P16, P17 P18, shaft well SI, according to the industrial landfills reclamation plan.

In the period of November 1993 – April 1994 the Katowice Geological Enterprise (KPG) installed 5 new piezometers: for Quaternary aquifer PQ1, for carbonate Triassic horizon: PT1, PT2, PT3, PT4. Piezometer PT2 was destroyed and in June 2000 KPG installed a new piezometer PT2 bis, which was again destroyed in 2002.

Geoprojekt Śląsk supplemented the network points in the period of April – October 1998. Nine piezometers were installed for monitoring Quaternary aquifers: P21, P22, P22A, P23, P24, P24A, P25, P27, P27A and four piezometers to monitor the roof section of Muschelkalk: PT5, PT5A, PT6, PT6A. Piezometer P 21 was destroyed.

The Katowice Geological Enterprise installed another new piezometers in the period of August – September 1999. They were incorporated into the monitoring network of Quaternary aquifers: 3 points (PQ26, PQ28, PQ29); and 2 points (PT7, PT8).for monitoring of the roof section of Muschelkalk.

At present (June 2002) the Local Groundwater Monitoring in the area of the Tarnowskie Góry Chemical Plant industrial waste landfills is performed in the following network (Fig. 3):

- for Quaternary waters P5, P6, P9, P20, P22, P22A, P23, P24, P24A, P25, P27, P27A, PQ1, PQ26, PQ28, PQ29,
- for Triassic waters of carbonate series: P14, PT1, PT3, PT4, PT5, PT5A, PT6, PT6A, PT7, PT8, STIII (according to records: SIII), STV (according to records: SV), STVII (according to records: SVII), STIX (according to records: S9).

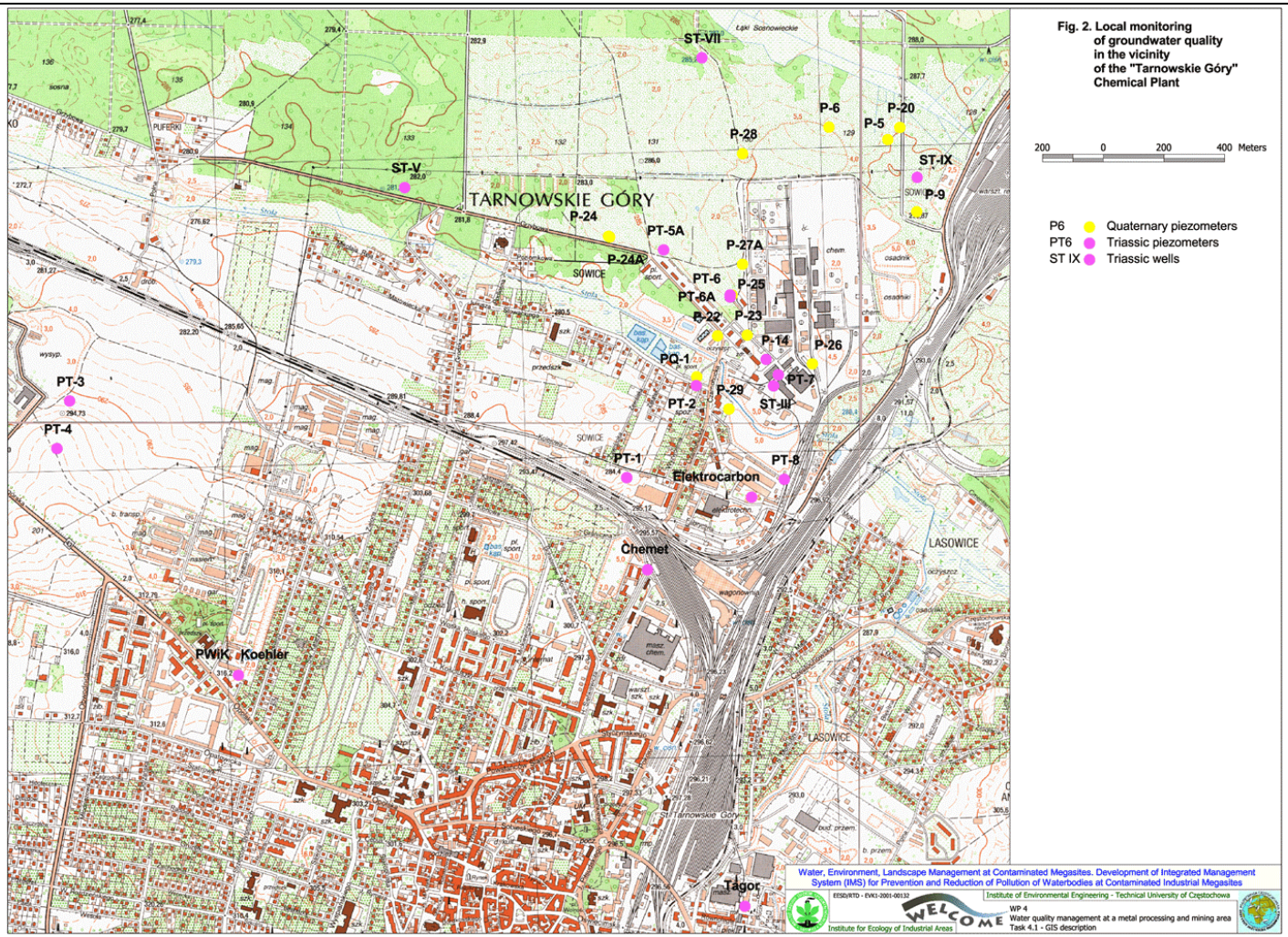


Fig. 2 Local monitoring of groundwater quality in the vicinity of the "Tarnowskie Góry" Chemical Plant

Three from the mentioned monitoring points: P22A, P27 and PT5 are quipped with installation for a continuous measurement of specific electrolytic conductivity.
Samples from the other piezometers are taken on a quarterly basis. The scope of the performed determination comprises: pH, specific electrolytic conductivity, dissolved substances, oxidizability (COD), NH_4, NO_3, NO_2, (only Quaternary aquifer monitoring points), chlorides, sulphates, arsenic, barium, boron, zinc, aluminium, cadmium, manganese, copper, nickel, lead, strontium, iron, calcium, magnesium, sodium, potassium, carbonates, hydrogen carbonates.

Taking into account representativeness of individual points it should be stated that:

- 14 monitoring points represent Quaternary aquifer; in that 13 points monitor the principal water horizon of undisturbed continuity in the area of the landfills. One point (P24A) represents lower - frequently isolated - water horizon, connected with depressions in the roof of Triassic formations (Table 2).
- 14 monitoring points represent Triassic aquifer; in that 1 piezometer (P14) represents waste rock of the roof section of carbonate formations; 10 points represent Muschelkalk water bearing horizon (in that 6 points represent roof, shallow section of Muschelkalk - PT2, PT5A, PT6, PT6A, PT7, PT8 and 4 points represent deeper, locally roof section - PT1, PT3, PT4 and STIII, 3 points represent Roet (Upper New Red Sandstone) horizon – Table 3).

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From the viewpoint of piezometers location in the hydrodynamic system of the Quaternary aquifer and in relation to the situation of the landfill sites, it was stated that one point (P9) represents the zone of water inflow to the landfill site; 9 points represent a broadly understood landfill site (P5, P22, P23, P25, P26, P27A, P28, P29 and PQ1), and 4 points represent the zone of water outflow from the landfill site (P6, P20, P24, P24A); while points P6 and P20 are located on NNW direction of outflow and points P24 and P24 at SWW direction of outflow (Fig. 2).

Taking into account the location of monitoring points in the hydrodynamic system of Triassic aquifer and in relation to the situation of the landfill site, it was stated that 2 points (STIX and

STVII) represent the zone of water inflow to the landfill site, and 5 points are located in the broadly understood area of the landfill site (PT6, PT6A, PT7, STIII, P14); while 7 points represent the zone of water outflow from the landfill site: three of them (PT2, PT5A, PT8) are located in a direct vicinity of the landfill, one point (PT1) is located in a close distance to the landfill and three are located in a longer distance from the landfill site (PT3, PT4 and STV) (**Błąd! Nie można odnaleźć źródła odsyłacza.**).

Within the discussed monitoring, additionally four wells from the area of the town have been monitored: Electrocarbon, Chemet, Tagor, PWiK-Koehler. They represent carbonate Triassic aquifer. Their frequency and scope of sampling varied and since 2002 it has been carried out according to the system used for other points monitoring Triassic waters.

Table 2 Piezometers representative for Quaternary waters

<table>
<tr><th colspan="5">Monitoring network of Quaternary aquifer</th></tr>
<tr><td>suspended water horizon on the 1st clay level, local occurrences</td><td colspan="4">lack of measurement points</td></tr>
<tr><td rowspan="5">main Quaternary aquifer, continuously spread in the landfill site</td><td>Zone of water inflow into the landfill site</td><td colspan="3">P9</td></tr>
<tr><td rowspan="3">landfill site zone</td><td rowspan="2">horizon without clay cover, free water table</td><td rowspan="2">roof</td><td>P25, P26, P28
right bank of the Stoła River</td></tr>
<tr><td>P29, PQ1
left bank of the Stoła River</td></tr>
<tr><td>bottom</td><td>P5, P22</td></tr>
<tr><td>horizon with clay cover, water table under pressure</td><td colspan="2">P23, P27A</td></tr>
<tr><td rowspan="3">Zone of water outflow from the landfill site</td><td>water outflow in NNW direction</td><td colspan="2">P6, P20</td></tr>
<tr><td rowspan="2">water outflow in NNW direction</td><td colspan="2">P24</td></tr>
<tr><td>water horizon in gutter and hollows of Triassic roof as isolated local structures</td><td colspan="2">P24A</td></tr>
</table>

Table 3 Piezometers representative for Triassic waters

Monitoring network of the Triassic carbonate series aquifers						
controlled water bearing horizon		location of measurement points in relation to landfills				
		Zone of water inflow the landfill site	landfill site zone	Zone of water outflow from the landfill site		
				direct	nearby	distant
weathered carbonate formation			**P14**			
Muschelkalk	aquifer roof		**PT6, PT6A, PT7**	**PT8, PT2, PT5A**		
	aquifer bottom		**St III**		**PT1**	**PT3, PT4**
Roet		**St IX, St VII**				**St V**

Local monitoring of groundwater quality in the area of the municipal landfill site in Tarnowskie-Góry Rybna.

The network consists of 7 piezometers: including 4 piezometers representing Quaternary aquifer (P-1, P-2, P-3, P-4), and 3 monitoring Triassic aquifer (T-1, T-2, T-3) (Fig. 3). The depth of piezometers representing Quaternary aquifer is small, in the range of 7,7 (P-3) to 13,2 (P-2) meters. Unfortunately there is practically no water in P2, so this piezometer is sampled only sporadically. Piezometers monitoring the Triassic aquifer are deeper (51-55 meters) and represent carbonate Triassic formations. The entire network has been functioning since 1996. The points are sampled twice a year (in spring and autumn). The scope of the performed determinations comprises 40 indicators: pH, total dissolved substances, dissolved mineral substances, volatile dissolved substances, $COD_{(Mn)}$ $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$, $N_{org.}$, PO_4, Cl, SO_4, F, SiO_2, total and mineral alkalinity, volatile phenols, carbon hardness, Ca, Mg, Na, K, Fe, Mn, Cr, Zn, Al., Cd, Cu, Ni, Pb, Hg, B, Ba, Sr, CN, aromatic hydrocarbons, BOD_5, detergents, coli titrent. However, there is no interpretation of this data.

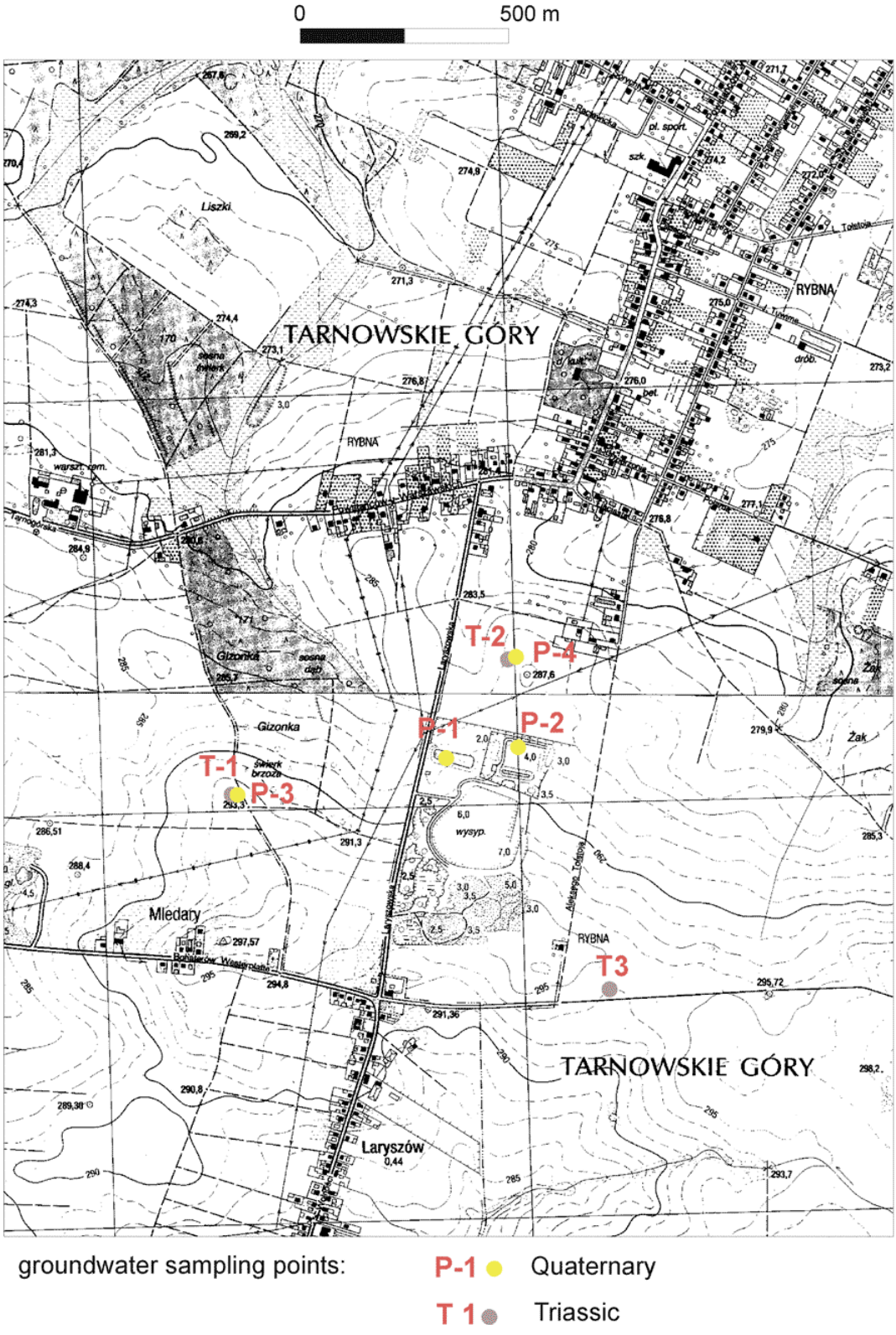


Fig. 3 Local monitoring of groundwater quality in region of the municipal landfill site in Tarnowskie Góry-Rybna

Research performed within the realisation of the "Concept of a regional monitoring network of ground and surface waters quality for the Tarnowskie Góry Poviat in the aspect of the impact of hazardous waste landfills at the Tarnowskie Góry Chemical Plant in liquidation on water environment."

As part of the monitoring network concept realisation in the area of Tarnowskie Góry Poviat only one sampling campaign of a total of 39 points representing groundwaters was performed. Among 39 sampled groundwater points, 34 represented Triassic aquifer (in that 32 of carbonate Triassic water-bearing horizon, 2 points of lower and medium Bunter - Świerklaniec layers) and 5 (4 piezometers and 1 well) represented Quaternary aquifer. In the vicinity of the Tarnowskie Góry town samples were taken from 14 points: 12 representing Triassic aquifer and 2 representing Quaternary aquifer. The performed chemical analyses of water samples comprised determinations of 30 physico - chemical indicators (pH, electrolytic conductivity, colour, ammonium, nitrites, nitrates, total hardness, arsenic, boron, barium, strontium, chromium, cadmium, lead, zinc, manganese, chlorides, sulphates, total and mineral alkalinity, carbon dioxide, phosphates, COD_{Mn}, trichloroethane, tetrachloroethane, surface-active substances, calcium, magnesium, sodium, potassium, 5 bacteriological indicators (number of bacteria in 1 ml at the temperature of 37 ^{o}C after 24 hours, number of bacteria in 1 ml at temperature of 22 ^{o}C after 72 hours, number of bacteria of Coli group in 100 ml at the temperature of 37 ^{o}C after 24 hours, number of thermotollerant Coli bacteria in 100 ml at the temperature of 44 ^{o}C after 24 hours, number of fecal streptococci in 100 ml at the temperature of 37 ^{o}C after 48 hours).

2 CHEMISTRY AND QUALITY OF WATERS

Characteristics of the chemistry and quality of groundwaters of Quaternary and Triassic aquifers in the area of Tarnowskie Góry was developed based primarily on the most up-to-date data from the research performed in May 2002 within the local monitoring of the landfills at the Tarnowskie Góry Chemical Plant. Also the latest available data on the chemistry of groundwaters were used. They originated from the studies performed in June 2002 within the realisation of the "Concept of a regional monitoring network of ground and surface waters quality for the Tarnowskie Góry Poviat in the aspect of the impact of hazardous waste landfills at the Tarnowskie Góry Chemical Plant in liquidation on water environment" (PIG, ZBU INTERGEO, 2002). In addition, data from the studies performed in 2001 for the needs of the local monitoring at the municipal landfill site in Tarnowskie-Góry Rybna were presented.

Evaluation of the trends of changes was developed based on data from research performed in the years 1999-2002 (until May), performed within the realisation of the groundwater quality monitoring in the area of landfill sites at the Chemical Plant.

The chemistry of the investigated waters was assessed based on a modified Szczukariev-Prikłoński classification. According to this classification, ions occurring in the amount higher than 17% of total anion and total cation mvals are recognised as macrocomponents which determine the hydrochemical type. Due to the possibility of potential errors in analysis a 3% tolerance was assumed in relation to the assumed 20% limit value.

A standard classification was used to evaluate the quality of groundwater. The classification was developed for the needs of environmental monitoring adopted by PIOŚ in 1993 and modified in 1995 (Błaszyk, Macioszczyk, 1993, Staniewicz-Dubois, 1995).

Due to the fact that the scope of the determined parameters was modified during the course of the studies, to compare the quality of the investigated groundwaters for the total period of monitoring the classes of water quality were set up based on the following, common scope which comprises 20 pollution indicators such as: pH, electrolytic conductivity, dissolved substances, oxidizability (COD), $N\text{-}NH_4$, $N\text{-}NO_3$, chlorides, sulphates, arsenic, barium, boron, zinc, aluminium, cadmium, manganese, copper, nickel, lead, strontium, iron.

The scope did not comprise all pollutant indicators of the above mentioned PIOŚ classification.

The quality of the studied groundwaters has been also evaluated from the viewpoint of organoleptic and physico-chemical requirements which should be met by drinking water and household water. The presently effective requirements are set up in a Regulation of the Minister of Health of 4 September 2000, published in the Journal of Laws No 82 (item 937, annex 1-3). Report of January 2001 characterised the changes which were made due to the enforcement of this regulation, compared with the regulation previously effective (Regulation of the Minister of Health and Social Welfare of 14 May 1990, published in the Journal of Laws No 35).
It should be also added that waters categorised according to the PIOŚ classification as high-class quality i.e. Ib will not always meet the standards for drinking and household waters what makes the comparison of water quality determined using these two criteria difficult. The reason is attributable to the fact that water categorised as class Ib in the PIOŚ classification may exceed permissible limit values of three indicators of that class, while in the case of drinking water exceedance of even one indicator is not permitted.

Reference was also made to recommendations set up by the European Union concerning the requirements for drinking water. It should be added here, that Polish standards are principally consistent with the EU recommendations concerning the analysed pollution indicators, however in some cases Polish standards are more liberal (e.g. in the case of chlorides, sodium, barium, electrolytic conductivity), while in some other cases they are more stringent (e.g. for copper, zinc, cadmium, nickel and lead).

2.1 QUATERNARY AQUIFER.

The chemical composition of the Quaternary aquifer waters in the area of the landfill sites of the Chemical Plant has been determined based on data from the up-to-date monitoring research (May 2002) of 14 piezometers of the existing local monitoring network. Reference was also made to analytical data from determinations performed within this monitoring since 1999; a survey of the recorded extreme values is presented in Table 4.

Generally, it should be stated that the chemistry of the Quaternary aquifer waters in the area of the landfill sites of the Chemical Plant is diversified. In the analysed period (May 2002), the amount of dissolved substances fluctuated in the range of 75 mg/dm^3 (in P-24) to 1960 mg/dm^3 (in P-24A). Total mineralization of Quaternary aquifer waters within the locally monitored area under study was in the range of 72,5 mg/dm^3 (in P24) to 3120 mg/dm^3 (in P24A in March 2000). Waters of the lowest mineralization level i.e. in which the content of total soluble substances did not exceed 200 mg/dm^3, were observed in four monitoring points (P6, P9, P20 and P24), whereas waters of the highest mineralization level, in which the content of total dissolved substances exceeded 1000 mg/dm^3 were identified in 4 points (PQ1, P5, P24A and P27A).

The pH of the analysed water was in the range of 4,55 (P29) to 8,3 (P26). Waters of acid reaction (pH<5) were identified only in P29, while waters of a slightly alkaline pH (7<pH<9) were observed in PQ1, P24A and P26. Waters of a slightly acidic reaction (7<pH<5) predominate in the studied Quaternary aquifer. During the course of the nearly four year studies, the lowest pH value i.e. 4,3 was recorded in March 2001.

Table 4 Maximum and minimum concentration of investigated contamination factors of Quaternary water horizons (on basis of local monitoring of Chemical Plant "Tarnowskie Góry" landfills)

Name of parameter	Unit	Minimum			Maximum		
		value	place of detection	date of statement	value	place of detection	date of detection
Acidity	pH	4,3	P-29	III.01	8,3	P-26	V.02
El.conductivity	μS	117	P-24	V.02	3970	P-24A	III.00
Dissolv.subst.	mg/dm^3	72,5	P-24	II.02	3120	P-24A	III.00
COD	mgO_2/dm^3	0,6	P-6 P-20	II.01, XI.01 IX.99	38	P-28	VII.01
Arsenic	$mgAs/dm^3$	0	all		0,04	PQ-1/P-26	VIII.00, X.00/XII.00
Barium	$mgBa/dm^3$	0	P-29, P-5, P-24, P-27A, P-20		88	P-25	VII.01
Boron	mgB/dm^3	0,09	P-9	IX.00	240	P-29?/14	XII.00
Zinc	$mgZn/dm^3$	0,016	P-24A	IX.00	57	P-27A	V.02
Aluminium	$mgAl/dm^3$	0	all beside P-29, P-9, P-28		3,7	P-26	IX.99
Cadmium	$mgCd/dm^3$	0	all beside P-24, P-9, P-27A		0,67	P-27A	V.02
Manganese	$mgMn/dm^3$	0	P-25/P-23	II.00/XI.01, V.01	22,5	P-27A	V.02
Copper	$mgCu/dm^3$	0	all beside P-5, P-9		0,7	P-5	XI.99
Nickel	$mgNi/dm^3$	0	all beside P-5, P-27A		0,21	P-5	XI.01
Lead	$mgPb/dm^3$	0	all		0,055	PQ-1	X.00
Strontium	$mgSr/dm^3$	0	P-6	XI.00, IX.01	40	P-25	VII.01
Iron	$mgFe/dm^3$	0	P-9	VII.99, IX.99, II.02, V.02	8,48	PQ-1	X.00
Ammonium	$mgNH_4/dm^3$	0	all beside P-29, PQ-1, P-27A		145,67	P-27A	IX.99
Nitrates	$mgNO_3/dm^3$	0	all beside P-5, P-22, P-25, P-26, P-23, P-27A, P-20		60,47	P-25	XI.99
Nitrites	$mgNO_2/dm^3$	0	all		0,49	P-26	XI.00
Chlorides	$mgCl/dm^3$	1,42	P-20	I.00	868,6	P-24A	IV.00
Fluorides		0	all beside P-25, P-23		15,4	P-26	X.99
Phosphates	$mgPO_4/dm^3$	0	all beside P-26, P-27A		3,34	P-27A	III.01
Sulphates	$mgSO_4/dm^3$	0	P-25	VII.99, II.00	1130	P-27A	VII.99
Detergenty		0	all		0,41	P-22	II.00
Fenols		0	all		2	P-5	X.00
Magnesium	$mgMg/dm^3$	1,99	P-24	V.02	61,72	P-5	II.02
Potassium	mgK/dm^3	1,09	P-6 P-20	V.02 V.02	12,12	P-26	V.02
Sodium	$mgNa/dm^3$	1,72	P-9	V.02	347,1	P-24A	II.02
Calcium	$mgCa/dm^3$	6,79	P-29	II.02	294,6	P-24A	II.02
Hydrogen carbonates	$mgHCO_3/dm^3$	0	P-29	V.02	485	P-25	V.02

The content of such basic anions as chlorides, sulphates and hydrogen carbonates was very diversified. The content of chlorides was in the range of 5,32 mg/dm^3 (P20) to 585 mg/dm^3 (P24A). The lowest Cl concentrations i.e. not exceeding 20 mg/dm^3 were recorded in 5 piezometers (P5, P6, P9, P20 and P24), whereas clearly increased Cl concentrations i.e. exceeding 250 mg/dm^3. Were observed only in P24A. A distinctively increased contents of chlorides were also recorded in PQ1 (228,7 mg/dm^3) and in P27A (237,5 mg/dm^3). Throughout the entire period of research, an extreme value of chlorides concentration amounting 869 mg/dm^3 was determined in April 2000. Generally however, a drop of chlorides content in the investigated waters can be observed.

The sulphates content was in the range of 13,5 mg/dm^3 (P25) to 825 mg/dm^3 in (P5). High seasonal fluctuations of sulphates content in P5 were recorded. Content of sulphates in a sample taken from P5 piezometer in November 2001 was 840 mg/dm^3 while in a sample taken in February 2000 it was on the level of 505 mg/dm^3. Presently, the lowest levels of sulphates content i.e. not exceeding 100 mg/dm^3 were noted in P6, P9, P20, P22, P24 and P25; the highest concentrations i.e. exceeding 250 mg/dm^3 were determined in PQ1, P5, P24A, P27A and P29. An elevated sulphates content of 248 mg/dm^3 was also determined in P23. Throughout the entire period of the four-year studies extremely high concentrations of sulphates amounting to 1130 mg/dm^3 were observed in P27A in July 1999.

The content of Hydrogen carbonates was in the range of 0 mg/dm^3 (P29) to 485 mg/dm^3 (P25). Low contents of these ions (<75 mg/dm^3) were recorded in piezometers P5, P6, P9, P20, P24, P27A and P29), while increased concentrations (>350 mg/dm^3) were observed in 3 piezometers: P22, P25, P26.

Calcium content was in the range of 8,08 mg/dm^3 (P29) to 274,5 mg/dm^3 (P24A); magnesium content was in the range of 1,99 mg/dm^3 (P24) to 60,51 mg/dm^3 (P5), sodium: from 1,72 mg/dm^3 (P9) to 321,9 mg/dm^3 (P24A) ; and potassium from 1,09 mg/dm^3 (P6) to 12,12 mg/dm^3 (P26). Distinctly elevated calcium contents (>200 mg/dm^3) were noted in PQ1, P5 and P24A, while in the case of sodium (>100 mg/dm^3) in PQ1, P23, P24A, P26, P28 and P29.

Generally, the content of basic cations in the investigated waters is stable and does not show significant changes. It should be added that determinations of the mentioned basic cations within the analysed monitoring have been initiated only in May 2001.

Content of mineral forms of nitrogen in the studied waters was diversified. Content of ammonium ions was in the range of 0 (in 8 piezometers: P5, P6, P9, P20, P22, P23, P24 and P25) to 11,95 mg/dm^3 in P27A. An elevated NH_4 content was determined also in PQ1, P24A, P26 and P29. Throughout the course of the four-year studies an extreme concentration of ammonium ions of 146 mg/dm^3 was recorded in P27A in November 1999. Currently a decrease of NH_4 content has been observed in this piezometer.

Nitrates content was in the range of below 1 mg/dm^3 (PQ1, P6, P9, P24, P24A and P29) to 41,3 mg/dm^3 in P5 and 37,98 mg/dm^3 in P22. The highest nitrates concentrations determined during the four-year study amounted to 60,5 mg/dm^3 and were recorded in P25 in November 1999.

No nitrites content was detected in water samples takes from 13 piezometers. Only in P26 a small content of nitrites i.e. 0,066 mg/dm^3 was recorded. Thought the entire four-year course of the studies, the highest content of nitrites (49 mg/dm^3) was determined in P 26 in November 1999.

Distinctly elevated concentrations of the following indicators were determined in waters of the Quaternary aquifer:

- barium – maximum concentration to 48 mg/dm^3 in P25 In other piezometers the content of barium, except for P26 (0,43 mg/dm^3), did not exceed 0,2 mg/dm^3. Generally however, the content of this ion in the studied waters is variable. Maximal determined concentration was 88 mg/dm^3 (July 2001) in P25.
- boron –maximum concentration to 220 mg/dm^3 in P5. Extremely high boron concentrations exceeding 100 mg/dm^3 were determined also in PQ1 (124 mg/dm^3) and P29 (102 mg/dm^3). Both in P5 as well as in PQ1 and P29 the content of boron

in the analysed waters undergoes significant seasonal changes. A distinctively elevated boron content (>20 mg/dm^3) was also observed in P24A, P25, P27A, P26 and P28. A relatively low boron content in the amount of <1 mg/dm^3 was observed only in 3 piezometers (P6, P9 and P24). Throughout the entire four-year courser of the studies an extreme concentration of boron in the investigated waters amounted to 240 mg/dm^3 and was noted in P29 in December 2000. Currently, the concentration of boron in water samples taken from this piezometer is by 50% lower, yet still very high.

- strontium – maximum concentration to 23,5 mg/dm^3 in P25 In other points the content of strontium in sampled waters was low and exceeded 1 mg/dm^3 only in 3 points: P5 - 1,35 mg/dm^3, P22 - 2,35 mg/dm^3 and P27A - 1,5 mg/dm^3. The highest concentration of strontium in the analysed waters amounting to 40 mg/dm^3 was recorded in P25 in October 2001.
- aluminium – maximum concentration to 0,44 mg/dm^3 in P29 and 0,3 mg/dm^3 in P26. Elevated concentrations of aluminium i.e. >0,2 mg/dm^3 were noted also in P28 (0,28 mg/dm^3). Throughout the course of the four-year studies a high variability of aluminium concentration in the analysed waters was observed. Maximum content of 3,7 mg/dm^3 was recorded in P 26 in November 2001.
- iron – maximum concentration to 1,18 mg/dm^3 in P24A. In other monitoring points (except for PQ1, P26, P28, P29), the content of iron in the analysed waters did not exceed 0,2 mg/dm^3. However, the content of iron was extremely variable. The maximum recorded content (8,48 mg/dm^3) was determined in PQ1 in October 2000.
- manganese – maximum concentration to 22,5 mg/dm^3 in P27A. Additionally, a clearly elevated manganese content was observed in PQ1 (3,66 mg/dm^3) and P28 (1,08 mg/dm^3). Increased concentrations i.e. >0,4 mg/dm^3 were recorded also in P5 and P24A. Only in P23, P24 and P25 manganese content did not exceed 0,05 mg/dm^3. A distinct increase in manganese content in waters of P27A has been observed Maximum manganese content observed in May 2002 was the highest throughout the period of the four-year studies.
- cadmium – maximum concentration to 0,67 mg/dm^3 in P27A. Cadmium contents (>0,003 mg/dm^3) were also detected in P5, P9, P23, P24 and P25. An increase in cadmium

concentration has been observed in PT27. Similarly as in the case of manganese, the maximum cadmium concentration determined in the studied waters was recorded in May 2002.

In some monitoring points elevated concentrations of the following indicators have been still observed:

- zinc – to 57 mg/dm^3 in P27A. Similarly as in the case of manganese and cadmium this concentration was the highest recorded throughout the course of the studies.
- nickel – to 0,2 mg/dm^3 in P5. Up-to-date the highest concentration of nickel amounting 0,21 mg/dm^3 was recorded in November 2001 also in piezometer P5.
- lead– to 0,033 in P5. The extreme value of lead concentration determined in the analysed waters was 0,055 mg/dm^3 in piezometer PQ1 in October 2000.

Assessment of the chemical composition of the Quaternary aquifer waters based on sampling campaign launched in May 2002 showed that SO_4 ions dominate among anions. Average content of sulphates was 51,06 % mvals and fluctuated in the range of 2,69 (P25) to 94,26 % mvals (P5). Sulphates dominated among anions in water sampled from 10 piezometers (PQ1, P5, P6, P9, P20, P23, P24, P27A, P28 and P29). Average content of chlorides was 21,65 % varying in the range of 1,65 (P5) to 54,25 % mvals (P24A). Among anions, chlorides dominated only in P24A. Significant amounts of chlorides (>17 % mvals) were stated also in PQ1, P22, P23, P24, P25, P27A, P28 and P29. Average concentration of hydrogen carbonates in the investigated waters (in 14 piezometers) was 26,12 % mvals, varying in the range of 0 (P29) to 76,27 % mvals (P25). Hydrogen carbonates dominated in waters of P22, P25 and P26.

Among cations, Ca ions were predominant. Their concentration in the analysed period varied in the range of 1,03 % mvals (P29) to 59,18 (P9), at average value of 31,03 % mvals. Sodium content was in the range of 0,38 % mvals (P5) to 55,54 % mvals (P26), at average content value of 22,27 % mvals. Magnesium content in the studied waters was generally low. Only in two piezometers P9 and P20 significant amounts of this ion exceeding 17 % mvals were determined: 23,20 % mvals in P9 and 17,72 % mvals in P20. Average magnesium content in the investigated waters was 10,41 % mvals and varied in the range of 0,60 % mvals

(P29) to 23,20 % mvals (P9). Generally, it can be stated that the content of basic cations in the studied waters is very stable. Boron plays still an important role in the chemistry of the analysed waters; its content falls in the range of 4,25 % mvals in P22 to 77,29 % mvals in P5. Average boron content in the analysed groundwaters (in 14 piezometers) was extremely high amounting to 32,99 % mvals.

Taking into account the modified hydrochemical classification of Szczukariev-Prikłoński, it should be stated that the analysed waters are characterised by an exceptional variability and belong to both: two-ion waters and five-ion waters. At each of the analysed 14 points a different hydrochemical type of water has been recognised (Table 5).
Beside six basic ions, high boron content was observed in the analysed groundwaters. This ion occurred in as many as 8 piezometers (PQ1, P5, P20, P25, P27A, P26, P28 and P29) reaching the value above 17 % mvals and determining the hydrochemical type of water. However, it should be mentioned that the original Szczukariev-Prikłoński classification took into account only 6 basic ions and referred only to natural waters.

In such situation classification of the highly anthropogenically transformed groundwaters is questionable, especially when some of the investigated waters could be classified to such abnormal types as SO_4-B (P5), SO_4-Ca-B-Mg (P20), HCO_3-Cl-B-Ca (P25) or SO_4-HCO_3-Cl-B-Na (P28).

Summarising in can be stated that the waters of the highest degree of anthropogenic transformation occur in piezometers representing the principal aquifer, located in the area of a direct impact of the landfill sites (P5, P23, P27A, PQ1 and P25, P26 and P29) in the Tarnowskie Góry Chemical Plant as well as in P24A piezometer representing lower aquifer in depressions of the Triassic formation roof, located in the area of water outflow from the landfill site on the SWW direction (Fig. 2). This proves a direct impact of the landfills on the monitored groundwaters.

Quaternary groundwaters have also been monitored in the area of the municipal landfill site in Tarnowskie Góry Rybna (Fig. 3). Waters of aquifer in this area (in 2001) were characterised by a diversified and variable total mineralization, falling in the range of 163 – 894 mg/dm^3, sulphates content (29,2 to 192,2 mg/dm^3), total hardness (108,4 to 715,9 mg

$CaCO_3/dm^3$). Seasonally, elevated concentrations of nitrogen nitrate have been observed in these waters (to 22,7 mg/dm^3), organic nitrogen (to 7,58 mg/dm^3), aluminium (to 0,456 mg/dm^3), iron (to 1,33 mg/dm^3) and manganese (to 0,161 mg/dm^3).

2.2 TRIASSIC AQUIFER

The chemical composition of Triassic aquifer waters has been characterised based on the most up-to-date data (May 2002) obtained from the local monitoring of groundwaters carried out in the area of the Chemical Plant landfill sites. For interpreting purposes, references were also made to data from determinations performed in the framework of the local monitoring since 1999. A survey of all extreme values recorded for the entire period of the monitoring is presented in Table 6. For chemistry characterisation data obtained during the development of the monitoring network concept for the area of the Tarnowskie Góry Poviat were also utilised. In the context of the local monitoring performed for the Chemical Plant landfills, chemical composition of the discussed waters is highly diversified. Amounts of substances dissolved in samples collected in May 2002 fluctuated in a very broad range: from 119 mg/dm^3 (STV) to 440 mg/dm^3 (PT7). Waters of the lowest mineralization level i.e. below 600 mg/dm^3 were observed in 8 monitoring points (PT1, PT3, PT4, PT5A, STIII, STV, STVII, and STIX). Waters of the highest content of dissolved substances i.e. above 3500 mg/dm^3 were identified in 3 points (PT6, PT6A and PT7). In PT14 wasters of significantly elevated mineralization level i.e. 2220 mg/dm^3 were observed. Throughout the four-year course of studies the highest mineralization of the discussed waters amounting to 5850 mg/dm^3 was noted in PT7 in March 2001. The presently observed maximum values in PT7 are approximately by 25% lower.

The pH of the Triassic aquifer waters fluctuated in a much narrower range than in the case of Quaternary aquifer waters i.e. from 5,95 in PT7 to 8,2 in STV. Waters of a slightly acidic reaction (5<pH<9) were observed in P7 and P14. Waters of slightly alkaline reaction i.e. (7<pH,9) predominated. They were identified in 11 piezometers. Presently, increased water acidity in PT7 has been observed. The lowest stated pH value in PT7 is also the lowest value for the entire four-year course of studies.

Chlorides content in the analysed waters varied in a very broad range: from 5,32 mg/dm^3 (STV) to 1826 mg/dm^3 (PT7). A very high content of chlorides exceeding 1000 mg/dm^3 was noted in PT6A (1329 mg/dm^3) and in PT6 (1127 mg/dm^3). During the course of

Table 5 Groundwater hydrochemical types in viccinity of landfills of Chemical Plant "Tarnowskie Góry"

	Sampling	Hydrochemical type					
	Year	2001				2002	
	Month	V	VII	IX	XI	II	V
Quaternary water-bearing horizons	Piezometer P9	SO_4-Ca-Mg	SO_4-Ca-Mg	SO_4-Ca-Mg	SO_4-Ca-Mg	SO_4-Ca-Mg	SO_4-Ca-Mg
	Piezometer P25	HCO_3-B-Ca	HCO_3-B-Ca	HCO_3-B-Ca	HCO_3-B-Ca	HCO_3-B-Ca	HCO_3-Cl-B-Ca
	Piezometer P26	HCO_3-SO_4-Na-B	HCO_3-SO_4-Na-B	HCO_3-SO_4-Na-B	HCO_3-SO_4-Na-B	HCO_3-SO_4-Na-B	HCO_3-SO_4-Na-B
	Piezometer P28	SO_4-HCO_3-Cl-B-Na	SO_4-Cl-HCO_3-B-Na-Ca	HCO_3-SO_4-Cl-B-Na-Ca	HCO_3-Cl-SO_4-B-Na-Ca	SO4-HCO_3-Cl-B-Ca	SO_4-HCO_3-Cl-B-Ca
	Piezometer P29	SO_4-Cl-B-Na	SO_4-Cl-B-Na	SO_4-Cl-B-Na	SO_4-Cl-B-Na	SO_4-Cl-B-Na	SO_4-Cl-B-Na
	Piezometer PQ1	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca
	Piezometer P5	SO_4-B-Ca	SO_4-B	SO_4-B	SO_4-B	SO_4-B	SO_4-B
	Piezometer P22	HCO_3-Cl-Ca-Na	HCO_3-Cl-Ca-Na	HCO_3-Cl-Ca-Na	HCO_3-Cl-Ca-Na	HCO_3-Ca-Na	HCO_3-Cl-Ca-Na
	Piezometer P23	SO_4-Cl-HCO_3-Na-Ca	HCO_3-SO_4-Cl-Na-Ca	SO_4-HCO_3-Cl-Na-Ca	SO_4-HCO_3-Cl-Na-Ca	HCO3-SO_4-Cl-Na-Ca	SO_4-HCO_3-Cl-Na-Ca
	Piezometer P27A	SO_4-Cl-B-Ca	SO_4-Cl-B-Ca	SO_4-Cl-B-Ca	SO_4-Cl-B-Ca	SO_4-Cl-B-Ca-Na	SO_4-Cl-B-Ca-Na
	Piezometer P6	SO_4-HCO_3-Ca	SO_4-HCO_3-Ca-Na	SO_4-HCO_3-Ca-Na	SO_4-HCO_3-Ca-Na	SO_4-HCO_3-Ca-Na	SO_4-HCO_3-Ca-Na
	Piezometer P20	SO_4-Ca-Mg	SO_4-Cl-Ca-B-Mg	SO_4-Ca-B-Mg	SO_4-Ca-B-Mg	SO_4-Ca-B-Mg	SO_4-Ca-B-Mg
	Piezometer P24	SO_4-Cl-Ca-Na	SO_4-Cl-Ca	SO_4-Ca	SO_4-Cl-Ca-Na	SO_4-Cl-Ca-Na	SO_4-Cl-Ca
	Piezometer P24A	Cl-SO_4-Ca-Na-B	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Na-Ca	Cl-SO_4-HCO_3-Na-Ca
Triassic water-bearing horizons	Piezometer P14	HCO_3-SO_4-Ca-Na-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Na	HCO_3-SO_4-Ca-Na	HCO_3-SO_4-Ca-Na	Cl-HCO_3-Ca-Na
	Piezometer PT6	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca
	Piezometer PT6A	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na	Cl-SO_4-Ca-Na
	Piezometer PT7	Cl-Na-Ca	Cl-Na-Ca	Cl-SO_4-Na-Ca	Cl-SO_4-Na-Ca	Cl-Na-Ca	Cl-SO_4-Na-Ca
	Piezometer PT8	SO_4-HCO_3-Cl-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-HCO_3-Cl-B-Ca	SO_4-HCO_3-Cl-B-Ca	SO_4-HCO_3-Cl-B-Ca
	Piezometer PT2	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	SO_4-Cl-HCO_3-B-Ca	
	Piezometer PT5A	HCO_3-SO_4-Cl-Ca-Na	HCO_3-Ca	HCO_3-Cl-Ca-Na-B	HCO_3-Cl-Ca-Na	HCO_3-Cl-Ca-Na	HCO_3-Cl-Ca-Na-B
	Well St III	SO_4-Cl-HCO_3-B-Ca-Na	HCO_3-SO_4-Ca-Na-B	HCO_3-SO_4-Cl-Ca-B-Na	HCO_3-SO_4-Cl-Ca-B-Mg	HCO_3-SO_4-Cl-Ca-B-Mg	HCO_3-Cl-SO_4-Ca-B
	Piezometer PT1	HCO_3-Ca-Mg	HCO_3-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg
	Piezometer PT3	HCO_3-Cl-SO_4-Ca-Mg-Na	HCO_3-Cl-SO_4-Ca-Na-Mg	HCO_3-SO_4-Cl-Ca-Na-Mg	HCO_3-SO_4-Cl-Ca-Mg	HCO_3-SO_4-Cl-Ca-Mg-Na	HCO_3-SO_4-Cl-Ca-Na-Mg
	Piezometer PT4	HCO_3-SO_4-NO_3-Ca-B-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-NO_3-Ca-Mg	HCO_3-SO_4-NO_3-Ca-Mg
	Well St IX	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Cl-Ca-Mg	HCO_3-SO_4-Ca-Mg	HCO_3-SO_4-Ca-Mg
	Well St VII	HCO_3-Cl-SO_4-Ca-Na	HCO_3-Cl-SO_4-Ca-Na	HCO_3-Cl-Ca	Cl-HCO_3-SO_4-Ca-Na-Mg	Cl-HCO_3-SO_4-Ca-Na-Mg	Cl-HCO_3-SO_4-Ca-Na-Mg
	Well St V	HCO_3-Ca-Mg	HCO_3-Ca-Mg-Al.	HCO_3-Ca-Mg	HCO_3-Ca-Mg	HCO_3-Ca-Mg	HCO_3-Ca-Mg

the four year studies, the extreme content of chlorides in the investigated waters was 2588 mg/dm^3 and was recorded in piezometer P14 in November 1999. The highest concentrations of chlorides are observed in piezometers located within the zone of water inflow to the landfill site (STIX) and water outflow zone from the landfills area (PT1 and STV). These points represent the roof section of Muschelkalk (PT1) and Roet level (STV and STIX).

The content of sulphates was in the range of 13 mg/dm^3 (STV) to 1070 mg/dm^3 (PT6). A distinctly elevated concentrations, exceeding 250 mg/dm^3 were stated in PT6A (815 mg/dm^3), in PT7 (635 mg/dm^3) and in PT8 (315 mg/dm^3). Concentrations of SO_4 below 100 mg/dm^3 were determined in 8 monitoring points (PT1, PT4, PT5A, P14, STIII, STV, STVII, STIX). High sulphates contents were recorded for piezometer PT6 throughout the course of the four year studies; the highest value was recorded during the May 2002 sampling campaign.

The content of hydrogen carbonates in the studied waters is relatively less diversified and fluctuates in the range of 51,85 mg/dm^3 (STVII) to 677,1 mg/dm^3 (P14). Low content of these ions (<75 mg/dm^3) was stated only in STV well, while elevated concentrations (>250 mg/dm^3) have still been observed only in 2 piezometers (PT7 and PT14).

Calcium content in the analysed waters was in the range of 20,44 mg/dm^3 (STV) to 563,1 mg/dm^3 (PT6A). Magnesium content was in the range of 5,59 mg/dm^3 (STVII) to 106,1 mg/dm^3 (PT6). Sodium content varied in the range of 2 mg/dm^3 (STV) to 958,7 mg/dm^3 (PT7). S Potassium concentrations in the analysed waters were in the range of 0,86 mg/dm^3 (STIX) to 29,76 mg/dm^3 (PT7). Abnormally high calcium content (>200 mg/dm^3) and sodium content (>100 mg/dm^3) were stated in PT6, PT6A, PT7 and P14.

In some points elevated concentrations of nitrogen compounds have been observed. An extremely high NO_3 content of 154,95 mg/dm^3 was recorded in PT6. Additionally, elevated NO_3 concentrations were noted in PT4 (68,48 mg/dm^3), in PT3 (53,48 mg/dm^3), in PT6A (56 mg/dm^3) and PT8 (30,99 mg/dm^3). Moreover, a distinctly elevated ammonium content (NH_4) in the amount of 22,81 was stated in PT7. During the four-year course of the studies, an extremely high content of nitrates exceeding the value of 277 mg/dm^3 was stated in piezometer PT6 in January 2000, while a concentration of ammonium above 27,6 mg/dm^3 was observed in PT7 in May 2001.

Table 6 Maximum and minimum concentration of investigated contamination factors of Triassic water horizons (on basis of local monitoring of Chemical Plant "Tarnowskie Góry" landfills)

Name of factor	Unit	Minimum			Maximum		
		value	place of detection	date of detection	value	place of detection	date of detection
Acidity	pH	5,95	PT-7	V.02	10,4	PT-2	V.00
El.conductivity	mS	154	ST-V	I.01	8530	P-14	XI.99
Dissolv.subst.	mg/dm^3	84	ST-V	I.01	5850	PT-7	III.01
COD	mgO_2/dm^3	0,5	S-IX	I.01,V.01	59	PT-7	I.00
Arsenic	$mgAs/dm^3$	0	all		0,03	P-14	VII.01
Barium	$mgBa/dm^3$	0	PT-3, PT-4, PT-8, PT-2		722	P-14	XI.99
Boron	mgB/dm^3	0	ST-V, S-IX, PT-1, PT-6A		116	PT-2	III.00
Zinc	$mgZn/dm^3$	0	ST-V, S-VII, PT-1, PT-6		4,7	PT-7	IX.01
Aluminium	$mgAl/dm^3$	0	all		4,7	ST-V	VII.01
Cadmium	$mgCd/dm^3$	0	all excluding PT-7, P-14		0,12	PT-7	IX.01,V.02
Manganese	$mgMn/dm^3$	0	ST-V, S-IX, PT-3, PT-4, PT-8, PT-2, P-14		6,45	PT-6	III.01
Copper	$mgCu/dm^3$	0	all excluding PT-7		51	PT-7	V.02
Nickel	$mgNi/dm^3$	0	all excluding PT-7		0,89	PT-7	IX.01
Lead	$mgPb/dm^3$	0	all		0,037	P-14	II.02
Strontium	$mgSr/dm^3$	0	PT-3	II.00, XI.00	30,6	P-14	XI.99
Iron	$mgFe/dm^3$	0	PT-3, PT-4, PT-8, PT-6		24,2	PT-7	XI.99
Ammonium	$mgNH_4/dm^3$	0	all excluding PT-7		27,63	PT-7	V.01
Nitrates	$mgNO_3/dm^3$	0	ST-V, PT-1, PT-2, PT-5A, PT-7, ST-III		277,40	PT-6	I.00
Chlorides	$mgCl/dm^3$	2,48	ST-V	I.00	2588	P-14	XI.99
Phosphates	$mgPO_4/dm^3$	0	all excluding PT-3		3,3	P-14	VII.99
Sulphates	$mgSO_4/dm^3$	0	P-14		1070	PT-6	V.02
Magnesium	$mgMg/dm^3$	5,58	ST-VII	II.02	106,1	PT-6	V.02
Potassium	mgK/dm^3	0,82	ST-9	II.02	30,15	PT-7	II.02
Sodium	$mgNa/dm^3$	2	ST-V	V.02	958,7	PT-7	V.02
Calcium	$mgCa/dm^3$	17,94	ST-V	II.02	563,1	PT-6A	II.02
Hydrogen carbonates	$mgHCO_3/dm^3$	39,65	ST-VII	II.02	683,2	P-14	II.02

In some points elevated values of the following indicators have been observed:

- boron – due to the fact that samples could not be collected from the destroyed piezometer PT2, in which the maximum boron concentrations were determined (in previous year quarter 82,1 mg/dm^3), an updated assessment of the extremely high concentration of boron in the investigated Triassic aquifer waters was not possible. At present, high boron concentrations are still recorded in PT8 (40,5 mg/dm^3), in

PT7 (34,5 mg/dm^3) and in STIII (10,6 mg/dm^3). In the up-to-date history of the performed studies an extremely high boron content in the analysed waters was 116 mg/dm^3 and was determined in piezometer PT2 in March 2000.

- copper - to 51 mg/dm^3 in PT7. No increased copper contents were observed in other monitoring points. Unfortunately, a continuous increase of copper concentration has been recorded in piezometer PT7 and the presently determined value is also the highest value noted in the four-year studies.
- strontium – to 8,2 mg/dm^3 in PT7. Strontium concentrations exceeding 1 mg/dm^3 were also stated in 2 points: PT6 (3,5 mg/dm^3) and P14 (6,7 mg/dm^3). An extremely high strontium content exceeding 30,6 mg/dm^3 was determined in the analysed waters in piezometer P14 in November 1999.
- iron – to 18,3 mg/dm^3 in PT7. In general, iron content in the analysed waters varied significantly from period to period. Its maximum determined content in the course of the four year studies was 24,2 mg/dm^3 and was stated in PT7 in November 1999.
- cadmium – to 0,12 mg/dm^3 in PT7. Concentrations of cadmium exceeding 0,003 mg/dm^3 were also stated in P14, PT6 and PT6A. Cadmium content in the analysed waters also undergoes seasonal variations. During sampling campaigns, in 12 piezometers (except PT7 and P14) cadmium occurred in concentrations below detection level.

Elevated contents of zinc (4,3 mg/dm^3), manganese (2,2 mg/dm^3) and nickel (0,86 mg/dm^3) are observed in PT7. Generally, concentrations of these metals stated in piezometer PT7 in May sampling campaign are higher than in previous campaigns. The highest determined during the four year studies concentrations of zinc amounted to 4,7 mg/dm^3 (in PT7 in November 2001), manganese 6,45 mg/dm^3 (in PT6 in March 2001), nickel 0,89 mg/dm^3 (in PT7 in November 2001).

Among anions, HCO_3 ions dominate in the chemical composition of the analysed waters of the Triassic aquifer. Average content of hydrogen carbonates was 37,87 % mvals and fluctuated in the range of 3,57 (PT6A) to 77,37 % mvals (STV). Average chlorides content was 34,51% mvals, varying within a broad range from 8,01 (STV) to 74,23 % mvals (PT7). Average concentration of sulphates in the investigated waters (in 14 piezometers) was 24,33 % mvals, ranging from 1,8 % mvals (P14) and 14,41 % mvals (STV) to 43,54 % mvals (PT8).

Among cations, Ca ions strongly dominated. Their concentrations varied in the range of 23,51 % mvals (PT7) to 67,72 % mvals (PT1), at average value of 47,32 % mvals. Sodium content was in the range of 2,22 % mvals (PT1) to 50,32 in P14 and50,27 % mvals in PT7. Magnesium content in the analysed waters was in the range of 7,72 % mvals (PT5A) to 39,52 % mvals (STV). Potassium content varied from 0,15 % mvals (PT8) to 7,78 % mvals (STVII).

In many observation points boron plays an important role in the chemical composition of the investigated waters. Its content was in the range of 0% mvals (STIX, STV, PT1) to 42,25 (PT8). Analysis has not been presently performed for the destroyed piezometer PT2 in which the highest boron concentrations have been observed in previous sampling campaigns (up to 53% mvals/dm^3). Average boron content in the studied groundwaters (in 13 piezometers, PT2 exclusively) was 8,95 % mvals. Extremely high relative boron contents exceeding % 17 mvals were stated in 3 observation points (PT8, STIII and PT5A).).

Taking into account the modified hydrochemical classification of Szczukariev-Prikłoński, it should be stated that the analysed waters belong to highly diversified waters: from three-ionic (HCO_3–Ca-Mg in STV) to six-ionic (e.g.: Cl-HCO_3-SO_4-Ca-Na-Mg in STVII). In the total of 13 analysed points as many as 11 various water types were identified what proves a very high variability of mutual proportions of main components (Table 5).

Waters which can be recognised as natural in the discussed area i.e. HCO_3-Ca-Mg type were identified only in STV. Waters of slight anthropogenic transformation i.e. of HCO_3-SO_4-Ca-Mg type were identified in two points (PT1 and STIX). Waters in other observation points should be recognised as highly anthropogenicaly transformed. Due to the already mentioned high boron content, this ion occurred in amounts exceeding 17% mvals in three points, deciding about the hydrochemical type of water (PT5A, PT8 and STIII). Similarly as in the case of Quaternary aquifer waters, it should be underlined that the original classification of Szczukariev -Prikłoński took into account only 6 basic ions and referred only to natural waters.

The most anthropogenically-transformed waters in the area of the Chemical Plant were observed in PT7. Beside the highest mineralization and electrolytic conductivity, the water in this piezometer contained also the maximum concentrations of Cl, NH_4, Zn, Cd, Mn, Cu, Ni, Sr, Fe, Na, K, as well as was characterised by the highest oxidizability and the lowest pH (5,95). Also waters in PT6 were recognised as highly contaminated (maximum concentrations of sulphates, nitrates, very high mineralization of 4000 mg/dm^3 and chlorides content -1127

mg/dm^3, sodium content – 689,7 mg/dm^3, magnesium content - 106,1 mg/dm^3 and strontium - 3,5 mg/dm^3), and waters of PT6A (maximum concentrations of calcium, very high mineralization – 3740 mg/dm^3, chlorides content – 1329 mg/dm^3 and sulphates content – 815 mg/dm^3).

Investigations of the Triassic aquifer waters performed in the area of Tarnowskie Góry town within the framework of the already mentioned realisation of the regional groundwaters monitoring concept for the Tarnowskie Góry Poviat proved significant anthropogenic transformation of these waters.

In the area of the town, the carbonate Triassic waters were generally characterised by mineralization below 1,0 g/dm^3. Sulphates content in the analysed waters was in the range of 44,1 mg/dm^3 (INSPOL-STAL well) to 195 mg/dm^3 (in a leak from a gallery at the Museum Mine), chlorides content varied in the range of 10,6 mg/dm^3 (in PWiK well S3) to 142 mg/dm^3 (in the FASER plant well). Locally, elevated contents of the following indicators were observed in the analysed waters: boron (up to 0,99 mg/dm^3 in piezometer P-14Tm in Puferki), strontium (up to 1,299 mg/dm^3 in PWiK well S3), chromium (up to 0,797 mg/dm^3 in FAZOS well), nitrates (up to 56,9 mg/dm^3 in the leakage from a gallery in the Museum Mine and 52,6 mg/dm^3 in PWiK Koehler intake). Presence of trichloroethane and tetrachloroethane should be regarded as a problem. Especially the presence of trichloroethane is a serious problem since it was detected in 6 observation points i.e.: in the wells at FAZOS (36 μg/dm^3), FASER (5 μg/dm3), PWiK Koehler water intake (16 μg/dm^3), GPW Staszic water intake (35 μg/dm3), at "Czarny Pstrąg" galleries (31 μg/dm^3). The highest trichloroethane concentration was observed in the well of the Meat Processing Plant - 841 μg/dm^3. Tetrachloroethene was detected in the well of the Meat Processing Plant and in the GPW Staszic water intake, in the amount of 3 μg/dm^3.

From the viewpoint of the modified hydrochemical classification of Szczukariev-Prikłoński, the investigated waters are characterised by a diversified chemical composition. Among anions, HCO_3 ions dominated in the analysed waters, while among cations calcium ions dominated in all analysed samples. The waters belong to four-, five and six-ionic types. Half of the analysed waters are four-ionic of HCO_3-SO_4-Ca-Mg type, which may be recognised as waters of only slight anthropogenic transformation. The other waters represent types of

waters strongly transformed: HCO_3-Cl-SO_4-Ca-Mg-Na, HCO_3-Cl-SO_4-Ca-Na, SO_4-HCO_3-Cl-Ca-Mg, HCO_3-SO_4-Ca-Na and HCO_3-SO_4- Cl-Ca.

3 QUALITY OF THE GROUNDWATERS

3.1 QUATERNARY AQUIFER

Taking into account the PIOŚ classification it should be stated that the highest purity class Ia and high purity class Ib could not be attributed to any of the waters of the monitoring points located at the Chemical Plant landfills area and investigated during the sampling campaign in May 2002. Waters of medium quality - class II, were identified in 2 piezometers P6 and P20. Waters of low quality - class III were identified in 2 piezometers: P22 and P24A (Table 7).

Waters not categorised to any class were observed in 10 remaining piezometers (PQ1, P5, P9, P23, P24, P25, P26, P27A, P28 and P29).

Low quality class of the analysed waters resulted mainly from elevated boron contents which concentrations exceeded threshold values for class III of water quality in 10 points (except for P6, P9, P20 and P24). The fact that some waters could not be categorised to any class was also attributable to elevated concentrations of such toxic metals as Cd (P5, P9, P23, P24, P25 and P27A), Al (P26, P28 and P29) and Ni (P5). Electrolytic conductivity exceeded the threshold values for III class of water quality in 8 investigated observation points (PQ1, P5, P22, P23, P24A, P26, P27A and P29), manganese content – in 3 points (PQ1, P27A and P28), strontium in 2 points (P22 and P25), sulphates in 2 points (PQ1, P5), ammonium nitrate in 2 points (PQ1 and P27A), and the COD in 2 points (P28 and P26). Also distinctly elevated (i.e. above the threshold value of class III of water quality) contents of barium (P25) and zinc (P27A) were recognised.

Additionally, taking into account the other basic ions determined since second quarter of 2001 (Ca, Mg, Na, K and HCO_3) it should be stated that sodium concentrations exceeded threshold values set up for class III of water quality only in P24A. HCO_3 content determined in 5 piezometers was below the threshold value of class III of water quality (P5, P9, P20, P24 and P29). However, from the viewpoint of the above mentioned 5 ions, only scarcity of HCO_3 influenced the change of the general water quality categorisation. In the case of P20 it would result in changing the categorisation of the studied waters from class II to class III.

Table 7 Groundwater quality classes in region of "Tarnowskie Góry" Chemical Plant landfills

year	1999			1999			2000			2000			2000			2000			2001			2001			2001			2001			2002			2002		
month	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI
Piezometer P9																																				
Piezometer P25																																				
Piezometer P26																																				
Piezometer P28																																				
Piezometer P29																																				
Piezometer PQ1																																				
Piezometer P5																																				
Piezometer P22																																				
Piezometer P23																																				
Piezometer P27A																																				
Piezometer P6																																				
Piezometer P20																																				
Piezometer P24																																				
Piezometer P24A																																				
Piezometer P14																																				
Piezometer PT6																																				
Piezometer PT6A																																				
Piezometer PT7																																				
Piezometer PT8																																				
Piezometer PT2																																				
Piezometer PT5A																																				
Well St III																																				
Piezometer PT1																																				
Piezometer PT3																																				
Piezometer PT4																																				
Well St IX																																				
Well St VII																																				
Well St V																																				

water of high quality - class Ib; water of average quality - class II; water of low quality - class III; water below any standards

Analysing the groundwater quality from the viewpoint of their suitability for drinking and household purposes based on a new Resolution of the Minister of Health of 4 September 2000 and published in the Journal of Laws No 82 (item. 937, appendix 1-3), it should be stated that in each of the analysed observation points at least 2 indicators of the 21 (pH, electrolytic conductivity, oxidizability, COD, NH_4, NO_3, NO_2, magnesium, sodium, chlorides, sulphates arsenic, barium, boron, zinc, aluminium, cadmium, manganese, copper, nickel, lead, iron) mentioned in the resolution have been exceeded.

The following concentrations were exceeded most frequently: manganese – at 11 points except for P23, P24, P25), boron at 11 points except for P6, P9, P24; and cadmium in 6 points : P5, P9, P23, P24, P25 and P27A. Permissible lead concentrations were exceeded in as many as 9 piezometers (PQ1, P5, P6, P20, P22, P25, P27A, P26 and P28). The following exceedances were observed in 5 different piezometers:

- ammonium: PQ1, P27A, P26, P28 and P29
- iron: PQ1, P24A, P26, P28 and P29
- sulphates: PQ1, P5, P24A, P27A and P29.

Additionally, too low pH of waters was recognised in 8 points (P5, P6, P9, P20, P24, P27A, P28 and P29) while too high COD values were observed only in 3 points PQ1, P26 and P28; elevated levels of aluminium in 4 points P6, P26, P28 and P29.

From the viewpoint of the requirements set up for drinking water, the worst quality waters were observed in P27A; their parameters exceeded permissible values of the following indicators: pH, NH_4, boron, zinc, cadmium, manganese, nickel, lead and sulphates. Moreover, exceedances of 8 indicators were identified in the case of waters from 4 piezometers

- in P29: pH, NH_4, boron , aluminium, manganese, iron, sulphates and sodium,
- in P28: pH, COD, NH_4, boron, aluminium, manganese, lead and iron
- in P26: COD, NH_4, boron, aluminium, manganese, lead, iron, and sodium,
- in P5: pH, boron, cadmium, manganese, nickel, lead, sulphates, and magnesium.

Exceedances of 7 indicators were observed in the following points:

- P24A: electrolytic conductivity, boron, manganese, lead, chlorides, sulphates and sodium,
- PQ1: COD, NH_4, boron, manganese, lead, iron and sulphates.

The lowest number of exceeded indicators was observed in P23 (boron and cadmium) and in P24 (pH and cadmium).

Taking into account the EU Directive it can be stated that the investigated waters do not meet many of the requirements set up in this Directive in a number of aspects. Nevertheless, it should be also underlined that EU regulations are not similar with Polish norms. Among 21 indicators considered in Polish standards, only 11 have values similar to those set up in EU standards (pH, oxidizability-COD, NH_4, NO_3, NO_2, boron, magnesium, sulphates, aluminium, manganese, iron). Moreover, 3 investigated indicators (amount of dissolved substances, potassium and calcium) are not subject to any standards in Polish regulations, yet they are set up in the EU recommendations. In the case of several other studied indicators, EU recommendations differ from Polish standards. Polish standards are more liberal for chlorides, sodium, barium and electrolytic conductivity while in the case of arsenic, cadmium, nickel and lead – they are more stringent. The relation between Polish and EU regulations concerning copper and zinc contents is not clear.

Taking into account barium content in the investigated groundwaters its should be stated that from the viewpoint of Polish standards (<0,7 mg/dm^3) exceedances were observed only in one piezometer P25 (48 mg/dm^3); however from the viewpoint of the more stringent EU recommendations (< 0,1 mg/dm^3) barium contents in the amount of > 0,1 mg/dm^3 were observed also in P26 (0,43 mg/dm^3) and in P22 (0,19 mg/dm^3) during the analysed period of time. EU lead content standard (<0,05 mg/dm^3), which is more liberal than the Polish standard, has not been exceeded in any of the analysed 14 points.

Beside the above mentioned indicators set up also in Polish regulations with equivalent permissible values expressed in EU laws, waters in P24A (1960 mg/dm^3), PQ1 (1700 mg/dm^3) and P5 (1560 mg/dm^3) contain excessive amounts of dissolved substances (>1500 mg/dm^3). Calcium concentrations in the analysed waters in: P24A (274,5 mg/dm^3), P5 (248,5 mg/dm^3), PQ1 (230,5 mg/dm^3), P27A (142,3 mg/dm^3), P22 (140,1 mg/dm^3) and P25 (106,4 mg/dm^3) exceed the values recommended by EU (>100 mg/dm^3). According to EU regulations, permissible potassium content in drinking water should not exceed 12 mg/dm^3. Excessive amount of potassium was stated only in P26 (12,12 mg/dm^3).

3.2 TRIASSIC AQUIFER

Quality of groundwaters of the carbonate Triassic formations in the area of the landfill sites at the Chemical Plant is much more diversified than the quality of Quaternary aquifer waters. Generally, these waters are less contaminated, however in some piezometers representing the roof section of the Triassic aquifer and located in the area of the landfill sites (PT6, PT6A, PT7), mineralization of waters along with the contents of chlorides and sulphates was higher than in the case of Quaternary aquifer waters.

When applying the PIOŚ monitoring classification for categorising the analysed groundwaters, it can be stated that no highest purity class Ia waters were identified in any of the 13 piezometers representing Triassic aquifer (without PT2) which were sampled during the sampling campaign performed in May 2002. Waters of high quality class Ib were identified in 3 points (PT1, STV and STIX). Waters in STVII and in PT8 (for the first time since 1999) were categorised as waters of medium quality class II. Before, water in PT8 was assigned class III. Low quality class III waters were stated in 4 observation points (PT3, PT4, PT5A and STIII). Waters in 4 points were determined as waters which cannot be categorised to any of the quality classes (P14, PT6, PT6A and PT7) (Table 7).

Moreover, taking into consideration the additional basic ions which have been determined since the II quarter of 2001 (Ca, Mg, Na, K and HCO_3) it should be stated that the following concentrations above threshold values set up for class II of water quality were determined: sodium (PT6, PT6A, P14 and PT7), calcium (PT6A) and potassium (PT7 and P14). Nevertheless, enclosing these indicators to the PIOŚ monitoring categorisation would not result in re-categorising of waters in any of the 13 investigated piezometers to a lower quality class.

The following indicators usually decided about the low quality of the analysed waters:

- boron, its concentration exceeded water quality class III permissible concentrations in 6 points (PT5A, PT6, P14, STIII, PT7 and PT8),
- electrolytic conductivity – values outside quality classes in 5 points (PT6, PT6A, P14, PT7, PT8),
- dissolved substances - values outside quality classes in 4 points (PT6, PT6A, P14 and PT7),
- chlorides – concentrations outside quality classes in 4 points (PT6, PT6A, P14 and PT7),

- sodium - concentrations outside quality classes in 4 points (PT6, PT6A P14 and PT7),
- strontium - concentrations outside quality classes in 3 points (PT6, P14 and PT7),
- sulphates - concentrations outside quality classes in 3 points (PT6, P6A and PT7),
- cadmium - concentrations outside quality classes in 2 points (P14 and PT7).

Definitively the worst quality waters were identified in piezometer PT7 (14 indices exceeded maximum permissible concentrations of water quality class III). High contamination of waters has also been stated in PT6 (7 indicators exceeded maximum permissible concentrations of water quality class III: electrolytic conductivity, dissolved substances, boron, strontium, SO_4, Cl, Na) and PT6A (6 indicators exceeded maximum permissible concentrations of water quality class III: electrolytic conductivity, dissolved substances, SO_4, Cl, Ca, Na). The quality of waters in P14 is very diversified. At present exceedances of 9 indicators have been observed in P14 (electrolytic conductivity, dissolved substances, barium, boron, cadmium, strontium, chlorides, potassium and sodium) while in early 2000 (February) exceedances of only 4 indicators were noted in this monitoring point (electrolytic conductivity, boron, aluminium and cadmium).

Points with waters of the highest level of contamination are located in the area of the landfill sites and represent the roof section of the Muschelkalk aquifer (PT6, PT6A, PT7).

Waters of low quality were also identified in monitoring points located in a direct vicinity of the landfill sites in the zone of water outflow from the area (PT5A and PT8) as well as in STIII well, which is also located in the vicinity of the landfill sites and it represents the roof section of the Muschelkalk aquifer. In all these three points elevated levels of boron content are still observed. They exceed permissible concentrations for water quality class III, however in PT8 some improvement in water quality can be observed.

Waters of the best quality are observed in STIX. This well represents Roet aquifer and is located in the zone of water inflow to the are of the landfill sites. Also in STV which is situated in the water outflow zone, the quality of waters is good.

High quality waters were also observed in PT1, which represents the roof section of Muschelkalk aquifer. Despite the fact that this point is located relatively close to the landfill sites, no negative changes in water quality have been observed in this piezometer.

Presently, waters analysed from the STVII well which intakes waters from Roet aquifer and which is situated in the zone of water inflow to the landfill sites area, have been categorised to class II (medium) of water quality. After sampling campaign launched in 2001, waters from this well were categorised to class Ib.

From the viewpoint of the requirements set up for drinking and household water, the quality of the analysed groundwaters of the Triassic aquifer is not very good. Taking into account the scope of 20 indicators (pH, electrolytic conductivity, oxodizability COD, NH_4, NO_3, chlorides, sulphates, arsenic, barium, boron, zinc, aluminium, cadmium magnesium, manganese, copper, nickel, lead, sodium, iron) the analysed waters did not meet standards set up for drinking water in any of the 13 investigated points during the analysed quarter of the year. Currently, the following exceedances have been identified: in PT3 lead concentration (0,012 mg/dm^3) and nitrates concentration (53,48 mg/dm^3), in STIX only iron concentration (0,43 mg/dm^3). In PT4 only exceedance of nitrates concentration was noted - 68,48 mg/dm^3 (before 66,98 mg/dm^3), and in STV well – exceedance of lead concentration (0,02 mg/dm^3) and iron concentration (0,24 mg/dm^3). A slightly worse quality of waters was observed in PT1 – exceedance of manganese concentration (0,23 mg/dm^3), iron concentration (0,26 mg/dm^3) and lead concentration (0,023 mg/dm^3). In PT8 exceedances of permissible concentrations of boron (40,5 mg/dm^3) and sulphates (315 mg/dm^3) were recorded while in STIII well, beside boron (10,6 mg/dm^3), exceedances of manganese (0,091 mg/dm^3) and iron (1,12 mg/dm^3) concentrations were stated. In other waters (5 piezometers) exceedances of at least 5 indicators were determined.

The following concentrations were exceeded most frequently: manganese (in 8 monitoring points: PT1, PT5A, PT6, PT6A, P14, STIII, STVII and PT7), iron (in 7 points: PT1, PT5A, STIII, STV, STVII, STIX and PT7), boron (in 6 points: PT5A, PT6, P14, STIII, PT7 and PT8) and lead (in 5 points: PT1, PT3, PT5A, PT6 and STV).

Waters of the worst quality were identified in PT7, exceedance of as many as 15 indicators was recorded there: pH, electrolytic conductivity, COD, B, Zn, Cd, Mn, Cu, Ni, NH_4, Fe, Cl, SO_4, Mg and Na. Highly contaminated waters were also observed in PT6 with 10 indicators exceeded: electrolytic conductivity, B, Cd, Mn, Pb, NO_3, Cl, SO_4, Mg, Na). Moreover, significantly contaminated waters occur also in: the following piezometers:

- PT6A – exceedances of 8 indicators: electrolytic conductivity, Cd, Mn, NO_3, Cl, SO_4, Mg, Na,

- P14 – exceedances of 7 indicators: electrolytic conductivity, Ba, B, Cd, Mn, Cl and Na,

Periodical deterioration of water quality has been observed in P14.

Taking into account the EU Directive, it can be stated that the investigated waters still do not meet the standards for drinking water set up therein in a number of aspects. Nevertheless, it should be underlined that EU regulations are not similar with Polish norms. Among 20 indicators considered in Polish standards, only 10 have values similar to those set up in EU standards (pH, oxidizability-COD, NH_4, NO_3, boron, magnesium, sulphates, aluminium, manganese, iron). Polish standards are more liberal for chlorides, sodium, barium and electrolytic conductivity while in the case of arsenic, cadmium, nickel and lead – they are more stringent. The relation between Polish and EU regulations concerning copper and zinc contents is not clear.

Taking into account barium content in the analysed groundwaters it can be stated that from the viewpoint of Polish standards (<0,7 mg/dm^3) exceedances of permissible standards were observed only in P14 (2,55 mg/dm^3); while from the viewpoint of EU, more stringent standards (< 0,1 mg/dm^3) exceedances were noted in 6 points: P5A, P14, STIII, STV, STVII and PT7. In the case of lead, from the viewpoint of the more liberal EU standard (<0,05 mg/dm^3) excessive concentrations have not been observed in any of the 13 analysed monitoring points. However, from the viewpoint of the Polish standard (<0,01 mg/dm^3), permissible concentrations have been exceeded in 5 points: PT1, PT3, PT5A, PT6. In the case of cadmium (EU standard <0,005 mg/dm^3) excessive amounts of cadmium were observed only in PT7 and P14 while when applying Polish standard (<0,003 mg/dm^3) permissible cadmium content was observed in 4 points (P14, PT7, PT6 and PT6A).

Beside the above mentioned indicators which permissible values are set in both Polish and EU regulations, indicators which permissible values have not been regulated by Polish law have also been characterised. Waters in 4 points: PT7 (4400 mg/dm^3), PT6 (4000 mg/dm^3), PT6A (3740 mg/dm^3), and P14 (2220 mg/dm^3) contained distinctly elevated permissible content of dissolved substances (EU standard >1500 mg/dm^3). Moreover, waters in P14 (23,38 mg/dm^3) and in PT7 (29,76 mg/dm^3) contain excessive amount of potassium (>12 mg/dm^3). Calcium concentrations in the analysed waters exceeded values set up by EU (>100 mg/dm^3) in 5 points: PT6 (446,9 mg/dm^3, PT6A (557,1 mg/dm^3), P14 (276,6 mg/dm^3), PT7 (390,8 mg/dm^3) and PT8 (164,3 mg/dm^3).

Characteristics of carbonate Triassic aquifer in the area of the town (based on data from studies developed for the needs of the Tarnowskie Góry monitoring concept) was carried out in a limited period of time, evaluating only the range of exceedances of standards set up for drinking water. A decision was made to withdraw from categorising the waters using PIOŚ water quality monitoring classification system due to a diversified scope of determinations in comparison to determinations performed for the needs of the local monitoring.

Taking into account the presently effective standards for drinking water it can be stated that the analysed groundwaters meet the standards only in 1 point i.e. in INSPOL-STAL well. In other points exceedances of 2 or 3 indicators were observed. The following indicators were exceeded most frequently: oxidizability (in 10 points), trichloroethane concentration (in 5 points) bacteriological determinations (in 4 points). Among other indicators, excessive nitrates concentrations (in 2 points) and individual cases of manganese and chromium standards exceedances were observed.

4 CHANGES IN GROUNDWATERS CHEMISTRY

Study of the changes in the chemistry of groundwaters in the area of the Tarnowskie Góry has been developed in two aspects: spatial variability and variability in time.

4.1 SPATIAL VARIABILITY

Studies on spatial variability have been based on an analysis of spatial distribution of selected indicators of the highest importance for the studied area: boron, barium, strontium, sulphates, chlorides and dissolved substances. The analysis was performed for Quaternary and Triassic aquifers. Maps of spatial distribution of the selected indicators have been worked out based on data from the studies carried out in May 2002 by the Central Institute of Mining within the local monitoring of the landfill sites at the Chemical Plant. These data were supplemented with results from the studies performed by the State Geological Institute in June 2002 as part of the realisation of the already mentioned Tarnowskie Góry Poviat regional monitoring concept.

4.1.1 Quaternary aquifer

Based on data from sampling campaign of piezometers representing Quaternary aquifer and located in the area of the Chemical Plant landfill sites carried out in May 2002 (13 monitoring points) maps of spatial variability of the selected contamination indicators (dissolved substances, chlorides, sulphates, boron, barium and strontium) (Fig. 16 - Fig. 32) were created. The maps were generated using kriging method and SURFER software.

Unfortunately, due to a very irregular distribution of the monitoring points (no points in the central and southern part of the area) the generated picture of groundwater quality spatial variability is simplified to a large extend.

A clear impact of the landfill sites is visible when analysing the variability of Quaternary aquifer waters mineralization level. Waters showing the highest contents of dissolved substances have been observed in the southern part of the area, in the vicinity of piezometer PQ1 (Fig. 4). Elevated mineralization level is principally noted in the entire central and southern part of the area (P27A, P23, P26), as well as in the NW section of the area, in the vicinity of piezometer P5. In relation to the picture generated for the previous quarter, a slight shift of the area with water mineralization above 500 mg/dm^3 towards NW.direction can be observed.

Analysing distribution of chlorides in the investigated groundwaters it can be stated that chlorides level is clearly elevated in the SW section of the area (PQ-1 and P29) (Fig. 5) and in the central part, close to P27A. Comparing the spatial distribution of this indicator to the situation from the previous quarter (February 2002) changes can be observed in the spread of the area with a potential occurrence of waters with chlorides level above 100 mg/dm^3 and its further extension in the P27A area (central section). This fact can be attributed to the increase of chlorides content both in P27A and in P25. A drop in the chlorides content in waters was observed only in P26 area. Similarly to the situation with dissolved substances, a limitation of the area with potential occurrence of waters with chlorides content above 50 mg/dm^3 has been observed in the SE section of the area along with its slight shift towards NW. A decrease in chlorides content in P25 and P22 has been inhabited.

There are three distinct centres of elevated sulphates content visible in the spatial distribution of this contamination indicator P5 area in NE section, P27A in the central section and PQ-1, P29, P23 area in the southern section (Fig. 6). Compared to the picture generated for previous quarter (February 2002) distribution of sulphates concentration remained similar in general. An increase of sulphates content in all the mentioned areas (P5, P27A and PQ1) is evident. A slight decrease is practically observed only locally in the P26 area (Fig. 6).

Picture of boron spatial distribution differs from the pictures generated for barium and strontium (Fig. 7-Fig. 8). Boron is a very mobile contaminant, which easily migrates in the groundwater environment. The highest concentrations of boron were identified in the NE section of the area close to P5 as well as in the SW section (PQ1 and P29). These piezometers are located in a direct vicinity of the landfill sites, on the direction of groundwater flow. Waste deposited in the landfills must have contained high amounts of boron. Practically, high boron content, exceeding permissible standards occurs in all waters of the Quaternary aquifer. Compared to February 2002 data, spatial distribution of boron content in the analysed waters based on data from May 2002 sampling campaign shows an increase of boron concentrations both in NE section (P5 area) and in SW section (PQ1 and P29). A shift of the area of potential occurrence of waters with excessive boron concentration (>1 mg/dm^3) towards NW has been observed.

Spatial distribution of barium and strontium content is determined by extremely high concentrations observed in P25 (Fig. 8 and Fig. 18). Compared to the spatial distribution data of February 2002 it seems that barium concentrations distribution based on May 2002 data is

practically identical. A slight increase of strontium content was observed in P25 compared to February 2002 data (Fig. 9) The general picture of spatial distribution of strontium concentrations is similar to the up-to-date picture.

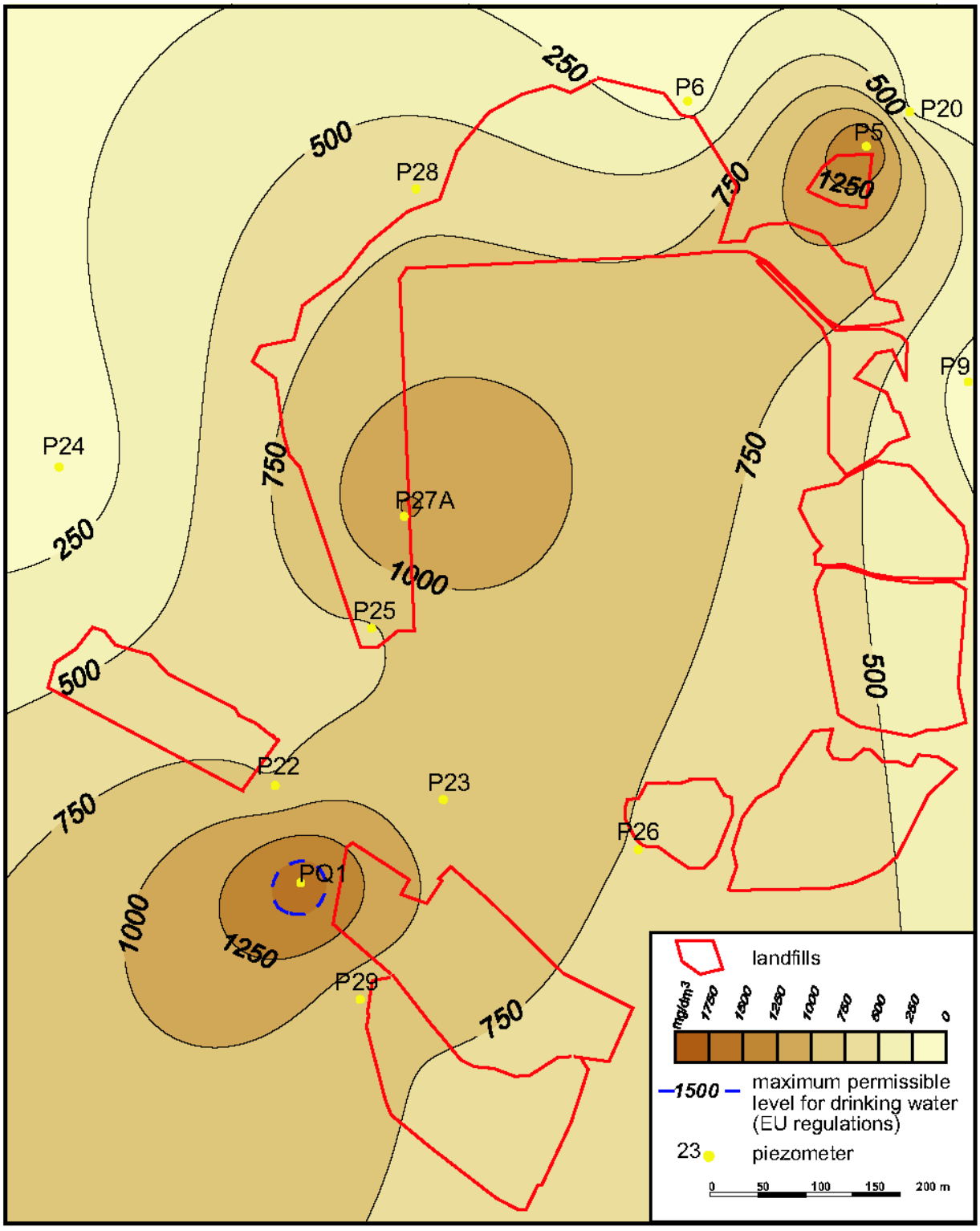


Fig. 4 Dissolved substances in groundwater of Quaternary horizon – state on 05.2002

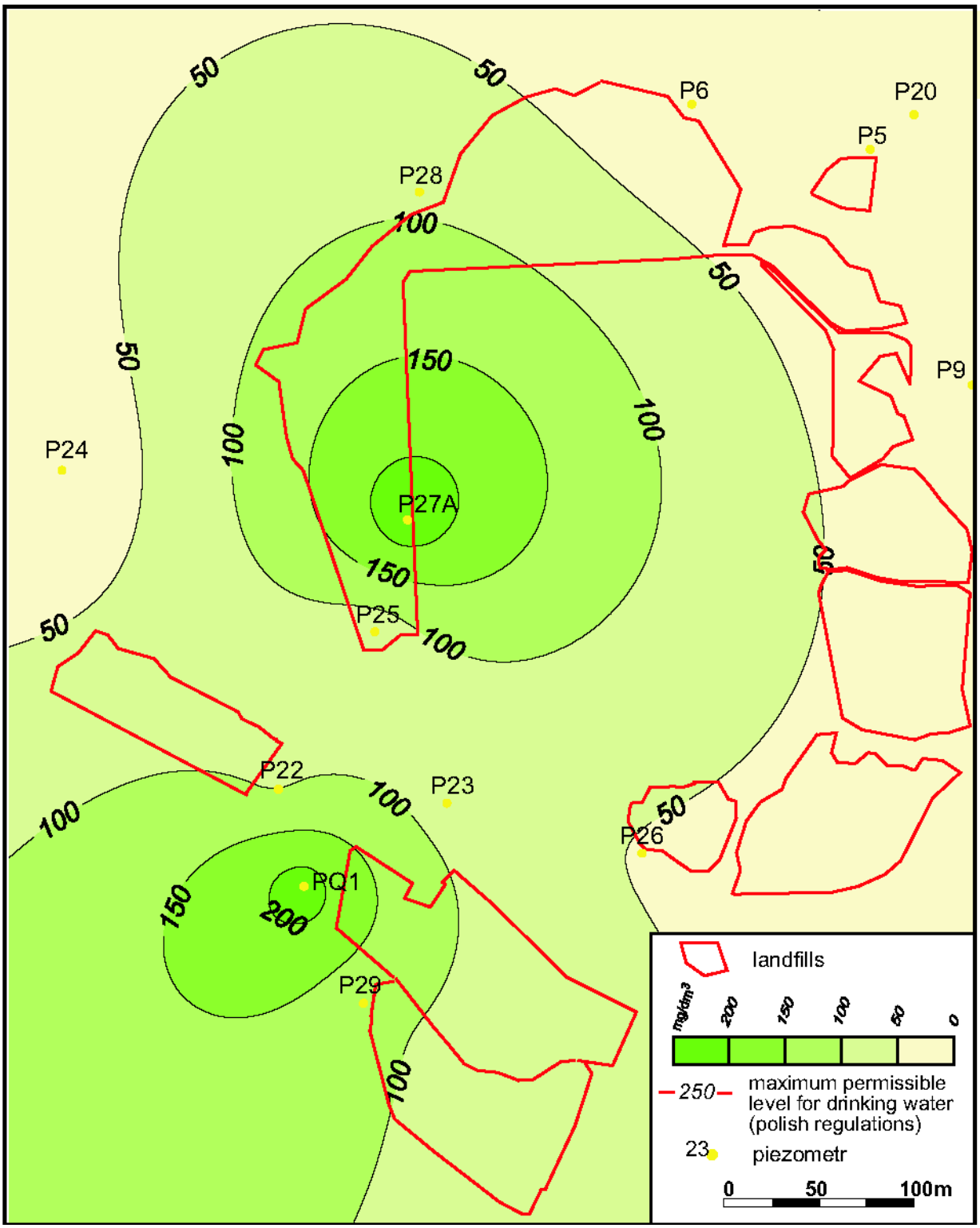


Fig. 5 Chlorides in groundwater of Quaternary horizon – state on 05.2002

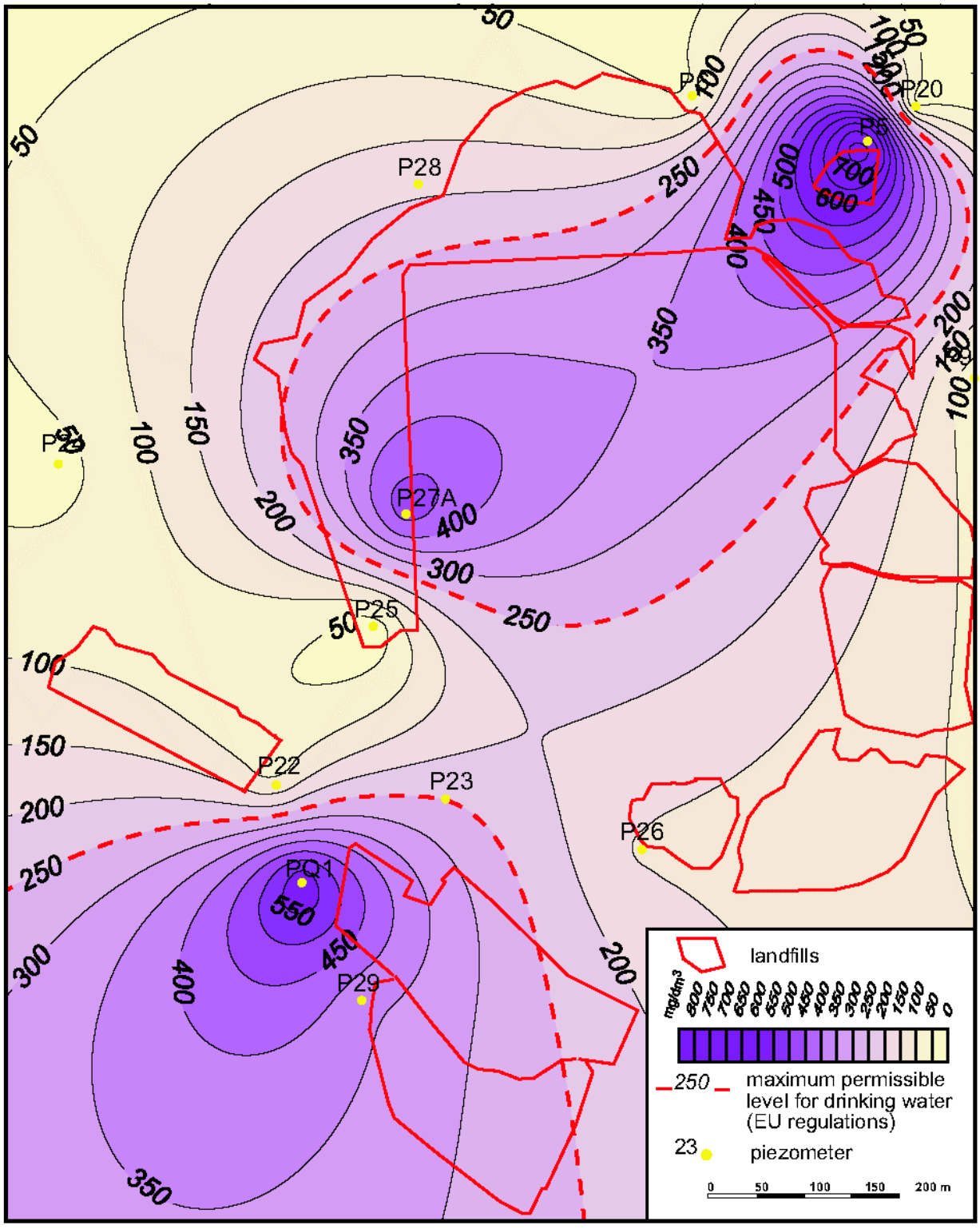


Fig. 6 Sulphates in groundwater of Quaternary horizon – state on 05.2002

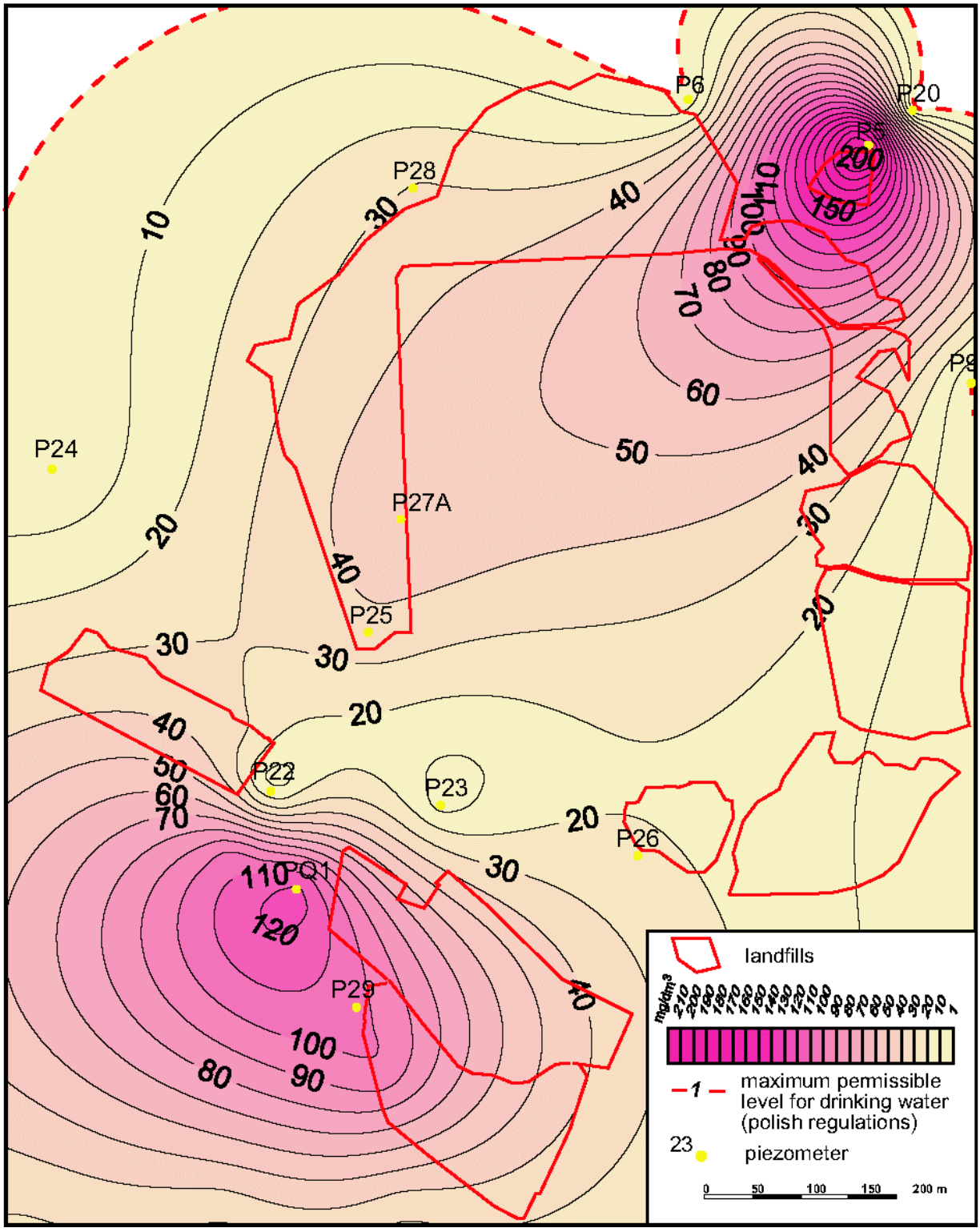


Fig. 7 Boron in groundwater of Quaternary horizon – state on 05.2002

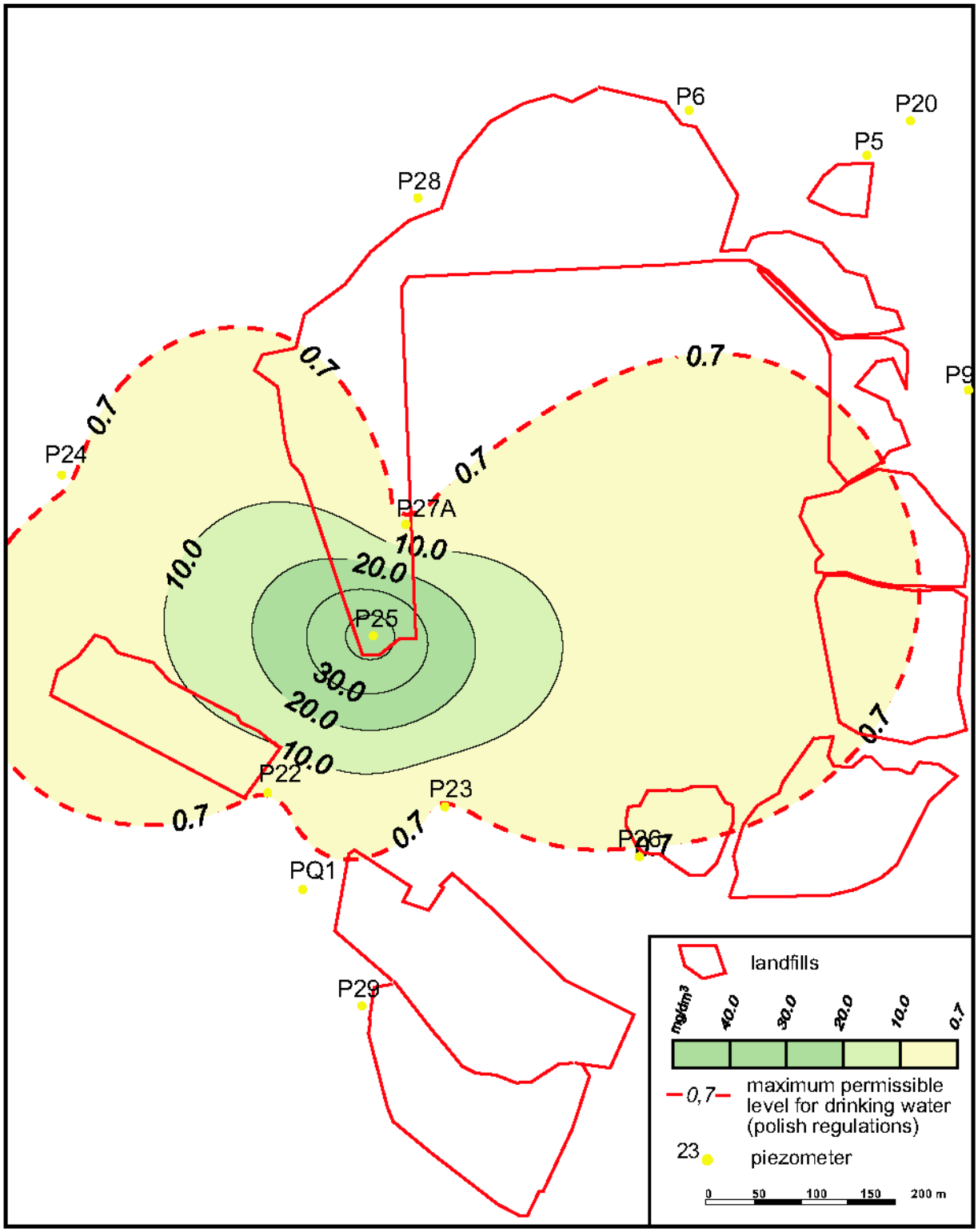


Fig. 8 Barium in groundwater of Quaternary horizon – state on 05.2002

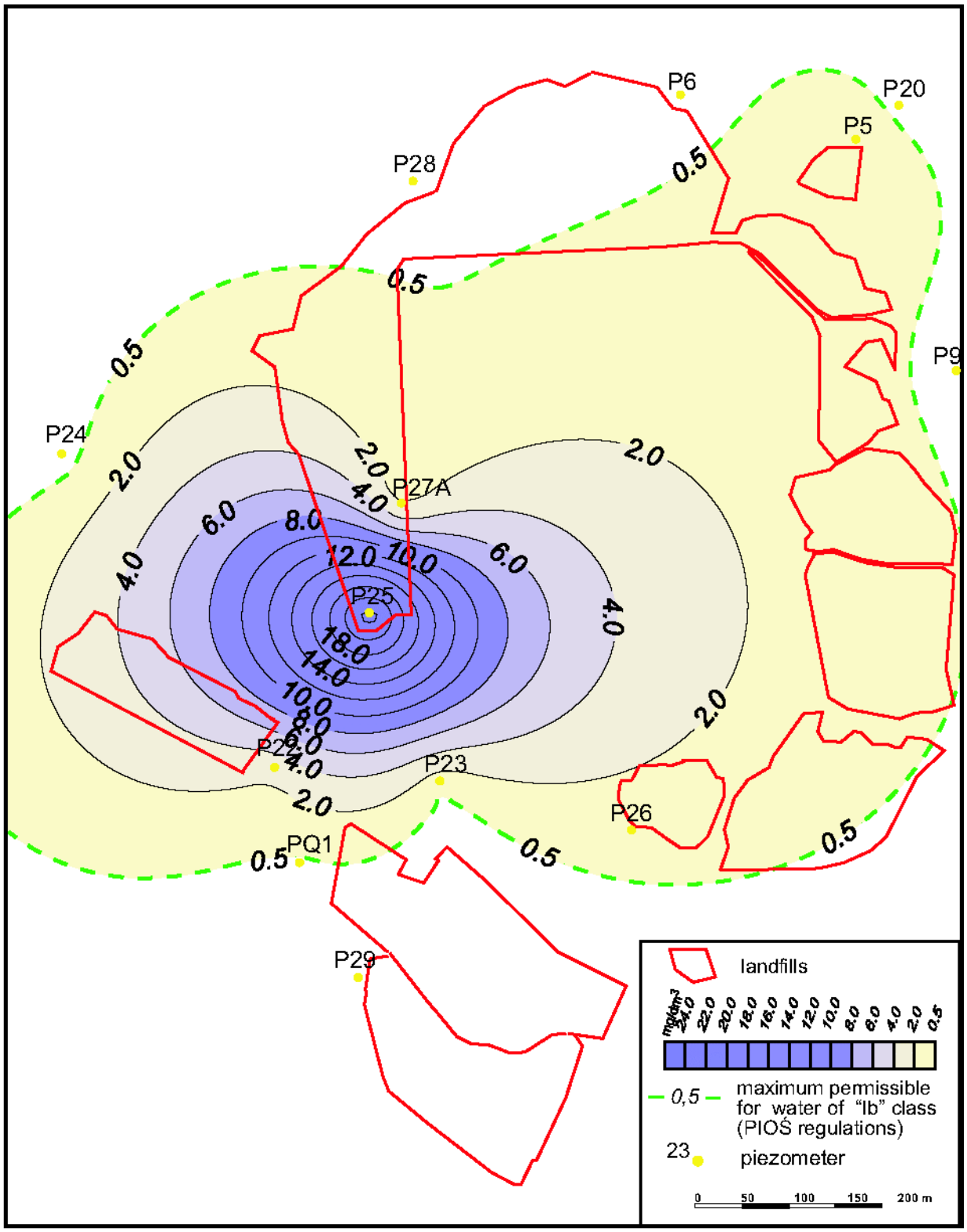


Fig. 9 Strontium in groundwater of Quaternary horizon – state on 05.2002

4.1.2 Triassic aquifer

Maps of spatial variability of six selected contamination indicators dissolved substances, chlorides, sulphates, boron, barium and strontium were generated based on data from sampling campaigns of the Triassic aquifer piezometers performed in the area of the Chemical Plant landfill sites and data from sampling campaigns performed for the needs of the realisation of the Tarnowskie Góry Poviat regional monitoring concept (Fig. 10 - Fig. 15). The sampling campaign was performed in May 2002. Maps were generated using kriging method and SURFER software.

Distribution of dissolved substances concentration i.e. an indicator which reflects a general contamination of waters, shows evident anthropopression in the area of the Chemical Plant landfills. Maximum concentration of dissolved substances in this area is 4,4 g/dm^3 and has been stated in the roof section of carbonate Triassic formations (PT7) (Fig. 10). Elevated contents of dissolved substances have also been recognised in the area of a cumulated impact of the urbanised and industrialised zone of the town; there the concentrations exceed the value of 500 mg/dm^3 reaching even 900 mg/dm^3 in a well close to FASER factory. Elevated contents of 828 mg/dm^3.have been also recorded in FAZOS enterprise area

Distribution of chlorides content in the area of the Tarnowskie Góry town is similar as in the case of dissolved substances. Chlorides serve as an indicator that reacts quickly and directly to the impact of anthropopressure. Thus, the maximum concentrations were determined in the area of the Chemical Pant landfills (1826 mg/dm^3 in PT7 which monitors roof section of carbonate Triassic). Similarly to dissolved substances, chlorides content values higher than 50 mg/dm^3 occur in the area of cumulated anthropopressure and in the FAZOS area (Fig. 11).

Spatial variability of sulphates concentrations proves the above mentioned relations spatial distributions identified for dissolved substances and chlorides. Maximum sulphates concentrations (1070 mg/dm^3 in PT6 which monitors roof section of carbonate Triassic) occur within the zone of a direct impact of the Chemical Plant landfills (Fig. 12). Elevated sulphates contents (above 100 mg/dm^3) occur in the zone of concentrated anthropopressure of the FAZOS area.

In the case of boron, barium and strontium i.e. contamination indicators related mainly with the impact zone of the Chemical Plant wastes, a maximum anomaly is observed in the area of the contamination source (Fig. 13, Fig. 14, Fig. 15).

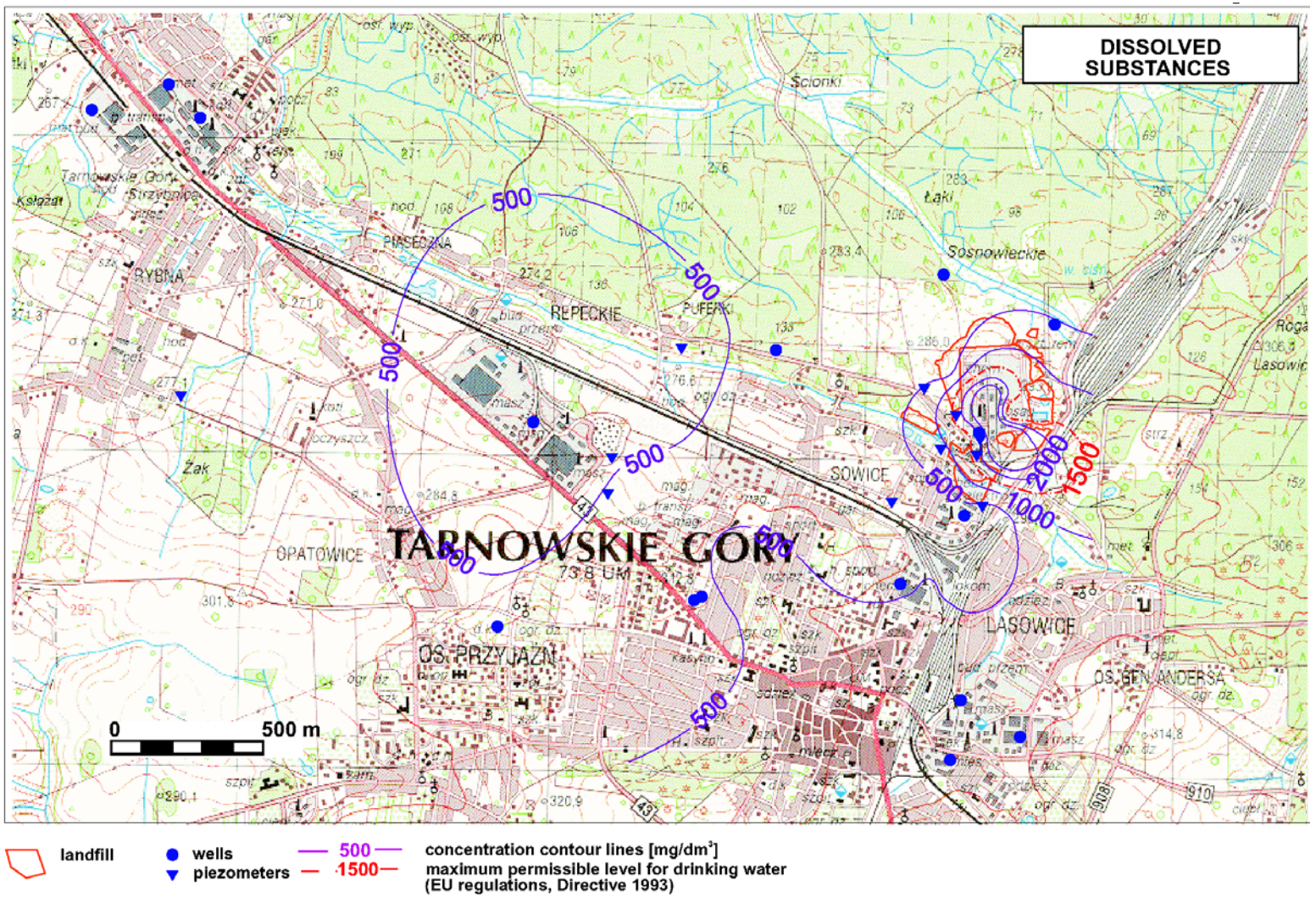


Fig. 10 Dissolved substances in groundwater of Triassic horizon – state on 05.2002

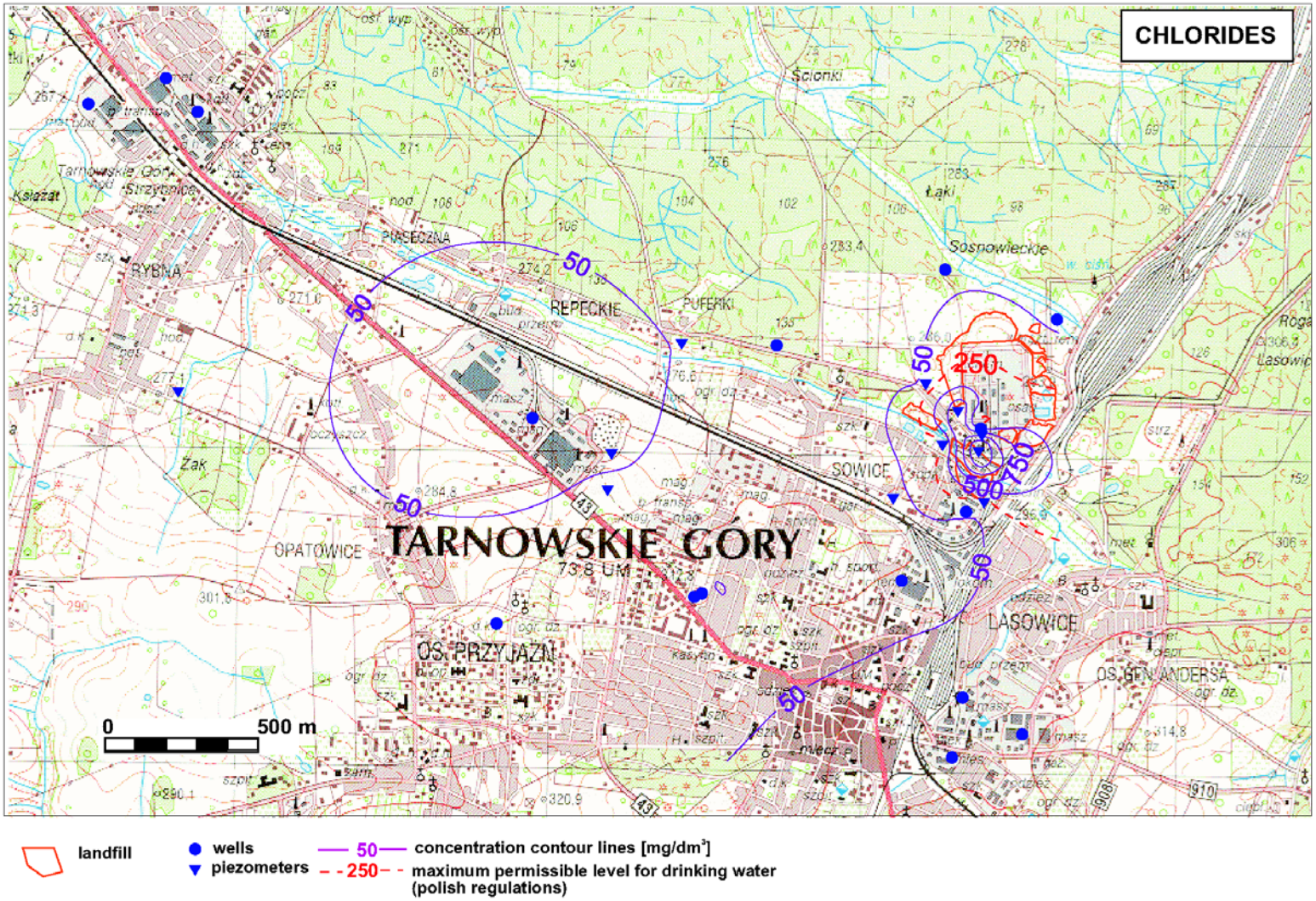


Fig. 11 Chlorides in groundwater of Triassic horizon – state on 05.2002

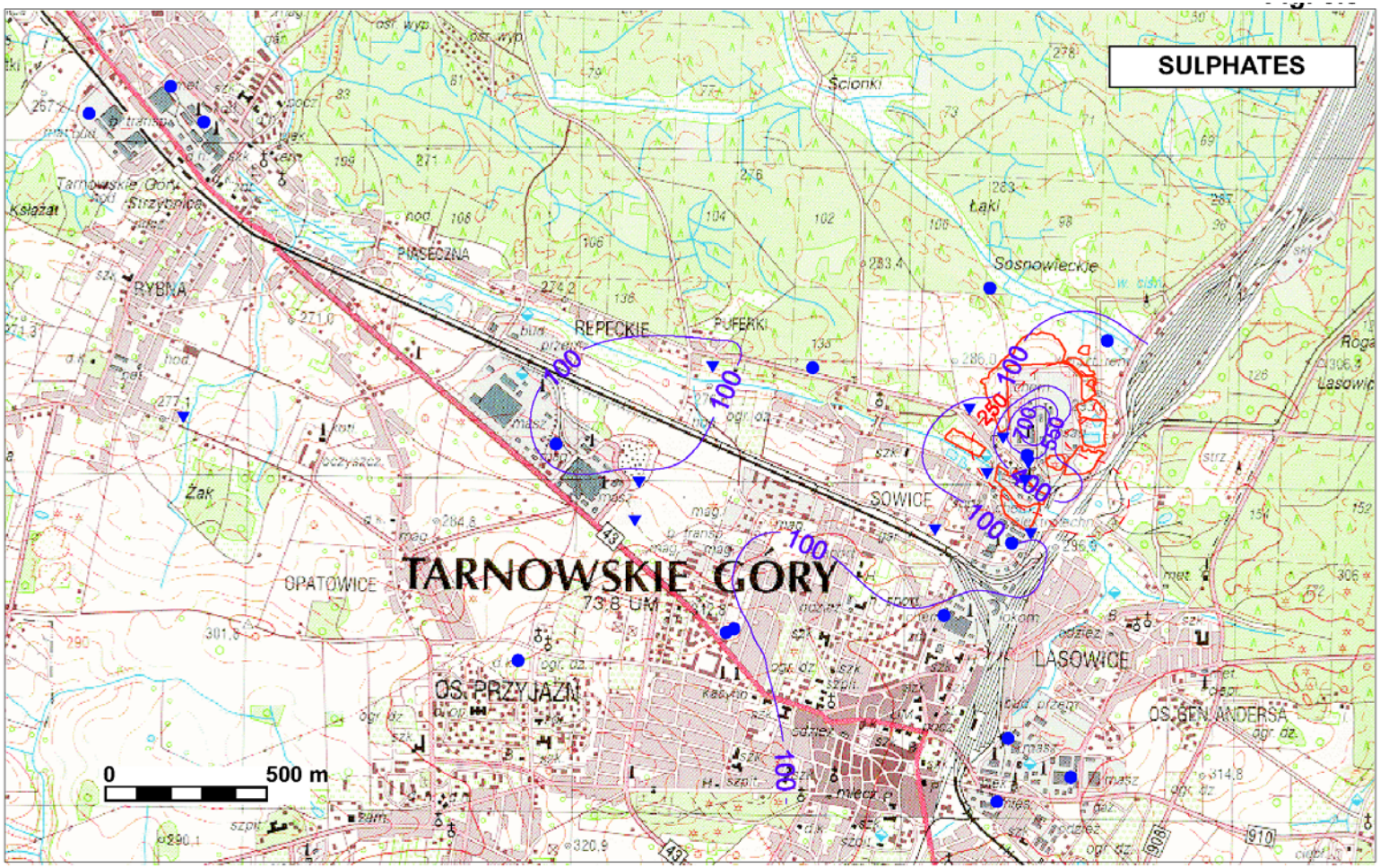


Fig. 12 Sulphates in groundwater of Triassic horizon – state on 05.2002

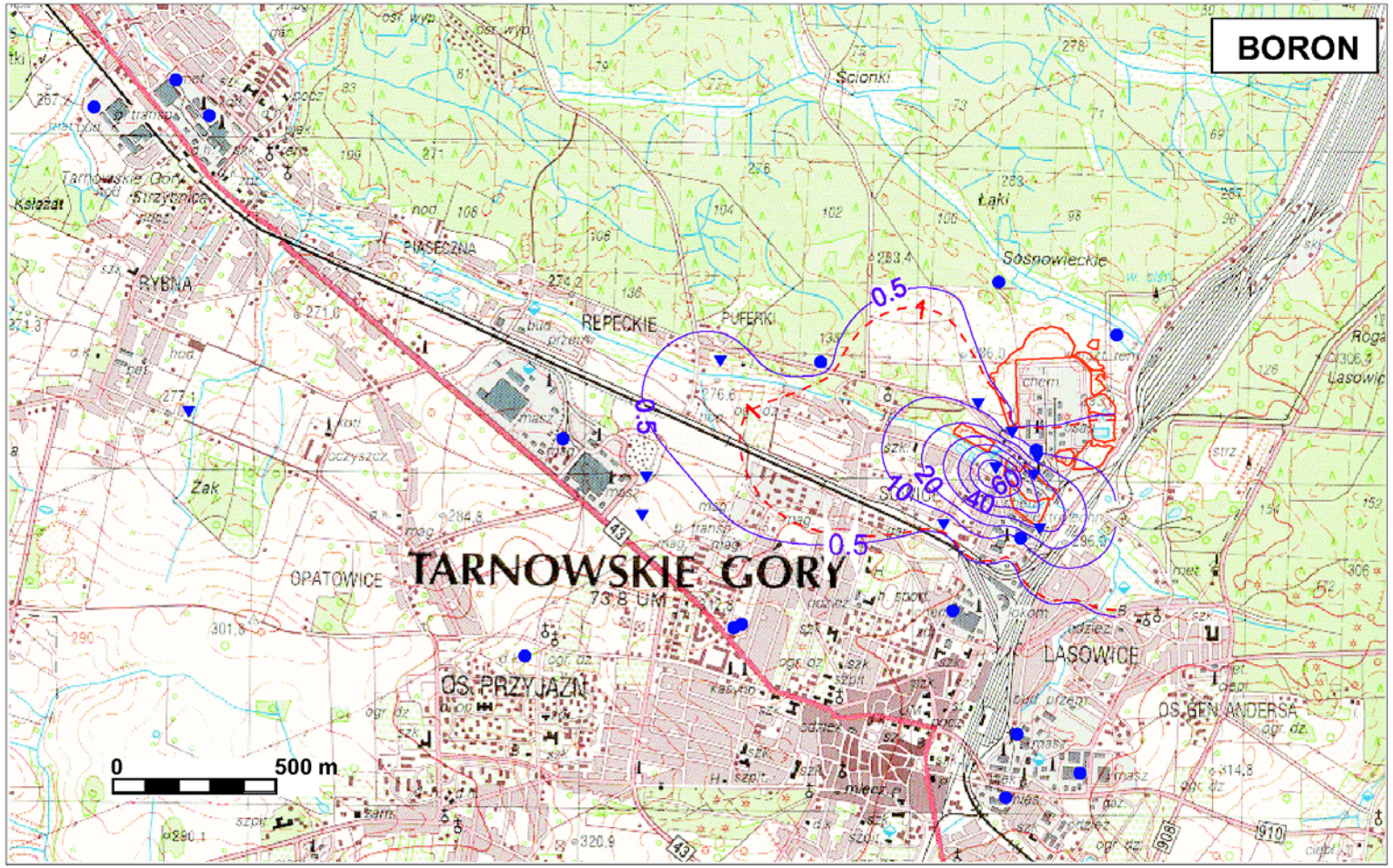


Fig. 13 Boron in groundwater of Triassic horizon - state on 05.2002

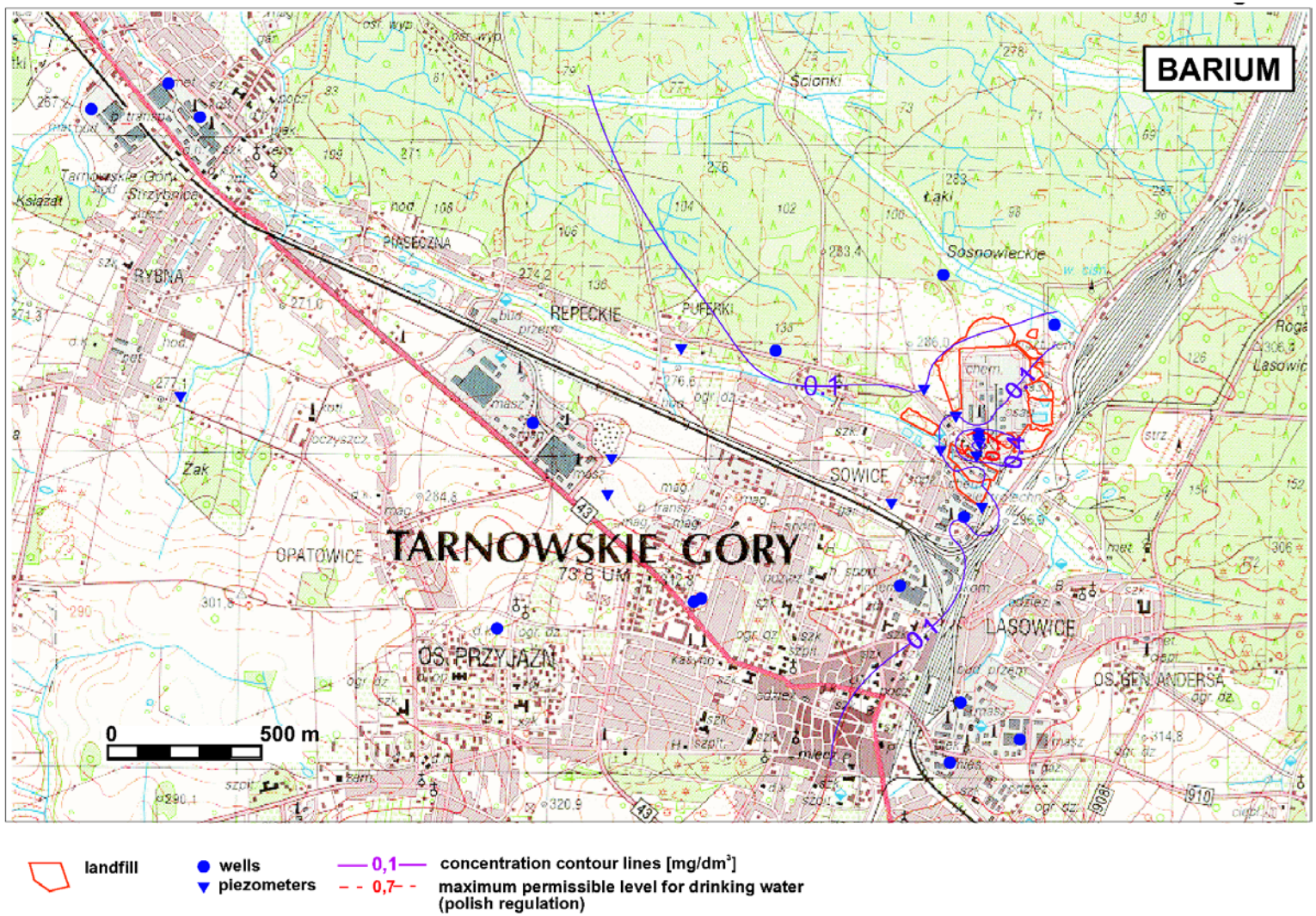


Fig. 14 Barium in groundwater of Triassic horizon - state on 05.2002

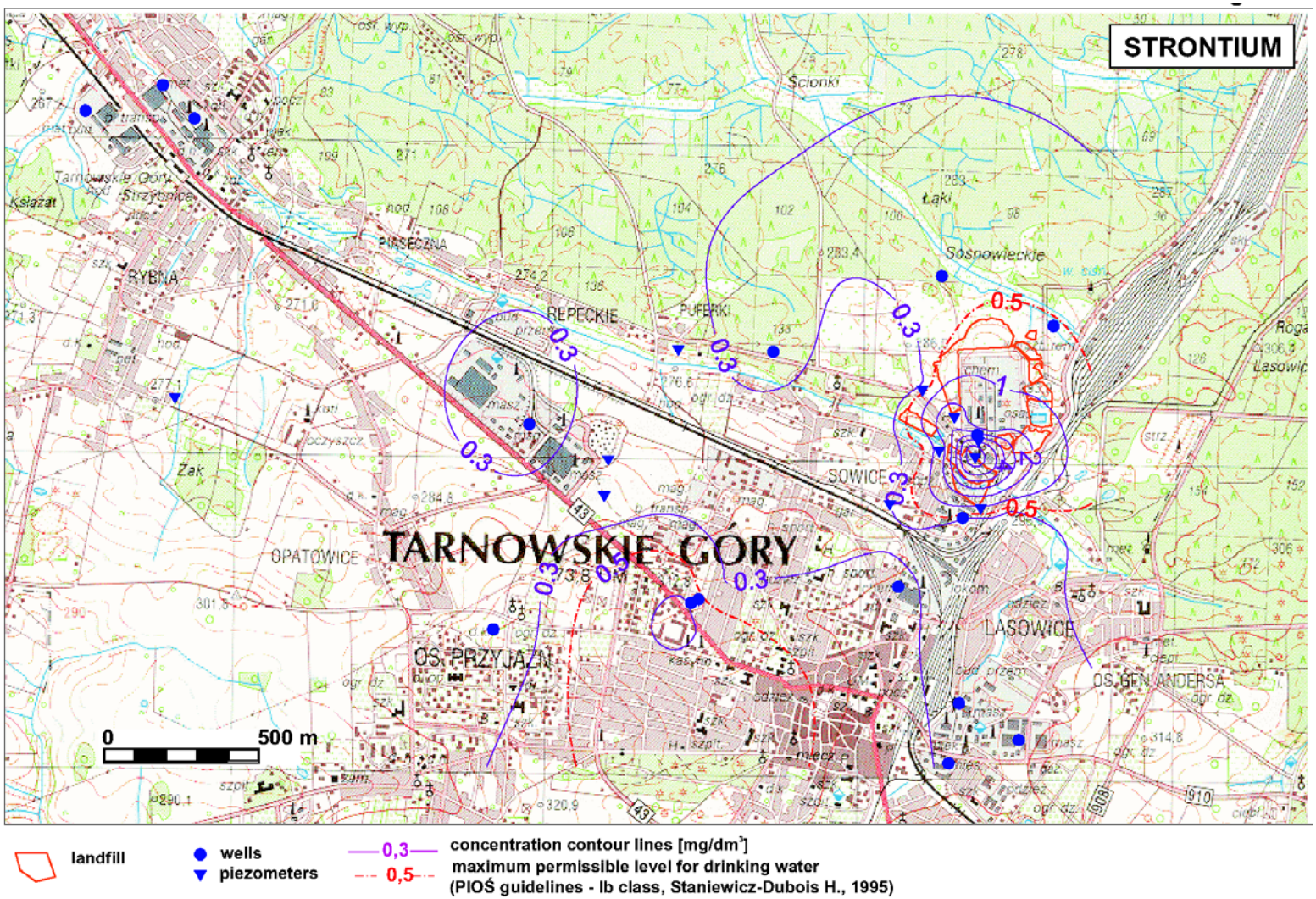


Fig. 15 Strontium in groundwater of Triassic horizon - state on 05.2002

Two migration directions of boron are visible: NWW and SWW. Due to boron mobility in groundwater, the underground plume of contamination is much more extensive than in the case of barium and strontium. In the case of barium, maximum concentration (2,55 mg/dm^3) was identified in the centre of landfills impact (P14). This concentration drops radically at the border of the landfill (below 0,1 mg/dm^3). Picture of the spatial variability of strontium concentrations shows a distinct anomaly in the area of the Chemical Plant landfills (maximum 8,2 mg/dm^3 in PT7). However, it should be noticed that the distribution of this indicator in carbonate Triassic aquifer is of a mosaic character and is related to the natural variability of geogenic origin. Nevertheless, this refers only to a range of concentrations that are much lower than in the landfills area.

4.2 VARIABILITY IN TIME

Study of the time variability has been based on data from analyses performed in July 1999 – May 2002 in the framework of the local monitoring of the Chemical Plant landfills. Trends of changes in individual monitoring points representing Quaternary and Triassic aquifers were studied. This analysis was supplemented by a variability assessment of mean concentrations of individual indicators observed in individual sampling campaigns.

Twenty-seven sampling campaigns were taken into account for the development of the trends of changes of Quaternary aquifer chemistry while for the Triassic aquifer – seventeen campaigns.

4.2.1 Quaternary aquifer

Analysis of the up-to-date data of water quality in Quaternary aquifer allows stating a general relative stabilisation of concentrations of the investigated contamination indicators with a slight tendency to rather positive changes. Unfortunately, the positive tendency of water quality improvement in some monitoring points is inhibited; in individual cases an increase of concentrations of some indicators has even been observed. Decreasing trends have still been observed for the following indicators: dissolved substances (P25, P26, P23, P24, P24A), chlorides (P25, PQ-1, P22, P23, P24, P24A, P29) and sulphates (P23, P24, P24A, P26). Piezometer P5 continues to be a negative example; an increase of sulphates concentrations and recently also concentrations of boron and nitrates have been observed there (Fig. 23).

Increasing trends have been identified practically for individual metals in individual points, e.g.: manganese and cadmium in P5 and 27A. A trend of elevating metal contents (Sr,

Mn, Cd and Ni) recorded in P 27A since the second half of 2001 continues to be observed. (Fig. 26, Fig. 27, Fig. 28). Additionally, seasonal fluctuations of contents of a number of indicators are observed, especially in P5 (B, Sr, SO_4, Ni, Mn) (Fig. 23, Fig. 24, Fig. 25), P9 (dissolved substances, SO_4, NO_3 Mn) (Fig. 16, Fig. 17), P22 (Sr, NO_3, Zn, Fe) (Fig. 23, Fig. 24), P25 (dissolved substances, Cl, B, Ba, NO_3) (Fig. 18, Fig. 19, Fig. 20), P28 (dissolved substances, SO_4, B, Mn) (Fig. 18, Fig. 19, Fig. 20), in P27A and P23 (NO_3) (Fig. 27).

Taking into consideration such area-important indicators as B, Ba and Sr, generally, no clear negative changes of their concentrations have been observed in most of the monitoring points. The originally clear tendency of strontium content drop in P27A has been inhibited and even reversed. An increase in strontium content has been also observed in P22 in 2002. A positive tendency of decreasing boron concentration has been practically observed only in P24A. In other observation points, a relative stabilisation of boron contents in the analysed waters has been noted, with negative exceptions of P25 P28, P5, P27A where an increase of boron concentrations have been recently observed (Fig. 18, Fig. 23, Fig. 26).

Analysis of the significance and character of the observed trends (Table 8) shows that the positive, decreasing trends of high reference ($R^2 > 0,3$) are observed for chlorides, (in 6 piezometers) and for dissolved substances (in 5 piezometers). Generally, decreasing trends dominate; they have been observed for at least one indicator in 13 piezometers, except for P5. The broadest range of positive trends have been recorded for P6 (decreasing trends of 5 indicators: dissolved substances, barium, copper, manganese, sulphates), P29 (decreasing trends of 5 indicators: dissolved substances, aluminium, chlorides, iron, manganese). Increasing trends (Table 8) refer only to individual cases: aluminium in P9, zinc in P26 and manganese and strontium in P5.

Analysing the mean concentration values of an individual indicator for all 14 monitoring points in individual sampling campaigns (27 campaigns), a distinctly positive tendencies (decreasing trends) have been observed for dissolved substances, chlorides and sulphates ($R^2 > 0,75$) throughout the period of the 4 year studies (Fig. 33). Negative increasing tendencies of high variability reference value ($R^2 > 0,3$) can be observed for zinc and copper.

Table 8 Changes trends of selected groundwater contamination factors in period from 07.1999 y. to 05.2002 y. For high correlation of concentration variability with time r2>0,3 (on basis of local Chemical Plant "Tarnowskie Góry" landfills monitoring)

	Piezo-meter	CONTAMINATION FACTORS														
		Diss. subst.	Al	B	Ba	Cd	Cl	Cu	Fe	Mn	NH_4	Ni	NO_3	SO_4	Sr	Zn
Quaternary water-bearing horizons	P9		0,37										0,35			
	P25												0,34			
	P26	0,32					0,3			0,34						0,33
	P28															0,38
	P29	0,51	0,35				0,42		0,34	0,7						
	PQ1						0,84									
	P5									0,83					0,39	
	P22						0,54									
	P23	0,39					0,41							0,48		
	P27A	0,53	0,62								0,8			0,69		
	P6	0,5			0,36			0,29		0,73				0,47		
	P20												0,31	0,33		
	P24					0,32				0,31						0,33
	P24A			0,36			0,37									
Triassic water-bearing horizons	P14															
	PT6	0,55					0,39						0,77	0,81	0,5	0,77
	PT6A	0,35					0,32									0,68
	PT7					0,63		0,78		0,71	0,31	0,71			0,32	0,43
	PT8	0,37		0,91			0,65			0,44			0,85	0,71		
	PT2															
	PT5A															
	St III															
	PT1						0,57		0,55					0,37		
	PT3										0,51					
	PT4						0,56							0,34		
	St IX								0,31							0,42
	St VII	0,36												0,41	0,49	
	St V									0,32						

0,4 Increasing trends, value of correlation coefficient r^2

0,8 Decreasing trends, value of correlation coefficient r^2

Trends determined for the mean concentration values prove a general decrease of the contamination load in the Quaternary aquifer waters. A local improvement of water quality is especially visible in P24 and P24A, situated in the zone of water outflow from the landfills area towards NWW (P6 and P20 area). A relative stabilisation of groundwater chemistry has also been noted in the area of piezometers: P9, PQ1 and P29. Unfortunately, water quality improvement in P27A, P22 and P23 has been visibly inhibited. The last sampling campaign showed an increase of contamination indicators in P27A (Cl, SO_4, B, Sr) and in P22 (Cl, Sr, Zn). Attention needs also an increase of such metal concentrations as Zn, Mn, Cd and Ni in P27A, Mn, Ni and Cd in P5, Zn in P22 observed since end of 2001. Increasing concentrations of boron recorded since May 2001 in P25 and P5 are also negative. Recently an increase of boron content was observed in P27A and P28.

The fact that the present, negative tendencies of increasing concentrations of individual contamination indicators, in that boron and strontium, observed in the investigated Quaternary waters occur only locally in the area of the landfills, mainly in the piezometers representing the roof section of the aquifer is of high importance.

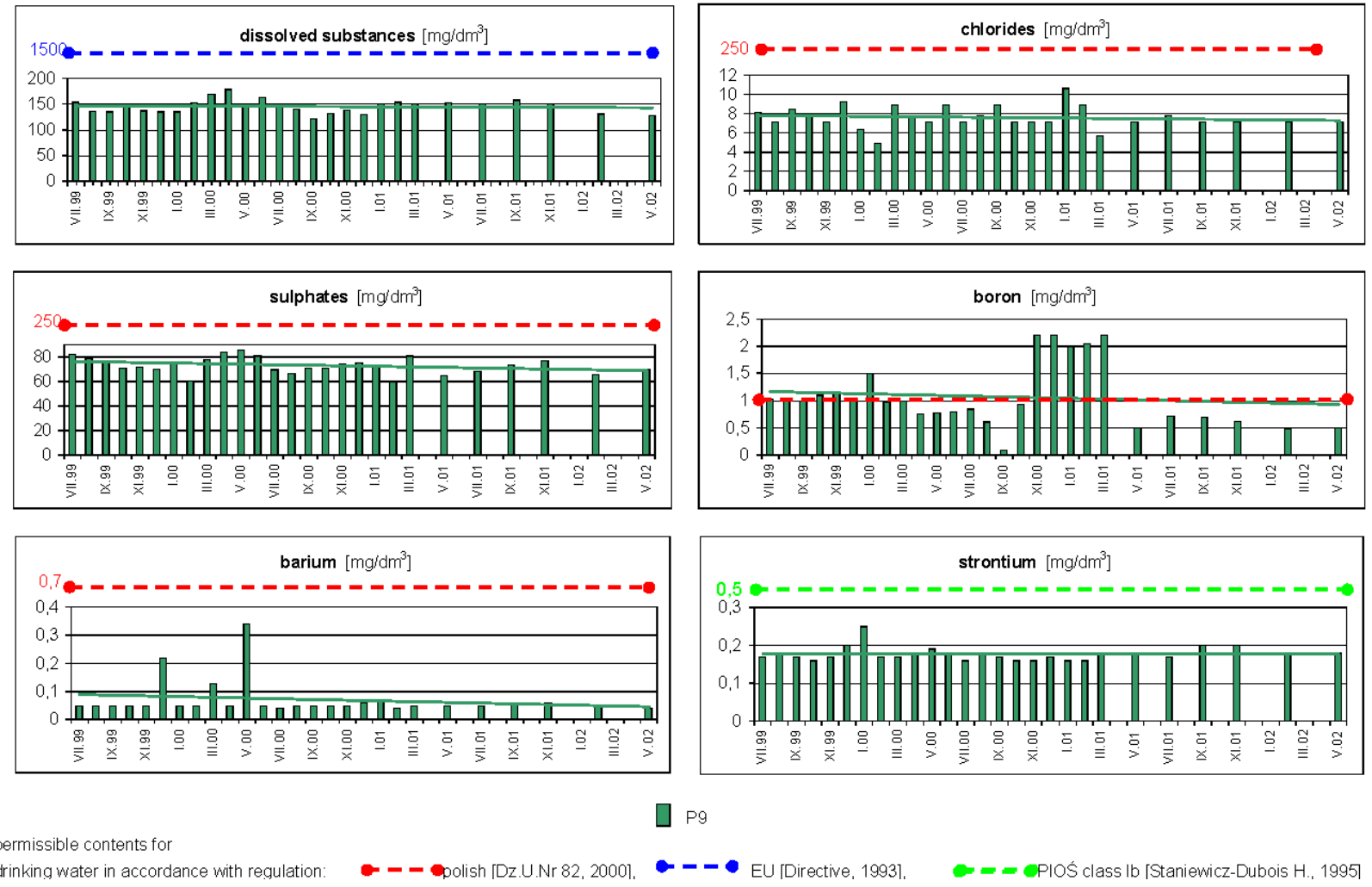


Fig. 16 Piezometer P9

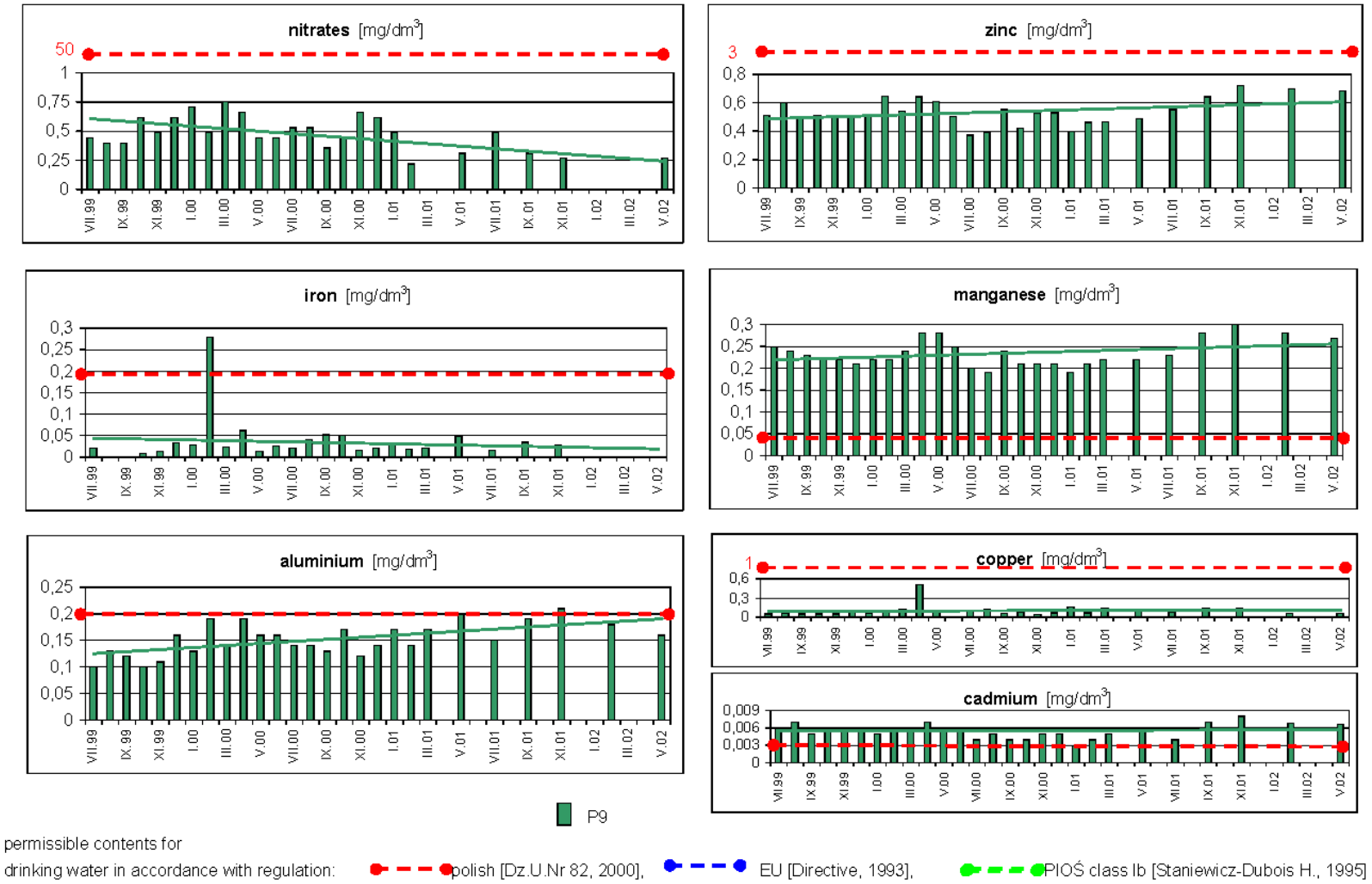


Fig. 17 Piezometer P9

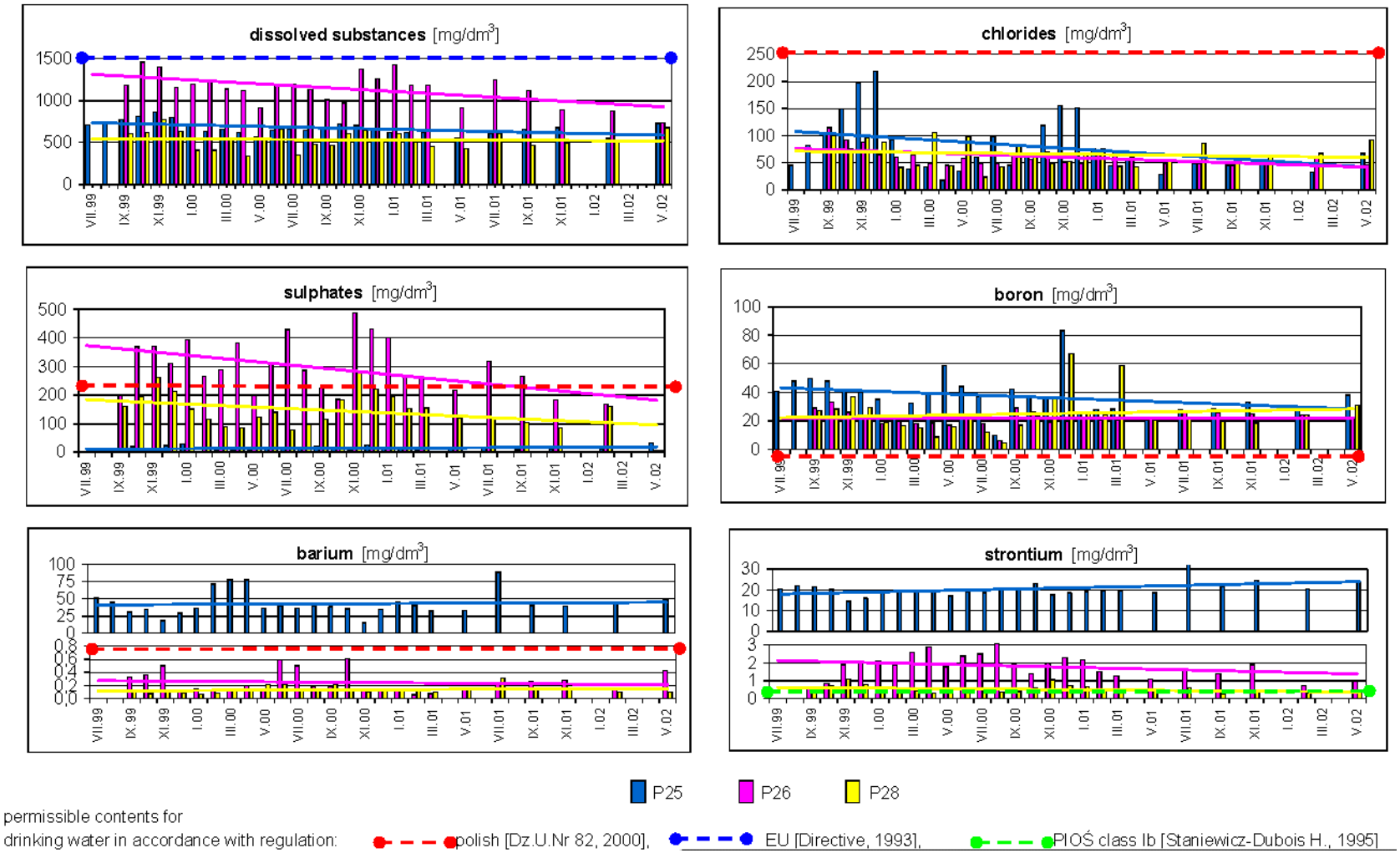


Fig. 18 Piezometers P25, P26, P28

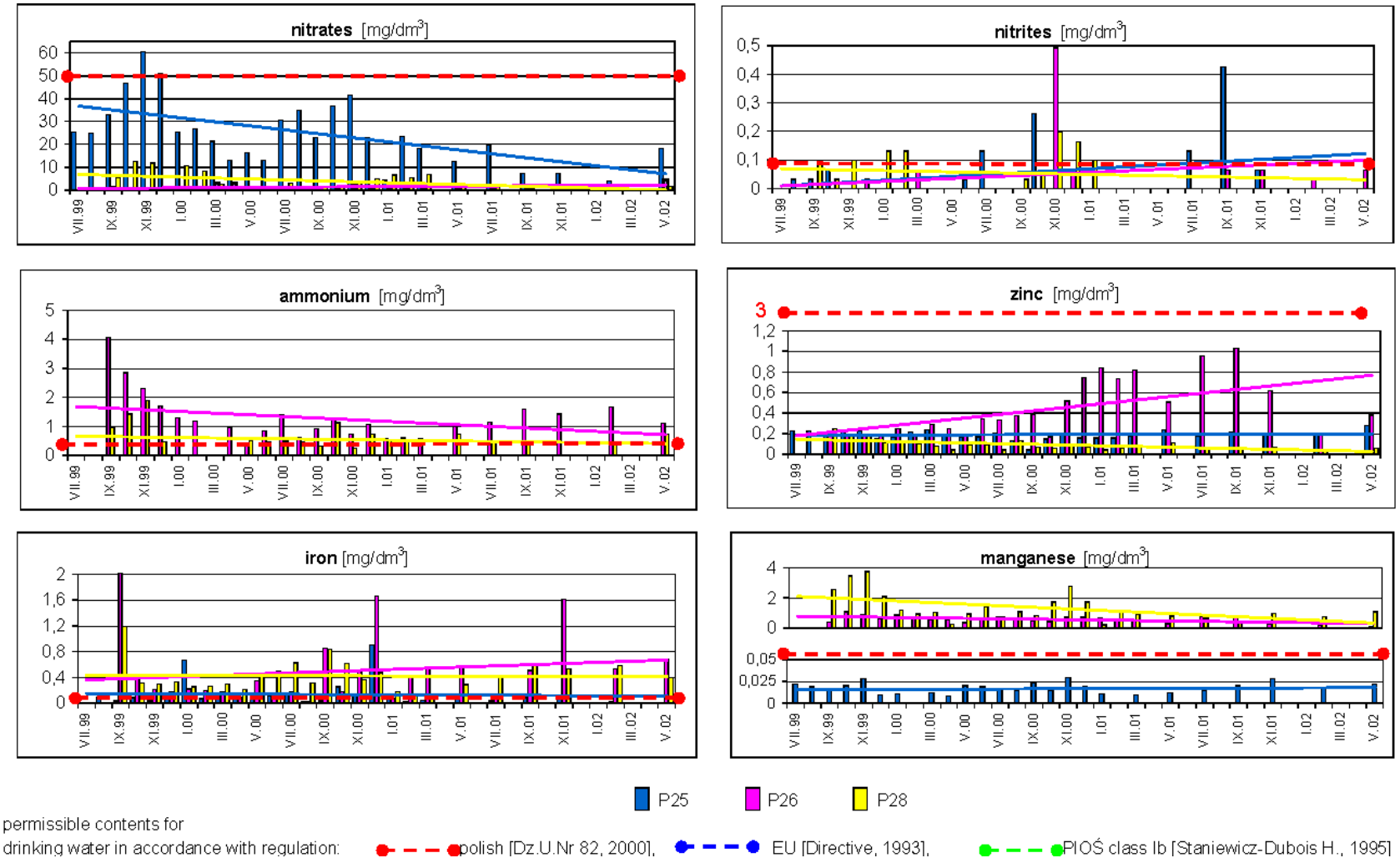


Fig. 19 Piezometers P25, P26, P28

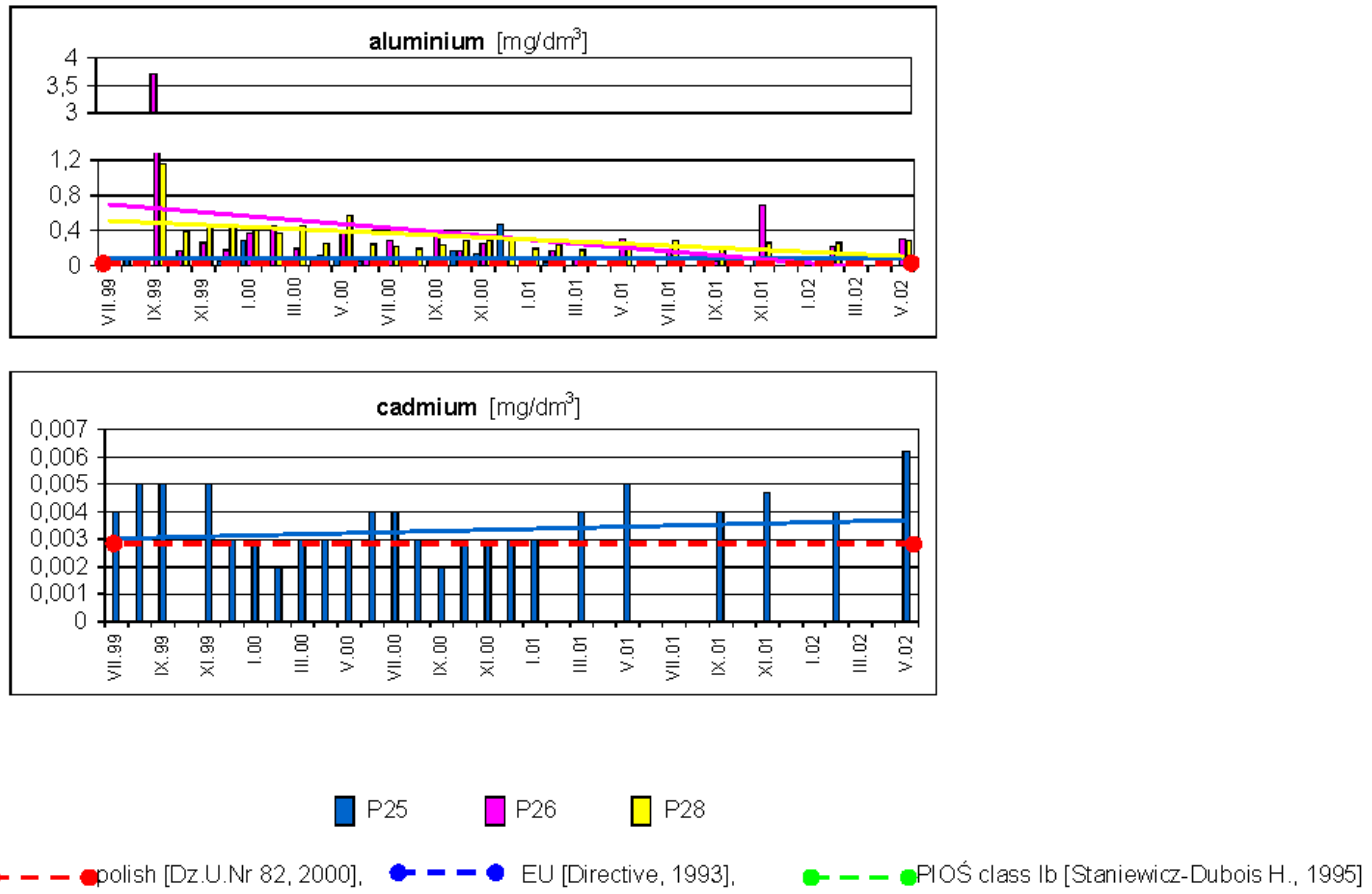


Fig. 20 Piezometers P25, P26, P28

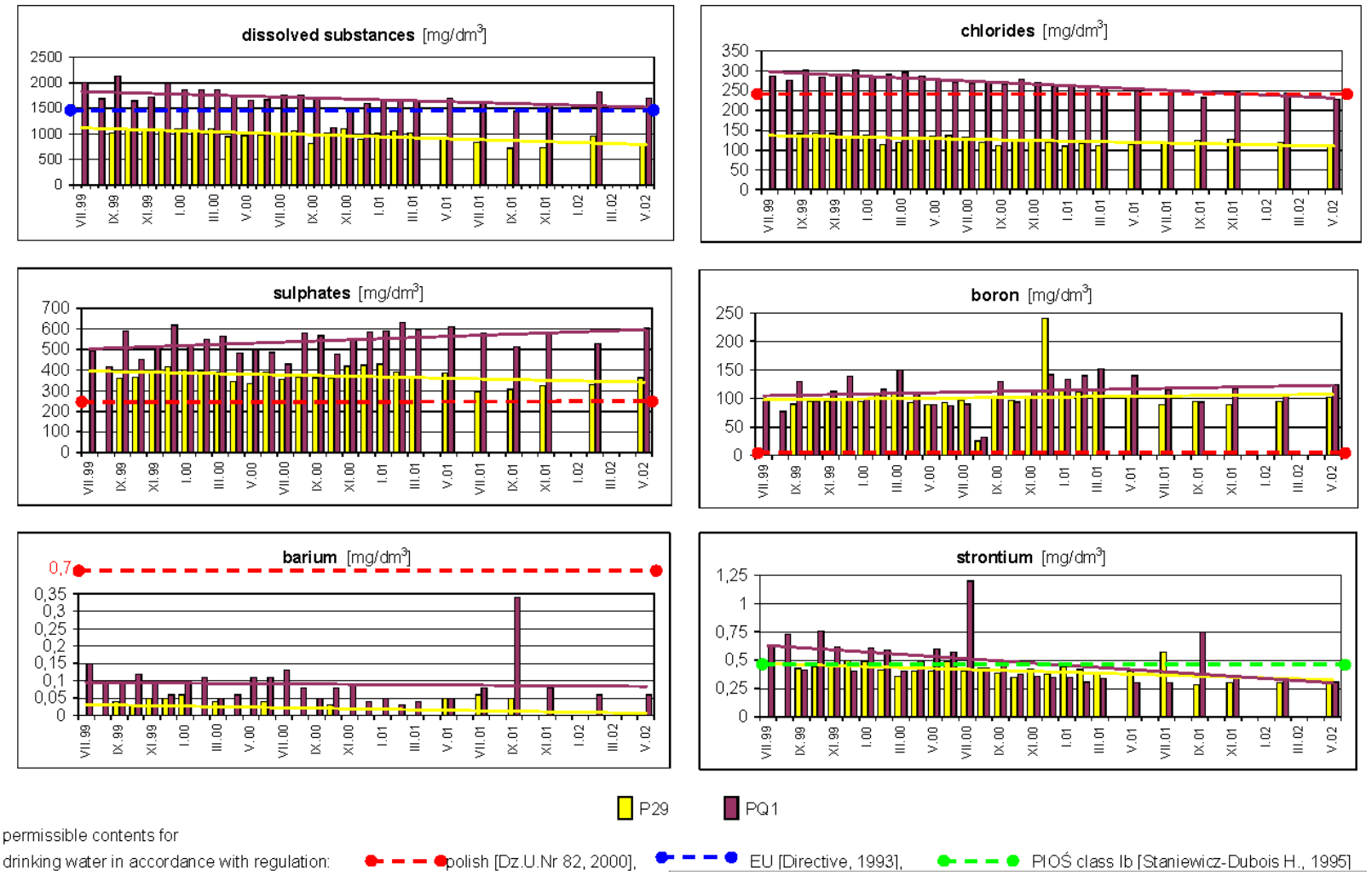


Fig. 21 Piezometers P29, PQ1

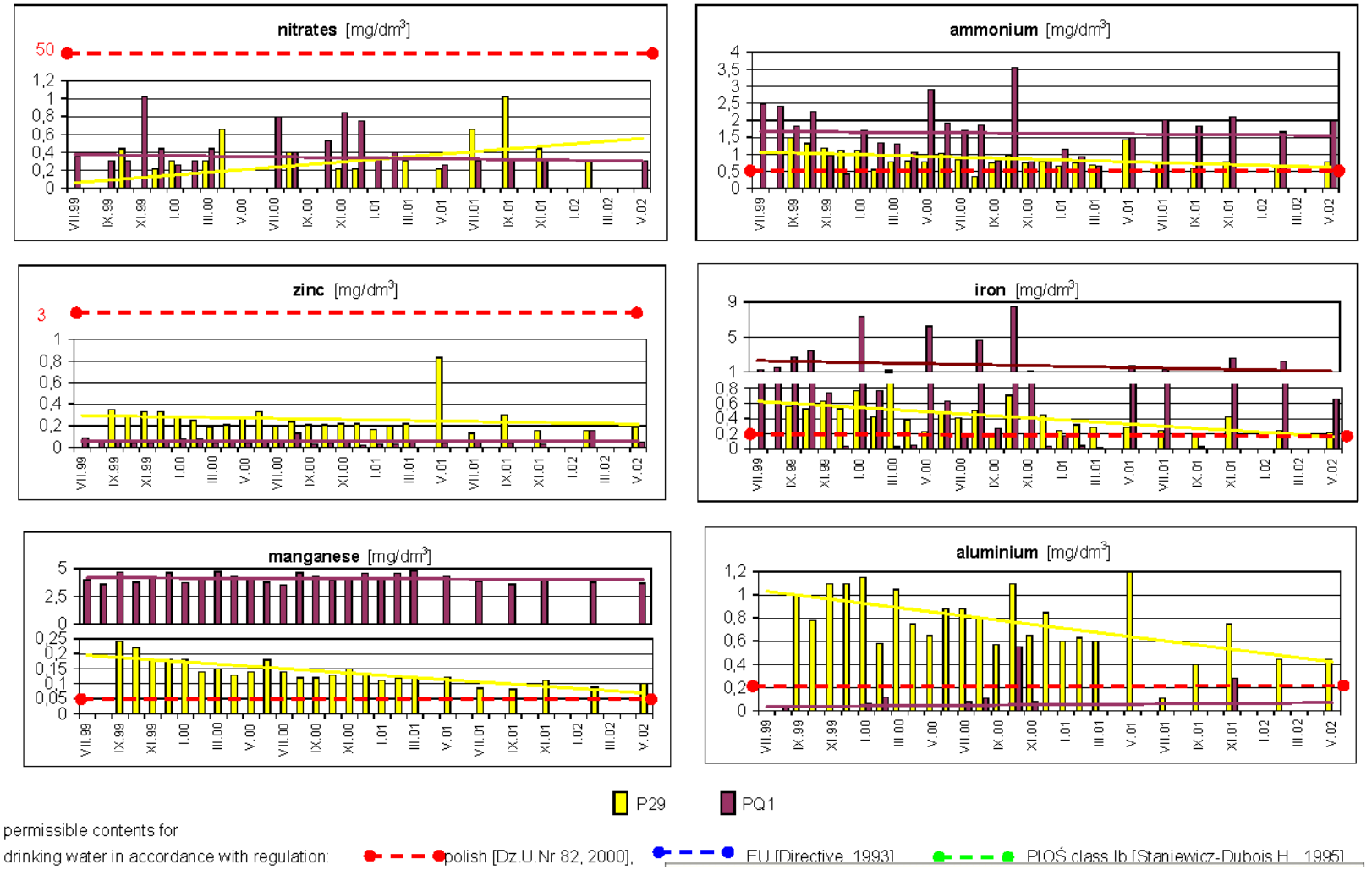


Fig. 22 Piezometers P29, PQ1

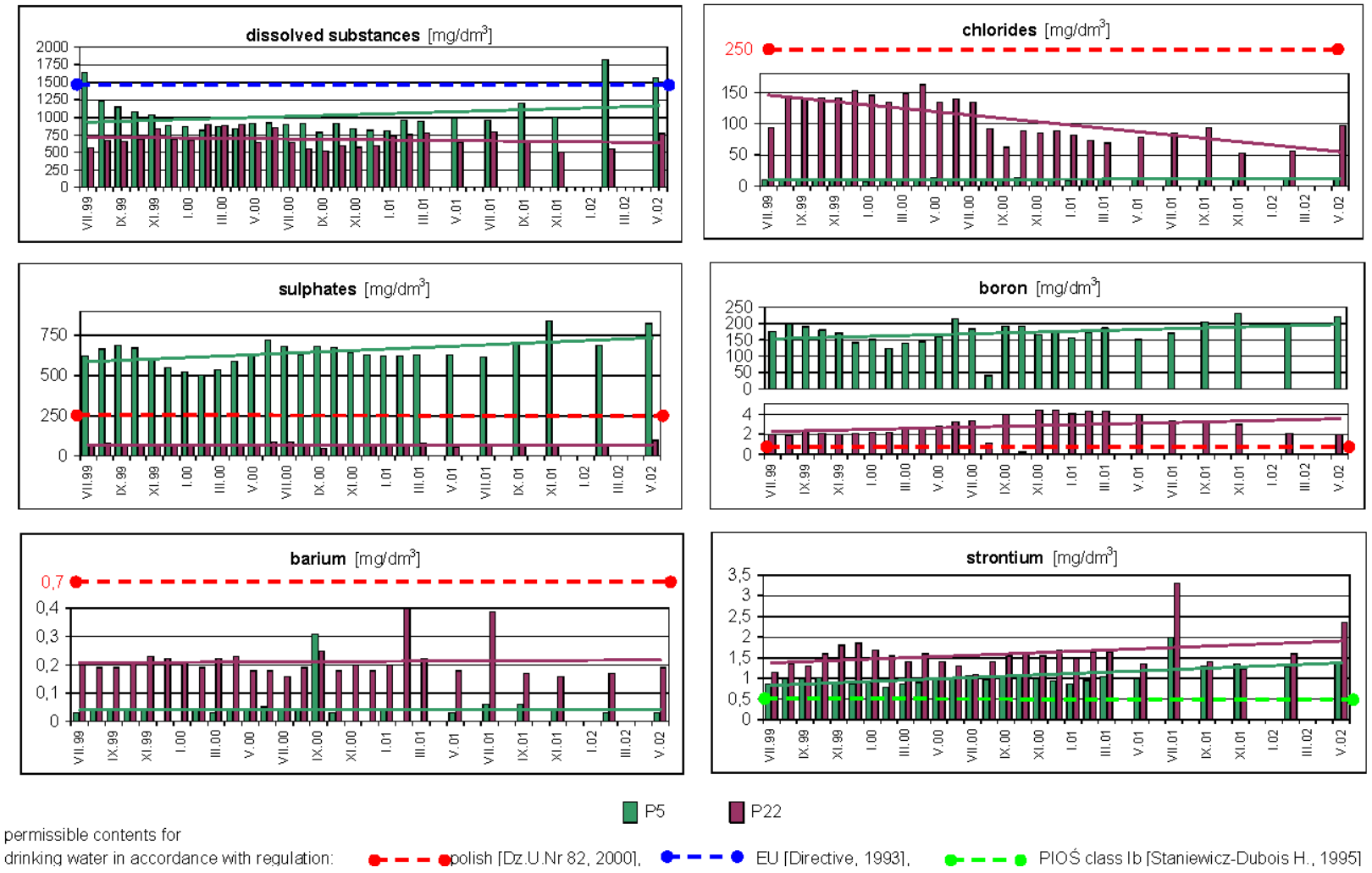


Fig. 23 Piezometers P5, P22

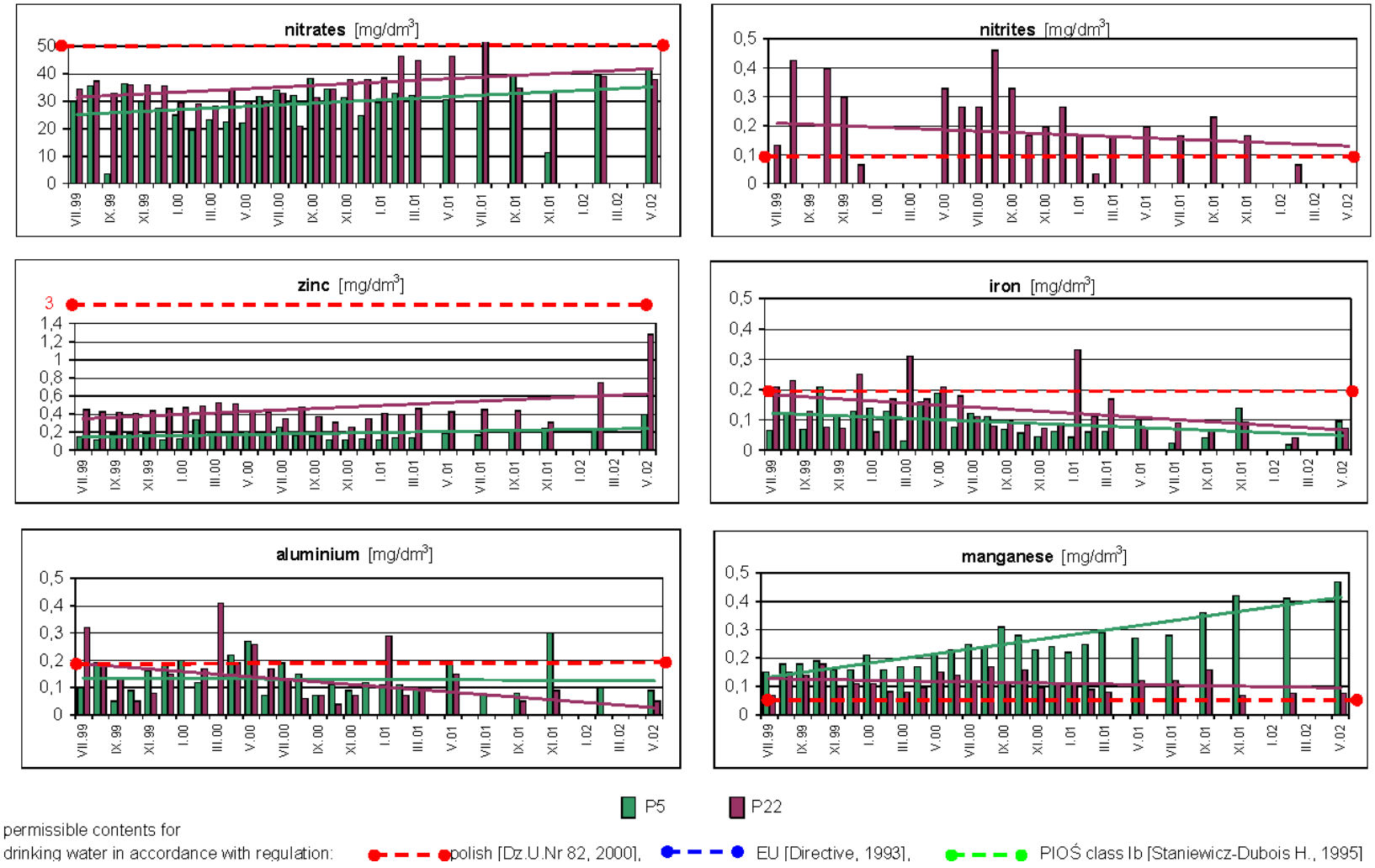


Fig. 24 Piezometers P5, P22

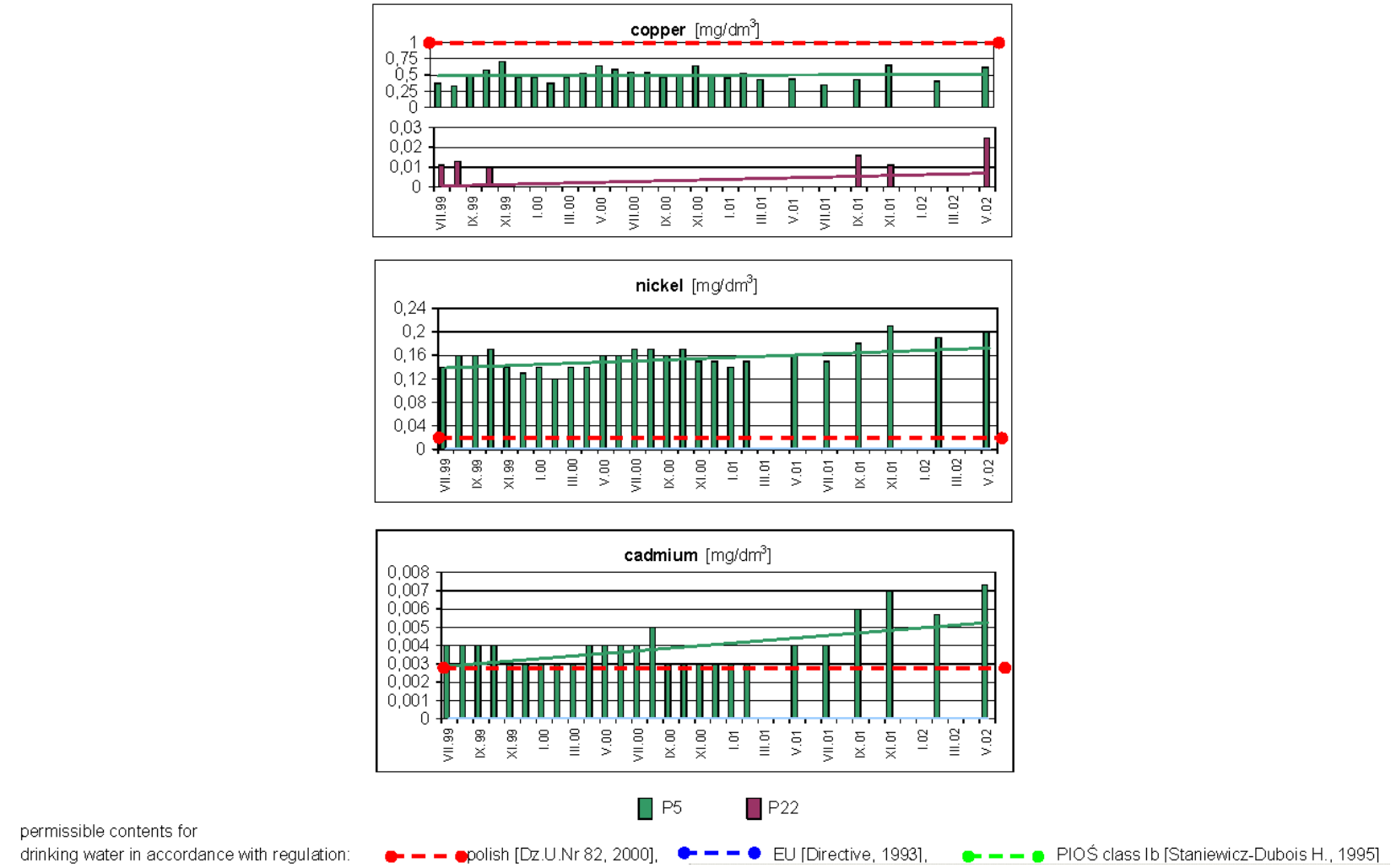


Fig. 25 Piezometers P5, P22

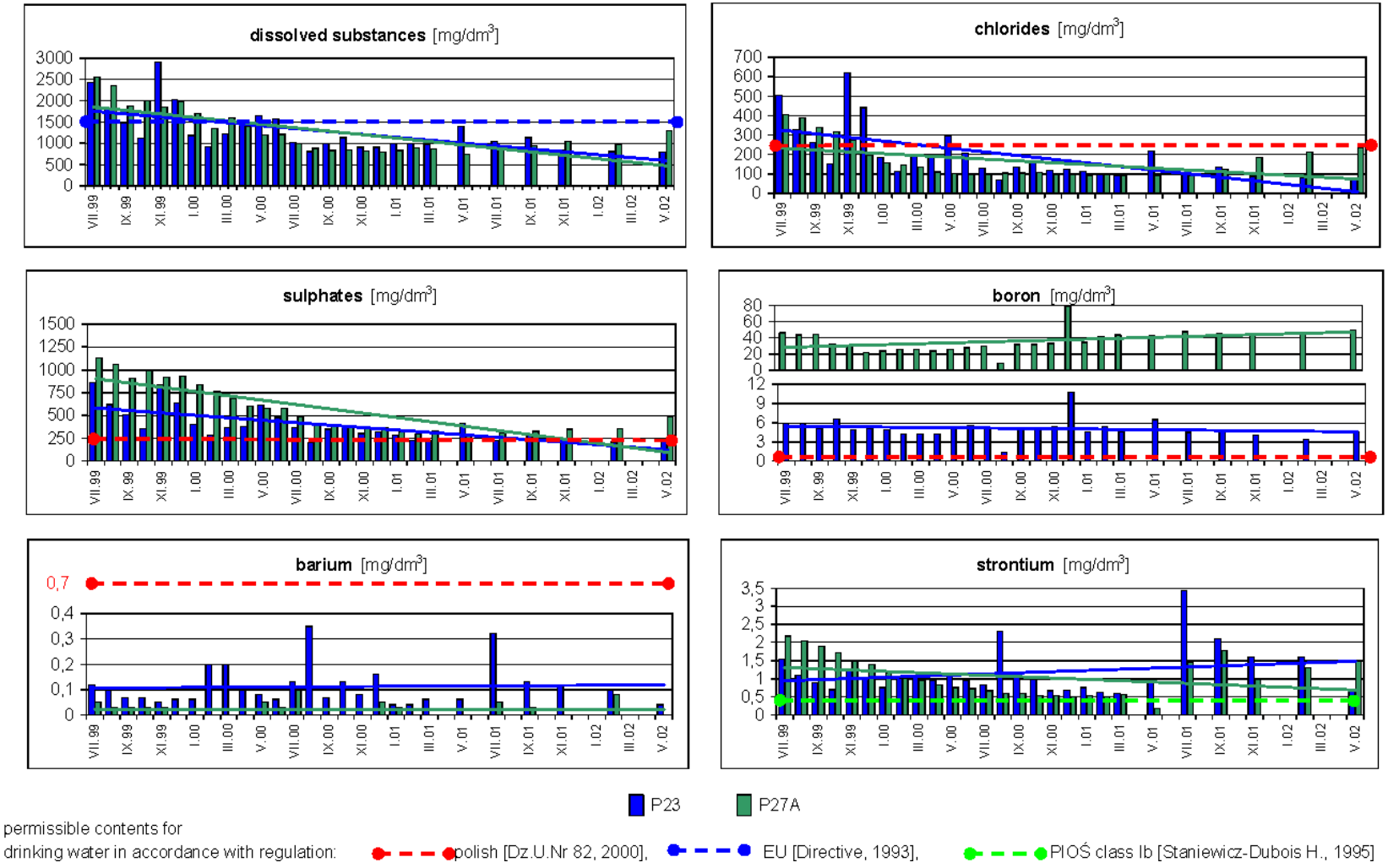


Fig. 26 Piezometers P23, P27A

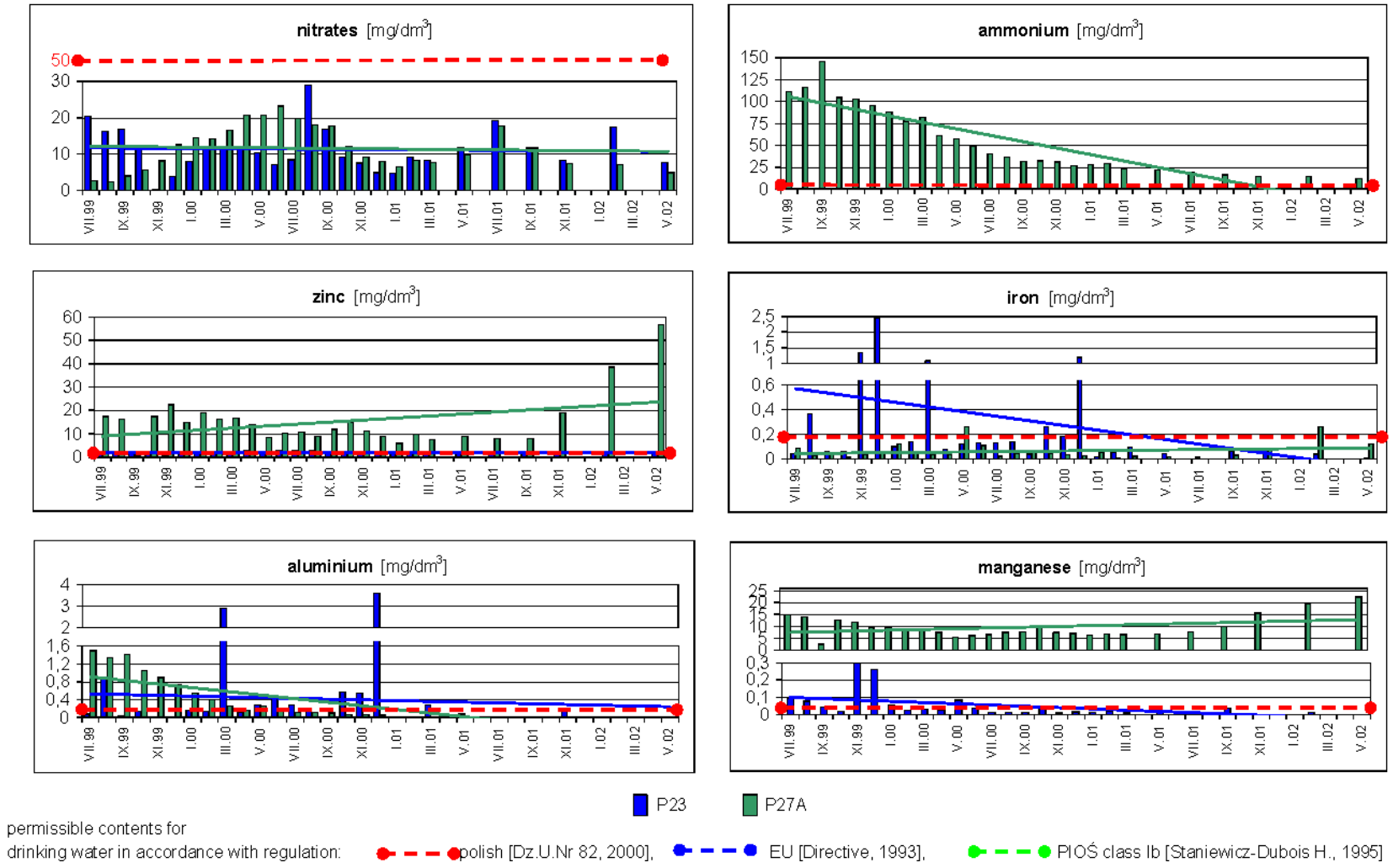


Fig. 27 Piezometers P23, P27A

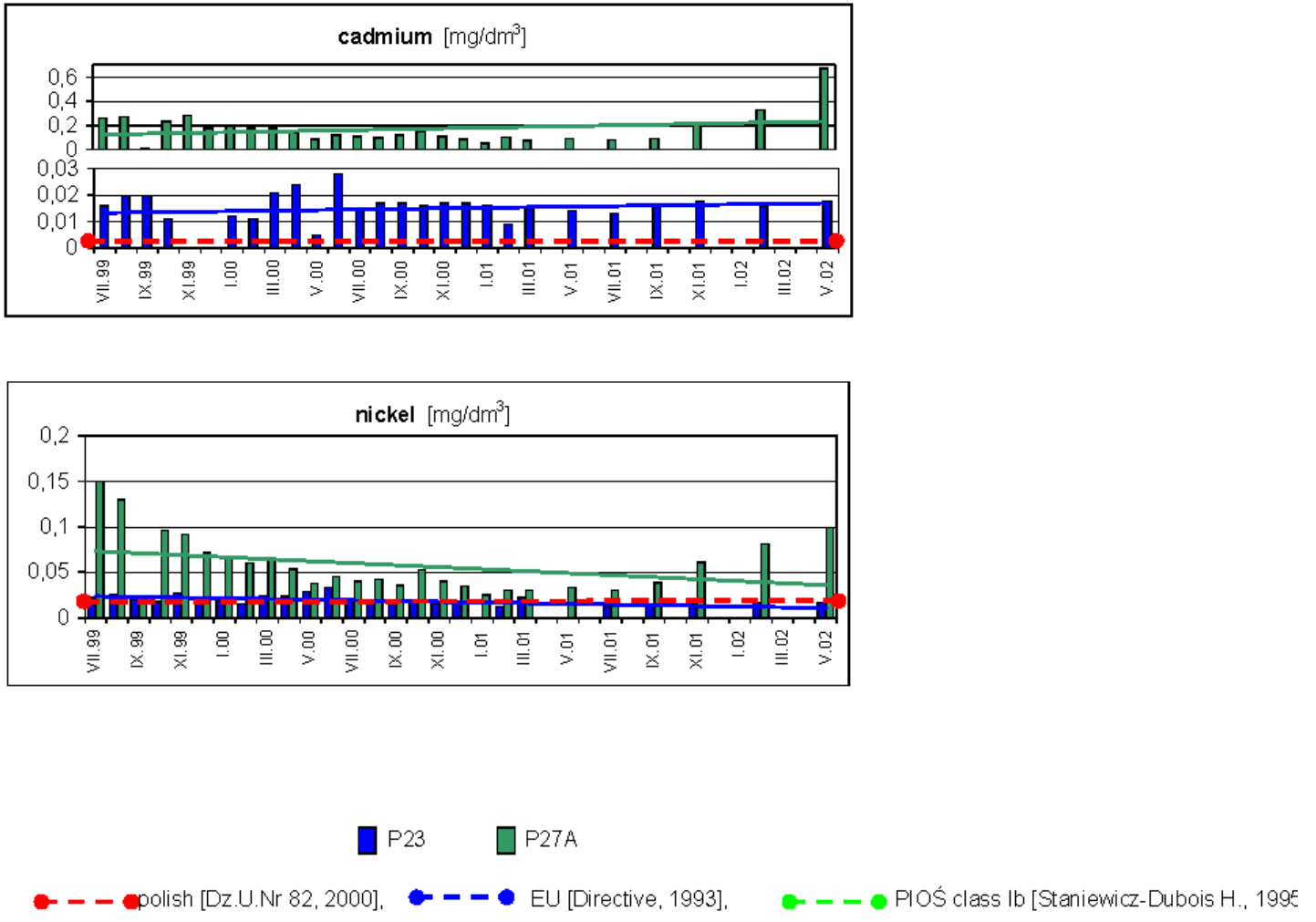


Fig. 28 Piezometers P23, P27A

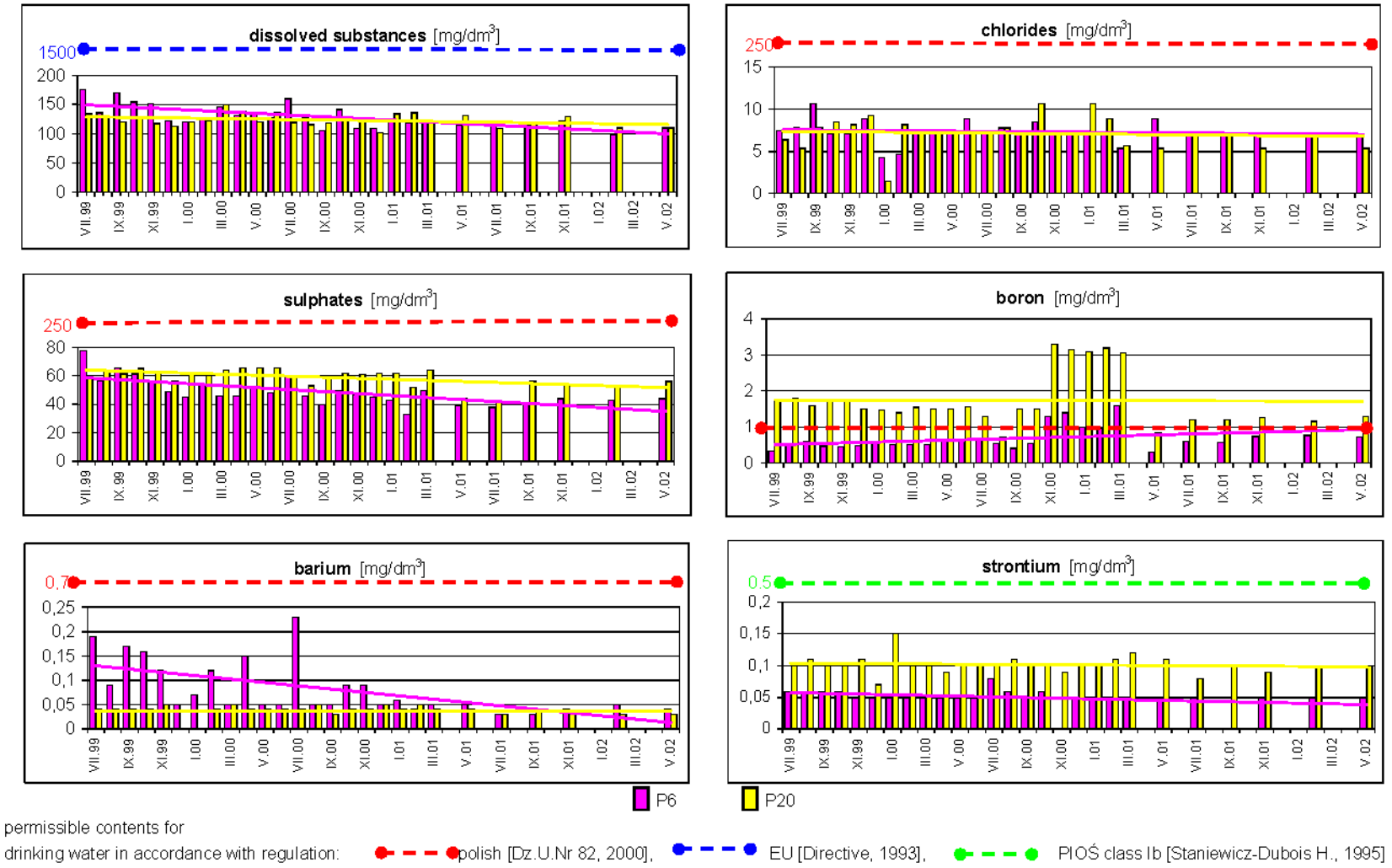


Fig. 29 Piezometers P6, P20

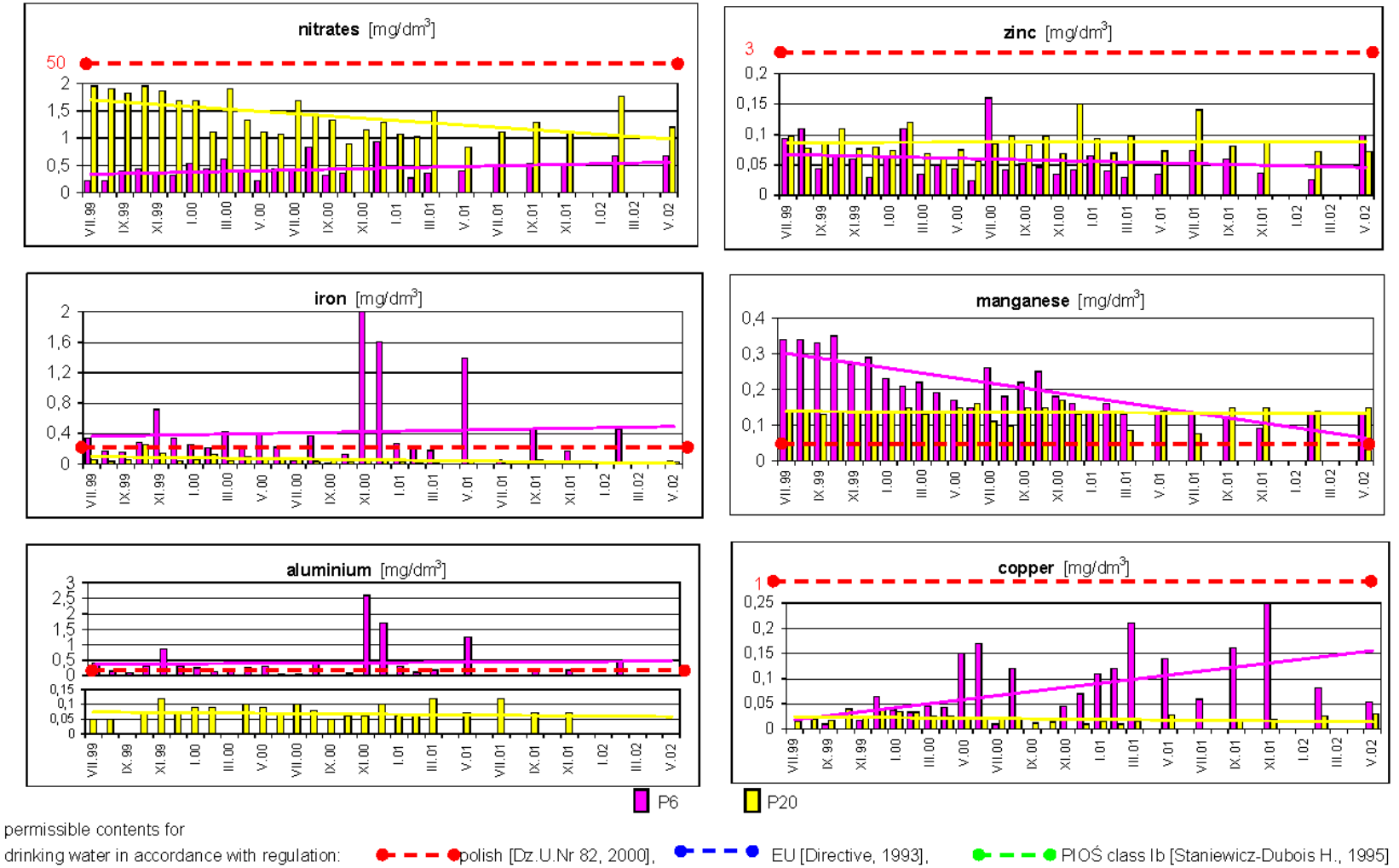


Fig. 30 Piezometers P6, P20

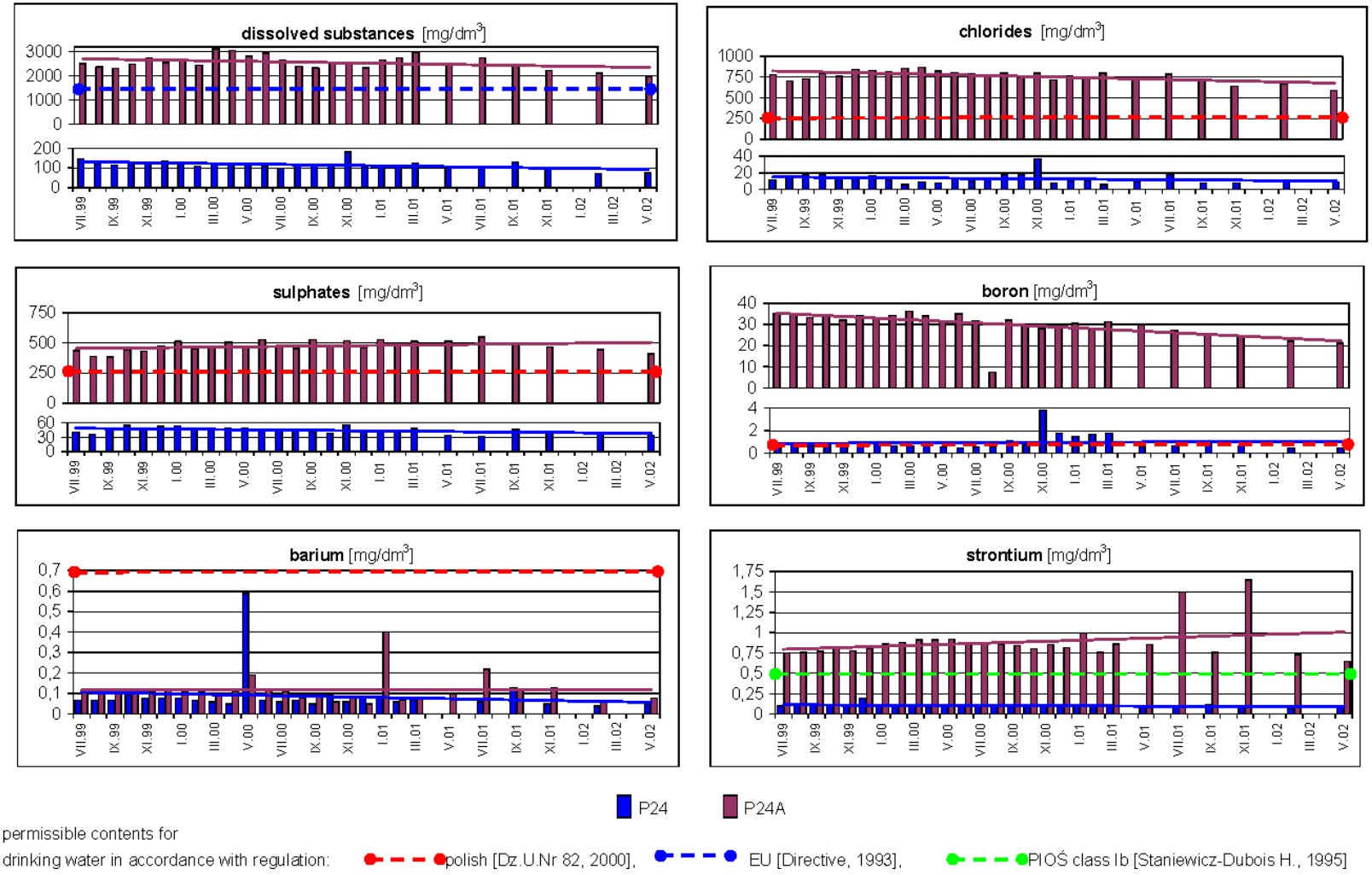


Fig. 31 Pieozmeters P24, P24A

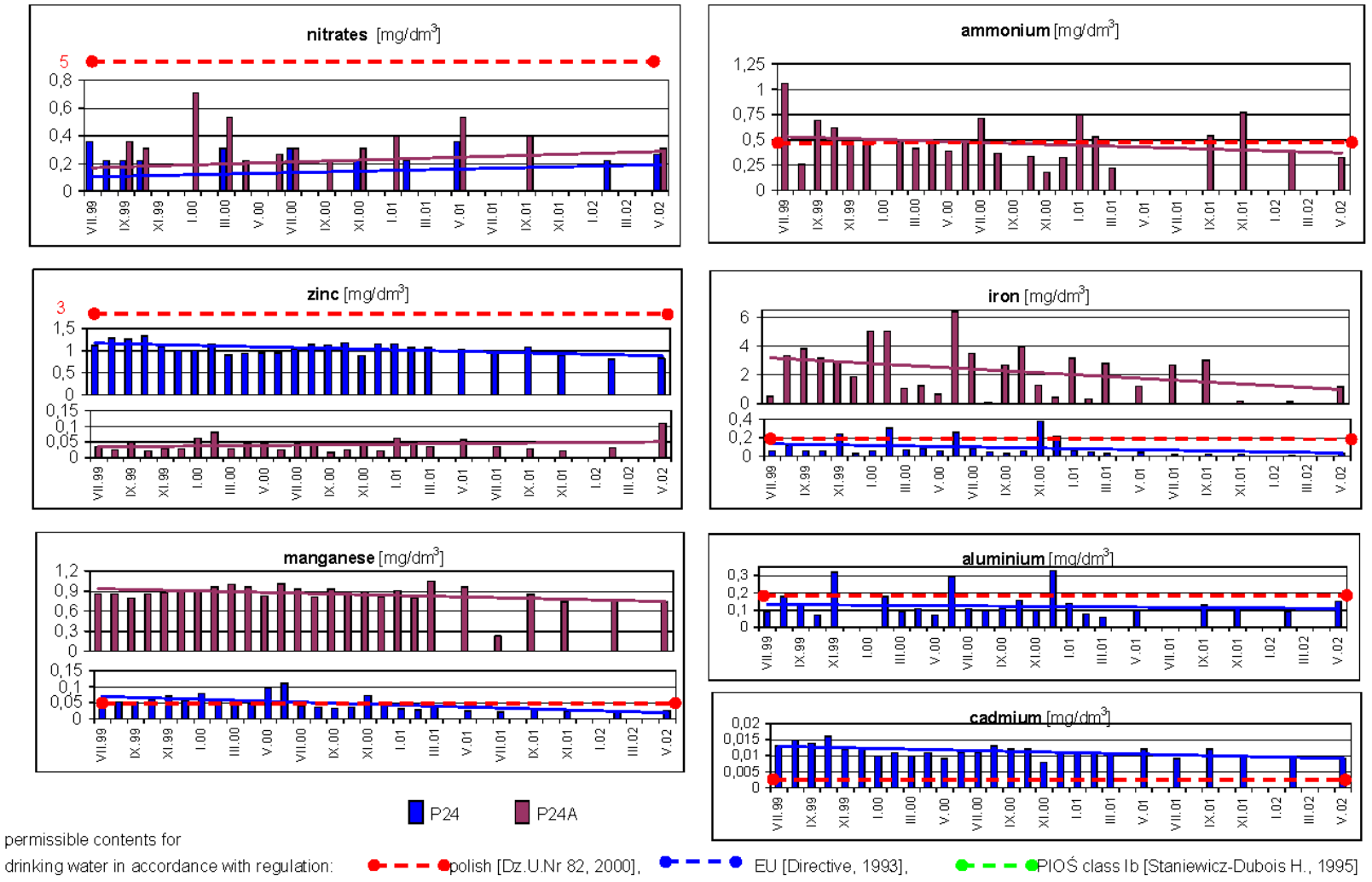


Fig. 32 Piezometers P24, P24A

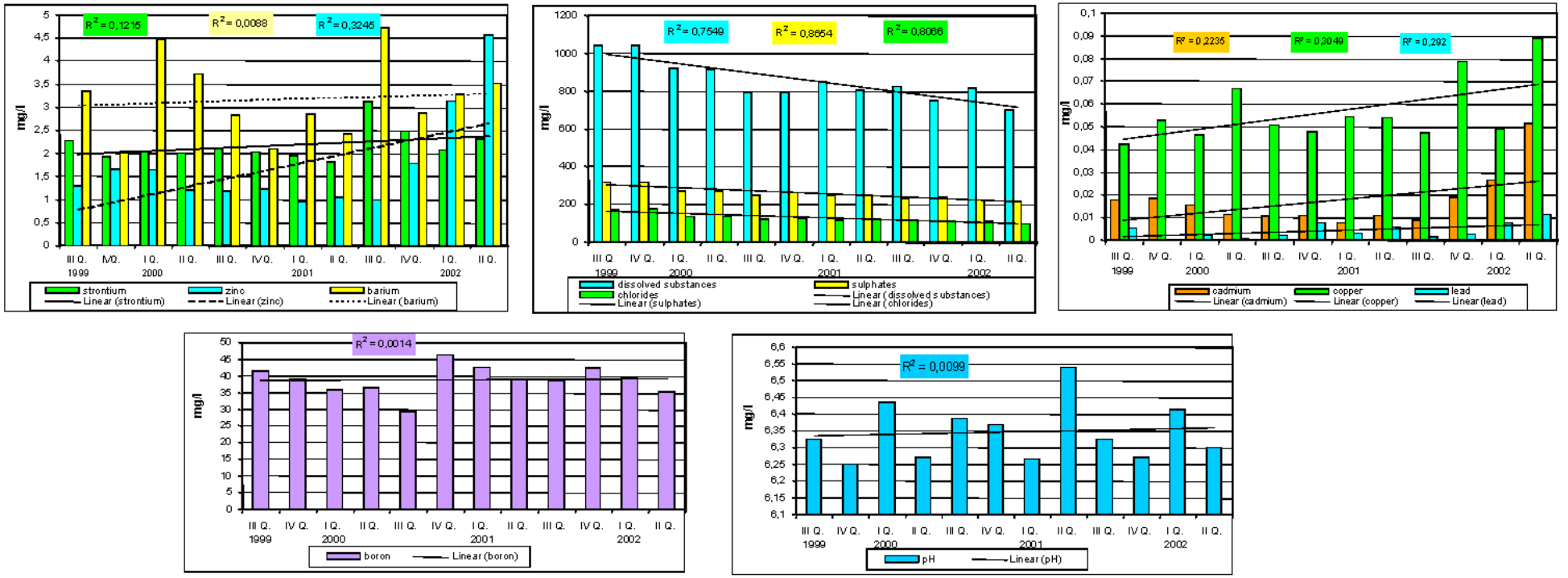


Fig. 33 Mean quarter concentration of selected contamination factors in water of Quaternary aquifer (based on results of local monitoring of Chemical Plant "Tarnowskie Góry" landfills)

4.2.2 Triassic aquifer

Based on the data from studies performed in the period of July 1999 to May 2002 (17 sampling campaigns), the character of the trends of Triassic water quality changes is still relatively difficult to determine. (Fig. 34, Fig. 45). Lack of any significant trends of changes at high seasonal fluctuations can be observed in a number of points (P14, PT3, STIII, STV). Recently (i.e. since early 2001) a drop in the fluctuation of the chemical composition of waters in P14 has been noted (Fig. 34). However, data from the last sampling campaign prove increase of water contamination in this piezometer i.e. a clear increase in the content of dissolved substances, chlorides, strontium and cadmium (Fig. 34, Fig. 35) Data from the upcoming sampling campaign will allow determining the seasonal character of these changes.

A relative stabilisation of the chemical composition and quality of water has been observed in PT1, PT3 (minimum tendency of water quality improvement) (Fig. 42, Fig. 43), PT4 (minimum increase of NO_3) (Fig. 43), STIII (Fig. 41), STV, STVII and STIX (minimum increase of nitrates content)(Fig. 45).

More or less clear trends of value changes for a number of indicators have been noted in some points during the period of the studies (July 1999 - May 2002). Analysis of these changes in individual points allows stating that relatively distinct, yet not uniform, trends of changes have been observed in monitoring points located in the area of the landfills or in their direct vicinity. These points represent the roof section of Muschelkalk aquifer (PT7, PT6, PT6A, PT8). In PT7, beside seasonal fluctuations, an increasing trend of strontium, copper, cadmium and nickel concentrations has been maintained (Fig. 36, Fig. 37). In PT6 an increasing concentrations trend of sulphates, chlorides, dissolved substances and strontium has been observed at simultaneous decreasing trend of nitrates content (Fig. 36, Fig. 37). A tendency of boron concentration increase was noted in PT6A A positive trend of water quality improvement has been observed in PT8 (a slight decreasing tendency of dissolved substances Cl, SO_4 and B concentrations and inhibition of an up-to-date clear tendency of nitrates concentration increase) (Fig. 38, Fig. 39). The above-presented data prove lack of uniform trends of changes in the analysed monitoring points. However, a slight worsening of water quality in the roof section of Muschelkalk aquifer has been still observed in the areas of the following piezometers: PT6 , PT6A and PT7. The trend of water quality decrease originally noted in PT6 has been well inhibited. In the case of boron, a tendency of concentration

increase has been recorded only in PT6A and also, in a less degree, in PT5A. Attention requires a continuously increasing content of metals in PT7 (Mn, Cd, Cu and Ni).

Some improvement of water quality in the southern section of the area (PT8) is a positive phenomenon. Unfortunately, since piezometer PT2 has been destroyed and no updated data are available, confirmation of this positive tendency for PT2 is impossible. Attempts should be made to reconstruct this piezometer (Fig. 36, Fig. 37). Lack of local negative trends in the quality of the roof section Muschelkalk waters (STIII area) should be positively evaluated. However, the situation in the roof section (e.g. PT14 area) is still unstable. The last sampling campaign showed a clear concentration increase of chlorides, dissolved substances, strontium and cadmium in this piezometer. Subsequent sampling campaign should provide data allowing determination of the character of these changes.

Analysis of the relevance and character of the observed trends of changes (Table 8) allows stating that relevant increasing trends of some indicators have been observed much more frequently in the case of Triassic aquifer than in Quaternary aquifer waters (Table 8). Especially attention should be paid to piezometers PT7 and PT6. Increasing trends of high relevance were observed in PT7 for as many as 7 indicators, including 6 metals (cadmium, copper, manganese, nickel, strontium and zinc) and ammonia. In PT6 increasing trends of high relevance were observed for 5 indicators (dissolved substances, chlorides, sulphates, strontium and zinc) at simultaneous trend of nitrates content decrease

Variability of water contamination has been also analysed based on a mean value of a given indicator content for 14 monitoring points investigated in the period of July 1999 – February 2002 (16 sampling campaigns). Since piezometer PT2 has been destroyed and there were no data for this point collected during the May sampling campaign, mean concentrations have not been calculated for this sampling. Analysis of the obtained data shows clear positive tendencies (decreasing tendencies) only in the case of boron (Fig. 46). Negative increasing tendencies of a relatively high variability reference ($R^2 > 0,3$) can be observed for zinc, cadmium and copper (Fig. 46).

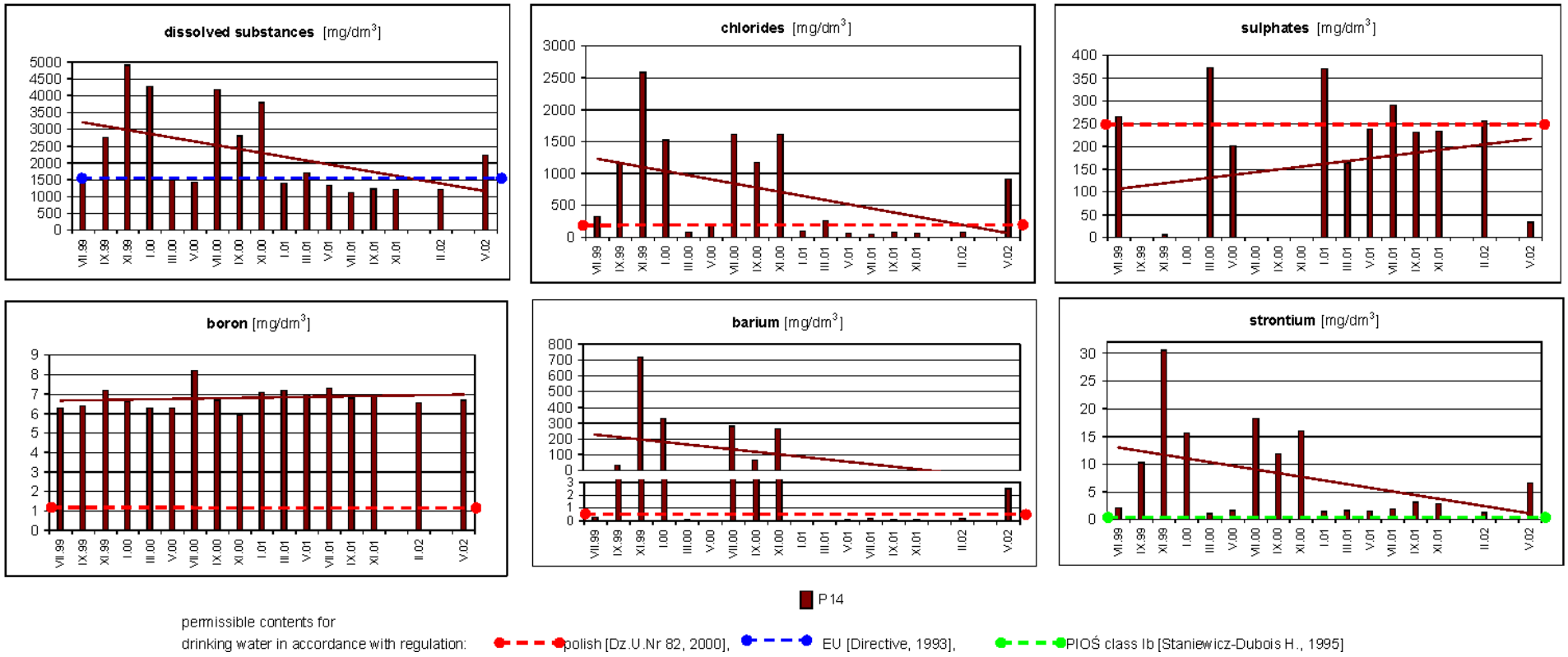


Fig. 34 Piezometer P14

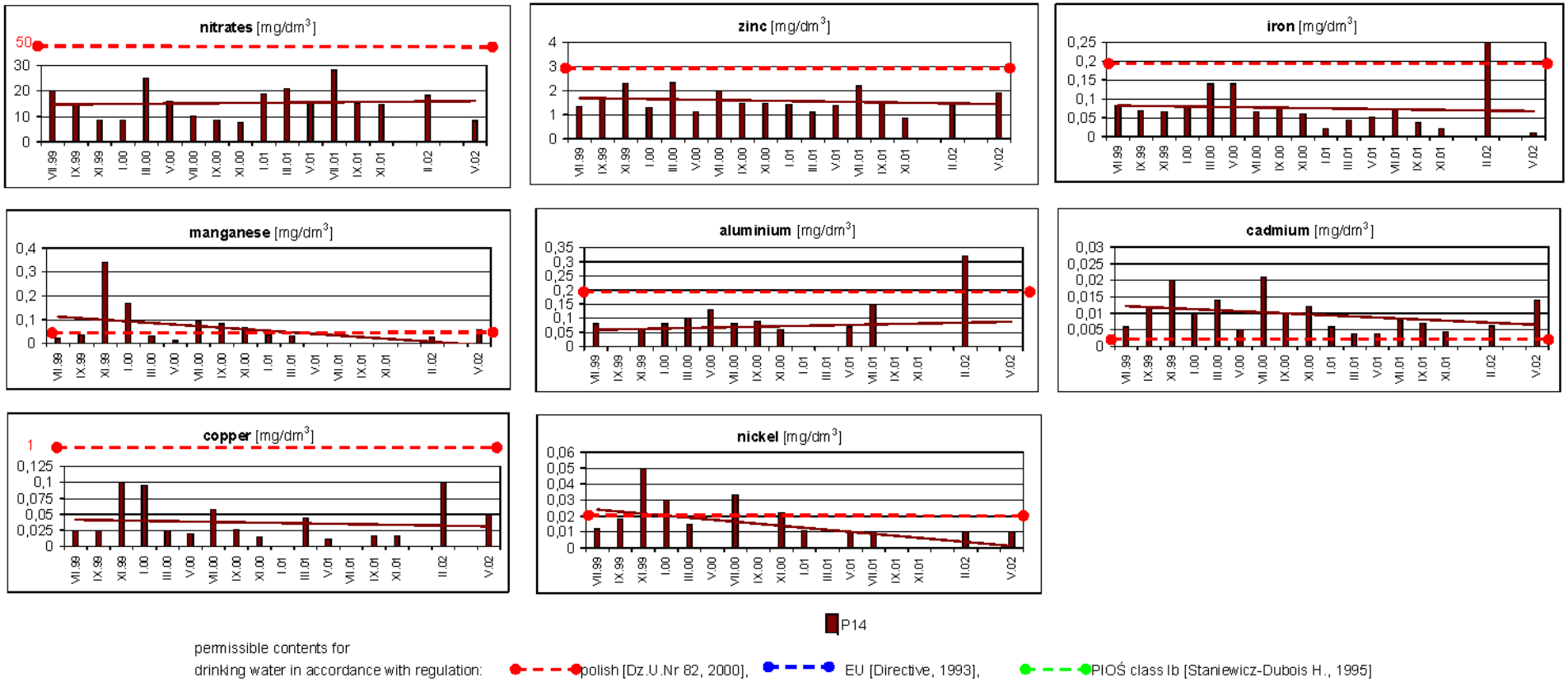


Fig. 35 Piezometer P14

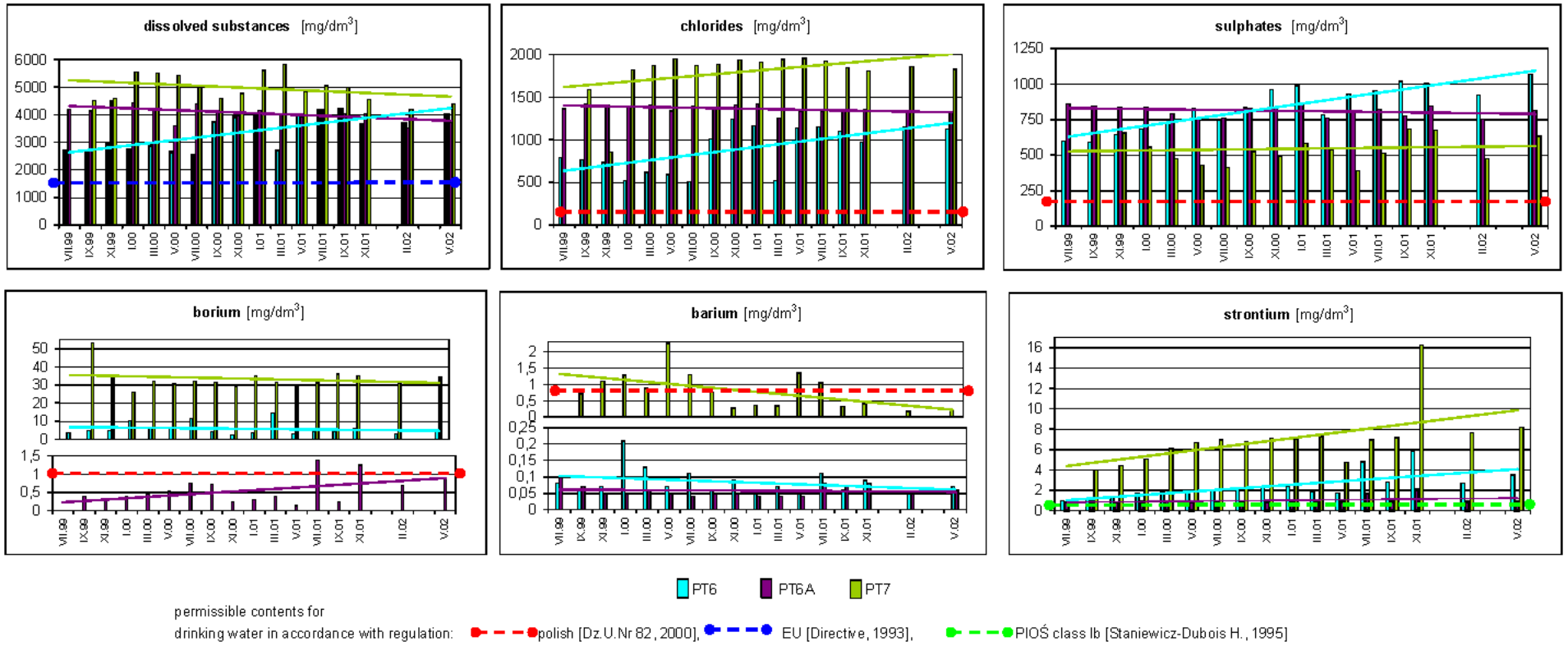


Fig. 36 Piezometers PT6, PT6A, PT7

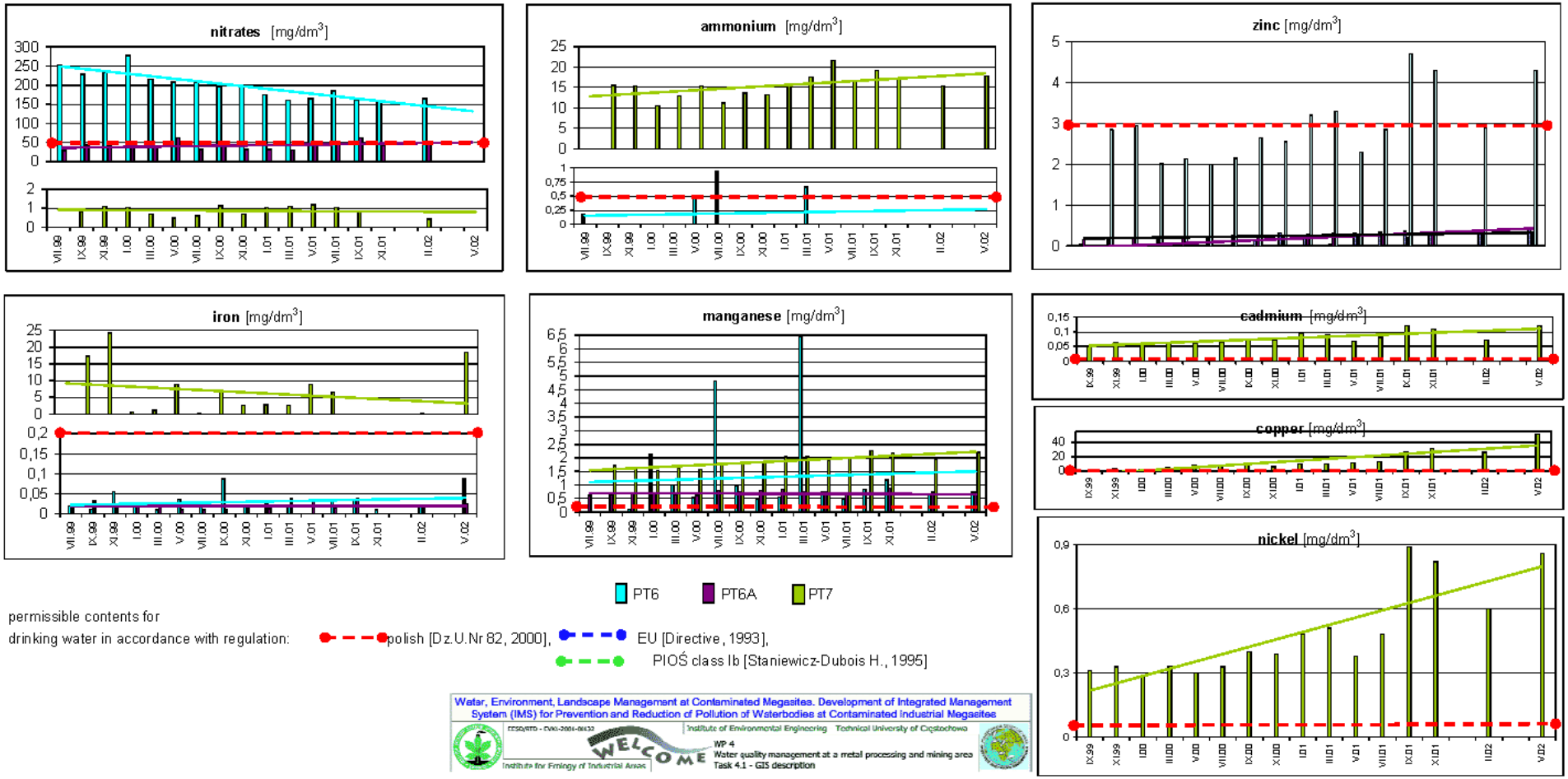


Fig. 37 Piezometers PT6, PT6A, PT7

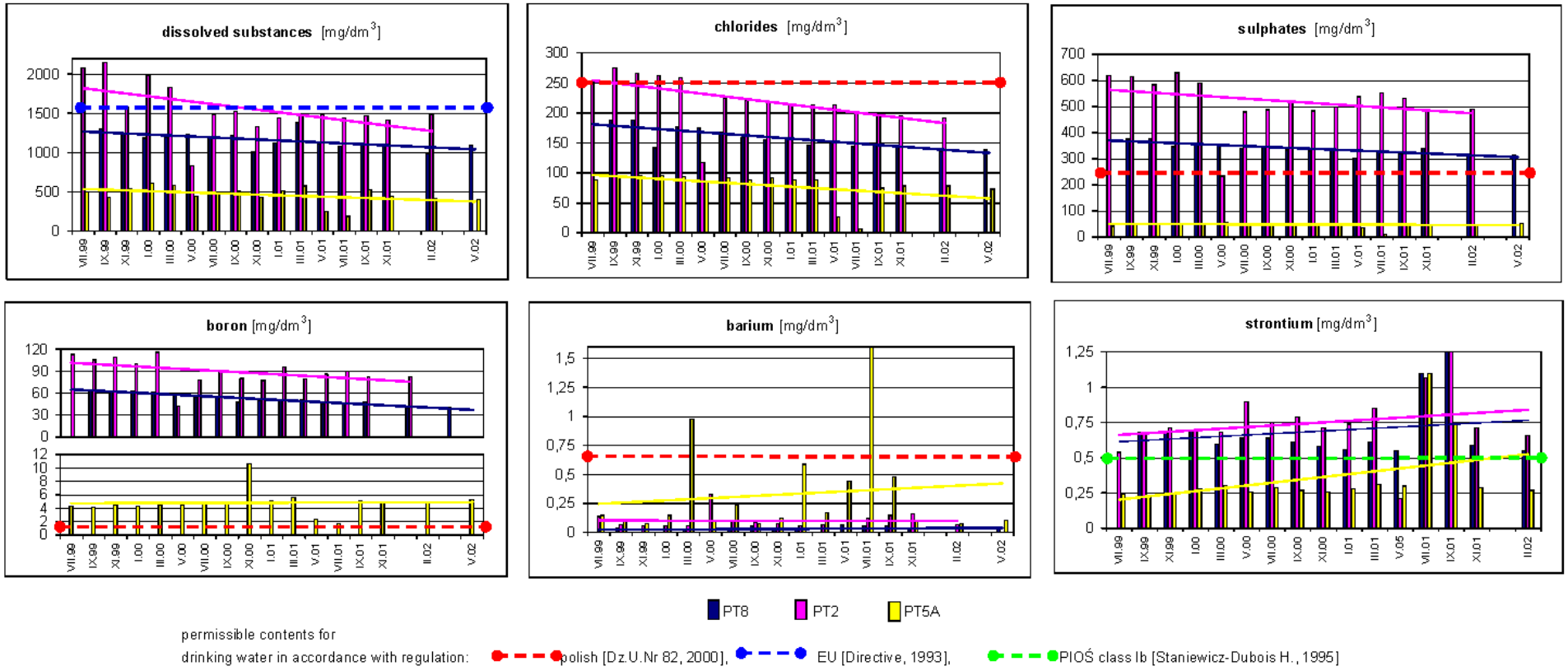


Fig. 38 Piezometers PT8, PT2, PT5A

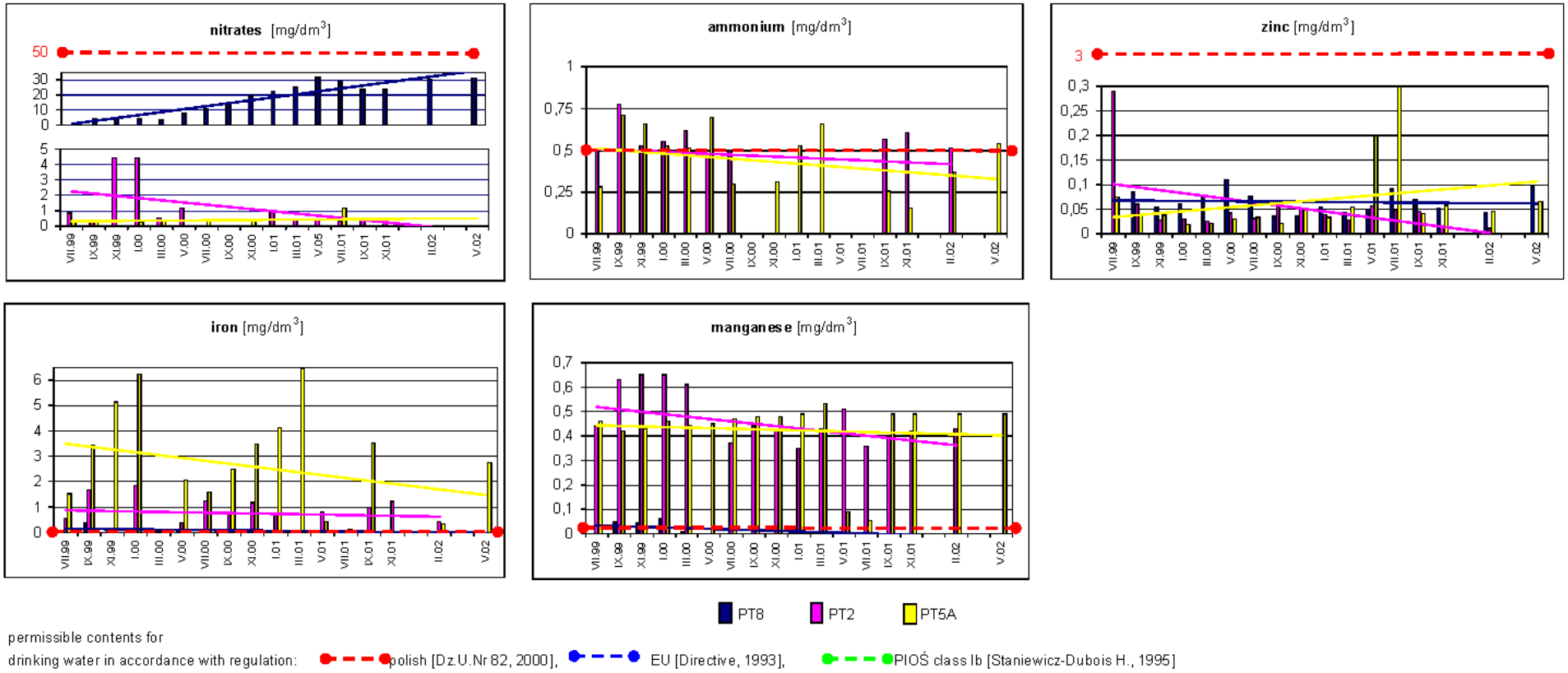


Fig. 39 Piezometers PT8, PT2, PT5A

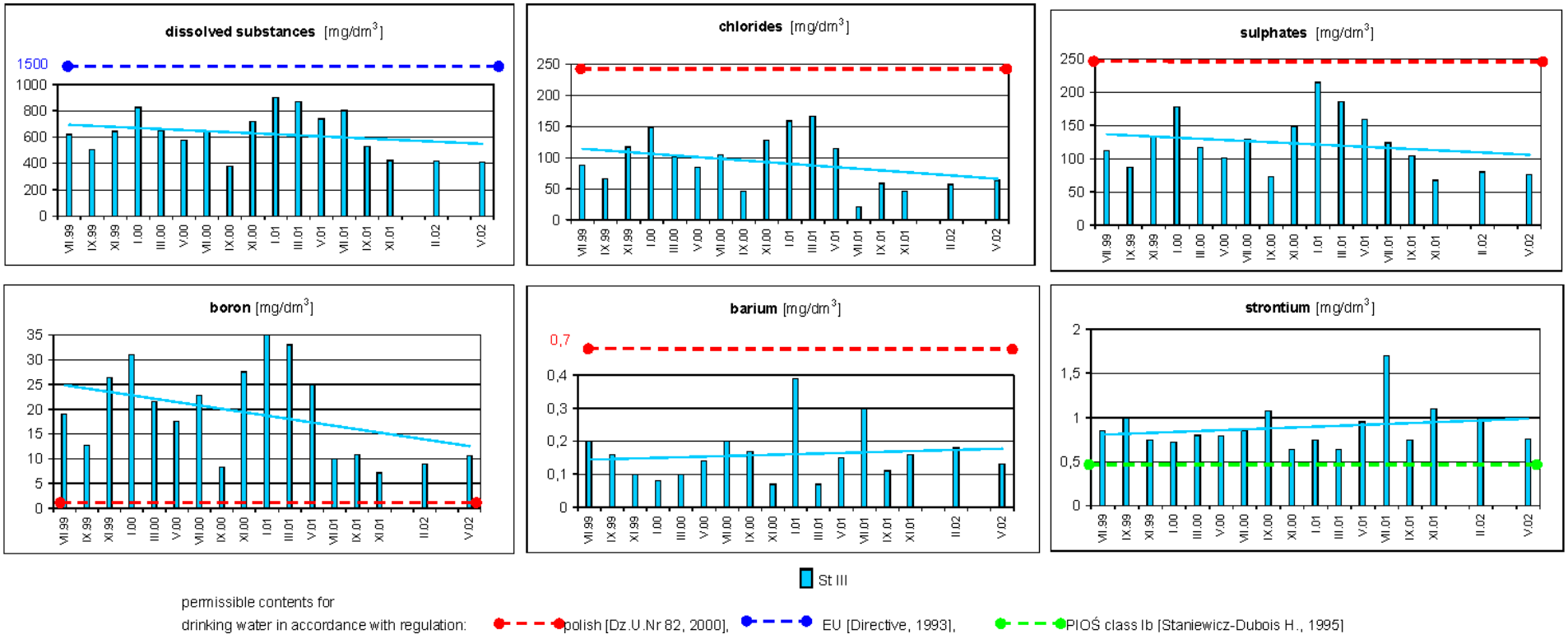


Fig. 40 Well St III

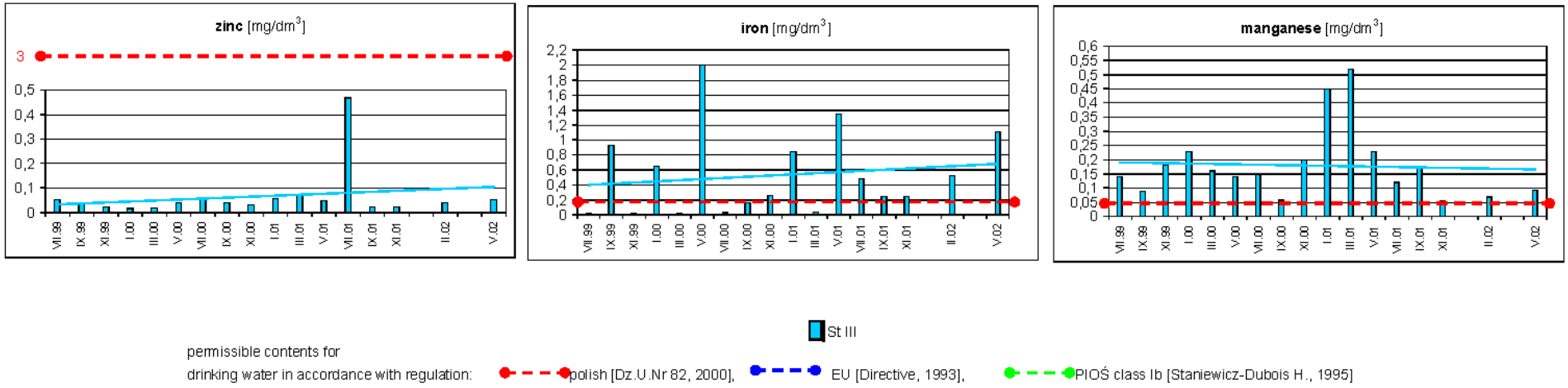


Fig. 41 Well St III

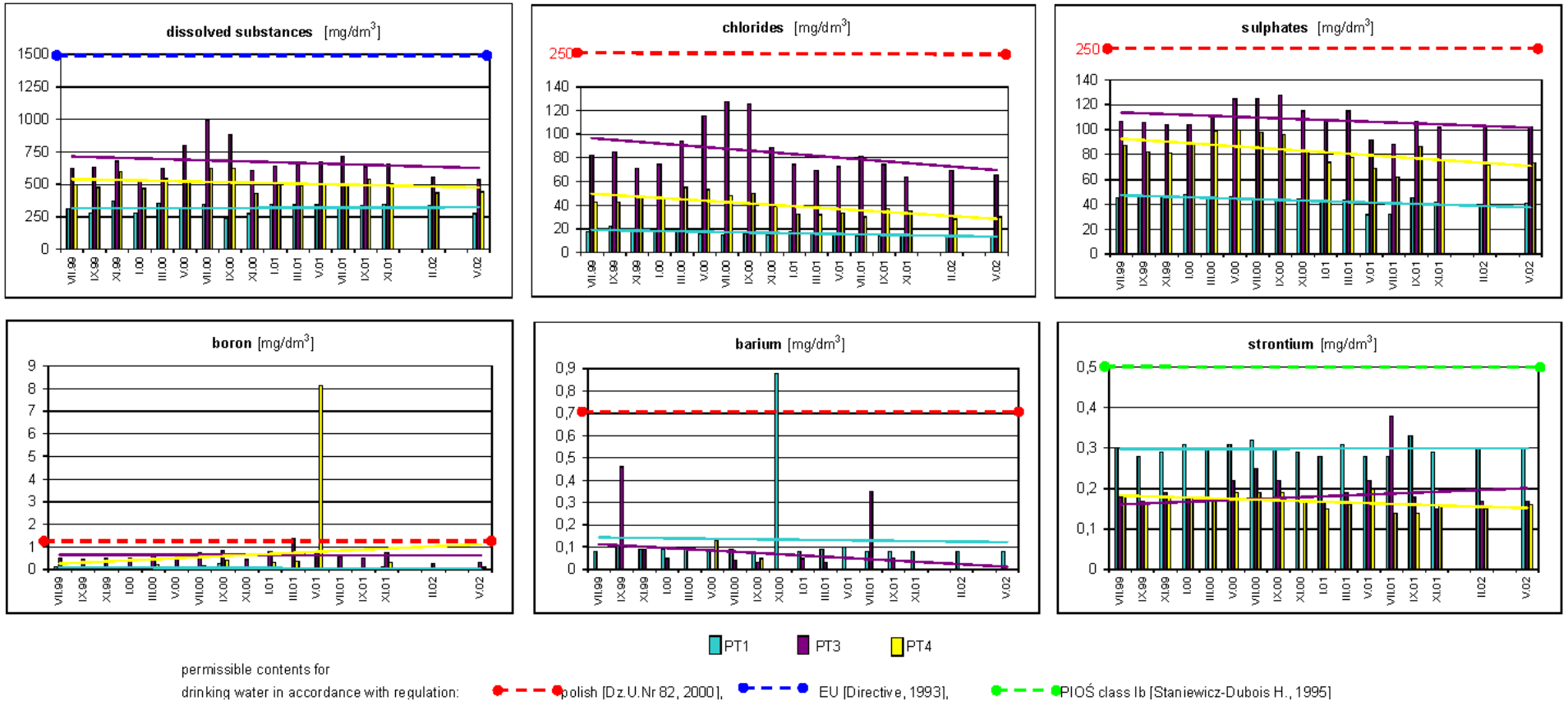


Fig. 42 Piezometers PT1, PT3, PT4

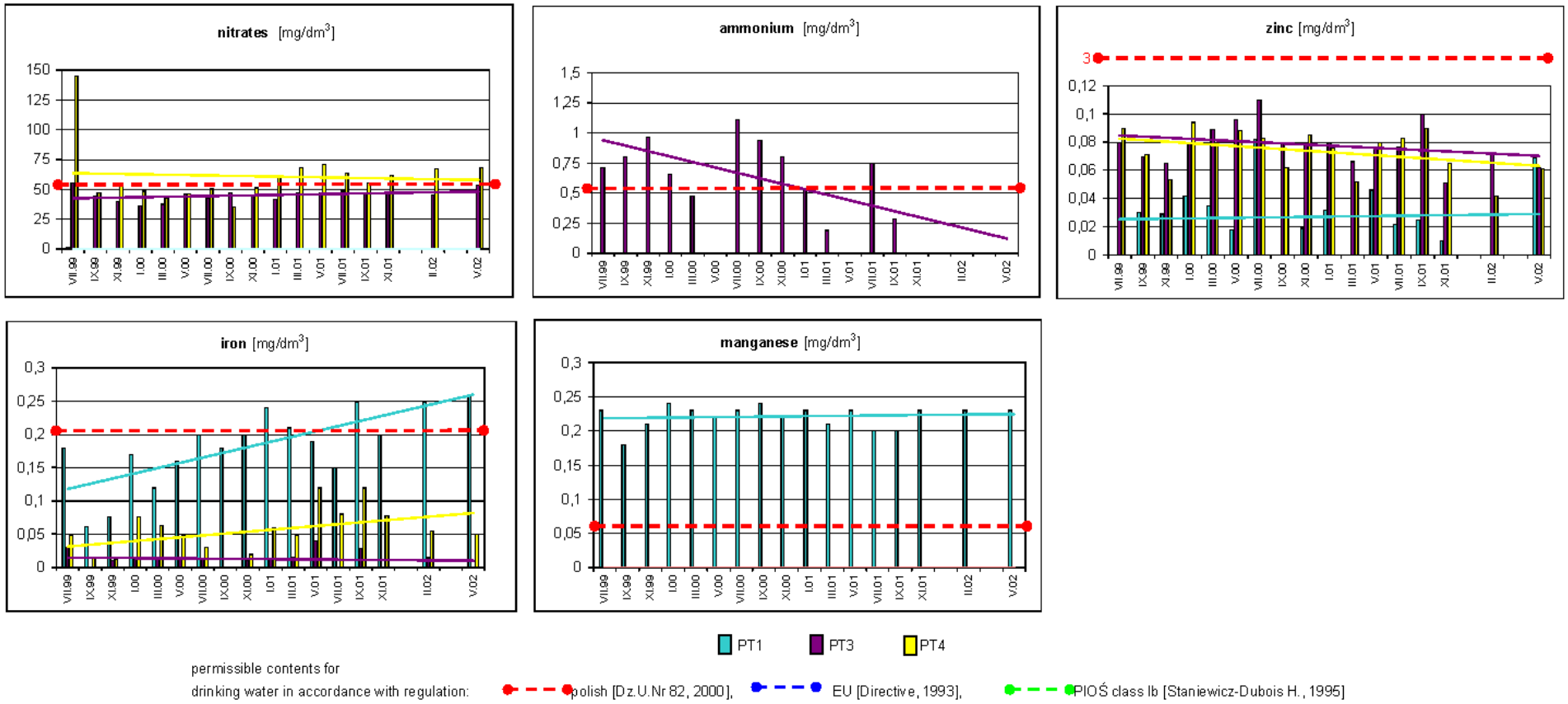


Fig. 43 Piezometers PT1, PT3, PT4

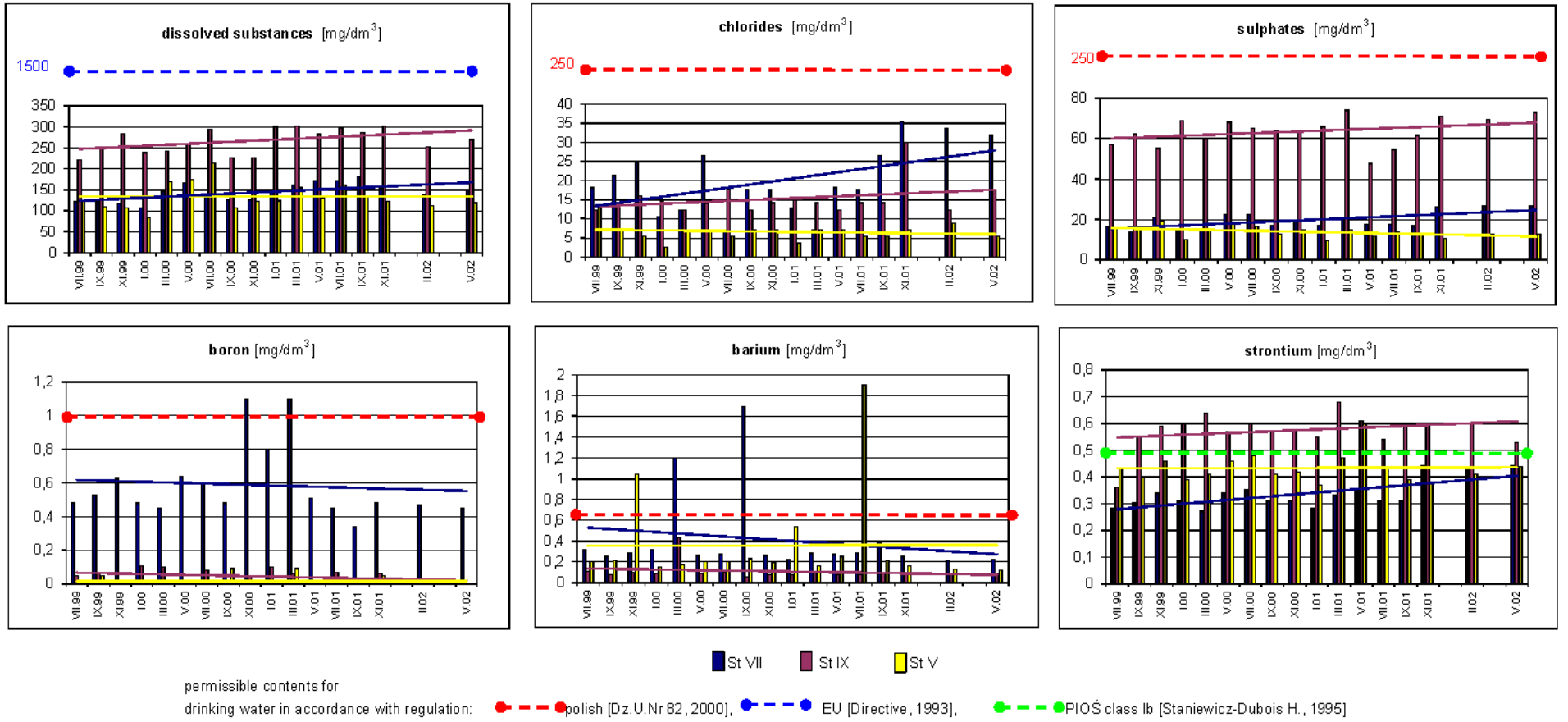


Fig. 44 Wells St VII, St IX, St V

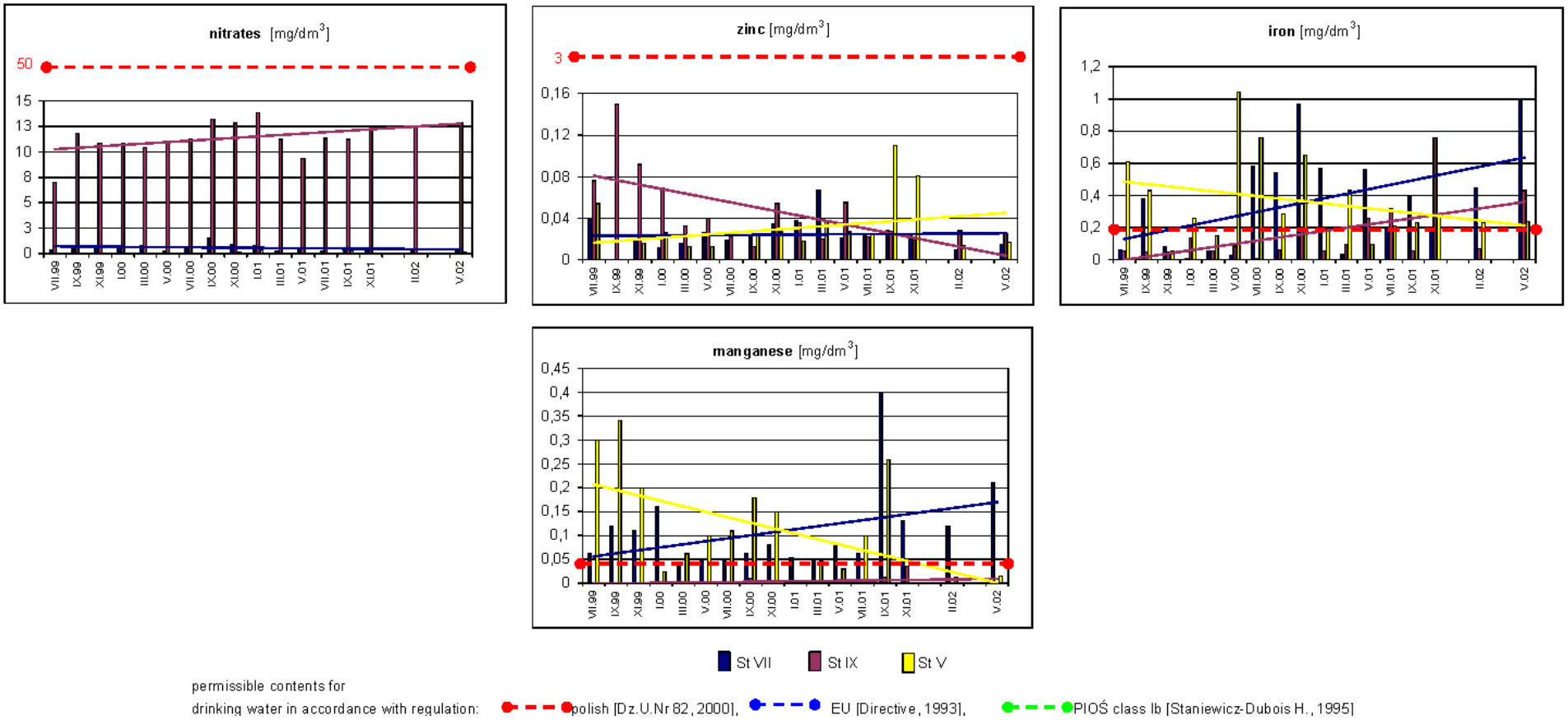


Fig. 45 Wells St VII, St IX, St V

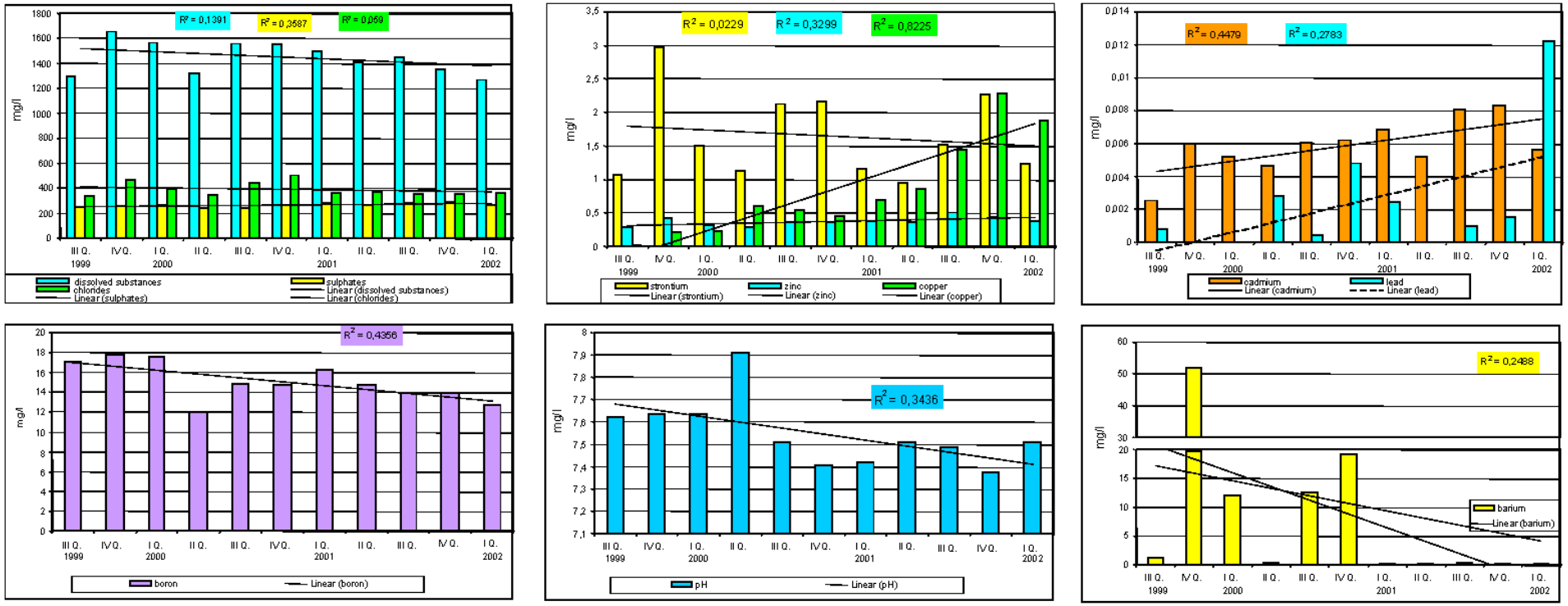


Fig. 46 Mean quarter concentration of selected contaminants factors in water of Triassic aquifer (based on results of local monitoring of "Tarnowskie Góry" Chemical Plant landfills)

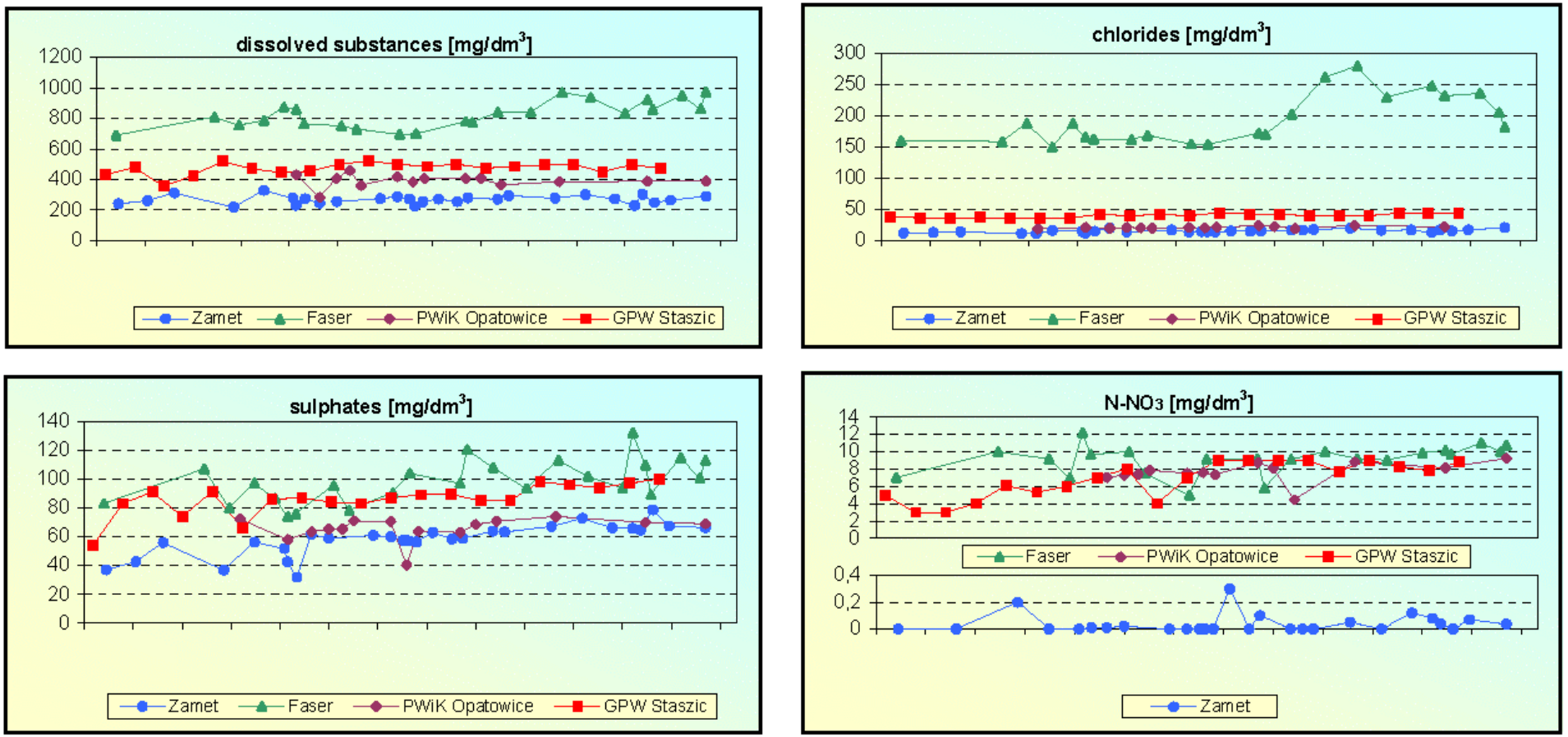


Fig. 47 The variability of concentration of selected factors in water of Triassic carbonate aquifer in region of Tarnowskie Góry town within period 1990-2000

Summarising, it should be stated that no significant one-way quality changes of the Triassic aquifer water monitored in the area of the Chemical Plant landfills sites can be observed. This fact is proved by the above presented examples of both increasing and decreasing trends of local character observed for some contamination indicators as well as a relative stability of categorisation of the analysed groundwaters to specific water quality classes. Generally, water quality stabilisation predominates, with some slight local positive tendencies of contamination decrease. The persisting tendency of water quality deterioration in the roof section of Muschelkalk aquifer (PT6, PT6A and PT7 area), though less distinct as before, is a negative exception.

Beside the above presented detailed analysis of trends in the quality of carbonate Triassic aquifer waters in the area under direct impact of the Chemical Plant landfills, trends of chemistry changes of these waters in the aspect of a general anthroporessure impact of the town have been studied.

Four wells of different impact of the Tarnowskie Góry town on the quality of the monitored waters were selected for analysis. Variability of selected contamination indicators has been presented for the period of the last decade (Fig. 47).

The "Zamet" well is located to the north from the watershed, which serves as a hydrodynamic barrier for the migration of contaminants from the industrialised, central part of the town. "Faser" well is located in the industrial area. PWiK Opatowice well is located to the west from the town, in the direction of water flow, while the GPW Staszic intake point is situated outside the area of condensed building, to the south west from the town, also in the direction of water flow.

Analysis of the content of selected contamination indicators shows that the waters monitored by "Faser" well are characterised by the highest concentration of all discussed indicators. Especially clear difference in concentration levels is visible in the case of dissolved substances – an indicator that characterises global water contamination and in the case of chlorides that serve as an indicator which quickly and directly reacts to anthropopressure. A clear increase in the content of dissolved substances has been observed in "Faser" well in the last decade. A slow, yet persistent increase of sulphates and nitrates in waters of practically all analysed wells has been also observed.

The problem of nitrates concentration increase addresses most of the wells in the area of Tarnowskie Góry. Analysis of a spatial distribution of wells extracting waters of elevated $N\text{-}NO_3$ concentrations shows that the problem concerns primarily waters from the shallow circulation level as well as waters migrating on higher depths (e.g. GPW Staszic well). Most probably, the source of nitrates is sewage discharged in an uncontrolled way in areas without sewerage system or sewage leaking from untight system.

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