ANALYSIS OF CURRENT SITUATION OF BROWNFIELDS IN BYDGOSZCZ-TORUŃ FUNCTIONAL URBAN AREA

„Zachem” Chemical Plant in Bydgoszcz City Factory of railway sleepers preservation in Solec Kujawski town	Version 1 12-2016

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1. General characterization of Bydgoszcz – Toruń Functional Urban Area

Administrative location

The Kuyavian – Pomeranian voivodeship is one of 16 Polish voivodeships, located in the north-central part of the country (Fig. 1a). It covers an area of 17,971.34 km², which represents 5.7% of the Polish territory. In the north-south direction it stretches over the length of 161 km. In the east-west direction the voivodeship's range is 168 km.

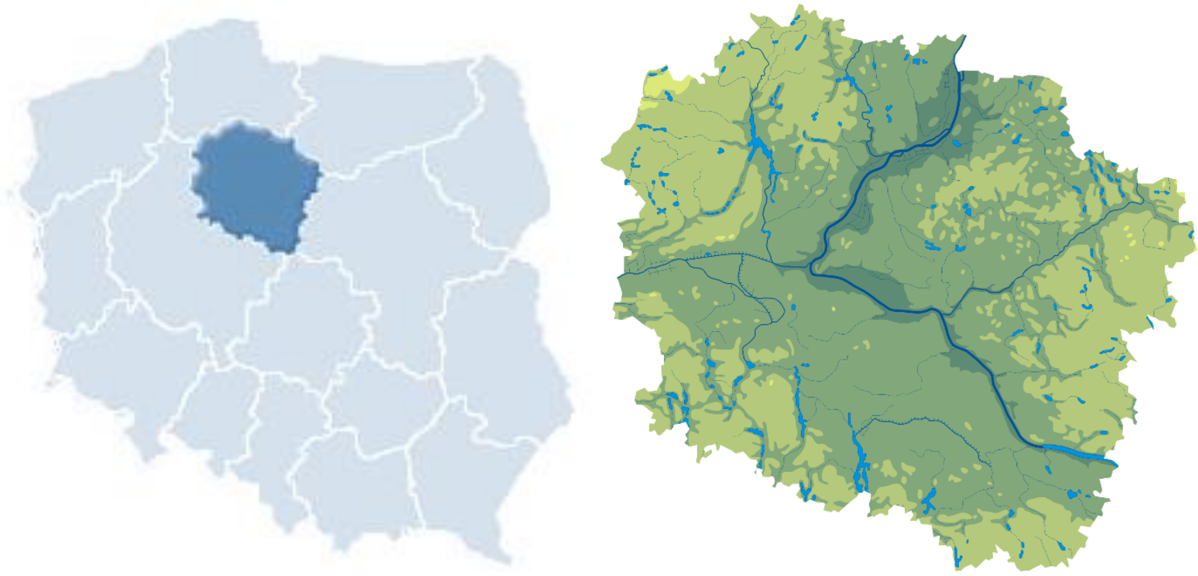

Fig. 1. Location of the Kuyavian – Pomeranian voivodeship in Poland (a) together with its topography (b)

Geographical location

According to the geographic regionalization, this region is located centrally in the northern part of Poland, on both banks of the Vistula river, in its lower reaches. It is located between the Pomeranian and Masurian Lakelands. The entire area of the Kuyavian-Pomeranian voivodeship is located in the young glacial landscape, shaped in the Baltic glaciation. The voivodeship's axis is the river Vistula, flowing within the macro-region of Toruń – Eberswalde Proglacial Valley, and below the lower Vistula bend – in the Lower Vistula Valley. The depression occupied by the Vistula river is surrounded by moraine uplands, characterized by great diversity of terrain, the presence of hills and numerous glacial lakes. They are located in macroregions: South-Pomeranian Lakeland (north west), Chełmińsko-Dobrzyńskie Lakeland (north east), Greater Poland Lakeland (south). They are divided into numerous smaller mesoregions. The morphology of the Kuyavian – Pomeranian region is clearly differentiated (Fig. 1b). In Kuyavia there are flat and undulating moraine plains, while in the north and east of the voivodeship – hilly areas. The most diversified in terms of morphology is the north-western part, where there are considerable land denivelations, terminal moraine ridges, eskers, kames and deeply indented subglacial channels (e.g. Byszewskie Lakes Tunnel Valley). The north part of the voivodeship is covered by a sandy glacial plain of the Tuchola Forest, diversified with numerous lakes. The voivodeship has one of the greatest Polish areas of inland dunes, covered by the Bydgoszcz Forest (Fig. 2). A unique creation of nature is also the Lower Vistula Valley, which is a kind of a threshold in the lakeland uplands.

In the vicinity of Bydgoszcz it begins with the Fordon Vistula Gorge, and in the slopes of the valley there are places with caves (Bajka, Klonowa, Pod Wierzbą).

The Kuyavian – Pomeranian region is lowland. Although it has a very diverse area of land, which is the result of the last glaciation and the subsequent geomorphological processes. Legal protection covered a large part of the surface of the region, creating the most valuable areas: parks (Tucholski, Wdecki, Krajeński, Brodnicki, Górznieńsko-Lidzbarski, Nadgoplanski, Chełmiński, Vistula, Gostynińsko-Włocławski), nature reserves (i.e. Cisy Staropolskie of Leon Wyczółkowski), natural monuments, i.e. stately oaks in Nogat and Bąków and Stone St. Wojciech in Leosia, protected landscape areas, nature and landscape, ecological areas and Natura 2000 areas.

Fig. 2. Legally protected areas in Kuyavian-Pomeranian region (Statistical Office in Bydgoszcz, 2015)

<u>Administrative structure</u>

The Kuyavian – Pomeranian voivodeship is the 10th largest in Poland. This area is inhabited by 2.085 million people, which is 5.4% in the national scale (Table 1). The degree of urbanization of this area is 61.1%, the voivodeship is divided into 25 poviats with 4 major cities, i.e. Bydgoszcz (362 thousand citizens), Toruń (203 thousand), Włocławek (113 thousand) and Grudziądz (96 thousand). This area includes 144 municipalities – both urban and rural. The population density in the region is 116 people/km^2. This region has a GDP per capita below the national average (82%) and higher unemployment also against national.

Average employment in the business sector in the Kuyavian-Pomeranian voivodeship in August 2016 reached the level of 247.8 thousand people, i.e. 2.4% higher than last year (against a growth of 1.1% in August 2015). The registered unemployment rate amounted to 11.9%, i.e. 1.2 percentage points less than last year (Fig. 3). At the end of August 2016 the number of unemployed registered in labor offices of the Kuyavian-Pomeranian voivodeship amounted to 95.6 thousand persons and was 9.8 thousand people less than in August 2015 (9.3%) and 0.9 thousand persons less (about 0 9%) than in July 2016 (Statistical Office in Bydgoszcz, 2016).

Table 1. Basic statistical data for the Kuyavian – Pomeranian voivodeship

Area:	17,971.34 km^2 *(5.7% of Poland)*
Number of citizens:	2.085 million people *(5.4% of Poland)*
Population density:	116 people/km^2
Unemployment rate:	11.5% *(at 8.5% in Poland)*
Gross domestic product (GDP):	16,835 mln € *(4.5% Poland)*
GDP per capita:	8,052 €/person *(82% of the Polish average, 56% of the EU average)*

The registered unemployment rate in the Kuyavian-Pomeranian Voivodeship at the end of August 2016 stood at 11.9% (in the country was lower by 3.4 percent. p.). In relation to August 2015 was lower than 1.2 percent. p., as compared to July 2016 lower than 0.1 percent. p. Kuyavian-Pomeranian was still among the provinces with the highest unemployment rate, soon after the Warmia-Mazury voivodeship (13.9%).

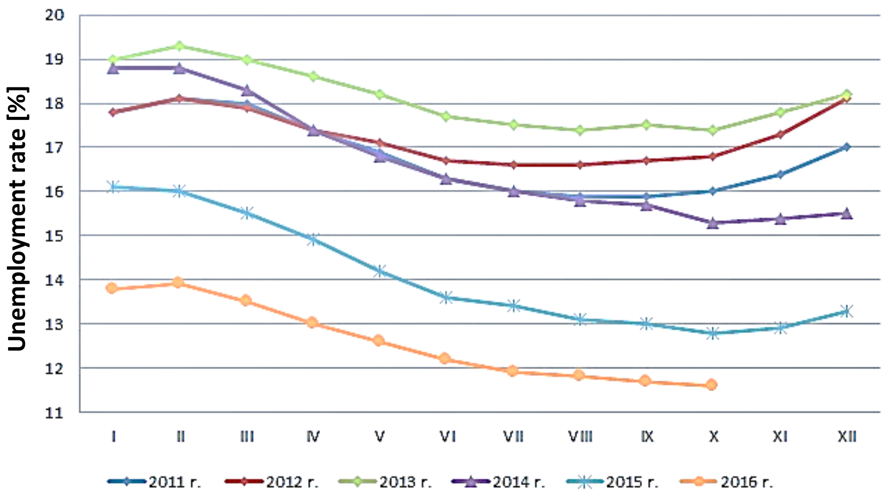

Fig. 3. The unemployment rate in the Kuyavian-Pomeranian Voivodeship (Statistical Office in Bydgoszcz, 2015)

In the Kuyavian-Pomeranian voivodeship to poviats with the highest unemployment rate in June 2016 were districts: lipnowski (21.1% against 20.9% in August 2015), włocławski (20.9% against 21.9%), and about lowest Bydgoszcz (5.0% against 5.8%) and Toruń (6.0% against 7.0% last year). During the year, the unemployment rate decreased in all poviats, to the greatest extent in the districts of: Golub-Dobrzyń (by 3.4 percent. p.) and Chełmno (by 2.6 percent p.) (Fig. 4a). In August 2016 of poviat labor offices registered 11.1 thousand unemployed people, i.e. 5.4% less than the year before and 1.9% more than in July 2016 (Statistical Office in Bydgoszcz, 2016).

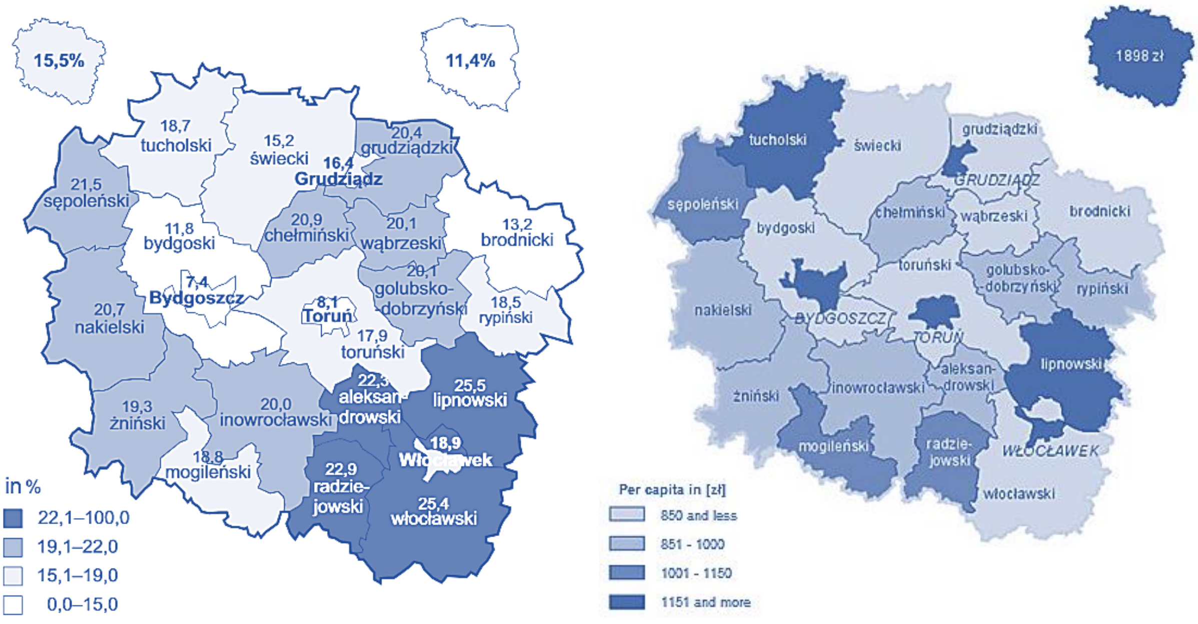

Fig. 4. The unemployment rate in the Kuyavian-Pomeranian Voivodeship (2) – a (Statistical Office in Bydgoszcz, 2015)**, revenue of poviats and cities with poviat status budget - b**

Comparison of living standards is often made on the basis of GDP per capita - it shows in monetary value as the region is rich in comparison with others. That basic indicator does not say much about the distribution of income within one region and does not provide information on non-monetary factors that could significantly affect the quality of life of the population. On the one hand, the uneven distribution of income can be an incentive for people to ensure that mending their situation through work, innovation or acquiring new skills. On the other hand, such income inequalities are often perceived as associated with crime, poverty and social exclusion. Therefore, presented diversity of income budgets of poviats and cities with poviat status (Fig. 4b). The highest values obviously are noted for the largest cities in the Kuyavian-Pomeranian region: Bydgoszcz, Torun and Grudziądz, i.e. higher than 1150 PLN per capita, while the lowest unemployment rate.

Analyzing data on the structure of society can be seen exhibiting the standard of living in major cities of the Kuyavian-Pomeranian voivodeshipe. With a low unemployment rate and highest income, it is worth noting that most of the residents are employed outside the agricultural and industrial (including construction). The following is a variation of employment in the various activities of the market (Fig. 5) on the background of the voivodeship.

Part of the Kuyavian-Pomeranian voivodeship, due to its role in the settlement system of the country and the socio-economic development of the entire country, acquired the status of a Functional Urban Area (pol. MOF). The spatial unit of duopoly character is created by the Bydgoszcz and Toruń zone, consisting of two core centers and an outer zone (Kaczmarek et al., 2013; Śleszyński, 2013; KPBPPiR, 2016) (Fig. 6). Bydgoszcz and Toruń play a special role of the capital cities of the voivodeship (as seats of the Governor and Marshal, respectively), they act as management centers, have the greatest economical, educational and cultural potential and they also play symbolic functions. These cities are characterized by different socio-economic character and the development of regional and transregional functions proves that although in some aspects they are complementary centers, only together they can create agglomeration with a strong potential. The total potential of both cities in respect of regional functions puts such perceived bipolar system at the 6 - 7 position in the country.

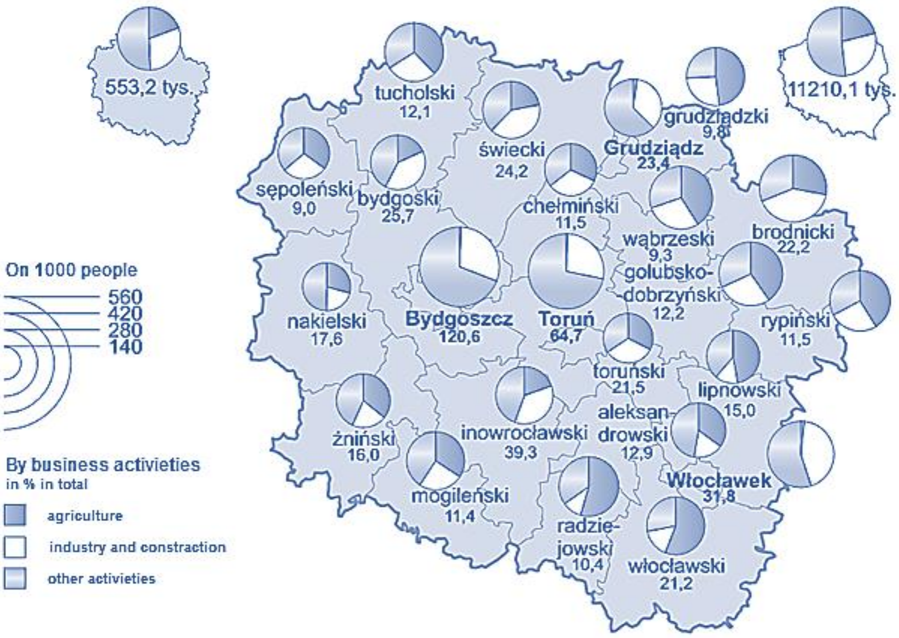

Fig. 5. A variation of employment in the various activities of the market

Problems of the development of Bydgoszcz and Toruń concern mainly: tasks from the scope of the municipal and spatial management, development of transregional functions, revitalization of degraded

Fig. 6. Bydgoszcz – toruń functional urban area (Kaczmarek et al., 2013)

areas, social aspects (progressive ageing of urban population, with simultaneous decrease in the number of population in cities caused by the migration to suburban areas), drawbacks of the inner-city transport system of the cities (inefficiency of transport systems, undetermined transit issue, lack of sections of connecting roads and assuring correct functioning of urban transport systems), insufficient transport connections with other regional centers within and outside the country. Therefore, the problems of Bydgoszcz and Toruń development connect spatial aspects and aspects related to shaping the position of those cities among the European regional centers.

Administratively, the Bydgoszcz – Toruń functional urban area is composed of 19 municipalities, including 2 cores formed by the cities Bydgoszcz and Toruń and 17 municipalities in the outer zone of the MOF (Table 2). The surface area is 3,199 km^2 with the total number of785 thousand residents, including 568 thousand in the two major cities and 218 thousand in the outer zone (acc. to RMRR, 2012).

Table 2. Basic administrative data of the Bydgoszcz – Toruń Functional Urban Area (Kaczmarek et al., 2013)

Major city	No. of municipalities			Area [km^2]			Number of registered residents [thousand]		
	Total	Core	Outer zone	Total	Core	Outer zone	Total	Core	Outer zone
Bydgoszcz	11	1	10	2,069	176	1,893	504	363	141
Toruń	8	1	7	1,130	116	1,015	281	205	77
B-T MOF	19	2	17	3,199	292	2,908	785	568	218
Mean for 18 MOF in Poland	17	-	15	1,793	237	1,531	783	533	249

After 2013 the functional urban area was increased to the total number of 23 municipalities, i.e.: Bydgoszcz, Toruń, Białe Błota, Chełmża (urban municipality), Chełmża (rural municipality), Czernikowo, Dąbrowa Chełmińska, Dobrcz, Koronowo, Kowalewo Pomorskie, Lubicz, Łabiszyn, Łubianka, Łysomice, Nakło nad Notecią, Nowa Wieś Wielka, Obrowo, Osielsko, Sicienko, Solec Kujawski, Szubin, Wielka Nieszawka and Zławieś Wielka. Thus, currently the area is inhabited by 853,007 residents (40.8% of the voivodeship's residents). The cities Bydgoszcz and Toruń are inhabited by 65.7% of residents of the entire area. The population density of the functional area is 228 people/km^2.

Suburban municipalities of Bydgoszcz and Toruń cover the most significantly urbanized area of the entire voivodeship, spatially and functionally strictly connected to both cities. These connections are long-term and solid, and were formed as a result of the development of the core cities and the co-occurring sub-urbanization process, including among others "spreading" of Bydgoszcz and Toruń beyond their administrative borders. The relations of suburban municipalities with the cities Bydgoszcz and Toruń are based on the everyday activity of their residents and have very diverse character: social, economic, administrative, etc.. They are expressed by, among others, increase in the number of residents of suburban municipalities, enterprise development, increased construction traffic in the field of housing development, or large share of every-day commuters to Bydgoszcz and Toruń (KPBPPiR, 2016).

The area of suburban municipalities of Bydgoszcz and Toruń stands out among the entire region by an exceptional dynamics of the occurring socio-economic processes, evidencing the development of spatial structures that are completely different from the typical rural areas, but also different from the traditional urban structure. From the viewpoint of spatial management in the voivodeship, suburban zones of Bydgoszcz and Toruń are characterized by the specificity resulting, among others, from the mentioned suburbanization processes. These processes affected the character of settlement, land use, infrastructure development, as well as the quality and cost of residency. Unfortunately, they also generate a number of unfavorable effects to the natural environment, spatial order, quality of living for the residents – suburban urbanization processes are identified as being among the main problems of the voivodeship management. One of unfavorable aspects of suburban urbanization is scattered and "spread" settlement – newly designed buildings are often situated in areas lacking social and technical infrastructure, which contradicts the idea of rational spatial management (KPBPPiR, 2016).

The cities Bydgoszcz and Toruń and their impact area commonly concentrate a significant amount of the voivodeship's residents, money, infrastructure, socio-economical potential, ability to produce and absorb modern technologies. It is the space for the development of specialized activities with inter-regional or even international range. The concentration of population and management creates a chance for further development of the potential of functions with inter-regional and international character, and therefore for shaping the potential of cities as their elements of a network metropolis. Relatively large potential with perspectives of further increase and the location in the network of constructed or modernized roads of the highest ranks, as well as the presence of the airport, show real predispositions of this area for functioning within the network of European metropolises. One of the most important facts is that the potential of both cities has very large impact on the recognition of the prestige and image of both individual cities as capital centers, and evidences the position and attractiveness of the entire voivodeship as compared to other regions (KPBPPiR, 2016).

When considering the administrative structure of the Bydgoszcz-Toruń functional area, attention must be also paid to Solec Kujawski. It is an urban-rural municipality in the Kuyavian – Pomeranian voivodeship, in the Bydgoszcz poviat. Seat of the municipality is the town Solec Kujawski. At the same time it is a town in the central part of the Bydgoszcz – Toruń functional urban area and the oldest town in the poviat. It is located on the right bank of the Vistula, at a distance of 20 km from Bydgoszcz (west) and 35 km from Toruń (east), by the national road No. 10. The municipality covers an area of 175.35 km^2, inhabited by 16 thousand residents. These values represent 12.6% of the entire area and 15.1% of population of the Bydgoszcz poviat. The Solec Kujawski municipality is characterized by the greatest forestation in the poviat and in the Kuyavian-Pomeranian voivodeship. Arable land covers 16.35 % and industrial areas cover 2.59% of the entire municipality area. The remaining type of land represents 8.98% of the entire area. Forests, being a part of the Bydgoszcz Forest, cover 72.8% of the entire area. The Solec Kujawski municipality also takes an important position in the perspective of enterprise development. This is because a Regional Enterprise Center LLC was created within its borders, which consists of an Enterprise Incubator and an Industrial Park.

Transport infrastructure

Both Bydgoszcz and Toruń are located by the road routes of the European and national levels (Fig. 7). The road of the highest importance, running across the voivodeship, is the route from Gdańsk via Toruń to the south, marked as E75 and in the Polish nomenclature – as DK1. A large fragment of this road has the class of a highway (marked as A1), while the remaining part is the road with G and GP parameters.

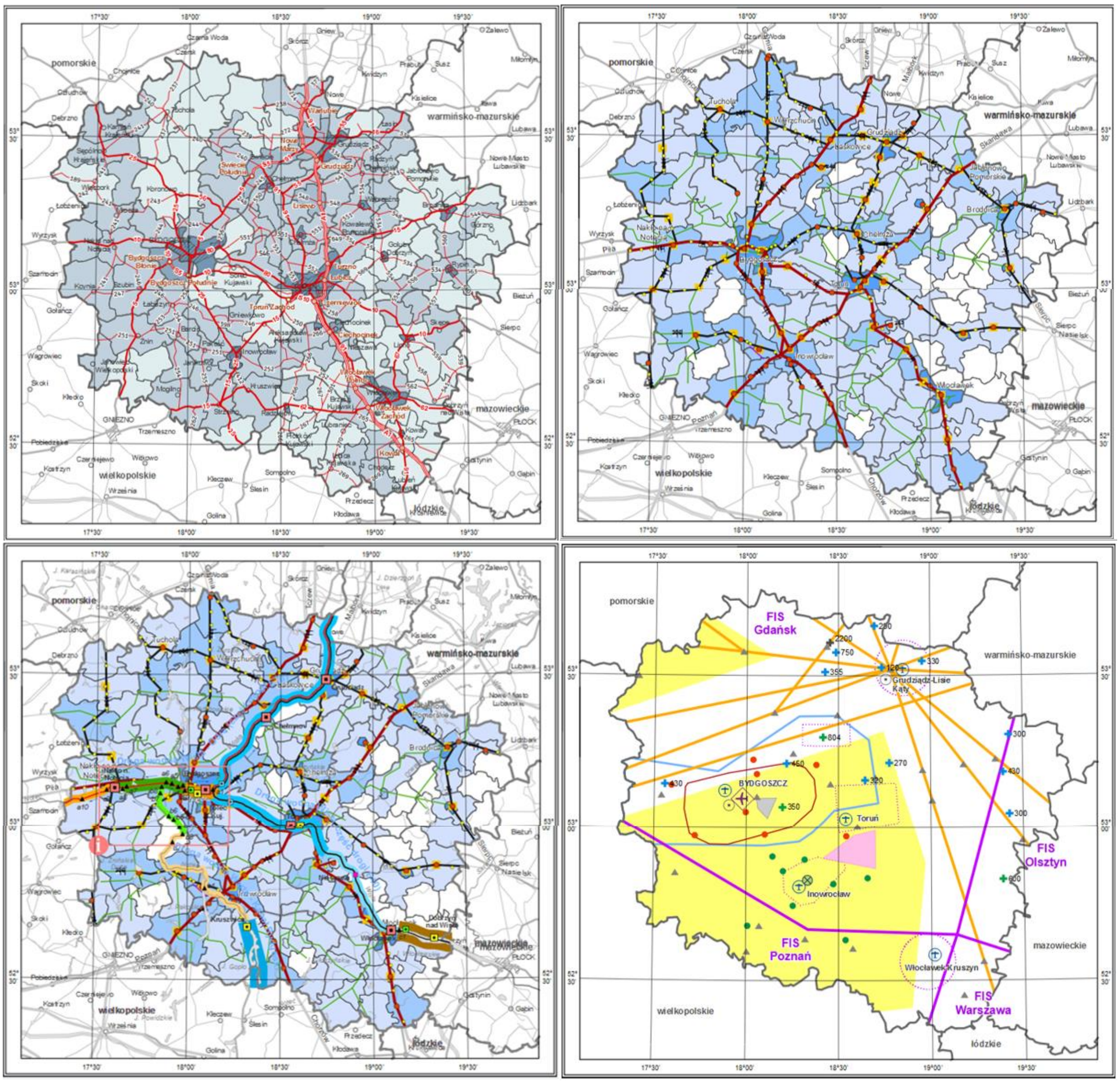

Fig. 7. The Kuyavian – Pomeranian voivodeship's road transport (a), railway (b), inland water transport (c) and air transport infrastructure (d)
(acc. to Internet Atlas of the Kuyavian – Pomeranian Voivodeship)

The second key route of this region is the road E261 from Nowe Marze to Wrocław, which connects, among others, Bydgoszcz with Poznań. Short distances of this road have the parameters of the expressway, in the Polish nomenclature marked as the road No. 5. Another important routes are also the remaining national roads, e.g. DK 10 and 80, connecting Bydgoszcz with Toruń, DK 15 from Wrocław, via Gniezno, Inowrocław and Toruń to Olsztyn, and the road No. DK 25, connecting among others Inowrocław, Bydgoszcz and Koszalin. Voivodeship roads also play the key role in the communication of major urban centers with their immediate hinterland (Kaczmarek et al., 2013). The timely accessibility in the Kuyavian-Pomeranian voivodeship – and at the same time in the Bydgoszcz-Toruń Functional Urban Area – by car is much better than by public transport (Fig. 8, 9).

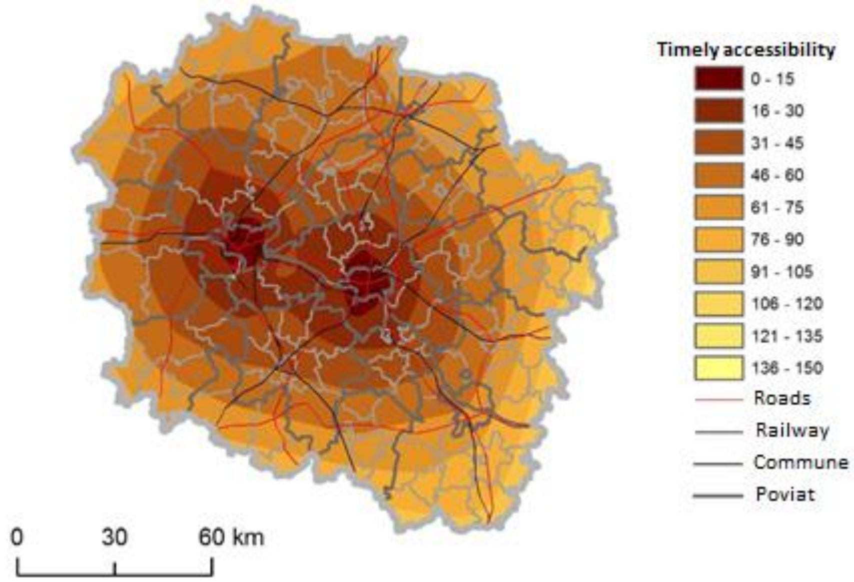

Fig. 8. Timely accessibility of Bydgoszcz or Toruń by car (Kaczmarek et al., 2013)

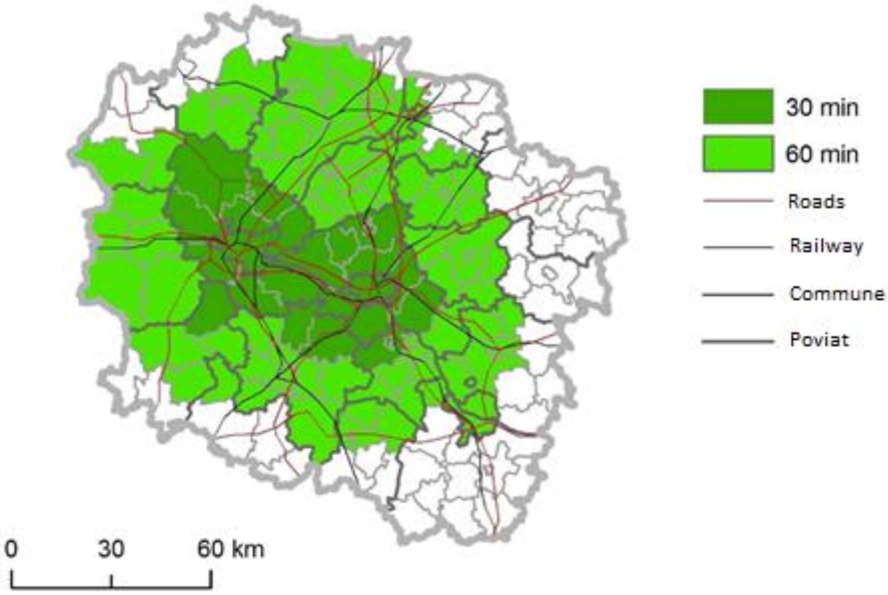

Fig. 9. Timely accessibility by car according to municipalities (Kaczmarek et al., 2013)

The travel time to Bydgoszcz is the shortest from the municipalities of the Bydgoszcz poviat. In most cases, reaching the city center takes 30 minutes. On the other hand, the accessibility within 60 minutes is characteristic for most of the poviat units bordering the country district. A similar situation occurs in the case of commuting to Toruń. The accessibility of a large share of municipalities located in the Toruń poviat to the city center is within 30 minutes. It is clear that the accessibility is significantly affected by the highway. Northbound isochrones deform longitudinally.

Railway lines are another important transport routes. The most important railway line is the so-called Polish Coal Trunk Line, passing through the region and connecting Gdańsk with the south of the country, marked as the line No. 131. The other important railway routes, passing through the core cities of the FUA are also: line No. 353 from Poznań to Skandawa, passing by, among others, Inowrocław and Toruń, as well as the line No. 18 connecting the major cities of the voivodeship (Bydgoszcz, Toruń and Włocławek). Smaller local railway lines also play a significant role in everyday commuting (Kaczmarek et al., 2013).

Another network being a part of the communication lines is Bydgoszcz Water Junction. It is recognized as the most valuable environmental resource in Bydgoszcz City. It is a set of hydrographic features of the Brda and the Vistula rivers, the Bydgoszcz Canal and Górnonotecki Canal and smaller water streams in the city of Bydgoszcz and in its immediate vicinity, along with the buildings and hydro-technical facilities and coastal buildings. Bydgoszcz Water Junction forms part of the international waterways: E70 linking the east and west of Europe and the E40 road connecting the Baltic Sea with the Black Sea. The Water Junction consists of connecting with each other, sewered or navigable waterways with a total length of quays approx. 100 km. Bydgoszcz Water Junction is the link on basins of the Vistula and the Odra rivers and further with the Warta river basin. It is the axis of development of the spatial arrangement of the city.

Bydgoszcz I. J. Paderewski Airport is the 9th largest airport in Poland. Airport is located in the south-western part of Bydgoszcz, 5 km from the city center partially within the municipality of Białe Błota. From the south, east and west is surrounded by the Bydgoszcz Forest, and from the north borders with settlements from Bydgoszcz: Szwederowo and Górzyskowo. he area of the airport is 146 hectares, and the length of the runway 2.6 km. The main destinations of flights from an airport in Bydgoszcz include 7 lines in 4 countries: Frankfurt, Rome-Fiumicino, Birmingham, Dublin, London-Stansted, Düsseldorf-Weeze and Glasgow International. The seasonally are operated additional flights in 4 directions in 3 countries Burgas (Bulgaria), Dubrovnik (Croatia) and Heraklion and Zakynthos (Greece).

<u>Post-industrial areas in the Bydgoszcz – Toruń FUA</u>

Detailed characteristics of individual brownfields of Bydgoszcz - Toruń FUA selected for the Interreg ReSites project should be preceded by a remark that in Poland there is no official catalog of contaminated areas, including brownfields. Such actions are not taken at national or regional level in contrast to policies in countries such as Italy or Germany. However, there are systems containing fragmentary inventory of contaminated areas. Unfortunately, these data are only available for selected administrative staff (including GDEP – General Direction of Environmental Protection, RDEP – Regional Direction of Environmental Protection) and do not represent the public domain. Subsequently described industrial areas were selected on the basis of the experience of officials of local units, knowledge and research of scientific institutions and documented strong environmental contamination from the point of view of valuable sites in the perspective of giving them new utility functions.

The "Zachem" Chemical Plant in Bydgoszcz: One of the oldest and at the same time largest in Poland, Chemical Plant "Zachem" JSC (Fig. 10), administratively is located in the Kuyavian – Pomeranian voivodeship, Bydgoszcz poviat, within the borders of the borough City of Bydgoszcz. It is located in the south-eastern part of the city, at a distance of approximately 7 km from the center. In the aspect of geographic regionalization, the Chemical Plant is located in the Central European Plain province, South Baltic Lakeland subprovince, macroregion of the Toruń – Eberswalde Glacial Valley and in mesoregion of the Toruń Basin (Kondracki, 2009), which is reflected in the climatic and hydrological conditions of the studied region.

The discussed study area has a surface of approximately 2,000 ha. Currently, a number of independent entities have their offices in the area occupied by the “Zachem” Chemical Plant before 1992. Most often they lease buildings, which at their expense have been adjusted to conduct various business activities. These entities have separate contracts for the supply of energy, water and discharge of sewage to the sewerage system. Some of the business operators purchased the grounds with buildings where they operate from the Chemical Plant. Therefore, in this paper the term – area of the “Zachem” Chemical Plant is a historic and conventional term, referring to the area occupied by the Chemical Plant in Bydgoszcz before the year 1992. The entire area has been included in the preliminary studies due to the high potential risk to the soil and water environment.

Fig. 10. The “Zachem” Chemical Plant in Bydgoszcz, bird's-eye view (source: Agencja Gazeta)

Factory of railway sleepers preservation in Solec Kujawski: Brownfield in Solec Kujawski is the area of former „The State Enterprise of Railway Sleepers Preservation” located in the eastern part of the town at 2 Kujawska Street. The area in question covers 16.44 hectares (Fig. 11). The area is located in the neighborhood of a multifamily housing estate, “JuraPark” entertainment and education park, objects of Sport and Recreation Centre with a swimming pool, sports and entertainment hall and sports stadium.

The area was in continuous industrial use from the end of the 19th century - leading to a steadily increasing contamination by a type of strongly harmful waterproofing oil (creosote). In 2001, the production of sleepers was ended, but the area degraded further after the sale to private investors. All buildings and installations were destroyed, leftover creosote was poured away onto the ground and oil residues were put on fire (Fig. 12). Strong contamination of the area with groups of compounds PAH, BTEX and phenols prevented even an industrial re-development. Due to the size and strategic position of the area in the central part of the city - authorities of Solec have decided to purchase the land and remediate it. The land was purchased in 2008, and an effective remediation project was developed in 2011-2012. Conceptual design of “in situ” method for cleaning the area was developed.

In the recent period (2013-2016) the area was subjected to remediation of soil and partially groundwater due to the work of co-financing from EU funds (Operational Programme ‘Infrastructure and Environment’). After the earth and purifying works area is still undergoes a bioremediation process. It is necessary to monitor the area, revitalization and reactivation consistent the social needs of the city residents.

Fig. 11. Brownfiels in Solec Kujawski, bird's-eye view (property of the commune)

Fig. 12. The mosaic and heavy contaminated soil in the area of railway sleepers preservation factory in Solec Kujawski (by W. Irmiński)

In the light of the objectives of the Operational Programme 'Infrastructure and Environment' a remediated land needs to be maintained as an renaturalized area for a period of 5 years (hence in Poland such projects typically aim to restore the productivity of the soil – the so-called land rehabilitation). Despite choosing the right remediation technology for the aeration layer, traces of creosote remain at larger depths, contributing to long-lasting contamination of some of the groundwater. This has an adverse effect on neighboring regions designated as residential, recreational and sports areas. During the lifetime of the project, the city cannot offer this area to private investors, however, long term land-use plans designate it as urban reserve intended for recreation. Objects and areas with this group may gain in value after finding investors/tenants, even without change of ownership (City), and currently constitute a reserve. Having public ownership allows the city to apply for aid from both the national funds and the EU e.g. for remediation.

2. Detailed assessment of former "Zachem" Chemical Plant in Bydgoszcz City

2.1. Historical background of a production in a chemical plant

The most important aspect in characterizing the condition of natural environment, and thus for the identification of soil and water environment pollutants in the vicinity of the "Zachem" Chemical Plant is identifying all substances used in the manufacturing processes. It is therefore necessary to conduct a detailed study of the history of production conducted in Bydgoszcz.

Until 2013 the Chemical Plant "Zachem" in Bydgoszcz was among the largest producers of organic chemistry on the Polish market. The study of the archival topographic maps shows that the Chemical Plant was established at the exact place of the former German explosives factory built during the Second World War (Schiegel, 1878; Sckerl, 1878). *Dynamit-Aktien Gesellschaft (DAG) Fabric Bromberg* was a huge armaments factory, designed for military tasks of the Third Reich. It was established nearby Bydgoszcz in 1939 – 1945. The most rapid development of the plant for the secret production of gunpowder and ammunition filling, due to the hard work of forced laborers, falls in the period of the Nazi regime. The main products of the DAG in the Bauleitung I (Kaltwasser) zone was nitrocellulose ($C_6H_7O_{11}N_3$), smokeless gunpowder and nitroglycerin ($C_3H_5N_3O_9$). Products of the Bauleitung II (Brahnau) zone included TNT ($C_7H_5N_3O_6$), dinitrobenzene ($C_6H_4(NO_2)_2$), V1 missiles, as well as aircraft bombs, artillery shells and fuse loads (Pszczółkowski, 2011). Mass production of gunpowder was started by the facility director Adolf Kämpf in July 1942, being systematically increased over time. In 1944 a total of 13.7 thousand tons of material was produced. Nitrocellulose production had not been started until 1943 and TNT – until January 1945, while even later the production of nitroglycerine was also undertaken (Pszczółkowski, 2011).

February 1954 is considered as the symbolic beginning of the "Zachem" Chemical Plant in Bydgoszcz, while the production was resumed in 1948 when blasting materials for mining were initially produced. Then the production was adapted for both military and civilian needs, when TNT, pentaerythritol tetranitrate and tetryl were produced. After five years dyes, dyeing intermediates, pigments and phenol started to be produced. Dinitrotoluene (DNT), nitrobenzene, aniline and products made from recycled PVC were also manufactured. Moreover, acid denitration and nitration acid management was conducted.

In the beginning of the 60s of the previous century experimental installations for the production of isocyanates, diene and polycarbonate were tested in the Chemical Plant. Studies for the construction of polyurethane complex were conducted and in the next decade the Plant invested in the production of flexible polyurethane foams, installations for electrolysis of brine, phosgene, DNT, toluene diamine (TDA), toluene diisocyanate (TDI) and epichlorohydrin (EPI) as well as rigid foams and fittings from polyurethane foams for the automotive industry. The production profile of the Chemical Plant evolved over the decades, having regard to the needs of the market and the political and economic situation of the country. It was also affected by the investment stagnation, which in the previous century resulted from economic difficulties of Poland. Basic and most important products manufactured in the Chemical Plant in the last period of its operation included toluene diisocyanate TDI, allyl chloride, epichlorohydrin EPI, hydrochloric acid, sodium hydroxide and sodium hypochlorite. Polyurethane foams were among the products manufactured on a large scale. These compounds (polyurethanes PUR or PU) are polymers that are produced by addition polymerization of polyfunctional isocyanates and amines and alcohols.

The primary feature distinguishing polyurethanes from other polymers is the presence of urethane groups [-O-CO-NH-] in their main chains. Quantitatively, polyurethanes are most importantly used in the production of foams. PU foams are used in furniture industry (upholstery and mattress sponges), automotive industry (upholstery sponges, rigid bumper foams, interior parts, shock absorbers) as well as footwear and textile industry (fabrics with spongy linings, insulation fabrics). The last application of these products include bath sponges and various insulating materials, sealing fillers, binders and adhesives.

On March 14th 2014 the company went bankrupt and its assets are managed by the trustee.

2.2. Environmental status description and critical aspects

2.2.1. Geological structure

Complex geological structure in the area of the “Zachem” Chemical Plant in Bydgoszcz is one of the key factors determining the conditions for the migration of pollutants in soil and water environment. Detailed study and understanding of the structure with emphasis on the morphology of the aquifer floor as well as poorly permeable inserts, are the key elements to characterize the natural environment condition. During the operation of the Plant a considerable amount of geological boreholes was made, however, due to their uneven distribution and small depth (these were mainly geological-engineering boreholes, 5-10 m deep) understanding of the geological structure is incomplete and in many parts of the Chemical Plant’s is limited to the top part of Quaternary deposits (Fig. 13).

Mesozoic rocks are mainly related to the sea deposition. Jurassic deposits are fragmented and occur in the western part of the Chemical Plant and lithologically they are represented by shales, slates and marls. Cretaceous deposits are represented by limnic, brackish-sea and sea sediments, belonging to the Lower (Berriasian, Valanginian, Hauterivian, Aptian) and Upper Cretaceous (Cenomanian, Turonian, Santon) (Kozłowska, 1992). In the area of the Chemical Plant the roof of the Cretaceous deposits lies on the ordinate -60 ÷ -40 m asl. However, lithologically, Cretaceous deposits in the Bydgoszcz region differ strongly from the limescale sediments, through shales and silty-clay sediments to fine-grained sands.

Cenozoic rocks are the Paleogene (Oligocene sediments, unconformably overlying on Cretaceous deposits), Neogene and Quaternary. Miocene deposits of the Neogene are built of lithologically diverse deposits, both quartz sands as well as clays and silts and muds. A characteristic feature of these rocks is the high proportion of dispersed organic matter, as well as independently existing layers of brown coal. Roof of the deposits lies on the ordinate of 15 ÷ 30 m asl. Thickness of deposits ranges within 30 ÷ 50 m. Pliocene deposits of Neogene are locally preserved. They were repeatedly destroyed and deformed. The overlying layers are disrupted by inserts of clay and brown coal deposits. Pliocene deposits are exposed on the surface at the edges of the Vistula valley and at the edges of the valley terraces, as well as nearby Bydgoszcz – Łęgnowo. Thickness of the deposits is varied and depends on the denivelation of roof, which is situated on the ordinate of 30 ÷ 40 m asl. The boundary separating the Neogene from the Quaternary is polygenic surface, on which Pliocene, Miocene or Oligocene and Cretaceous sediments are exposed.

Complex geological structure of the ground at the “Zachem” Chemical Plant in Bydgoszcz results from large lithological (and tectonic) diversity of Quaternary deposits. These rocks are key in the perspective of the terrain characteristics and the possible contamination of the natural environment, including the pollution of soil and water. The location of the “Zachem” Chemical Plant in Bydgoszcz within the Pomeranian Wall played a significant role in the formation and preservation of Quaternary sediments. Vertical movement upwards, raising the Pomeranian Wall began in the Upper Cretaceous period. The tendency of raising the Pomeranian Wall caused that glacial sediments of reduced thickness were accumulated during glacial periods in this study area. In general, thickness of the Quaternary sediments, with the exceptions caused by anthropogenic factors, is small (Kozłowska, 1992). In interglacial periods the processes of surface denudation were on the other hand intensified. A large river valley was formed during the Eemian interglacial. Waters of this river flowed through the south-eastern region of Bydgoszcz, further reaching Solec Kujawski, where they connected with the river valley of the ancient Vistula, known from the literature.

The Quaternary deposits in the area of the Chemical Plant are represented by Pleistocene, undivided Quaternary and Holocene sediments. The study area is covered by a complex of Quaternary deposits with the thickness from 0 to 170 m. The distribution and thickness of the sand-gravel complex and boulder clay with silt and muds are varied. The Vistula and Brda valleys are dominated by different grain size sands with the thickness from a few to several meters, while in the Vistula valley they are covered with alluvions and peats with the thickness up to 5 m. In the Brda valley there are places lacking Quaternary sediments. North-eastern part of the ancient valley is characterized by a sand-gravel complex, overlying the Pliocene clays, with the thickness of 15 ÷ 25 m. This complex is covered with a discontinuous layer of boulder clays, frequently cut by inserts with sands and muds, with the thickness of 8 m. The overlying layer is formed of sands with different grain size with the thickness up to 5 m, as well as eolian fine-grained sands.

Two Quaternary fossil valleys have been found within the area of the Chemical Plant, where the Neogene sediments are strongly reduced or absent. The valley, with the WSW – ENE course is the deepest in the studied area and cuts into the Cretaceous deposits up to a depth of about 80 m (ordinate of approximately -20 m asl). It is filled with boulder clays. Another fossil valley, much shallower, with the NW-SE course, is filled with different grain size sands and gravels and cuts up to the ordinate of -30 m asl. The course of the remaining valleys is unknown, because so far they have been studied by one or two drillings (Narwojsz, 1989). The Holocene sediments occur in the area of the Vistula floodplain terraces and within a narrow strip along the Brda river. Within the terraces (thickness of 1 – 2 m) there are sands and gravels on alluvial soils.

Legend to Fig. 13 (pp. 20): 1 – ${}_{t}Q_{h}$ torfy; 6 – ${}_{ma}Q_{h}$ silts and clay, in places mixed with sand (alluvial); 9 – ${}^{f}_{p\dot{z}}Q^{t}_{h}$ sands and gravels of the river floodplain terrace; 13 – ${}^{e}_{p}Q$ aeolian sands; 14 – Q^{w} aeolian sand in the dunes; 16 – ${}^{f}_{p\dot{z}}Q^{2\ tI-tVIIIb}_{p4}$ sands with gravels river flood terraces (I, IIa, IIb, III, IV, V, VI, VII, VIIIa, VIIIb); 25 – ${}^{fg}_{p\dot{z}}Q^{2\ P}_{p4}$ glaciofluvial sands with gravels; 27 – ${}^{g}_{g}Q^{2\ L}_{p4}$ clays; 29 – ${}^{fg}_{p\dot{z}}Q^{2\ L}_{p4}$ glaciofluvial sands with gravels (in places river); 30 – ${}^{g}_{g}Q^{1}_{p4}$ clays; 31 – ${}^{fg}_{p\dot{z}}Q^{1}_{p4}$ glaciofluvial sands with gravels; 33 – ${}_{im}Pl_{1p3}$ clays, silts, lignite and brown coal - the upper layer Poznań; 35 – ${}^{gc}_{p\dot{z}}Q^{1}_{p4}$ sands with gravels, gravel and boulders moraine; 36 – ${}^{fg}_{p\dot{z}}Q_{p}$ 3-4 river sands and gravels (c - a series of sediment); 39 – ${}^{g}_{g}Q^{2}_{p3}$ clays; 40 – ${}^{fg}_{p}Q^{2}_{p3}$ glaciofluvial sands; 41 – ${}^{b}_{i}Q^{1}_{p3}$ clays, silts and sands dammed; 42 – ${}^{g}_{g}Q^{1}_{p3}$ clays; 50 – ${}_{Tr,Cr}Q$ clays, silts, sands and clays with lignite and tertiary marl and limestone chalk as ice in Quaternary; 53 – ${}_{p}M_{3a}$ quartz sands and silts and clays with interbeds of brown coal - layer Adamów; 54 – ${}_{p}Ol_{3}$ quartz sands with inserts silt and lignite; 55 – ${}_{m}Ol_{1}$ m+cz Part silts clay, mudstone, clay and claystone with glauconite - layer Mosiński and Czempiński unseparated; 59 – ${}_{p}Cr_{al}$ sands of fosforytami and glauconite and marl; 60 – ${}_{p}Cr_{h}$ sands and sandy claystone - marl; 61 – ${}_{m}Cr_{v}$ siltstones, mudstones and claystones with siderites; 62 – ${}_{mc}Cr_{b}$ mudstones, silts, clays marl, limestone and sandstone

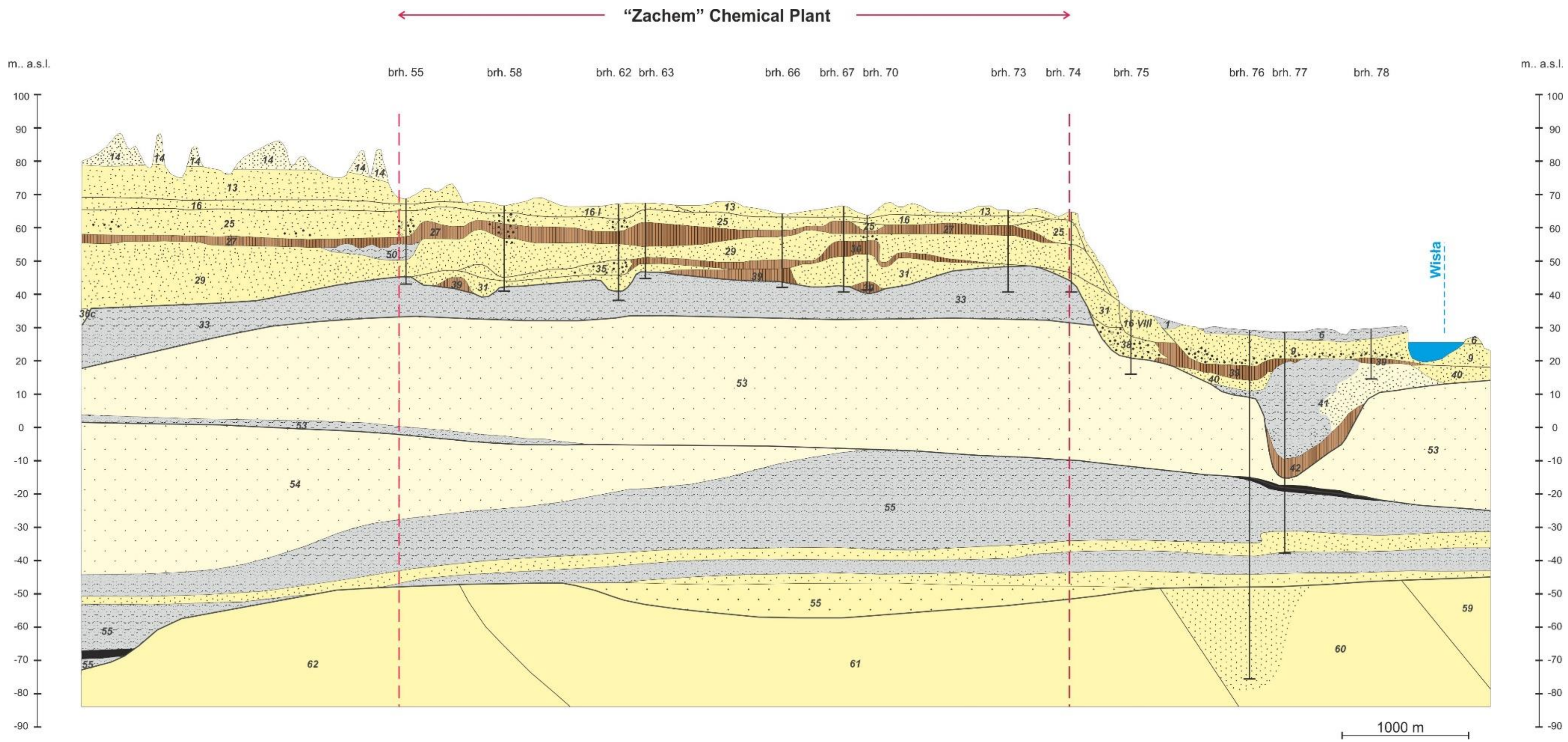

Fig. 13. Geological cross section in the area of former „Zachem" Chemical Plant in Bydgoszcz (Pietrucin, 2015)

These are mainly fine-grained sands with small interbeds of medium and coarse-grained sands with gravels. The deeper parts of the Vistula valley are dominated by medium- and coarse-grained sands with gravel interbeds. The thickness of sediments reaches up to 15 m. Locally there are also muds and clays mixed with sands, sandy and peaty alluvions, bulk sands and gravels of shallows and riverbeds, as well as peats.

2.2.2. Groundwater quality and its impact on superficial water

The main surface watercourses, which flow in the vicinity of the former "Zachem" Chemical Plant are rivers Vistula and Brda. Vistula is the longest, 1,047 km-long, Polish river, flowing into the Baltic Sea. It enters the Gulf of Gdansk and its mean annual flow in the estuary section is 1,046 m^3/s. In the neighborhood of the Chemical Plant it forms the so-called Bydgoszcz Vistula river bend, which is the part of the Bydgoszcz Water Junction and forms the natural eastern border of the administrative area of Bydgoszcz over the length of 13.8 km, from 768.2 to 782.0 kilometer of the Vistula. The river is approximately 500 m wide with the maximum depth of on average 3 to 4 m, and the flow of approximately 90% of the one recorded at the mouth of the Vistula to the sea. A characteristic feature of the bend of the Vistula River is the environmental asymmetry between areas situated to the west and east of the river. The left bank is the area within the Bydgoszcz city borders, strongly anthropogenically transformed. The right bank (inside of the bend) is occupied by environmentally valuable floodplains. Water in the Vistula in the Bydgoszcz section, biologically, physico-chemically and hydro-morphologically represents class II of water quality. Status/ecological potential of the river water is good, as well as its chemical condition. It is worth noting that at the outflow of the river Vistula from the region of the former "Zachem" Chemical Plant in Bydgoszcz, the quality of water in the river deteriorates, resulting in its moderate condition (WIOŚ, 2015).

Brda is a left tributary of the Vistula, with a length of 238 km and catchment area of 4,627 km^2. Mean flow increases along its course from 1.25 m^3/s in Nowa Brda town to 19.9 m^3/s in the middle course to 27.8 m^3/s in its lower reaches. Brda is characterized by the lowest flow fluctuations in Poland, as a result of: (a) large number of lakes, (b) dam reservoirs in its lower reaches, (c) permeable substrate and forestation of the area, which promotes water infiltration and underground supply of the river, (d) small precipitation (average of 545 mm) (Frączak, 2005; Walenty, 1928). The river Brda is among the cleanest rivers of the Kuyavian-Pomeranian voivodeship. Water quality throughout the river course is good (class I and II) and only over the 10-km estuary section its waters are of class III.

The hydrographic network within the area of the former Chemical Plant, in addition to the rivers Brda and Vistula, is composed of drainage ditches, settling tanks, pumping stations and retention reservoirs in the north-eastern part of the area. Anthropogenic reservoirs were used for the retention and filtration of surface water. Fish ponds and small lakes situated in glacial depressions were also inventoried.

The main rivers of this area, i.e. the Vistula and Brda, are of draining character and constitute regional bases of groundwater drainage. The general water flow is towards their direction, to the north-east to the Vistula and to the north to its left tributary - Brda. This is because the local groundwater watershed runs through the area of the Chemical Plant. In the area of the "Zachem" Chemical Plant normal waters occur in Mesozoic and Cenozoic deposits up to the depth of approximately 500 m (Kozerski, 2000). Three aquifers have been recognized: Cretaceous, Neogene and Quaternary.

Cretaceous aquifer is composed of two levels: Lower Cretaceous occurring within the sands and sandstones, and Upper Cretaceous associated with the carbonate deposits. These deposits form levels with porous, fissure and porous-fissure waters. The aquifers are locally isolated with claystones and mudstones of the Lower Cenomanian. However, due to discontinuous isolation, both aquifers form a common hydrodynamic system of water circulation (Kozerski, 2000). The main aquifer, commonly exploited in Bydgoszcz is the Lower Cretaceous level. Groundwater level is of confined character and stabilizes at the ordinate of 43 ÷ 45 m asl (Narwojsz, 2007).

The main aquifer of the Neogene layer is the Miocene level that occurs in fine-and medium-grained silty sands. It is isolated from the Quaternary and Cretaceous levels by a layer of poorly permeable clay. Locally, however, in the Vistula valley and within the fossil valley it connects with Quaternary sands, forming one Neogene-Quaternary aquifer with free water table (Narwojsz, 1989). In the area of the “Zachem” Chemical Plant the Vistula valley forms the most extensive zone of hydraulic contact. This area is dominated by one Neogene—Quaternary aquifer.

Complex geological structure in the area of the “Zachem” Chemical Plant in Bydgoszcz implies complex conditions of groundwater circulation. This situation is particularly evident in the Quaternary aquifer, frequently exploited in the Plant. Deposits which form this aquifer are genetically associated with fluvioglacial deposits with highly diverse granulation – from silty sands to gravel. The aquifer is supplied by groundwater infiltration from the overlying, subsurface layer and by infiltration of precipitation water. Thickness of the main aquifer is 15 ÷ 20 m, and in the fossil valleys - up to 80 m. Filtration coefficient reaches on average $1.5 \cdot 10^{-4}$ m/s.

During the operation of the plant there was another subsurface Quaternary aquifer distinguished, occurring in sands over boulder clays, isolating the main aquifer. The thickness of this aquifer is 2 ÷ 3 m, in some places exceeding 5 m. Groundwater table is of free character, highly dependent on the amount of precipitation. Detailed characteristics of hydrogeological conditions of the discussed layer is difficult due to the small number of manholes, diverse morphology of clay roof and small thickness of this layer. Moreover, groundwater flow directions in the area of the Chemical Plant are disturbed by highly developed utilities: pipelines, sewers and other underground equipment which forms the preferred flow paths in this aquifer. In a considerable fragment of the area this aquifer occurs after intense rainfall or in wet years. Additional supply of this layer was artificial during the operation of the Chemical Plant. This process took place in the area of irrigation fields of the urban water supply system, ash landfill of the power plant, sedimentation pond and aniline sludge landfill, as well as by leaks from the collectors and pipelines. According to the literature, the subsurface layer connects to the main aquifer in two large hydraulic contact zones, mainly in the southern part of the Chemical Plant and in the Vistula valley.

Recognition of the hydrogeological conditions of the area Chemical Plant "Zachem" in Bydgoszcz dates back to the early 20th century. The first boreholes and wells were made in the years 1939 - 1945, when the workers of the Third Reich erected combine of secret production of gunpowder and fulfillment of ammunition belonging to the Dynamit Aktien-Gesellschaft company (Pszczółkowski, 2011). With the development of the plant for 75 years of operation, additional holes were drilled and a grounwater monitoring network was widened. Description of hydrogeological conditions of the research area is based on data from 10 drilled wells (including 3 old German, deep to Cretaceous) and about 120 piezometers as well as measurements of the flow of surface water, springs, leakages and model research (Czop, 2010). Currently, after a critical assessment of the monitoring network on the remaining area of the former “Zachem” Chemical Plant in Bydgoszcz, in the area of 1600 ha are approximately 100 active holes (mostly piezometers) to measure the depth of groundwater level and sampling groundwater. Due to the fact that present monitoring network was designed in the '80s of the last century, does not meet the requirements currently posed and commonly known in practice hydrogeological. The study of groundwater quality in the area of brownfield, conducted by the AGH University in Krakow, based on the methodology individually adapted to the geological - hydrogeological conditions in the area of research.

The quality of groundwater is of mosaic character, i.e. in the area of the former "Zachem" Chemical Plant in Bydgoszcz there are areas of clean waters, drawn for drinking purposes with class I of quality and good chemical status, but there are also areas of water highly contaminated due to industrial activities with V class quality and poor chemical status. Uncontaminated groundwater of the Quaternary aquifer is characterized by the $Ca\text{-}HCO_3$ hydrogeochemical type and mineralization values from 242 to 406 mg/L. On the other hand, waters heavily contaminated (Fig. 14) with co-occurring inorganic and organic substances occur within plumes of contaminated water, genetically associated with surface pollution hotspots.

Differentiation of the quality of groundwater and the co-existence of clean water and heavily contaminated is evident in the results of the regional hydrogeological modeling (Fig. 13). The main purpose of performed research was to create a reliable regional hydrogeological model for the region of "Zachem" Chemical Plant in Bydgoszcz based on real measurement data from existing piezometers. In the next stage of the research were carried out prognostic simulations characterizing the migration of pollution existing in the groundwater flow and coming from potential sources of pollution. Assuming the worst case scenario of migration of pollutants focuses on conservative components, i.e. non-undergoing any reactions with the liquid phase (water) and solid phase (ground) during the movement in the stream of groundwater. As a conservative component (non-reactive) was chosen to research model - chloride ions (Cl^-), migrating in the aquatic environment with the speed of the water. Such an approach to the problem gives the possibility of use the Modpath module to visualize the directions of movement of pollutants and the range of groundwater contaminant plumes.

Among the main inorganic pollutants one should mention chloride (Cl^-) and sodium ions (Na^+), while among organic pollutants there are phenol, AOC substances, diphenyl sulphone, hydroxy biphenyl, oktylphenols and oktyl-phenyl-oxy-ethylene esters as well as chlorinated methanes and ethenes. Chemical analyzes of groundwater, referred to hydrogeochemical background, indicate that the entire area of the "Zachem" Chemical Plant in Bydgoszcz should be treated as polluted, and even as constituting an average-area pollution hotspot.

The results of the regional numerical modeling was verified on local models made for individual pollution sources with much greater precision mapping of the geological structure of the rock mass. Model layers were developed in terms of their morphology and variable thickness which from the point of view of accuracy of model research is more appropriate to use than the methodology of flat layers of constant thickness. To map an actual conditions of migration of organic and inorganic substances in the aquifer were performed 3 scenarios of migration models. They are intended to illustrate the diverse nature of the spread of contamination with regard to their physic-chemical properties. Modeling of contaminants migration was carried out using a computational engine MT3DMS V.5.1., and sources of pollution were simulated with boundary condition for the migration Constant Concentration. Assuming the worst case scenario of migration of pollutants focuses on conservative components chloride ions (Cl^-) were chosen as migrating in the aquatic environment with the speed of the water (Fig. 15).

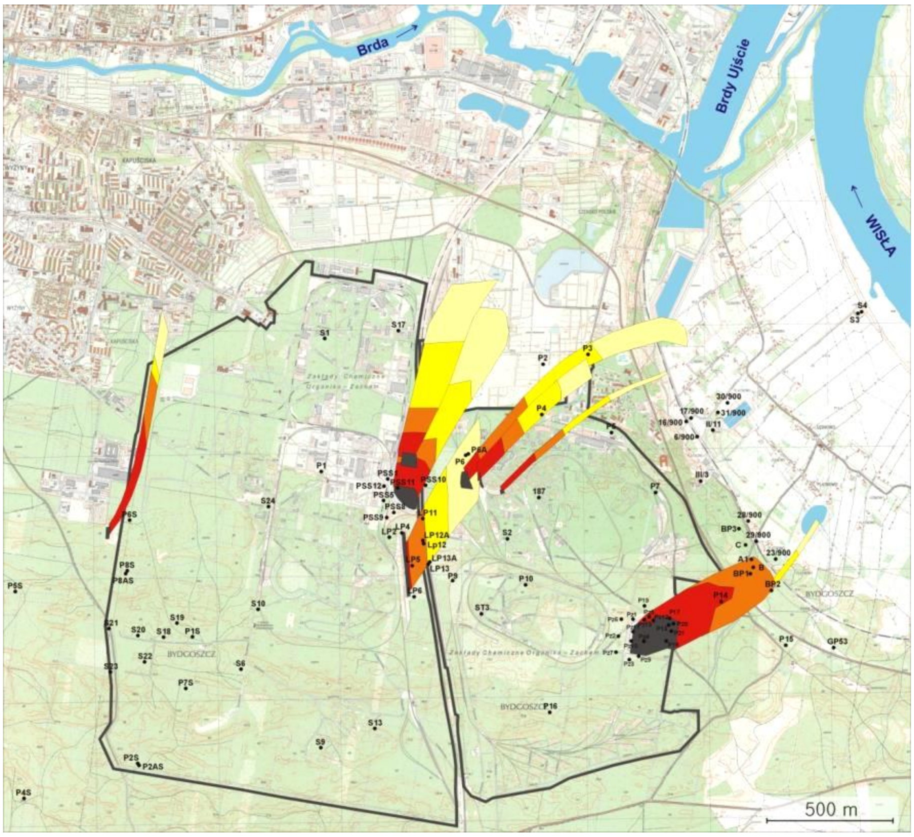

Fig. 13. Contaminant plumes from sources of pollution located in the area of former „Zachem" ChP in Bydgoszcz based on regional numerical modeling (Czop, 2010)

Migration ranges in specified time are marked by colors: black color – sources of pollution, red – 25 years, orange – 50 years, yellow – 75 years, cream – 100 years

The results clearly show that the prognostic ranges of contaminant plumes as a result of the regional model, in fact, they are much greater.

Fig. 14. Heavily contaminated groundwater and a 0.45 µm filter before and after filtration of water

(by D. Pietrucin)

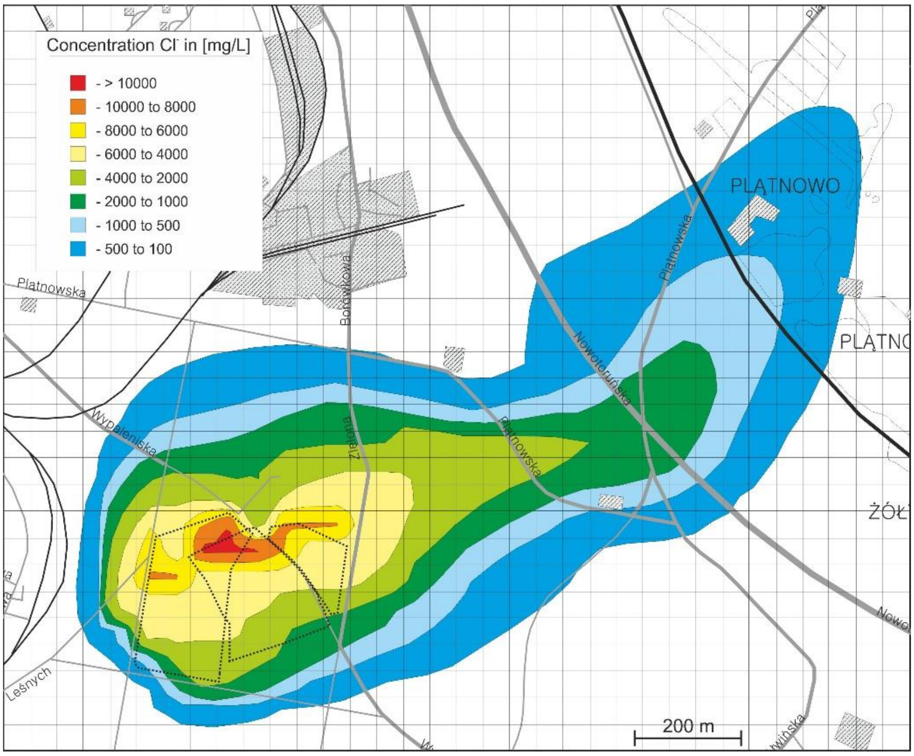

Fig. 15. Map of chlorides (Cl-) migration in the area of „Zielona" industrial waste site (Pietrucin, 2015)

(contaminant plume represents t = 18250 dni, i.e. 50 years = state at 2015)

2.2.3. Soil quality

Most soils within the city borders were created from light sandy and sandy-loam deposits. Leached pseudopodsolic soils, formed from loose dune or loamy sands, are predominant in this area. Soils have generally acidic to neutral pH and are characterized by high content of phosphorus, mean content of potassium and low magnesium content (POŚ, 2012). The analysis of pollution of soil and ground, an element of soil and water environment, in industrial areas is a relatively difficult and complex task, during which one must determine not only the amount and type of pollutants, but also the source of their origin. The quality of soil and ground is strongly associated with the location of individual pollution hotspots within the area of the Chemical Plant, therefore it is of mosaic character, similarly as in the case of groundwater (Fig. 16, 17). It should also be noted that the pollutants may occur in different forms and differently affect the natural environment components.

Soil and ground pollution is most frequently the result of an event occurring in the area, where as a result of different types of incidents, including failures, various forms of pollutants are emitted, i.e.: (a) solid – e.g. by dusting, spreading or exhaustion of solid pollutants from landfills, (b) liquid – penetration of pollutants from the surface to the ground, followed by further infiltration to groundwater, often resulting from failures such as perforations in sewer systems and pipelines of liquid materials (e.g. fuels, chemical solutions and brines) or direct pouring of solutions and wastewater onto the ground. Liquid pollutants have a great ease of penetration to the surface layer of the ground and may leak into its deeper parts. The same effect has the process of dissolution of solid pollutants released into the environment by rainwater, followed by the penetration of this solution into the ground. Soil contamination at great depths, particularly including the watered area, is usually the cause of emissions of substances from the surface hotspot, which results in the groundwater contamination and then side arrival of contaminant plume to a certain area of the ground even at a depth of several to several dozen meters away from the primary pollution hotspot. The zone of contaminated ground is determined by the direction and velocity of groundwater flow.

Fig. 16. Soil contaminated with phenol in the area of „Zielona" industrial waste site (by D. Pietrucin)

Fig. 17. The recrystallized sodium sulfite heavily contaminated with phenol (by D. Pietrucin)

Environmental reports and geological documentations showed that in the areas of clean water occurrence, soil and ground is also of natural and uncontaminated character. These are areas situated mostly in the south-western region of the post-industrial area. The number of landfills and potential pollution hotspots increases towards the north-east. In these areas the grounds are polluted and in the immediate vicinity of landfills and/or below them they are heavily polluted with toxic organic substances of carcinogenic and mutagenic character. The maximum measured concentrations of e.g. 2-phenylphenol (biphenyl) reached 22,000 mg/kg in dry matter and phenol - 8,960 mg/kg, whereas within the landfill body – 74,030 mg/kg (Andrzejewski, 2010). These results clearly indicate that in some parts the grounds are saturated with pollutants and their type is directly related with the production profile of the facility and the type of substances deposited in landfills.

During the AGH study is accomplished a series of tests on soil samples collected in the field. Material derived from boreholes, both from the landfill, and the unsaturated zone below the landfill, were subjected to leaching tests (PN-EN 12457-2: 2006). The tests were performed on 24 samples at L/S=2 and L/S=10, depending on the amount of material available. Eluates after filtering (0.45 µm) and the measurement of physical and chemical parameters (EC, redox potential, pH, temperature) were analyzed to determine the concentrations of organic and inorganic substances. The test results allowed to determine a vertical variation of contaminants present in the unsaturated zone (Fig. 18).

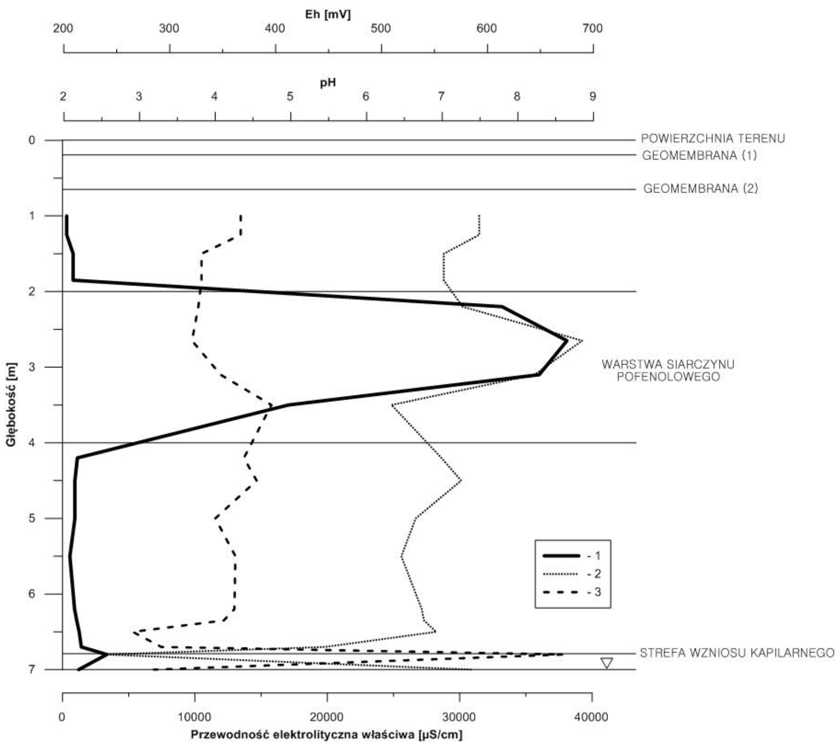

Fig. 18. Physical and chemical parameters in the in eluate with L/S = 10 on the „Zielona" industrial waste site (Pietrucin, 2015)

Legend: 1 – electric conuctivity (25°C), 2 –pH level, 3 – Eh (redox potential)

The highest values of electric conductivity (38100 µS/cm) in the eluates L/S=10 correspond to the depth at which is secondarily recrystallized sodium sulfite heavily contaminated with phenol. Below the layers of phenol eluates have EC equal to 1300 µS/cm. Considering the degree of dilution of L/S=10, this value indicates a high degree of leaching of pollutants from the layer of sodium sulfite. The samples are accompanied by high values of pH (8.85) which then on the capillary fringe decreases to a value of 2.56.

Ground contamination is most often the result of an event occurring on the surface, where as a result of various types of events including a failure, are emissions in the form of: (a) solid - eg. by dusting, spreading, stripping contaminants from the landfill in solid form, (b) liquid - infiltration of contaminants from the surface into the ground and then further infiltration to groundwater which is often a result of a failure, such as sewer and liquid materials pipelines puncture (eg. fuels, chemical solutions and saline) or direct pouring the solutions and waste water on the surface. Liquid contaminants have a high ease of penetration of the surface layer of the ground and may leak into the deeper parts. It has the same effect in the dissolution process of pollutants by rainwater released into the environment in the form of a solid, and then the penetration of the solution to the substrate. Soil contamination at great depths, in particular in the saturated zone, are usually the cause of emissions from the contaminant source on the surface. Occurs to pollution of groundwater and inflow of contaminated groundwater (lateral) to a certain area of ground, even at a depth of several tens of meters - far away from the primary source. Zone of contaminated soil is determined by the direction and speed of groundwater flow.

2.2.4. Air quality

The main source of air pollution in Bydgoszcz is the anthropogenic emission. It consists of emission from industrial activities, from the domestic sector and communication emission (IOŚ, 2010). Research conducted within the State Environmental Monitoring showed that in the Kuyavian-Pomeranian voivodeship there is the downward trend in the concentrations of sulfur dioxide, nitrogen dioxide (with the exception of the communication stations) and PM10 in atmospheric air, whereas mean concentrations of this parameter increase in the case of occasional adverse weather conditions. Since the year 2000, large investments have been conducted in Bydgoszcz, which allowed to reduce emission of pollutants into the air. In relation to atmospheric air the fine-grained particulate matter and benzo(α)pyrene pollution is an important issue, as their basic source is low emission. The Air Protection Programs, implemented in the voivodeship, together with other actions taken by local governments, aim to achieve the quality standards within the next few years, as an extended process due to the coal-based energy acquisition system, embedded in the country's tradition. Also, the increasing trend in the concentration of NO_2 has been observed, which is associated with the number of motor vehicles.

The quality of atmospheric air in the area of the former "Zachem" Chemical Plant in Bydgoszcz is better. In comparison to the town center, the values of 24-hour PM10 concentrations and mean annual concentration of 20 $\mu g/m^3$ for PM2.5 are not exceeded. The only exceeded values concern the mean annual concentrations of benzo(α)pyrene (1 ng/m^3) in PM10 and the level of long-term target of 120 $\mu g/m^3$ for ozone, whereas this value is common for the entire Kuyavian-Pomeranian voivodeship (IOŚ, 2010). According to the criteria of atmospheric air quality for the protection of human health, the air quality is A, similarly as in the case of the criteria for the protection of plants – it is also A. The assessment was conducted based on the results of measurements for the year 2015 according to the "Guidelines for conducting the annual assessment of air quality in the zones for the year 2015 in accordance with the Article 89 of Environmental Protection Act based on the applicable national and EU law" (GIOŚ, Warsaw, 2016).

However, the importance of atmogeochemical research should be noticed, in order to assess the quality of soil air. The analysis of state of soil and water environment showed that gas exhalation (hydrogen sulfide H_2S, methane CH_4) is possible from the plumes of contaminated groundwater, through the aeration zone to the ground surface. Such studies have not been conducted in the area of the former “Zachem” Chemical Plant in Bydgoszcz but are strongly recommended by the AGH University in Krakow.

2.2.5. Natural heritage

There were no deposits of basic minerals documented within the city, but there are common natural resources, whose exploitation on an industrial scale dates back to the late 19th century. Silts and clays, used for the production of construction ceramics, were mined here as well as sands and gravels, mined even in the area of the “Zachem” Plant during its construction. Currently, however, only natural aggregate is exploited from the bottom of the Vistula river in the region of Brdyujście and the Old Fordon.

Natural heritage, including flora and fauna, is rich in Bydgoszcz. As many as 167 phytocoenoses, which represents 35% of Polish plant communities, have been identified here. Half of them are indigenous and the rest are communities formed as a result of human activity. The legal basis for habitat protection is the European Union Habitats Directive of 1992 and the Regulation of the Minister of the Environment of 2005. They indicate the types of natural habitats, for which legal protection within the Natura 2000 framework is recommended.

The area of Natura 2000, located the nearest to the former Chemical Plant, and being within the reach of the potential impact of post-industrial areas is the “Valley of the Lower Vistula” (area code PLB040003). There is a number of different forms of nature conservation within this valley. The largest of them is the Association of Chełmiński and Nadwiślański Landscape Parks, which extends from Bydgoszcz to Nowe, protecting the watershed section of the Vistula river valley through the Southern Baltic Lake District. It covers 26.3% of the entire protected area of the “Lower Vistula Valley” (Natura, 2000). This area provides a bird refuge of the European importance rank E39. There are at least 44 bird species from the Annex I of the Birds Directive and 4 species from the Polish Red Book. Valley is a breeding ground for approx. 180 species of birds, and also a very important refuge for migrating and wintering birds. During the breeding season the area inhabited by at least 1% of the national population of the following species of birds: white-tailed eagles, mergansers, ohara, little tern, common tern, kingfisher, oystercatchers. The relatively high density is also corncrake, gull, little ringed plover. During migration of wetland birds are present in concentrations up to 50 thousand individuals, and in winter to 40 thousand. In winter there is at least 1% of the national population migration route birds such as white-tailed eagle, common goldeneye, merganser and smew. It is a rich fauna of other vertebrates. Among the species listed in Annex II of the Habitats Directive was observed among:

- fish: lamprey, asp, an eel, a goat, bullhead, blow;
- amphibians: great crested newt, fire-bellied toad;
- mammals: beaver, European otter, wolf and bats: Barbastelle western, greater mouse-eared bat.

The most valuable plant communities in the Valley include various types of riparian forests and xerothermic grasslands. Flora of the vascular plants consists of approximately 1,350 species. There are also numerous species of endangered and legally protected plants.

Local land use plans, also in areas including former “Zachem” Chemical Plant in Bydgoszcz, contain provisions related to the establishment of an area of protected landscape due to their location within the Protected Landscape of the Dunes in Toruń - Bydgoszcz Basin in its western part. In particular, it applies here rational forest management, which consists in maintaining the biodiversity of habitats of the Bydgoszcz Forest and protection of the dunes, dune fields to maintain their stability. Applies also to provide the conditions to maintain the natural balance and rational management of the environment, with particular emphasis on land earmarked for construction projects, where the felling of trees to be carried out in a minimal degree, necessary for the project. It is also mandatory to protect landform permitting biological methods to counter the erosion of the slopes. It is recommended to introduce elements and the activities to facilitate the migration of animals and plants, e.g. by: isolation of paths of intensified animal migration and its orientation in safe places and zones, execution of culverts for small animals under the road surface. The most protected element is a biotope, understood as the natural habitat of plant and animal organisms characterized by a specific, homogeneous unit of environmental factors in the area (local land use plans No. 144).

The potential impact of the former “Zachem” Chemical Plant on the area of the “Lower Vistula Valley” is possible only if the contaminant plume in the form of contaminated groundwater reaches the Vistula river bed and then further - with flowing surface water – leads to the contamination of water-associated natural environment. In this case a huge load of contaminants may enter the environment – both inorganic and organic chemical substances, originating from various industrial waste landfills.

Another enclave of flora and fauna is the Bydgoszcz Forest, which is entirely located in the mesoregion of the Toruń Basin, formed as a result of erosion activity of glacial and fluvial waters, as well as aeolian processes. In the north and south it is bounded by the terraced slopes of the surrounding lakeland plateaus. It is characterized by the presence of vast inland dune fields, covered with pine forest with admixtures of deciduous species of oak, birch, hornbeam and others. The impact of contaminated groundwater on the condition of the Bydgoszcz Forest stand has not been proved. Nor has there been a detailed inventory of habitats of plants and animals protected by law, and located within the area of former “Zachem” Chemical Plant in Bydgoszcz City.

2.2.6. Land consumption

The policy of land use and management in the area of the former “Zachem” Chemical Plant in Bydgoszcz has its origins in the late 19th century. Founded at the exact place of the former German explosives factory, built during the Second World War, Dynamit-Aktien Gesellschaft (DAG) Fabric Bromberg, faithfully followed the land use convention. This is because it was associated with the safe arrangement of buildings and factories in the case of possible emergency events or explosion. Built-up and urbanized areas occupy, however, only about 30% of the post-industrial area, the so-called brownfield. According to the Polish law (RMRRiB, 2001), it consists of the following types of land: post-industrial (Ba), other built-up areas (Bi), urbanized undeveloped or under development land (Bp) rail transport land (Tk) and other transport areas (Ti). Some parcels, due to their convenient location within the city borders and the existing transport network and transmission lines, were used to create the Bydgoszcz Industrial and Technological Park. Also, due to the rich history of this area, part of the land was allocated for the Exploseum, i.e. Exploseum DAG Fabrik Bromberg Leon Wyczółkowski District Museum in Bydgoszcz.

The largest part of the area (approximately 70%) is covered by forested land, including (a) forests within the regulations on forests, (b) reclaimed for the needs of forest management and (c) under the access roads to forest lands, as well as land covered with trees and shrubs. This results from not occupying naturally-forested areas, as well as the natural succession of pioneer plants on the unused parcels. Obviously, there are no arable lands within the borders of the former “Zachem” Chemical Plant, due to not-fulfillment of the quality standards for the type A of soils (land properties included in the area subject to the protection under the provisions of the Water Resources Law, i.e. protected areas, including the protection zones for groundwater intakes (for drinking purposes - RMŚ, 2002).

City of Bydgoszcz has no integrated land use planning. However, there are a number of local municipal use plans as planning documents, and among them should be mentioned these documents that partially cover the area of former "Zachem" Chemical Plant in Bydgoszcz: 144 Łęgnowo – Technology Park, 168 Kapuściska – Chemiczna Street, 170 Łęgnowo – Skansen, 174 Czersko Polskie – Hutnicza Street, 178 Czersko Polskie – Mokra Street, 204 Łęgnowo – Herman Franky Street and 205 Łęgnowo – Bogdan Raczkowski Street, as well as two areas for which they are adopted resolutions on the accession to the preparation of the local municipal use plans, i.e. 219 Łęgnowo – Edmund Matuszewski Street and 227 Łęgnowo – Petersen Street. For areas of the former Chemical Plant, which are sites of production facilities, warehouses and storage facilities shall follow the general arrangements for these areas. Basic purpose includes the development of production with a preference for activities utilizing modern technologies, development and component warehouse, office and social development, as well as buildings and structures related to road transport, including parking areas for trucks. Purpose of these complementary use of areas include: administrative buildings, services, buildings and structures of technical infrastructure, railway sidings associated with development associated with handling sidings and also loading and unloading of goods, roads associated with internal communication, as well as greenery. It is very important that the maintenance of the industrial character of land use, and no renaming of its functions to a completely new, not yet used. The positive aspect is also an emphasis on activities using modern technologies, which means a production or service business activities which are characterized by high added value of its products or services, and a significant share of highly qualified staff profile of technical engineering, including in particular research labs, financial institutions and insurance companies, design and consulting units, economic institutions, means of mass communication, as well as those where these groups are not directly related, but they have the nature of their operation (local land use plans No. 144).

2.3. Socio-economic status description

2.3.1. Local community

In the immediate vicinity of the former "Zachem" Chemical Plant there are areas inhabited by the Bydgoszcz citizens, including the Emergency Housing Estate, Łęgnow, Brdyujście and towns Plątnowo and Otorowo. Any environmental pollution has always direct impact on the local community. In the discussed case this is associated with the migration of plumes of contaminated groundwater, contamination of new residential areas, inflow of contaminated water to farm wells and the potential gas exhalation in the river valleys. Citizens of the town Łęgnowo are subjected to the greatest threat, as they are exposed to direct contact with organic chemicals, often toxic and of carcinogenic and mutagenic character. In such cases not only people's health but also lives are in danger.

Łęgnowo is a housing estate situated within the Bydgoszcz city borders and is divided into two parts: Łęgnowo I and Łęgnowo II. Population does not exceed 3 thousand people, ie. Łęgnowo I has 1,985 inhabitants, while Łęgnowo II 814 inhabitants. In Łęgnowo I there are vast post-industrial areas of the former "Zachem" Chemical Plant and the Bydgoszcz Industrial and Technological Park, as well as the Exploseum museum. A large area is also occupied with a pine Bydgoszcz Forest. Łęgnowo II is a former village, protected by flood embankments against the Vistula river flooding. There are, among others, "Kapuściska" sewage treatment plant, agricultural lands, as well as Czersko Polskie Weir, which is a hydrotechnical construction with great importance for the backpressure of the river Brda, which in this section flows into the Vistula river. In floodplain areas there are also riparian forests.

2.3.2. Economic development and production activity

A number of independent entities have their offices in the area of the former “Zachem” Chemical Plant. Most often they lease buildings, which have been adjusted for various business activities at their expense. These entities have separate contracts with the Chemical Plant’s successor for the supply of energy, water, as well as wastewater discharge into the sewerage system. Some entities bought the land together with buildings where they operate.

The “Zachem” Chemical Plant remained a state enterprise until May 2003. It has renounced the right of perpetual usufruct of a large part of the area to the State Treasury - first (in 2002) of forest areas and then industrial areas. While signing the notarial deed of renunciation of land in the south-western part of the Plant, the land was divided by geodetic survey. Then, areas with buildings and installations were separated. As a result of these ownership transformations, the “Zachem” Chemical Plant renounced the right of using only forest areas. It still used, among others, the area occupied by the wells of drinking water intake ”S” within the borders of direct protection, the water pumping station area along with water balancing tanks and the areas of the NGL department, excluded from the production since the forties of the 20th century. In January 2005 during the reorganization, an independent entity, which leased the installations from the former Dye Plant, was separated from the Chemical Plant. In May 2005 the Bydgoszcz Industrial – Technological Park was also separated from the part of the “Zachem” area.

Until 2013 the “Zachem” Chemical Plant in Bydgoszcz was one of the largest organic chemistry producers on the Polish market. Basic and most important products manufactured in the Chemical Plant in the last period of its operation included toluene diisocyanate - TDI, allyl chloride, epichlorohydrin EPI, hydrochloric acid, sodium hydroxide and sodium hypochlorite. Among the products manufactured on a significant scale one can mention polyurethane foams.

From August 14th 2013 the “Zachem” Chemical Plant in Bydgoszcz functioned as Kapuściska Infrastructure JSC (Infrastruktura Kapuściska S.A.), still being the property of the Ciech Chemical Group. Four months later the production of organic and inorganic compounds stopped. The company’s activity focused primarily on providing services related to the infrastructure management and the media supply for entities running service businesses in the vicinity of the Kapuściska Infrastructure company. On March 14th 2014 the company was declared bankrupt and its assets have been managed by a trustee.

2.3.3. Employment situation

The maximum number of people employed in the “Zachem” Chemical Plant, i.e. 7,278 employees, was recorded in the year 1976. However, after thirty years, and a few years before being put into bankruptcy liquidation, the number of employees was gradually reduced. Currently, the Chemical Plant does not exist in the discussed area, while only private service companies or small companies of various type function here. Persons working for the former Chemical Plant include the trustee and employees of the trustee office.

2.4. Infrastructure, logistics and legal constraints

2.4.1. Sewage treatment plants and waste landfills

The largest sewage treatment plant which is also the nearest to the former “Zachem” Chemical Plant is the biological “Kapuściska” Sewage Treatment Plant, owned by the “Chemwik" LLC, a subsidiary of the Municipal Water Supply and Sewerage Systems LLC in Bydgoszcz. The capacity of the facility is 28 thousand m^3/d for industrial sewage and 43 thousand m^3/d for municipal sewage (Fig. 19).

Fig. 19. „Kapuściska” sewage treatment plants in Bydgoszczy (www.chemwik.pl

The Central Sewage Neutralizing Station (CSN) established in 1977 with an area of 7 ha, where sludge formed as a result of sewage mixing was delivered, is the additional infrastructure for the sewage management. No longer operating reservoir was largely filled with sludge. In the years 1986-87, as a result of failure it did not operate, and the effluent from the chemical industry was discharged into the Vistula river by an open ditch. In 1987 – 1991 an Isolated Waste Landfill (ISO) was built. During the construction, sludge from the area of ISO was deposited in the general landfill. The facility with an area of 4 ha was designed to receive 188 thousand m^3 of waste. Since 1992 the landfill received sludge from the CSN. After launching the CSN, the sludge was pumped directly to ISO, and after implementation of the sewage centrifugation process – it was transported by cars. Another, already existing, element was the Central Sewage Averaging Tank (CZU). The sewerage system was also supplemented with sewage pretreatment plant and the so-called barrier intake, unsuccessfully capturing contaminated groundwater, and the facility sewerage system (combined, post-production acidic and neutral) with old collectors, mainly of acidic sewerage in the southern part of the facility.

The factor particularly distinctive of industrial areas, such as the “Zachem” Chemical Plant in Bydgoszcz, is the formation over decades of numerous contamination hotspots on a relatively small area. Contamination hotspots existing for many years, such as industrial and municipal landfills, settling tanks or sedimentation ponds, significantly increase the pollution load infiltrating into groundwater through aeration zone. A large number of industrial infrastructure elements, having potentially negative effect on the natural environment, makes the entire industrial area usually regarded as an area threatening the aquatic environment and constituting a territorial pollution hotspot.

In the course of the conducted inventory of the industrial waste landfills in the area of the Chemical Plant, based on literature data, as many as 26 pollution hotspots were cataloged (Table 3). There is information that there are additional landfills, whose documentation is only fragmentary or was destroyed. The location or origin of those landfills is, however, unknown as they are the result of unorganized deposition. On the background of the conducted study, the industrial waste landfill "Zielona" is the pollution hotspot with the greatest potential for soil and water environment contamination. It should therefore be treated as the one selected for detailed study, due to: complicated history of heavily-toxic waste deposition, co-occurrence of organic and inorganic substances, complex hydrogeological processes and considerable extent of contamination.

In this study the name "Zielona" landfill is used in relation to the complex of nameless landfills, i.e. (1) inactive pit which functioned as a hazardous waste landfill, mainly for phenolic pitch from the production of phenol and Rezokol glue, (2) hazardous waste landfill which was transformed in the years 1984 – 1994 into non-hazardous waste combustion place, hazardous waste from special productions (waste nitro-compounds) and combustion of rubber coated appliances and fittings, and (3) Isolated Waste Landfill (ISO) (Fig. 20, 21).

Fig. 20. „Zielona" industrial waste site in „Zachem" (1) (by D. Pietrucin)

Moreover, among landfills which also should be treated as a priority and requiring immediate corrective actions there is an industrial waste landfill at the Lisia Street, where waste associated with the production of phenol and Rezokol glue, i.e. phenol-contaminated sodium sulfite, is deposited.

In addition, since 1972 (exploitation of the land for 44 years) hazardous organic substances in the form of waste from the production of dyes and dyeing intermediates, as well as tar voids from the production of TDI and TDA – including toxic waste - were stored in this region. It should also be noted that remedial actions in the area of the former sedimentation pond for post-neutralizing sludge from the production of epichlorohydrin, which is also heavily polluted with organic substances, should be immediately started.

Fig. 21. „Zielona" industrial waste site in „Zachem" (2) (by D. Pietrucin)

From the viewpoint of hazard to the soil and water environment, both currently operating industrial waste landfills and historical ones - possible to identify based on the literature studies of archival materials - are similarly dangerous. What is important in this regard is to take into consideration the specificity of the "Zachem" Chemical Plant in Bydgoszcz, both in terms of the production range and the applied technological methods. While analyzing the chemical composition of the production profile of the Chemical Plant, one can see a strong relationship between the type of production and the pollutants entering the soil and water environment, particularly including groundwater of the Quaternary aquifer.

Table 3. Inventory of industrial waste landfills in Chemical Plant (Czop & Pietrucin, 2016)

No.	Industrial waste landfills
1.	Area of the Dye Production Department
2.	Pit with dyeing and intermediate-dyeing waste
3.	Area of the Monomer Complex Installation
4.	So-called cold headquarters of chemical plant
5.	PURINOVA region (former T-7300)
6.	Place for extinguishing TDI tars (toluene diisocyanate) – former galvanic waste burial ground
7.	Area for brine electrolysis, NaCl brine tanks
8.	Propylene magazine for the chemical plant

9.	Landfill of ash, slag and dust from coal combustion in the power plant (ECII) and brine sludge
10.	TDI/TDA contaminated site (toluene diisocyanate/toluene diamine)
11.	EPI installation area (epichlorohydrin)
12.	Landfill area of EPI-SOE post-neutralization sludge (epichlorohydrin settling pond)
13.	Storage pits in the I and II synthesis regions (area of landfills at the Lisia Street)
14.	CSN area (Central Sewage Neutralization Station)
15.	Heap area of aniline sludge and 3 settling tanks of aniline sludge
16.	DNT installation area (dinitrotoluene)
17.	Area of the so-called old boiler house of the chemical plant
18.	Complex of landfills at the Zielona/Elektryczna Street: (1) general plant landfill, (2) combustion place, (3) Isolated Waste Landfill (ISO) – sludge from the Central Sewage Averaging Tank (CZU)
19.	Route of the brine pipeline
20.	Nitrobenzene pocket
21.	Sludge pits (Department WT-12)
22.	Settling tanks for muds from the industrial water intake station: (1) reinforced concrete settlers for post-filtration backwash water, (2) panel-lined drainage station for mud from settlers
23.	Combustion place in Żółwin (outside the "Zachem" ChP)
24.	Central Sewage Averaging Tank (CZN)
25.	Combustion place in Glinki near Dąbrowa
26.	Irrigated fields – municipal sewage dumping site (owner other than ChP)
27.	Landfill for Bydgoszcz power plant ash (owner other than ChP)

2.4.2. Power plants

Combined Heat and Power Plant Bydgoszcz JSC, the branch of the PGE Mining and Conventional Power JSC, includes three power plants, i.e. I, II and III respectively, whereas PP III does not constitute a separate production unit and is organizationally a part of the structure of PP II. This power plant is located in the area bordered to the north with the former "Zachem" Chemical Plant, and its history of post-production waste deposition is strongly associated with the Chemical Plant. In 1971 the Combined Heat and Power Plant Bydgoszcz was established, which included the newly built Bydgoszcz II Power Plant in Czersko Polskie (northern part). In 1972 an industrial power plant of the "Organika-Zachem" Chemical Plant, i.e. the current PP III, was also taken over. The production capacity of PP II includes the generating thermal capacity of 664 MW, installed electric capacity of 227 MW and generating electric capacity at the level of 187 MW.

2.4.3. Communication network

The communication network in the area of the former "Zachem" Chemical Plant in Bydgoszcz is closely related to roads and transmission lines used during the operation of plant. In this network are included consequently neglected many asphalt and concrete roads and railway tracks. The area of "Zachem" is divided into two parts: the western and eastern by the railway line Bydgoszcz - Inowrocław, currently in use to transport such cargo. The main railway line Bydgoszcz - Toruń runs parallel to the eastern border of the Plant. Former “Zachem” Chemical Plant are located in the city of Bydgoszcz, which means that they are directly connected to the infrastructure, including the south of national road No. 10.

An important aspect of communication is the location of the Bydgoszcz Water Junction about 500 meters from the plant in the north - easterly direction. Bydgoszcz Water Junction is recognized as the most valuable environmental resource in Bydgoszcz. It forms part of the international waterways: E70 linking the east and west of Europe and the E40 road connecting the Baltic Sea with the Black Sea.

2.4.4. Legal acts and planning instruments

The main limitations are legal issues of economic law:
- a long time of operation of the Plant,
- privatization (2004 – 2007),
- liquidation (2013 to the presence),
- no entity responsible for environmental damage,

which led to the ceding responsibilities for the State Treasury. From the point of view of environmental law the most important constraints are:
- destruction of an integrated monitoring network,
- difficulties in ceding responsibilities for a monitoring research on entities acquiring ground of former plant,
- unclear legal regulations in the field of groundwater research.

The main legal acts in force in environmental studies at the “Zachem” ChP:
1. RDW, 2000 – EU Water Framework Directive. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (OJ L 327) on 22 December 2000. Brussels *in polish*
2. RMŚ, 2002 – Regulation of the Minister of the Environment of 9 September 2002. On soil quality standards and earth quality standards (Journal of Laws No. 165 item. 1359)
3. RMŚ, 2016 – Regulation of the Minister of Environment on 1 September 2016. On how to conduct the assessment of contamination of the surface of the earth (Journal of Laws 2016 pos. 1395)
4. POŚ, 2001 – The Act of 27 April 2001. Environmental Protection Law (Journal of Laws 2001 No. 62, item. 627), as amended

Planning instruments

<u>List of obligatory and optional plans, along with the hierarchy of plans:</u> a region of former “Zachem” Chemical Plant in Bydgoszcz is one of the most polluted industrial areas, not only in Poland but also in the world scale. The name of “ecological bomb” in this context is very adequate because in this area there is a large concentration of pollution sources and also soil and water environment is polluted with substances of a high potential for toxicity, including carcinogens. Methodical solution of the problem of contaminants migration in the aquatic environment is not limited only to perform computer simulations for the numerical hydrogeological model of the study area, but made up for it as well: laborious and detailed field research, understanding and accurate representation of the geological structure and hydrogeological conditions, and above all hydrogeochemical processes occurring in the aquifer. Taking into account all stages of the research allows the creation of the final model of contaminant migration. This is because only on the basis of reliable and verified migration studies, it is

possible to develop and design the optimal scenarios for soil and water environmental remediation for the individual sources of pollution and contaminant plumes (Czop & Pietrucin, 2016):

1. Identification of a source of pollution of soil and water environment in the area of former "Zachem" Chemical Plant in Bydgoszcz, together with the assumptions for the design of future effective remediation work is a very complex process. The first stage of the research is to analyze the current degree of recognition of soil and water environment contamination.
2. The next stage of research aiming to create a reliable and effective remediation scenario is to analyze the current state of environment pollution in the area of the former "Zachem" CP along with the implementation of detailed monitoring studies.
3. The diagnosis of the current state of the environment enables the realization of next, very important stage of research, including the evaluation of the degree of contamination with an indication of the type of pollution and the amount of contaminated water and soil.
4. The final and crucial stage of the project is to develop a framework environmental remediation of soil and water, taking into account the specificities of each contaminants

The primary objective is reliable diagnosis of the state of the soil and water environment in the area of "Zachem" Chemical Plant in Bydgoszcz, together with an indication of pollution sources with the greatest potential threat to the individual components of the environment. The current state of pollution was shaped by several dozen year period of operation of the plant during which there was a penetration of pollutants into the soil and water environment and their migration within it. It is important to define further possibilities for propagation of pollutants and forecast potential future effects of their of remaining or movement in the environment. For contaminant sources with a potentially large scale effects both current and future on the components of the environment, in particular, constitute a threat to the biosphere (also for the overall health of local inhabitants), it is necessary to take adequate corrective actions to completely remove or significantly reduce the amount of contaminants occurring within the soil and water environment. These activities are aimed at environmental remediation, i.e. restoring it to its natural state, and in practice to the acceptable state in a light of the applicable formal – legal laws. A preliminary draft of remediation actions for individual contaminant sources, as a part of the crucial stage of a final framework, proposed that it should be made based on modeling studies, which will be crucial to have local migration models from individual sources. On their basis should be developed reliable schedule of time - finances for effective environmental remediation of soil and water in the separation of the individual contaminants. Due to the significant complexity of the conditions of occurrence and groundwater flow in the area of "Zachem" ChP and the migration in a groundwater stream of mixture of organic and inorganic substances, reliable remediation scenario is possible to present only based on the results of numerical modeling. Presented stage should also contain information about any studies that detail the range of contaminant plumes and testing for the level of concentration of specific contaminants.

Development and design of an optimal scenario for the remediation of soil and water environment for individual pollution hotspots should be balanced between social, environmental and economic factors. Due to economic limitations, which are always among the decisive factors in the selection of remediation techniques, it is proposed to adopt the order in which the priority corrective actions from the environmental point of view should be undertaken:

1. Industrial waste landfill "Zielona", including:
   a) inactive excavation adopted as the hazardous waste landfill, mainly for phenolic pitch from the production of phenol and glue Rezokol,

   b) hazardous waste landfill converted into place for combustion of non-hazardous waste, hazardous waste from special productions (waste nitro-compounds) and combustion of rubber coated appliances and fittings,
   c) Isolated Waste Landfill (ISO),
2. "Lisia" industrial waste landfill,
3. Landfill of waste from the production of epichlorohydrin, including:
   a) Target sedimentation pond for post-neutralization sludge from the EPI production,
   b) Landfill of sludge and ash from the Bydgoszcz power plant,
4. Aniline sludge landfill, including 3 sludge pits and a heap,
5. Pollution hotspots situated in the central part of the Chemical Plant, including:
   a) Area contaminated with toluene diamine and toluene diisocyanate,
   b) Former propylene storehouse,
   c) Dinitrotoluene installation area,
6. Nitrobenzene pocket.

Subsequently, apart from the ranking list, one should - if possible - conduct remediation of soil and water environment for pollution hotspots, which have less negative impact on the individual components of the environment than the above mentioned sites. In the history of the "Zachem" Chemical Plant there are known cases of random deposition of pollutants directly into the pits on the ground surface. The most common points of discharge of pollutants were situated in the nearby forest. Another problem related to the former operation of the "Zachem" ChP may be also the drinking water intake "S", which is situated in the south-western part of the facility, at the inflow of clean, unpolluted Quaternary groundwater. The intake is characterized by the stability of chemical composition of waters and is under constant control of the Poviat Sanitary and Epidemiological Station in Bydgoszcz and the drawn water is suitable for consumption, without the process of iron and manganese removal. During the exploitation of the intake "S", various concentrations of phenols in groundwater were detected several times. This situation occurred during the increased consumption of groundwater at the intake, which was directly linked with the increase in the depression cone and inflow of pollutants from more distant hotspots. This indicates that despite a thorough inventory of waste landfills in the area of the "Zachem" Chemical Plant, identified as objects representing pollution hotspots for aquatic environment, the occurrence of previously unrecognized pollution hotspots is still possible. At the same time, as a result of long-term operation of the Chemical Plant, as well as the lack of structured waste management, particularly in the initial stage, there may be much more unidentified pollution hotspots of such type. Another region, worth paying attention to, is the area of the current Exploseum Museum, founded at the remaining infrastructure of the Dynamit Aktien-Geselschaft Fabrik Bromberg, specializing in the production of nitrocellulose, smokeless powder and nitroglycerin, as well as trinitrotoluene, dinitrobenzene, V1 missiles, aerial bombs, artillery shells and powder charges. Field data from similar facilities indicate that there may still be even a few thousand tons of trinitrotoluene in the remaining industrial infrastructure.

Environmental pollution in the area of the former "Zachem" Chemical Plant in Bydgoszcz includes both soil and groundwater, but also the subsurface zone consisting land, as well as the air contained in the soil. Very often, contamination of soil and ground has a point character or is a minor in. However, it requires a reliable diagnosis in the evaluation of chemical contamination of soils and soil air. The basic guidelines for making such assessments are included, among others, in references: (1) Regulation of the Minister of the Environment of 9 September 2002. On soil quality standards and earth quality standards (Journal of Laws No 165, item. 1359), (2) Determination of areas in which standards of soil quality are exceeded. Methodological Guide for Administration - Environmental Inspectorate (Library of Environmental Monitoring, Warsaw 2004), (3) Basic assessment of chemical contamination of soils. Heavy metals, sulfur and PAHs - State Inspectorate for Environmental Protection, Institute of Soil Science and Plant Cultivation (Environmental Monitoring Library, Warsaw 1995) and (4) the ISO standard 10381-1: 2008 / Soil quality. Sampling. Part 1: Principles of design sampling programs.

Correctly performed assessment of the degree of contamination of soil and ground should include key elements: i.e. (a) establish a list of substances, the occurrence of which is expected due to the activities carried out on the property or in its vicinity, (b) performing initial measurements, the aim is to determine whether contaminants are present in the soil, (c) performance of sampling soils for two depths: the surface soil layer 0 ÷ 30 cm, and the innermost layer of 2.0 ÷ 3.0 m by making a borehole, (d) the performance of soil air sampling, (e) execution of chemical analyzes of soil samples and soil air (atmogeochemical tests), (f) evaluation of the quality of soils and land in accordance with the Regulation of the Minister of the Environment.

A very important aspect, while perform reliable field research for the assessment of chemical contamination of soil and ground, is a systematic way of sampling, i.e. grid of a regular random sampling spot. The advantage of the regular grid is the ease of recreate. Regular grid, however, allows to increase the density of sampling points in zones which are potential sources of pollution. Expected standards of quality of soil or ground, including the current and planned function should be compared to the criteria for the types of soil: group A and/or group B and/or C: (a) group A - land included in the area subject to protection under the provisions of the Water Act, i.e. protected areas, including the protection zone of groundwater intakes (for drinking purpose), (b) group B - land classified as agricultural except land under ponds and ditches, forest and wooded land, and built and urbanized areas with the exception of industrial, mining areas and areas of communication, (c) group C - industrial areas, mining areas and areas of communication.

Remediation of soil and water at the site of the former “Zachem” Chemical Plant in Bydgoszcz is necessary due to the high toxicity of contaminants and their migration an urban areas or used for agriculture. The high cost of remediation of all contaminant sources mean that it should be initiated such activities from the objects posing the most serious threat i.e. (1) “Zielona” industial waste site, (2) “Lisia” industrial waste site, (3) landfill of waste from the production of epichlorohydrin, (4) aniline sludge landfill, (5) pollution sources situated in the central part of the Chemical Plant and (6) nitrobenzene pocket.

<u>Horizon and time planning system:</u> According to the methodology for assessing the activity of invasive systems, the removal of 80% of the pollution of soil and water environment may take about 11 to 12 years.

2.4.5. Ownership aspects

Due to the fact that the area of the former “Zachem” Chemical Plant in Bydgoszcz is managed by a trustee in bankruptcy, the main objective of the company in liquidation is oversold assets, provision of services and the settlement of liabilities.

Accordingly, the test area in terms of ownership can be divided into 4 types (Fig. 22). These land is managed by:

- the State Treasury administered by State Forests,

- the State Treasury in perpetual usufruct of the Kapuściska Infrastructure JSC in liquidation – the legal successor of "Zachem" Chemical Plant in Bydgoszcz,
- the State Treasury in perpetual usufruct of other entities,
- the State Treasury - Municipality of Bydgoszcz.

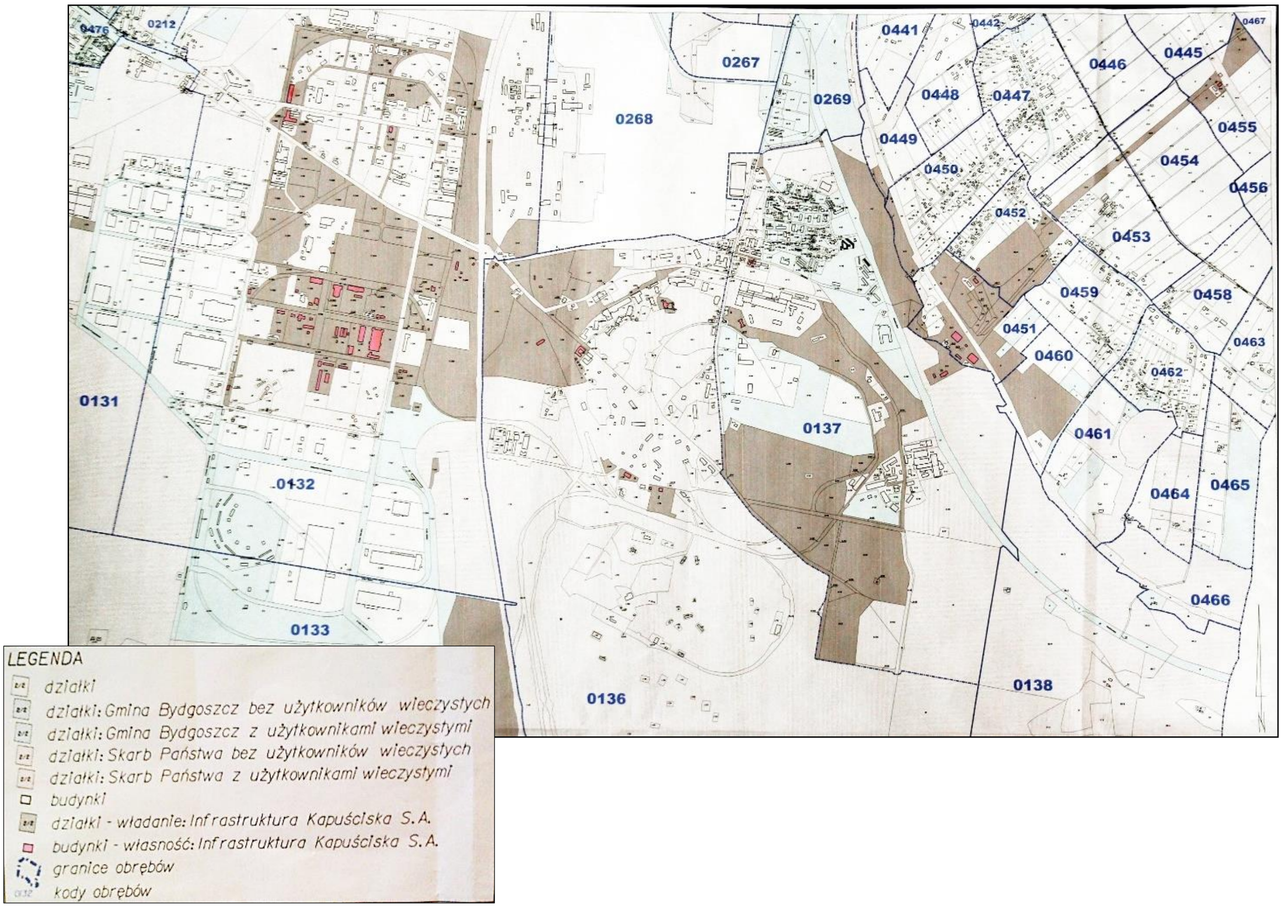

Fig. 22. The division of the area of former Chemical Plant by the ownership parcels (Bydgoszcz City data)

Legend: 1 – land plot, 2 - land plot of Bydgoszcz Municipality without perpetual users, 3 - land plot of Bydgoszcz Municipality with perpetual users, 4 - land plot of the State Treasury without perpetual users, 5 - land plot of the State Treasury with perpetual users, 6 – buildings, 7 – land plot used by Kapuściska Infrastructure JSC, 8 - buildings of Kapuściska Infrastructure JSC property, 9 – border of cadastral district, 10 – codes of cadastral districts

3. Detailed assessment of a factory of railway sleepers preservation in Solec Kujawski

Solec Kujawski brownfield is the site of former wood preservation factory. It is the area located close to the city centre also near the largest housing estate and recreation and sports facilities. Heavy contamination of the terrain with compounds from PAHs, BTEX and Phenols groups forbade even re-development for industrial use. In years 2011-2012 a conceptual project of an 'in situ' decontamination method was developed. After several excavations and decontamination activities the area is still undergoing a process of bioremediation. Its further revitalization and reactivation is required in accordance with the needs of the city inhabitants.

3.1. Historical background of a factory of railway sleepers preservation

In 1879, during the period when these lands formed a part of the German Empire, a wood preservation plant was built in Solec (Julius Ruettgers from Dresden). Plant was located on the sandy terrace of Vistula, about 500 yards from the river. It was therefore possible to provide a constant supply of wood: from river-rafting of timber and cooperation with numerous sawmills. A nearby important railway line guaranteed an additional route for delivery of wood, a safe transportation of impregnation oil for the preservation of wood and easy way to dispatch a large quantity of finished products. In the year 1920, when the land was returned to Poland again, the plant sustained production (Fig. 23).

Fig. 23. The wood preservation manufactory from the period before World War II
(The Solec Kujawski Prince Przemysl Museum collection)

After the World War II the production was started again in 1948. Dynamic development of production occurred between 1960 and 1980, when the rail network in Poland was renovated and modernized. Conditions of socialist economy and the fact that the production for the railway was considered strategic, prompted a number of adverse environmental effects - for example, all the way until 1985 there was a hole on the factory site into which the leftover impregnating oil was poured. Also the imperfect technology of the day, rush, strained production timelines and overused - often breaking machines - caused numerous oil spills to the ground.

Shortly after the war, the old rail track layout-was changed - there is an archival map (unknown date) illustrating the construction plans for the „New Wood Preserving Plant in Solec Kujawski" (**Błąd! Nie można odnaleźć źródła odwołania.**24). In the years 1965-1968 some of the buildings on site were rebuilt, due to the need to increase production – new autoclaves with higher pressure were installed as well. Six small cylinders have been replaced by two large cylinders (27 m in length and capacity of 95 m^3 each). This allowed impregnating poles and larger quantities of sleepers in a single cycle. In the main production building there were two oil heating tanks, each 65 m^3.

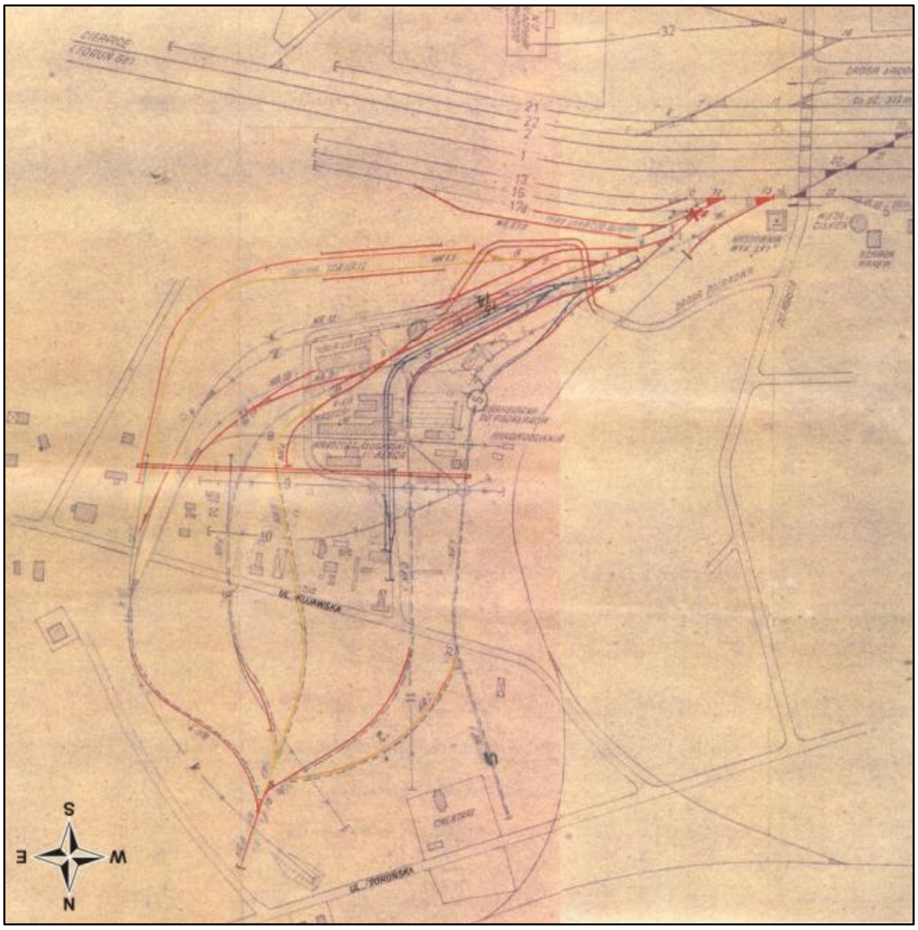

Fig. 24. Archive map of the construction plans of "New Wood Preserving Plant in Solec Kujawski"

Wood was impregnated chiefly with creosote, i.e. an oily mixture of liquid and volatile organic compounds - waste from the production of gas and hard coking coal. Creosote oil protected wood from water, insects, fungi and more. The most important components of creosote are BTEX (benzene, toluene, ethylbenzene, xylenes), phenols, pyridine and polycyclic aromatic hydrocarbons (PAHs). Aliphatic hydrocarbons were added into the mixture in the form of crude oil and waste oils in order to increase the liquidity of creosote. Some of these compounds are characterized by high toxicity and the majority of them are cancerous. A gradual increase in awareness about the dangers of these substances lead to the factory being upgraded. In 1975, a concrete drip board was built to dry sleepers freshly brought out from autoclaves after saturation. Originally creosote was stored in two steel containers standing on the ground (each approx. 250 m^3), but since 1975, with the increase in production and larger demand for impregnating oil (for creosote storage) four additional metal (single skin) underground tanks were built with a capacity of 2 x 40 m^3 and 2 x 60 m^3. They were filled from tank cars parked on a railway siding - next to which they were buried. Under the main building a rectangular brick cellar was buried with a capacity of approx. 450 m^3. It served as an underground pool for emergency discharges of oil from the installation in the event of a leak or a fire installation in the plant.

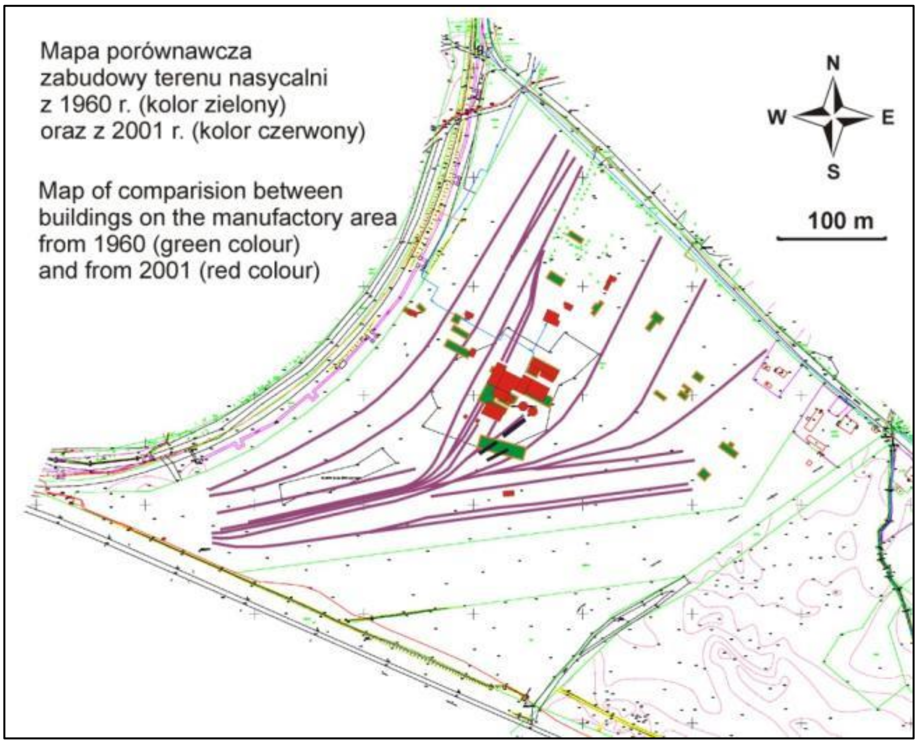

Fig. 25. Map o comparision between buildings on the manufactory area from 1960 and 2001

The information acquired from witnesses - workers of the plant - shows that at times, up to a dozen fires were extinguished annually (e.g. between 1976-1978 there were 13 large fires) - oil and saturated sleepers were easily ignited by accident or through arson. Creosote fires were extinguished with foam and water then covered in sand, and the remains were left on site of the plant. Therefore, there were numerous burial sites of strongly creosote contaminated waste not always related in location-wise to the technological process. In the 1960s. the surface of the plant was significantly larger and extended beyond the Kujawska st. all the way to Toruńska st. (**Błąd! Nie można odnaleźć źródła odwołania.** 25). This part of the plant was the so-called "white side", where raw wood was stored for several months at a time in form of logs and poles. This part of the former plant has been detached in the 1980s and currently is a reserve of land set aside for the expansion of the housing estate.

At the time of the maximum expansion of the plant there were approx. 150 people employed there, and the volume of production reached 1 million sleepers per year (more than 100 m^3 of wood). In years 1989-2001 wooden boards were also infused with copper salts to expand the product range. This technology was relatively modern, with little effect on the environment. However it was in use for only a short amount of time.

In 2001 the production on site was terminated. Plant closure procedures lasted until 2005. At that time, the insolvency administrator of the Wood Preserving Plant Company commissioned studies to determine the extent of contamination and produce an environmental impact report. Meanwhile, "wild" devastation of the remnants of buildings and installation was carried out on the deserted grounds of the plant. In 2005, the land was sold. Through illegal extraction of steel tanks and emptying them out of the remnants of creosote and sludge directly into the leftover pits, ground has been very heavily contaminated (Fig. 26). Creosote oil was burned again. As the land was now in private hands interventions of authorities (local municipality council, Environmental Protection Inspector, the Public Prosecutor's Office) had no effects.

Fig. 26. Unveiling tanks with pouring creosote into the ground (2005) (by W. Irmiński)

In 2008, the city and the municipality of Solec Kujawski acquired the strongly contaminated and devastated area after the plant. Environmental study conducted in 2009 suggested for the city to extract and remove from Solec Kujawski almost the entire volume of the soil within 16 hectares of the plant to a depth of 4 meters. As a plan it was impossible to achieve. In 2010 on the basis of additional geochemical studies and the first microbiological tests performed here, an alternative concept of land and groundwater bioremediation was proposed - using the indigenous (inoculated and multiplied) micro-organisms capable of decomposition and reduction in the concentrations of several aromatic hydrocarbon compounds. This concept, when expanded to include the initial step of soil-washing, was the basis to obtain funds from the EU Operational Programme 'Infrastructure and Environment' to conduct a cleanup of the area.

3.2. Environmental status description and critical aspects

3.2.1. Geological structure

The studied area is relatively small and until 2001 was not subject to detailed geological documentation. From the two former wells existing in the preserving plant, only the card for the well Railway Preserving Plant 1 has been preserved (archive of the Hydro Data Bank in PGI-NRI). It was the deepest hole made in this area (depth of 19.5 m) and probably revealed the entire thickness of a series of river sands of the left side of the Vistula River ice marginal valley in the region of Solec Kujawski.

As described in Section 2.2.1, also this part of the vast Vistula valley by Solec Kujawski is located in the area of the Pomeranian Wall built of Mesozoic sediments. Based on the Explanatory Notes to the sheet Bydgoszcz East of the Detailed Geological Map of Poland 1:50 000 (Kozłowska, Kozłowski, 1992) it may be stated that the youngest sediments of this structure, carbonate rocks, mudstone-schist rocks and sands, are of the Cretaceous age.

The overlying Tertiary rocks were leveled into Paleogene-Oligocene, Neogene-Miocene and Pliocene sediments based on the results of analyzes of microflora and microfauna. The uppermost Pliocene sediments (clays and silts with lignite and brown coal) were heavily destroyed and currently in the reduced form (approx. 10-12 m of thickness) are exposed in places of edges of the Vistula valley. In the discussed, small area after the Preserving Plant in the already made holes, variegated loams of this type are drilled at a depth of 19 m (the mentioned well Railway Preserving Plant 1) or even already at a depth of 8-9 m in some wells and piezometers made for monitoring of the remediation process in the period of 2013-2016. Variegated loams might, however, belong to Pliocene floes located within postglacial clays, similarly as documented in the so-called exaration basin in the nearby Kapuściska on the left bank of the Vistula river towards Bydgoszcz. As shown by several dozens of shallower holes and research outcrops made in the period of 2001-2015 (Andrzejewski et al., 2001; Machowiak et al., 2009a; Irmiński, Dębicka, 2010; Łukaczyński, 2016) up to an average depth of 10 m the entire ground of this area is composed of Quaternary fine- and medium-grained quartz sands, in some places mixed with gravels. The sands have good fluvial-aeolian separation and create slanted layerings – typical for the construction of a dune field. Such uniform structure affects infiltration of water and pollutants. Based on the particle size analyzes, the permeability coefficient was determined as $k=4\cdot10^{-4}$ m/s and $k=6\cdot10^{-3}$ m/s (Machowiak et al., 2009a), or even $k=10^{-2}$ m/s (Bieszczad, Leszman, 1985).

This part of the left side of the Vistula river valley has the character of erosion-accumulative terrace. This means, among others, that the sediments deposited in the fluvioglacial sands, i.e. boulder clays and variegated loams, were heavily eroded. This process results in the existence in the ground of fossil valleys with large height differences. Such geological situation determines not only the directions of groundwater and pollutant flow, but also creates traps for fractions heavier than water, as indicated in the following part.

3.2.2. Groundwater quality and its impact on superficial water

In the brownfield area there are no surface waters. In the neighbouring area, behind Kujawska street, on the East side, there is a small no-name stream Fig. 27). At this point it is put into a canal and run through a concrete ditch. After a couple of hundreds of meters it flows into the Vistula river. The quality of the surface water has not been tested, however, there is no interaction between the area of former wood preservation plant and the stream. The stream also does not drain groundwater, although an ice-marginal valley of that stream is probably the main receiver of heavily contaminated groundwater flowing from the brownfield.

The Vistula river, the main river in Poland, flowing through the valley 500 metres away is a base for drainage of groundwater. However, there is no research, which could show the influence of contamination coming from the brownfield on the surface water quality.

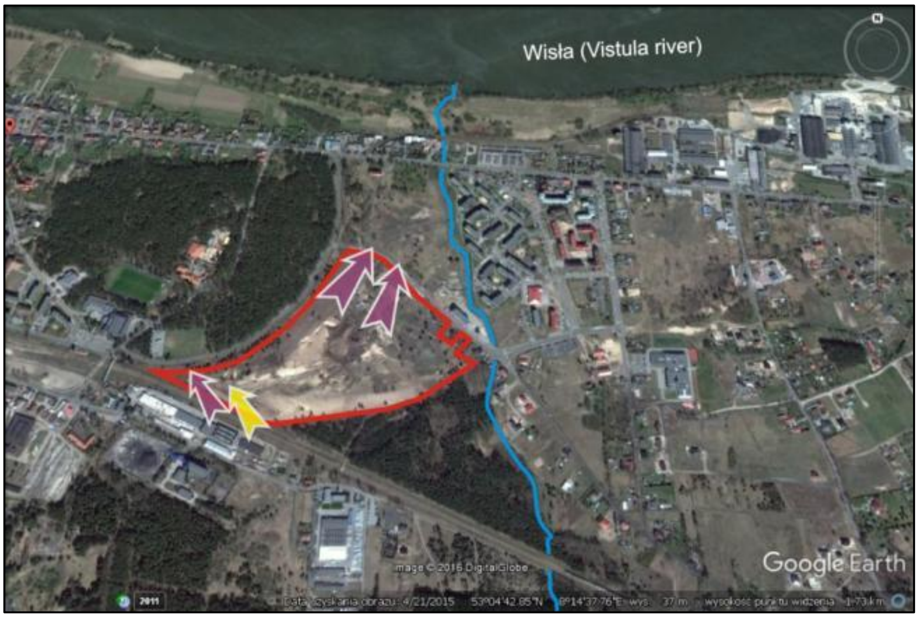

Fig. 27. Location of brownfield (red line) in relation to the surface waters

Legend: arrows - zones and directions of contaminants migration in groundwater: purple - compounds derived from creosote (BTEX, PAH, phenols), yellow - biogenic compounds of nitrogen and phosphorus

After a successful completion of remediation work on the surface and in the area of land heavily contaminated with creosote (VII.2013-VII.2016), currently a major problem for the environment is indicated to be a poor quality of groundwater. Existing here earlier for decades, hot spots created so-called secondary hot spots in the saturation zone, before they have been removed or significantly reduced. They cause the current long-term contamination of groundwater. In several drillings carried out in 2013 and 2015, presence of heavy non-aqueous phase liquid (DNAPL) was indicated. Creosote oil is a mixture of components, many of which are heavier than water and this oil falls by gravity to the bottom of the aquifer. However, phenomena such as viscosity, interphasic tension and capillary pressure prevent it. After getting into groundwater, components of creosote migrate in three phases:

- in the gas phase (it concerns volatile compounds, such as BTEX and naphthalene);
- in the phase dissolved in water (in spite of the low or negligible solubility of hydrophobic organic compounds this process nevertheless takes place and to a sufficient extent deteriorates water quality) – this migration forms streaks - so called plumes in a water layer;
- in the phase DNAPL – migration occurs on relatively the shortest path, is caused by gravity and shaping of the aquifer base. Such contamination generates constantly a dissolved phase with periodical reinforcements caused by e.g. seasonal temperature’s increase. This is the most durable type of contamination and may persist for hundreds of years.

During the remediation work, monitoring of the level and quality of groundwater was carried out in 31 holes (19 piezometers and 12 wells). The level of water contamination at different points undergoes changes, which mainly depend on the intensity of the emission source and time of the year, while directions of water flow (including plumes) are very stable. This facilitates the control of water quality changes and may be helpful in the future activities alongside the underground remediation. Exemplary changes in quality of water tested in wells and piezometers are shown on diagrams and maps.

Drillings performed so far let us outline geological cross-sections (Fig. 29, 30). Clearly visible is the upper part – sandy and the lower part – clays, which constitute isolation against water. Sands formed in the valley of the Vistula river in the Quaternary, after a phase of glaciation, with different grain sizes, have twofold origins - their lower part is the river sediment, definitely thicker, sometimes with admixtures of gravel, of good permeability, and a part located above (usually above the surface of water) are aeolian sands. Often the method of distribution of oil has to do with the genesis and construction of sandy sediments – Fig. 28.

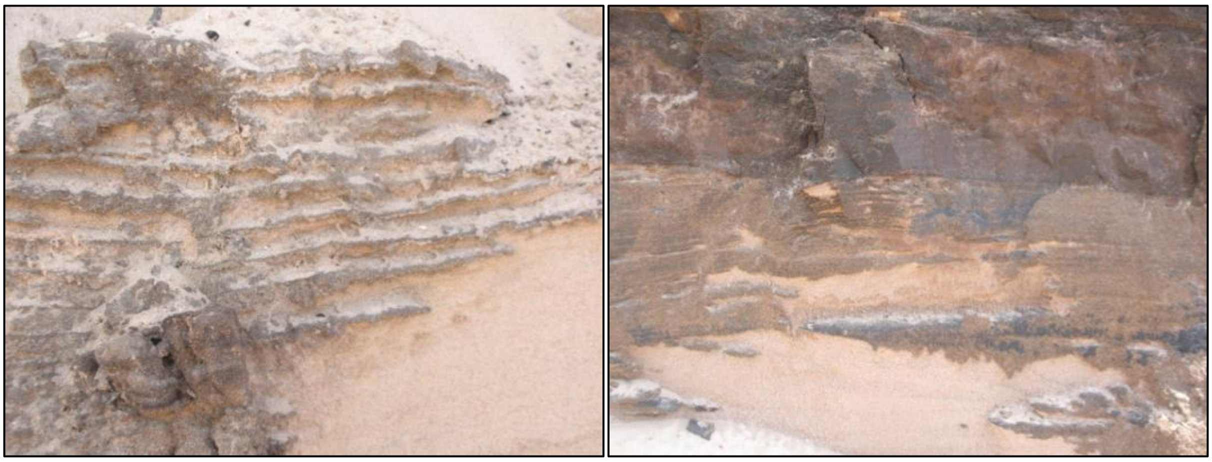

Fig. 28. Layers of sand contaminated by impregnation with creosote (a) and the entry of creosote oil sludge into the embankment of sand (b) (by W. Irmiński)

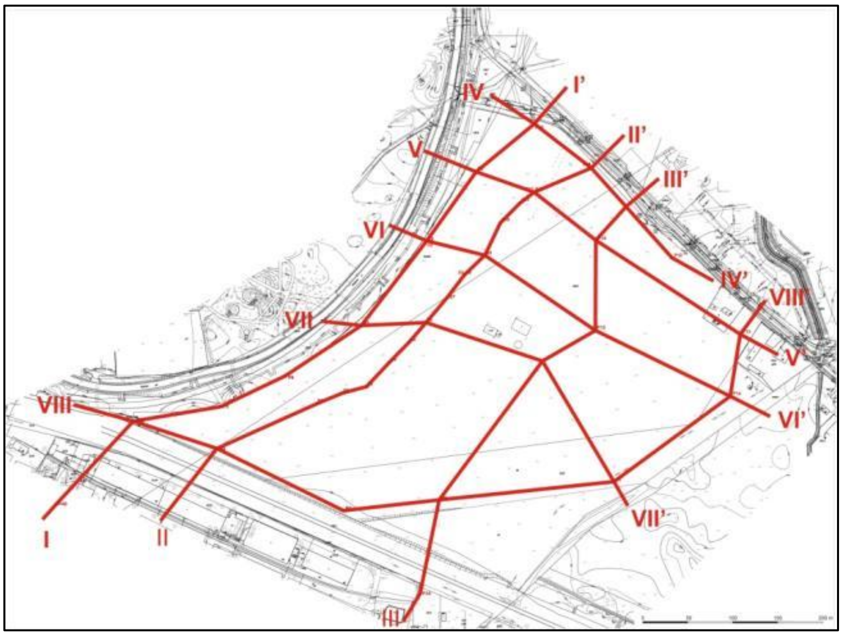

Fig. 29. Lines of geological cross-sections performed for the interpretation of the hydrogeological conditions

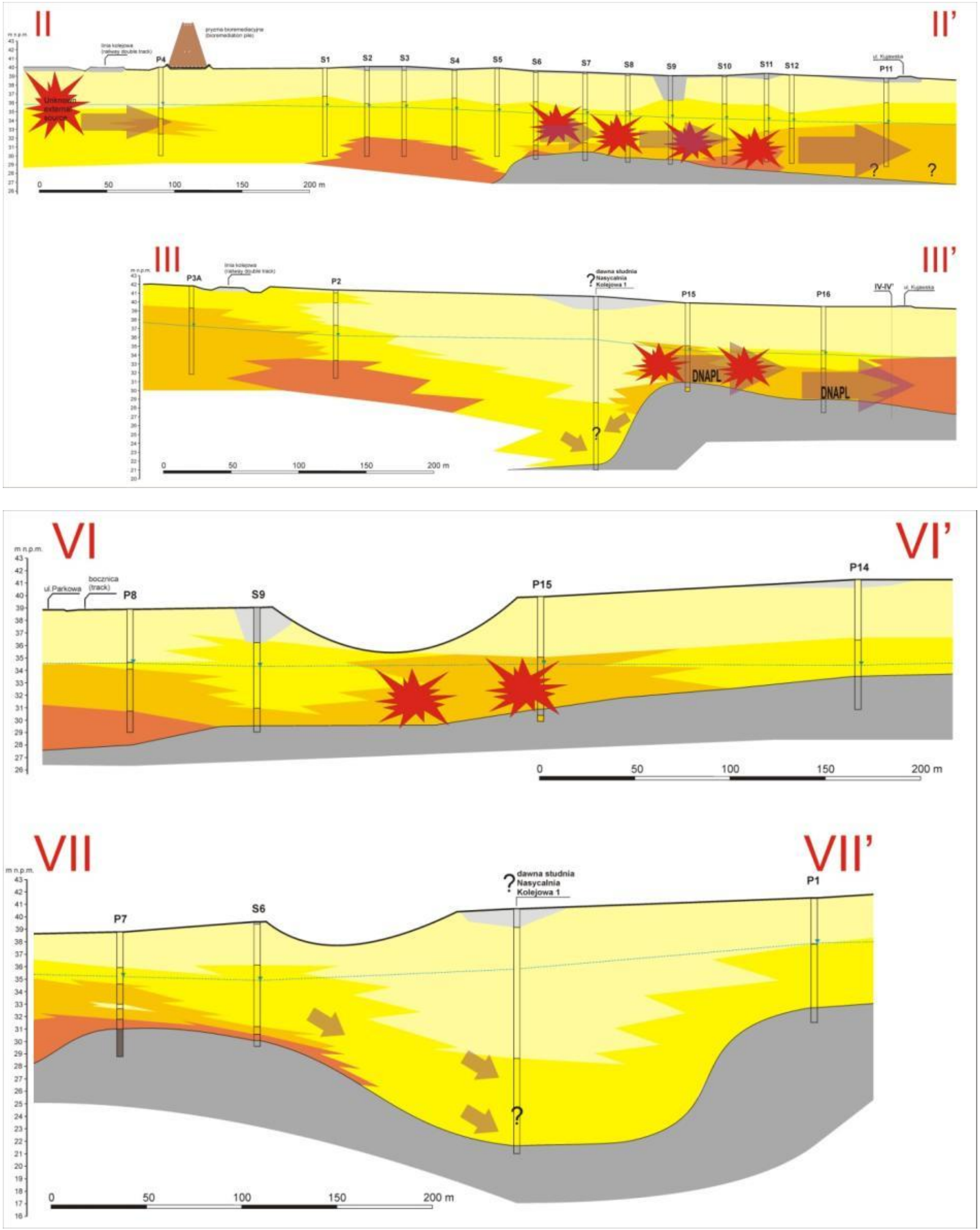

Fig. 30. Sections II-II ', III-III', VI-VI 'and VII-VII' show the morphology of the sand ground and direction of contaminants migration

Morphology of the surface of the clay (Tertiary) determines the presence of traps, where DNAPL is accumulated. In the process of water quality monitoring there were not only zones detected, through which heavily contaminated water flows, but also it was shown that on the South side of the area there is a flow of water, similarly heavily contaminated with BTEX, PAHs and phenols from a different old postindustrial area. It is used by private companies which type of activities is not related to the use of creosote and it therefore limits chances to determine the cause of contamination. Also on the South side, but in a slightly different area, there is a flow of water containing excessive amounts of nitrogen and phosphorus. This may be related to the migration of leachate from underground reservoirs at the former tannery. Paradoxically, however, the two zones of contamination while connecting each other produce favourable conditions for the occurrence of a natural process of natural attenuation (NA). However, control of this interesting and environment-friendly phenomenon still needs further testing and observations.

Summing up, organic components of creosote oil migrate in the waters in a characteristic way – they create a condensed braids and streak (plumes). It therefore means that, depending on the site of testing, underground water quality varies on the 5 steps-scale from the class III to the unclassified water (below class V).

3.2.3. Soil quality

Results of soil and land quality testing obtained in the process of remediation, and especially the last control testing after the end of earthwork, are very positive. Basing on these results, Regional Director of Environmental Protection found that low concentration levels of organic compounds and a clear decreasing tendency are proofs of remediation effectiveness and a fulfilment of imposed requirements. Earlier, because of the concentration of contamination, there was even prohibition of industrial activity here. Currently, most of the area meets the requirements for land for housing. It should be emphasized that in the central area, where the last excavations took place (VII.2016), processes of bioremediation have not yet fully developed. Therefore, on the attached map in this section you can still see a small area of anomaly (**Błąd! Nie można odnaleźć źródła odwołania.**31, 32, 33). However, it is a matter of a few months for microorganisms to effectively carry out the degradation of hydrocarbons.

A single result in the central part of the site showing high concentrations of BTEX, phenols and PAHs is the analysis of the sample taken from the saturated zone, below the technology and works in the years 2013-2016.

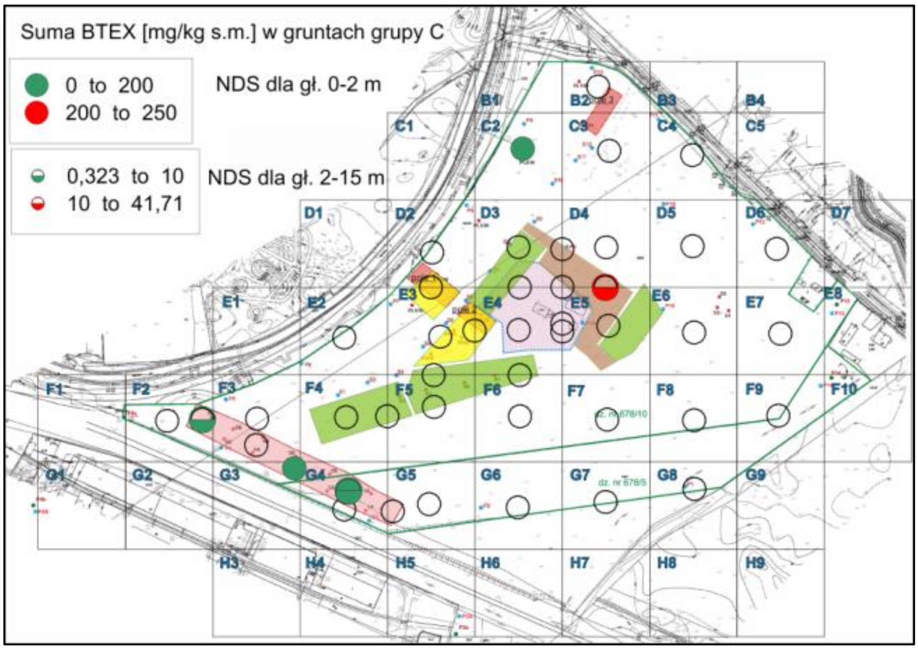

Fig. 31. Map of the sum of BTEX at two zones of depth (VIII 2016 year)

No color - the content of BTEX below the threshold determination

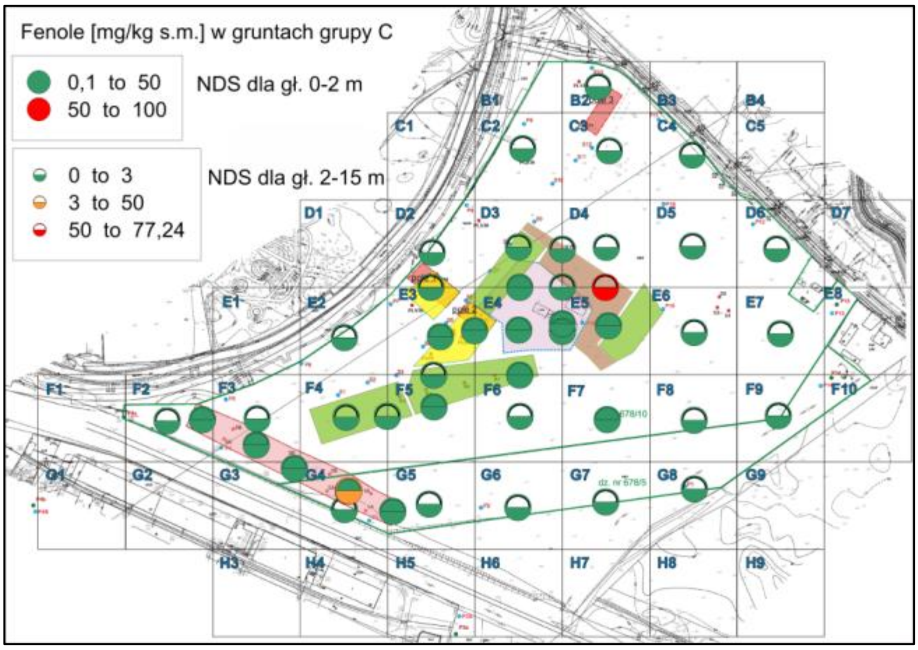

Fig. 32. Map of phenol concentration at two zones of depth (VIII 2016 year)

No color - the content of phenol below the threshold determination

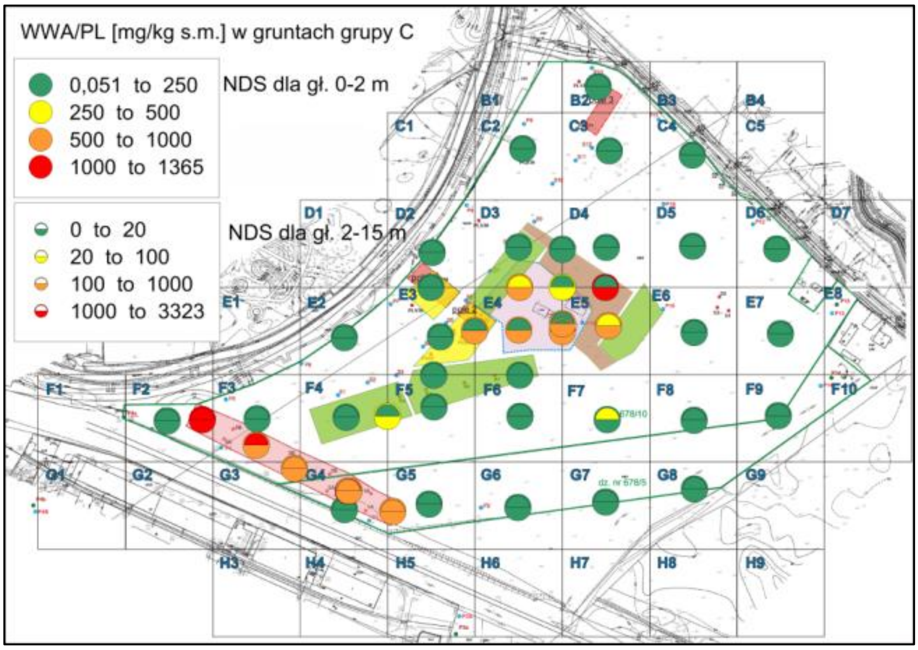

Fig. 33. Map of the sum of PAHs at two zones of depth (VIII 2016 year)

Clearly distinguished a bioremediation prism at the railway line

After a detailed assessment of the state of the soil and the ground (in 2009-2016 several sample testing from drillings and from the surface were performed) it can be seen that the concentration level of heavy metals is very low and it does not pose any threat. It is a good forecast for the bioremediation process.

Also, organic compounds are dominated by polycyclic aromatic hydrocarbons (PAHs). There are co-occuring compounds of the groups BTEX and phenols that have greater solubility and, therefore, greater bioavailability - this implies relatively rapid biodegradation and disappearance of these substances. Indigenous soil microorganisms could not fully function in this industrial area mainly due to lack of a soil layer (including humus) - it was easily and irreversibly destroyed during the construction of the plant which was built on infertile and sandy soil. At present, on the entire area which was cleaned, especially where sand after the wash was deposited, hydrocarbons are diluted. Such concentrations are no longer a toxic barrier to micro-organisms and fungi. Hydrocarbons become a source of carbon for the building cellular structures.

This process depends nevertheless on the energetic requirements towards groups of microorganisms, which are often very specialised and competing with each other. Firstly, the monocyclic compounds (benzene and other BTEX and phenols) become degraded, then they are followed by petroleum derivative compounds (gasoline and oil) and finally by naphthalene and other PAHs. It was observed that despite of decrease in sum of concentrations of PAHs, there is an increase in concentration of some of the compounds – for example there is a rapid and long-lasting increase of high concentration of anthracene. The field tests clearly demonstrated that anthracene concentration decrease after 3-8 weeks. Biodegradation processes are closely dependant on climate conditions (optimal temperature), sufficient humidity of soil and presence of nutrients. The latter should be supplied similarly as in field crops.

3.2.4. Air quality

Air quality in the Kujawsko-Pomorskie region is monitored primarily by the Provincial Inspectorate for Environmental Protection (WIOŚ). There is also a small number of test stations owned by large industrial companies. Measurement network and the range of tested substances are constantly being expanded. Unfortunately, in the area of Solec Kujawski, which is located between the largest cities of the region - Bydgoszcz and Toruń - there were no stationary tests carried out. Air quality monitoring stations installed in the neighbouring towns, with their own problems, cannot be of any reference level to assess the situation in Solec Kujawski.

Closure of the wood preservation plant in 2001 was surely an important factor reducing gas and dust emission into the atmosphere, especially emission of dust containing molecules of PAH. However, paradoxically, it reduced the chances of creating a test station in Solec.

Additionally, WIOŚ has at its disposal so called airpointers, which are installed near the biggest industrial plants in the region. The third group of measures, so called mobile airpointers, is sent in a case of intervention into the areas, where excessive air pollution for people was reported. Measurements of that type were not conducted in Solec Kujawski.

Archive analysis of WIOŚ reports (2007-2015) shows that in a case of compounds such as benzene and benzo(a)pyrene in dust (norm since 2008), the maximum levels are registered in winter. Only these two compounds can be correlated with the potential influence on atmospheric air of the brownfield area in Solec Kujawski. It is interpreted as a so called effect of low emission from fuel combustion in household fireplaces and small boiler houses in housing estates.

In the last report of WIOŚ summarising 2015 there were 146 air monitoring points included, however only 12 of them conducts passive measurements of benzene concentration. There is still no such point in Solec. The City and the Municipality of Solec Kujawski are also not mentioned in any summary of municipalites at risk of any air pollution.

However, residents of the former wood preservation plant neighbourhood emphasise that, especially in the summer time (high temperatures), they could sense unpleasant odour coming for that area – it was described as a smell of phenols.

The remediation project at the beginning did not contain a special air monitoring, but it assumed that the earthworks – excavation of contaminated soil – would be performed in the smallest possible area at one time. Moreover, the extent of the site and its location in a well-ventilated valley of the Vistula guaranteed a relatively small inconvenience because of odours during the work. Despite this, at the end of the land clearance, in June 2016, the City Mayor received a complaint from a group of residents who felt uncomfortable with the excessive odour of compounds derived from creosote. At a meeting with residents, which was organised by the City Council, there are present: a designer and representatives of the consortium of companies carrying out the clearance. It was explained that the cause of increased emissions of volatile organic compounds may be caused by the work carried out in the central, the most contaminated part of the area and the exceptionally adverse weather conditions, especially in the evening hours. It was agreed that the burdensome work will be completed within the next three weeks. There is no data on any measurements made by WIOŚ using the mobile station.

After completion of the ground works and rearrangement of land surrounding the residences near the streets Toruńska and Kujawska, odour of organic compounds is no longer noticeable.

3.2.5. Natural heritage

On the area above the floodplain of the Vistula River valley, also in the area of Solec Kujawski, natural conditions for development of soils of full profile are very difficult. A thin layer of humus, low retention of rainwater, and even frequent aeolian processes limited development of many types of plants. The best opportunities for survival had plants adapted to dry regions, namely xerophytes, which at the same time could tolerate low temperatures in that climate zone. On the sandy sail of eroding river valleys there existed natural grasslands and xerothermic oak woods. In 19 century at a raftsmen's settlement, Solec created an industrial plant with numerous tracks, building and storing sites. It led to a complete forest logging and soil devastation.

During preparation to remediation work it was found that there occur many of special trees which development was limited for a long time because of lack of access to the aquifer and enough water and oxygen in the rhizosphere. In a process of excavating the heaviest contaminated zones of soil it was necessary to remove a few trees. It was shown than rhizospheres are degenerated and there are no chances for their further development.

The potential impact of organic contamination, and especially spillage of creosote oil impregnating the land, on vascular plants started to be visible on this degraded area (before the remediation) in a very distinct way. There were grey tracts of land, which were being covered with pioneer organisms (such as mosses, fungi and lichens) only at the time of early spring and autumn, when the temperature was lower and water condensed on the surface.

Fig. 34. Degeneration of the roots of trees growing on highly contaminated surfaces (a) and natural succession on the cleaned sand – sharp-leaf grass and St. John's wort (b) (by W. Irmiński)

The possibility of buffering water in this place is crucial for herbaceous plants and grasses. For trees, e.g. pines having a taproot, it is necessary that there is an access to water containing dissolved oxygen. A simple interpretation of the vegetation ground cover in the area of this brownfield coincides with areas where there are no streaks of organic contamination, which results from the study of water quality in wells.

At present, when the process of soil rinsing is completed (VII.2016) there are still a few months of vegetation needed in order to prove the favourable change for naturally occurring xerothermic plants. In places, where natural succession is too slow, it was planned to plant trees, shrubs and sow grass and clover. There are already numerous examples of natural succession – **Błąd! Nie można odnaleźć źródła odwołania.**4. Protection and leaving old trees to remain (if it was only possible), return of vegetation cover and disappearance of burdensome odours, they all contribute to the return of nature – it was already observed that relatively rare species of birds and insects appeared in that area. Hoopoe (Upupa epops) **Błąd! Nie można odnaleźć źródła odwołania.**5 – a small but a very distinctive bird, eager to prey on sandy grasslands, for breeding sites it usually selects old trees with hollows, including old alleys with trees near open areas; species strictly protected.

Fig. 35. Hoopoe (Upupa epops) (a) and swallowtail (Papilio machaon) (b)

Swallowtail (Papilio machaon) **Błąd! Nie można odnaleźć źródła odwołania.**5 – the largest butterfly in Poland, it likes especially open meadows with many wild herbaceous plants. Golden-bloomed grey longhorn beetle (Agapanthia villosoviridescens) **Błąd! Nie można odnaleźć źródła odwołania.**6 – an insect, a beetle with characteristic long antennas and interesting colouring. Therefore, it is reasonable to think that a restoration process of this brownfield area leads to favourable changes, including renewal of very typical habitats and preservation of biodiversity.

Fig. 36. Agapanthia villosoviridescen - Solec Kujawski 04.08.2016 year

3.2.6. Land consumption

Use of land in urban areas, especially for buildings and industry, is a serious problem in many cities. There is a trend to move industry, trade and storage out of the city as they are troublesome and take a lot of space. Solec Kujawski also had to face this problem. In the suburban areas of farmland, in 2005 it initiated construction of the industrial zone under the name Industrial Park (area of 36.3 ha). The main assumption was to create a place for investors which is well located with easy access and has wide-ranging development possibilies. At the time when this zone was created, there was no simultaneous recover of postindustrial areas located in a more densely urbanised part of the city. What is even worse, moving industrial plants from the present industrial district and attracting new investors only to the Industrial Park lead inevitably to creation of brownfield areas, unless some new specific application methods are found quickly or at least a way for transition use is determined. This is not always possible, given that the reduction in the number of users of underground infrastructure (water supply, sewerage, heat pipelines) lead to an increase of unit costs for maintenance of these installations, which ultimately discourages next potential users. Therefore, it generates further degradation, plots become unattractive, and moreover, no one wants to invest near brownfield areas. Even frequent changes of owners, without undertaking needed remediation, repair or investmenets, as well as changes in activities profile can forecast the coming collapse and transition into brownfield.

In Solec Kujawski, the historically established industrial district – area between Powstańców and Garbary streets – gradually loses the investor's interest due to the present condition of the infrastructure, bad neighbourhood and requirements and restrictions imposed by local law. It gives rise to next brownfield areas, adjacent to the existing ones (area of the former base building, a former tannery and shoe factory, a part of an area of the former Polmozbyt, as well as and old housing estate at Robotnicza street). However, the City has already undertaken actions to revive this old industrial district and connect it more closely to the city center and thus to make it more attractive. Such actions were presented for instance by building a tunnel under the railway line LK18, which have for years crossed the city in half, and with the growing importance of railways (traffic increased) hindered communication between parts of the city. The second step is to build a modern and visually attractive train stop on the line called BIT-CITY – it is a railway connecting the two biggest cities in the region: Bydgoszcz i Toruń.

Regeneration of a very large area (16.44 ha) of the former wood preservation plant, located in the central part of the city is also an element of action that improves the city image. It also improves the living conditions in the neighbourhood (improvement of health, safety, reduction of fear and anxiety, creating proper aesthetics and good use of owned space). In this way the ground after the plant becomes a reserve land for 2-3 years, but now it already begins to fulfil its planned transitional functions as an area of recreation and urban green area. At the same time, concerns of investors in neighbouring areas decrease – on a plot at Kujawska street, opposite of remediated area, a first multifamily building appeared and the next two are planned.

The area of the former wood preservation plant was thus far the largest brownfield area in Solec Kujawski and occupied almost 0.9% of the city's area.

3.3. Socio-economic status description

3.3.1. Local community

Seemingly, the described area of the former wood preservation plant without any housing buildings at the moment but after the successful remedation, can have some, even if small impact on improvement of demographic conditions in Solec Kujawski. Firstly, the city's image improves rapidly – as of a place which cares about its residents, their health and creating an environment for safe living. This might have an influence on individual decisions of families and it reduces migration of (especially young) people to bigger cities in the region.

In the neighbourhood of the cleaned area investment conditions get better. There has already been built a multifamily residential block, which extends a housing offer on a local and regional market. This might even lead to further settlement of new residents.

Direct benefit from the removal of immediate danger, which were carcinogenic substances present in old reservoirs, in waste and in contaminated soil, is a chance to reduce health risk among residents. It is statistically connected with greater life expectancy and improvement in fertility.

3.3.2. Economic development and production activity

It is not without significance for Solec Kujawski, as the owner of the land and for the planned future recreation and sport objects in the future, the fact that some of these objects may be commercially rented and available, for example, to visitors and to local groups and sports clubs as a place to organise trainings, sports camps, hold back a backroom for summer camps, green schools, etc. This will require, however, also development of hotel accommodation at different price levels. Development in this direction will also increase the demand for food services, catering, etc.

Production activity, typically understood, will not be carried out here, because the area will lose the status of the industrial area as soon as the check will show sufficient improvement in the quality of the environment and the forecast of progress in this direction.

According to the planning documents the site is located in the zone of so-called ecological system including the existing natural system of the city and areas destined for transformation. The main directions of the land use are focused on maintaining urban green recreational function through the protection of the existing forest habitats and development of sport and recreational base.

3.3.3. Employment situation

In the long term, the planned land use after the regeneration of brownfield should create new jobs. They will be mainly related to the creation and operation and then maintenance of recreational objects that are planned here. Ultimately, it may generate a dozen to several dozen new jobs (security, cleaning, bars, equipment rentals, coaches in sports school, etc.).

3.4. Infrastructure, logistics and legal constraints

Brownfield area after the former wood preservation plant in Solec Kujawski was completely robbed of its industrial installations in the years 2005-2008, including the underground water mains, electrical cables, etc. Sewage system there was poorly developed, and installation to collect rainwater was both contaminated with creosote and obstructed. The rest of previous manufactory buildings is only the small transformer tower, in the border zone of the area – currently empty, dismantled and partly destroyed (Fig. 37).

Fig. 37. The old transformer tower – the last building of old wood preservation plant (by W. Irmiński)

In the years 2013-2016 during the extraction of contaminated soil (for soil washing) the remains of both underground installations were removed. To provide and maintain welfare facilities for employees engaged in remediation process and for technological needs (power pumps, lighting and Office) new connections were made from Kujawska st. In the former preservation plant area there are 12 wells and 16 piezometers secured in special wells.

After completion of the work (VII 2016) construction containers were removed while the new mains and sewage installations have been closed and may be available for further use or development of the site. Electrical system has been developed so that it can power all 12 wells (if necessary). Wells are now closed, and pumps removed. In addition, a pump supporting the installation, which recycles leachate from the bioremediation heap, is constantly powered (Fig. 38). Power supply for the electrical network is located at Kujawska st. while the bioremediation heap is located at the opposite end of the grounds – for that reason an underground, low-voltage, electric line has been laid down following the line of the aforementioned wells. On the westernmost, inwardly curved border of the terrain, lays an underground heat pipeline, which supplies heating and hot water to the whole housing estate on Toruńska st. Heating plant is located to the south of the site, at Garbary St.

Fig. 38. The bioremediation heap is fenced and inaccessible (by W. Irmiński)

The infrastructure includes also the roads, pedestrian paths and fences. In accordance with the urban greenery plan, which was agreed with the city at the time of remediation, a dirt road has been built from Kujawska st. across the terrain to the bioremediation heap. It premits rainwater infiltration to the ground and is reinforced with an under-layer of 'clean' debris of concrete and brick. This debris comes from waste separation after demolishing of the remnants of buildings and the foundations of the former wood preservation plant. Before crushing into smaller pieces, debris was ranked as "clean" or "dirty" depending on the degree of contamination with creosote. In this way, in accordance with the project, certain types of waste, useful in construction, have been re-used on-site, eliminating the need to move those off-site.

No special paths for pedestrians were built. The goal is to provide areas with natural xerothermic grassland habitats and areas sown with grass and clover, where people can take walks or play outdoor games that require no specialized playing fields, e.g.: frisbee, ringo, flying models, kites, etc. Fence surrounding the area forming the social base of the plant is re-used as a fence for the bioremediation heap. Access to the heap is currently prohibited. The total size of land excluded temporarily from general use is approx. 0.75 ha.

At this stage (the land after reclamation must remain as undeveloped for a period of 2 years) there is no need to invest in infrastructure, because the case for further development of the recovered land is still open and can be discussed by the residents and the City Council.

In terms of logistics, area in Solec Kujawski is very well located. Despite the location in the central part of the city it is easy to reach from the Toruńska st., good access from the main road No. 10 (for trucks by the railway crossing, for cars more easily through the new tunnel). Solec Kujawski plans to build a ferry crossing on the River Vistula (ferry for 15 cars, 3 times an hour), which should further increase transit traffic by Solec and facilitate access to the regional tourist Jura Park, which is located near the brownfield site (and has several large parking lots).

A double track railway line no. 18 runs along the southernmost border of the terrain, with the Solec Kujawski railway station approximately 500 metres to the west. Several railway sidings spread out from there. One of them runs along the western border of the site and leads towards the Vistula River to "Solbet" building material manufacturing plant. The unique communication system is the remnant of the industrial history of the area – good transport and railway sidings were indispensable for the functioning of the wood preservation plant. Today, however, it offers added value for several directions of new development, while also contributing some constraints - for example, limiting access to the site for pedestrians and offering no direct driveways into the site from Parkowa st. (north-west border of the terrain).

Legally, the site has a dual status currently: on one hand, the brownfield site, where remediation works have been finished in July 2016 and where the remediation effects survey is still being carried out, is classified as an industrial area - in accordance with the provisions of the adopted local spatial plan, on the other hand, this area may not be subjected to any investment activities for a period of 5 years from the receipt of funding for the remediation of the Operational Programme 'Infrastructure and Environment'. The remediation work lasted 3 years, therefore 2 years are left when the area must be designated as municipal green area. This status is very convenient, as it allows for the process of soil improvement after bioremediation to progress unimpeded.

3.4.1. Sewage treatment plants

After completion of remediation work and creating a heap of bioremediation, a water recirculation system is running, to self-clean the water circulating within the heap. However, this is not a typical sewage treatment plant and may not be used as a sewage plant for other facilities that might be placed here in the future.

The system operates as follows: Heap built mainly of land subjected to soil washing still contains a significant amount of processed water (with some amount of leftover surfactants). The mixture migrates under gravity toward the base of the heap, slowly dissolving hydrocarbons along the way. In addition, rainfall water seeps into the heap - flushing and diluting the contaminants further. All the contaminated water leaches through the heap, reaches the bottom drain and is filtered through a geomembrane HDPE (high density poliethylene), which insulates the base of the heap. From there, leachate flows gravitationally through the so called grit chamber and oil separator to the underground tank with a capacity of 40 m^3. Automatic float switch pump located in the tank periodically pumps out excess liquid into a small well positioned on the top of the heap. From here, through a branching system of perforated pipes (approx. 40 cm below the surface of the heap) the cleaned leachate seeps again into the heap and helps flushing more contaminants. In dry periods (at high and even low temperatures) evaporation and transpiration through plant cover (shrubs and grass) reduces the amount of water throughout the system.

Soil placed on the heap was subjected to inoculation, or in simple terms – poured over with biopreparation. Biopreparation was also added to the underground tank. This forces an even distribution of micro-organisms capable of biodegradation of hydrocarbons causes throughout the recirculated liquid and homogenizes their concentrations throughout the heap. Oxygen, necessary for the development of indigenous soil microorganisms, is supplied through the surface of the heap as well as through an aeration system inside of it - in the form of several perforated pipes arranged in the core of the heap. The core of the Prism was made of a porous material - a finely crushed debris, which was heavily contaminated with creosote. This leads to a gradual (bio-) degradation of heavy hydrocarbons both on the surface and in the debris.

This system requires periodic inspection and a periodic check on the liquid level in the underground tank – there is a plan to install there a sensor notifying of an excessive amount of liquid in the tank. This can occur after extended rainfalls, in the event of pump failure or lack of power supply. In such an event it is possible to pump out the contaminated water parts into a road tanker and carry it to the local urban waste water treatment plant. The quality of the liquid circulating in the system is periodically tested in a laboratory for the presence of hydrocarbons, allowing for an assessment of the effectiveness of this technology and to evaluate the period, after which the bioremediation heap will no longer pose a threat to the environment.

The heap is likely to remain permanently as the local terrain feature, constituting a soundproof barrier from the noise of the railway line. Once the heap finished settling into the ground, it may also find use as a support for the stands on the of the football pitch planned in this area. In the long run, leachates with low concentrations of harmful substances will not be sent to the tank but flow gravitationally into a small cane-root sewage treatment pool, and finally (after periodic check-up) into the ground. Currently, at the initial stage of operation, it is not yet possible to specify the time after which it will be possible to turn off the pump.

3.4.2. Power plants

Not exist.

3.4.3. Communication network

The site is integrated with the road and railway system. There is an access to the terrain and possibility to use a railway track. The distance to the airport – approximately 30 kilometers (Bydgoszcz). It is planned to build (2020) a ferry crossing Vistula river linking two national highways 80 and 10.

3.4.4. Ownership aspects

A period of devastation of the area after 2005 was difficult to stop, as two parcels on which it lays were owned by two different private companies. These companies initially planned to build here the housing estates, but without planning for the expenditure required to clean the land of contamination at any point. When it proved to be impracticable and above the ability of either of the companies, one of them reduced the value of one of the parcels drastically allowing for the owner of the second plot to buy it. The city benefited from the right of preemption and with the consent of the City Council the Mayor acquired the first one in 2008, then another, which individually was not of very high value. In this way, Solec Kujawski took over ownership rights to the entire area after the former wood preservation plant. After the accomplishment of the remediation project the ownership status will not change. It should be noted that only through this form of ownership it was possible to apply for the funds (both from the European Union and from national sources) required to do the remediation work. Private owner could apply for such funds. The city, however, must retain ownership of this property and cannot sell it. The cost of maintaining the site, its periodic surveying and security will be borne by the municipality.

4. Summary

Brownfields represent degraded, not used or not fully used areas designated primarily for economic activity (industrial), which has been completed. Ultimately, for the industrial areas should be created conditions and mechanisms for their rational use and optimal use in accordance to the principles of sustainable development. This requires in general to take actions that are coordinated and aimed at the revitalization of industrial areas. Often against a significant degree of contamination and degradation of the environment also requires the execution of works of a reclamation and remediation.

In the Polish conditions there is no reliable data on the number of brownfield sites, including requiring urgent repair work (i.e. reclamation and remediation) in connection with a strong degradation and threat to local inhabitants. Several strategic documents only mentions that the number of such areas may be up to several thousand.

In conditions when the industrial site is located in an attractive location, it has a high value and in addition is not contaminated revitalization process occurs very quickly, including without the need for financial resources by local governments or the State Treasury. These conditions are universal and are numerously confirmed all over the world. The situation is much more difficult if the industrial site is not especially attractive or valuable and in addition may be contaminated. As a result of historical developments and state form of ownership of most industrial areas (to the year 1990), environmental liability usually falls to the State Treasury. In addition, in the Polish conditions usually there is a very strong environmental degradation with often extremely high level of pollution of individual components of the natural environment. Typically, concentration levels of pollutants are an order of magnitude or even higher than the values recorded in developed countries. This follows directly from the fact that most of the areas degraded by industry arose in the period from 1945 to 1989, where the level of development of applied technology in Poland was rather low, while a lack of or inadequate legal regulations concerning environmental issues.

The problem of brownfield regeneration is not well solved or aided in conditions conducted in Poland after 1989 restructuring and privatization of the industry. Process have undergone only the best and most promising plants. The most dangerous objects for the environment and often requiring expensive remedial actions due to lack of investors and funds, has been declared bankrupt and then left without even a framework plan or strategy development.

The areas of former „Zachem” Chemical Plant in Bydgoszcz and State Enterprise of Railway Sleepers Preservation in Solec Kujawski are typical examples of brownfields in Poland. Despite the attractive location in the immediate vicinity of the urban areas in connection with a strong environmental pollution there is a lack of investors who undertake the remediation, including in particular the cleaning of soils, land and groundwater. This is due to the obvious fact that the high cost of this type of actions, which necessitates a more active role of local governments. A good example in this regard are all active actions carried out by the Commune Solec Kujawski. The municipality took over the contaminated area and using EU funding has made land reclamation and treatment of soils and land. At the same time in the next stages of the remediation of the former State Enterprise of Railway Sleepers Preservation is planned effective remediation of groundwater. Physicochemical properties of the contaminants present in the vicinity of this object rank them in the category of very mobile in the soil and water environment, where the main polluted components are soil and land, and where the potential migration of contaminants in groundwater flow takes place with low intensity. The area of contaminated groundwater in these conditions only slightly may extend beyond the area of the former Railway Sleeper Preservation where additional factor limiting the migration is a close proximity of Vistula river. These factors provide a real basis to take effective remediation actions until it is clean to an acceptable level.

In the case of former „Zachem" Chemical Plant in Bydgoszcz repeat the path of actions developed in Solec Kujawski can be difficult or impossible. This follows directly from the fact of a large size of brownfield land (including 2,000 ha) and a complicated ownership structure. In addition, as a result of long-term activities of the former "Zachem" ChP areas outside of these plants have been also contaminated. At the same time the large size of a brownfield, the presence of tens of pollution sources as well as high level of contamination of soils, land and groundwater make it possible that a costs of remediation achieve very high level of up 1-1.2 billion €.

The main requirements for future needs related to the planning and implementation of effective remediation of both the former site of "Zachem" ChP in Bydgoszcz, as well as the State Enterprise of Railway Sleepers Preservation in Solec Kujawski include:

1. execution and current operation of groundwater monitoring network in order to gather reliable data for the optimal selection of techniques and methods of effective remediation; an important goal of environmental monitoring is also the current control of state of pollution, which allows to take any recovery operations in case of adverse developments, including in particular the impact on local residents,

2. remediation project execution based on advanced numerical models; this is a crucial stage for further action aiming to propose optimal methods, but of course also a low cost of implementation and operation,

3. raising funds for the often long-term remediation, where due to its high cost is necessary participation of the government at the level of voivodeship and even central; the involvement of budget funds in this context is justified in view of the fact of state nature of the companies responsible for the creation of pollution almost to the end of their activities, i.e. 1990-2013 years,

4. to take effective remediation, which must include a minimum of 4-5 years of active actions, in order to significantly reduce environmental pollution and unspecified set period of time "more thorough cleaning" of the environment, i.e. to bring its parameters to an acceptable level.

Restoration of utility functions of the area of the former "Zachem" Chemical Plant in Bydgoszcz requires the cooperation of all local government and administrative units, i.e. The City of Bydgoszcz, the Regional Direction of Environmental Protection, the Regional Inspectorate of Environment, academic and other units. Joint actions taken for the development of the whole area should be done in order (1) remediation, (2) the rehabilitation and (3) revitalization. The initial guidelines were included in the study entitled: "A comprehensive assessment of the state of environmental contamination of soil and water in the area of the former "Zachem" Chemical Plant in Bydgoszcz, including an identification of the list of activities necessary for the effective remediation" executed by the AGH University of Science and Technology in Krakow.

The situation requires to build a platform of cooperation and exchange of information between local government and administrative units, as well as in the public domain for the inhabitants of areas adjacent to the brownfield. Such actions can also be extended with specialized training raising environmental awareness of local communities, inhabitants of Bydgoszcz, Łęgnowo, Plątnowo and Otorowo. All of these guidelines should therefore be carefully developed in the so-called “master plan”, which will be a continuation of the “A comprehensive assessment (...)” and will contain guidelines for the management of the area of former plant in order to restore the utility functions.

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<u>The standards and guidelines used in the study *(in Polish)*:</u>

1. PN-72/C-04550.03 – Woda i ścieki. Badania zawartości syntetycznych substancji powierzchniowo czynnych oraz ich biochemicznego utleniania. Oznaczanie niejonowych polietoksylowych syntetycznych substancji powierzchniowo czynnych metodą kolorymetryczną z rodanokobaltynem amonowym

2. PN-EN 12457 – 2:2002 Charakteryzowanie odpadów. Wymywanie. Badanie zgodności w odniesieniu do wymywania ziarnistych materiałów odpadowych i osadów. Część 2: Jednostopniowe badanie porcjowe przy stosunku cieczy do fazy stałej 10 l/kg w przypadku materiałów o wielkości cząstek poniżej 4mm (bez redukcji lub z redukcją wielkości)
3. PN-EN 12457-2:2006 – Charakteryzowanie odpadów. Wymywanie. Badanie zgodności w odniesieniu do wymywania ziarnistych materiałów odpadowych i osadów. Część 2: Jednostopniowe badanie porcjowe przy stosunku cieczy do fazy stałej 10L/kg w przypadku materiałów o wielkości cząstek poniżej 4 mm (bez redukcji lub z redukcją wielkości)
4. PN-EN 12673:2004 – Jakość wody. Oznaczanie niektórych wybranych chlorofenoli w wodzie z zastosowaniem chromatografii gazowej
5. PN-EN ISO 10301:2002 – Jakość wody. Oznaczanie łatwo lotnych chlorowcowych pochodnych węglowodorów. Metody z zastosowaniem chromatografii gazowej
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12. PN-ISO 6439:1994 – Jakość wody. Oznaczanie indeksu fenolowego. Metody spektrometryczne z 4-aminoantypiryną po destylacji
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