Załącznik 3/Appendix 3

Summary of professional accomplishments

(Autoreferat)

1. Name and surname: Beata Jaworska-Szulc

2. Scientific degrees

a) 1998 r. – Master of Sciences, Faculty of Environmental Engineering, Gdańsk University of Technology, field of studies Environmental Engineering, specialization Water Resources Management, MSc thesis title: *The evaluation of groundwater quality changes in Quaternary aquifer of pommeranian voivodeship in the light of monitoring studies.* Promoter prof. dr hab. inż. B. Kozerski.

b) 2002 r. – Philosophy Doctor, discipline: environmental engineering, PhD thesis title: *The influence of aquifer aggregation on the precision of groundwater flow model analysis on the basis of the gdańsk aquifer stystem*. Promoter prof. dr hab. inż. B. Kozerski. Gdańsk University of Technology, Faculty of Civil and Environmental Engineering.

c) 2004 r. – Postgraduate Studies Diploma in the field of Geology, Adam Mickiewicz University in Poznań, Faculty of Geographical and Geological Sciences. Thesis: Tertiary stratigraphy of the Gdańsk area. Promoter prof. dr hab. W. Stankowski.

3. Employment in scientific institutions

a) 01.10.1998 r. do 30.09.2002 r.: doctoral studies at Geotechnics and Environmental Engineering, Faculty of Civil and Environmental Engineering, Gdańsk University of Technology. PhD student in the Department of Hydrogeology and applied geology.

b) Since 15.12.02: assistant professor in the department of Geotechnics, Geology and Marine Engineering, Faculty of Civil and Environemental Engineering, Gdańsk University of Technology.

4. Scientific achievement indicates as the basis for habilitation degree according to regulation dated from 14th March 2003 (No 65, item 595 with amendments):

a. Title

Series of monothematic publications: ***Forming of groundwater resources in the young glacial multiaquifer system.***

b. Publications included in the achievement:

1. **Jaworska-Szulc B. (2015)**. Formowanie się zasobów wód podziemnych w młodoglacjalnym systemie wodonośnym na przykładzie Pojezierza Kaszubskiego / Forming of groundwater resources in the young glacial multiaquifer system of the the Kashubian Lake District. Wydawnictwo Politechniki Gdańskiej, Monografia nr 152, 160 s. **Zał. 7.1.**

2. **Jaworska-Szulc B. (2009).** Groundwater flow modelling of multi-aquifer systems for regional resources evaluation: the Gdansk hydogeological system, Poland. Hydrogeology Journal, 17: 1521-1542. ***IF – 1,417.* Zał. 7.2.**

3. **Jaworska-Szulc B. (2015).** Impact of Climate Change on Groundwater Resources in a Young Glacial Multi-Aquifer System. Pol. J. Environ. Stud. Vol. 24, No. 6 (2015), 2447-2457. ***IF – 0,871.* Zał. 7.3.**

4. **Jaworska-Szulc B. (2016).** Role of the Lakes in Groundwater Recharge and Discharge in the Young Glacial Area, Northern Poland. Groundwater, early view doi: 10.1111/gwat.12385. ***IF – 2,307.* Zał. 7.4.**

5. **Jaworska-Szulc B. (2006).** Problem zasobów odnawialnych wód podziemnych w wielowarstwowych systemach wodonośnych na przykładzie Regionu Gdańskiego / The problem of groundwater renewable resources evaluation in multi-aquifer systems base on the example of Gdańsk Region. Modelowanie przepływu wód podziemnych. Poznań, Uniw. A. Mickiewicza. GEOLOGOS 10, 91-99. **Zał. 7.5.**

6. **Jaworska-Szulc B.**, Pruszkowska-Caceres M., Przewłócka M. **(2014)**. Analiza kontaktu wód podziemnych i powierzchniowych na podstawie badań ich jakości na młodoglacjalnym obszarze Pojezierza Kaszubskiego / Investigation of groundwater-surface water contact based on the quality research in a young glacial area of the Kashubian Lake District. Przegląd Geologiczny. Tom 62, 4: 204-213. **Zał. 7.6.**

7. **Jaworska-Szulc B.**, Pruszkowska-Caceres M., Przewłócka M. **(2015)**. Zmiany wydajności wypływów wód podziemnych młodoglacjalnego obszaru morenowego na Pojezierzu Kaszubskim / Changes of groundwater discharge in the young glacial area of the Kashubian Lake District. Przegląd Geologiczny. Vol. 63., nr. 10/1 (2015), s.774-779. **Zał. 7.7.**

8. **Jaworska-Szulc B. (2015).** Ocena zasilania wód podziemnych na Pojezierzu Kaszubskim z zastosowaniem różnych metod i różnej skali opracowania / Groundwater recharge estimation in Kashubian Lake District different scale studies, comparison of methods. Przegląd Geologiczny. Vol. 63., nr. 10/1 (2015), s. 762-768. **Zał. 7.8.**

c. Objectives and results of the work

Forming of groundwater resources in multi-aquifer systems is a very complex issue. A distinctive feature of young glacial areas is a very diverse land relief, especially in elevated marginal zones. Consequently, conditions of groundwater occurrence are particularly complicated; aquifer system includes altering water bearing strata and aquitards. The highest elevations constitute recharge areas for aquifer systems formed there. Subglacial channels and meltwater valleys create discharge zones, extensive outwash plains play various functions depending on the specificity of the area; usually they constitute recharge or transit zones. Therefore, recharge of young glacial multi-aquifer systems is influenced by many various factors, principally by geology and the extent of aquifers and aquitards, land relief, interactions between groundwater and surface water, surface and subsurface runoff and also by climatic factors, mainly precipitation and evaporation. The aim of my investigations was to recognize the above-mentioned factors which influence forming of groundwater resources in multiaquifer systems and also to analyze the resources in a regional approach.

My research was carried out in the years 2004 – 2013 in the area of the Kashubian Lake District. On the regional scale, the study included the whole gdańsk aquifer system and on the local scale I have focused on the szymbarskie hills constituting the recharge zone of the system. The regional investigations served as the basis for discussion on groundwater resources of the whole aquifer system, based on multilayered regional flow model covering the area of 2800 km^2 (I.B.2 zał. 4 & zał. 7.2) and including four main aquifers: upper Quaternary, lower Quaternary together with Miocene, Oligocene-Eocene and Cretaceous.

In the studies conducted on the local scale, I have investigated and analyzed the most important factors influencing the groundwater resources formation. My research focused on both, the impact of climatic factors, including the analysis of the effect of expected climatic changes on groundwater and also on hydrographic factors, where apart from the analysis of groundwater and surface water interaction, I have investigated the role of endorheic areas in forming of groundwater resources. I have also created a detailed, local groundwater flow model, covering an area of 30 km^2 and including the above mentioned factors. This model has been built for the central part of the Kashubian Lake District (szymbarskie hills) constituting the recharge zone of the gdańsk aquifer system and it included 5 Quaternary aquifers of a diverse extent. I have performed comprehensive analysis of recharge and discharge with the use of different methods and on different scales of approach. The whole research has been described in a collective monograph (I.B.1 zał. 4 & zał. 7.1), and several issues have been singled out and presented in separate publications (I.B.3, I.B.4, I.B.6, I.B.7, I.B.8 zał. 4 & zał. 7.2, 7.3, 7.4, 7.6, 7.7, 7.8).

On the basis of regional groundwater flow model calculations, I have presented **analysis of renewable resources in respective multiaquifer formations**. I have also introduced **confrontation of disposable resources (safe yield) and sustainable yield** according to the Bredehoeft [2,3], as discussion on different concepts of groundwater resources assessment are in progress in hydrogeologic literature. On one hand there are views, popular also in polish hydrogeological research community, that recharge of aquifer systems is determined on the basis of infiltration recharge, mainly precipitation, but also surface water infiltration. This natural recharge is regarded as crucial, because it determines the upper limit of possible volume of extracted groundwater [26]. However Bredehoeft [2] disputes the idea of the assessment of safe yield on the basis of recharge. Bredehoeft [2] and also Sophocleous [24] believe that Theis expressed the same view in 1940 in his article „The source of water to wells: essential factors controlling the response of an aquifer to development" [25]. In order to determine optimum water extraction, runoff analysis is more important than the amount of infiltration recharge. In natural conditions, before groundwater exploitation, groundwater systems were in flow balance; for hundreds of years recharge was balanced by runoff. Together with groundwater output, a part of water is taken out from an aquifer and a new balance can be achieved only by decreased runoff and increased infiltration. Recharging infiltration wouldn't change during groundwater exploitation, only in case of shallow aquifers, additional portion of infiltration from surface water may be induced. This is why capture should be calculated on the basis of difference in runoff caused by exploitation [3,4]. Discussions on safe yield and the role of runoff in their determination [1,2,3,24,26] aim to the concept of sustainable yield.

In the light of the above considerations I have determined the value of the capture based on model calculations for gdańsk aquifer system and also the recharge – runoff difference caused by exploitation; I have also established whether the current exploitation can be regarded as sustainable. This is the first analysis of sustainable yield of that type applied for Polish conditions. The model calculations have shown that exploitation of both usable aquifers Quaternary-Miocene and Cretaceous, is carried out at sustainable yield level. However for Oligocene- Eocene aquifer the difference in runoff is higher than yield, therefore it is possible to increase exploitation in the conditions of sustainable yield. On the other hand, in upper Quaternary aquifer exploitation is higher than the difference between runoff and recharge. In other words, the yield is not sustainable and a part of resources was removed from the aquifer without possibility of balancing them neither by increased recharge nor by decreased runoff . In the upper Quaternary aquifer the response expressed in runoff is least noticeable, because this water bearing bed disappears before the edge of the upland and is absent in areas of main discharge zones. Water of this horizon predominantly descends to Quaternary-Miocene aquifer or is discharged by surface water; lateral outflow is only a small part of the runoff. As a result, total runoff varies less dynamically than in horizons where lateral outflow constitutes essential part of the runoff. It doesn't mean however, that it is necessary to decrease current abstraction in the upper Quaternary horizon.

Current groundwater exploitation in the gdańsk aquifer system constitutes barely 30% of the safe yield. Nevertheless, the above presented analysis of sustainable development has proved that the current abstraction is close to sustainable yield and in the upper Quaternary aquifer even exceeds this value. The concept of sustainable development concerns dynamic conditions and doesn't determine value of yield for a given location or region. If capture depends mainly on runoff response, it means that it may be increased in those areas, where such a reaction occurs, that is in areas of base level of groundwater drainage. Therefore, it may be concluded, that marine lowlands are the best areas for groundwater abstraction in the gdańsk aquifer system. Here, water flowing laterally from the upland can be captured before it is drained in the Bay of Gdańsk and in the Bay of Puck. Model calculations have proved that groundwater exploitation is reflected in decreased undersea drainage. However, abstraction must be carried out with great caution, because of the risk of affecting balance between groundwater and salt water from the Bay of Gdańsk.

I have also attempted to determine renewable resources for respective multiaquifer formations. In shallow horizons, renewable resource is regarded as infiltration recharge and in deeper layers as descent percolation. In this way we obtain the module of renewable resources in the upper Quaternary aquifer 19,4 $m^3/h/km^2$, in

Quaternary-Miocene aquifer 17,1 $m^3/h/km^2$, in Oligocene-Eocene aquifer 16,9 $m^3/h/km^2$ and in Cretaceous aquifer 6,5 $m^3/h/km^2$. It leads to recognize the same resource for following aquifer formations, because recharging infiltration in a first horizon makes up a part of descend percolation to deeper layers. On the other hand, descend percolation may take place within several horizons, just like in case of the gdańsk aquifer system, beginning from the upper Quaternary water bearing strata till the Cretaceous horizon. As an effect, a part of water volume "captured" e.g. by exploitation, at any stage of the descent, decreases resources for deeper aquifers. Thus, renewable resources for the whole gdańsk aquifer system, identified with recharging infiltration, are more than twice as small as the sum of resources for respective aquifers (I.B.5 zał. 4 & zał. 7.5). In order to avoid the risk of overestimation of groundwater resources, I have estimated renewable resources on a regional scale and next I have isolated from the value, resources for each aquifer.

If we regard the whole recharging infiltration together with infiltration of lakes situated in the recharge zone and elevated above groundwater table of the upper horizon as total renewable resource for the Gdańsk hydrogeological system, we arrive at the value of 45 852 m^3/h which must be devided into four aquifer formations. For deeper horizons it can be concluded that the value of descent reduced by the ascent to overlying aquifers and by a further descent to lower aquifers. As an effect, we obtain value 1741 m^3/h for Oligocene-Eocene aquifer and 2735 m^3/h for the Cretaceous one. The remaining value of 41 376 m^3/h is the renewable resource for Quaternary aquifers together with Miocen horizon, with the vast majority referring to Quaternary-Miocene aquifer because of its wide extent and high hydraulic parameters. It is really difficult to assess precisely the value of resource referring to the first and the second Quaternary water bearing strata. It is strictly connected with the structure of groundwater abstraction, because output from the upper layer in the upland area decrease the resources and reduces possibility of groundwater exploitation from the second Quaternary aquifer in the area of marine lowlands.

Based on the research carried out on a regional and a local scales I have distinguished several characteristic features influencing groundwater resources forming in the area of young glacial uplands.

1. Altering sediments of subsequent glaciations in the form of permeable and semi permeable layers cause that **groundwater systems** are in this case **multilayered**. As an effect, **vertical flows between layers** plays important role in forming of groundwater resources. In recharge areas, shallow perched waters are drawn

downwards by descent seepage. However, in discharge areas ascent from deeper groundwater horizons to shallower ones takes place.

2. The next specific factor influencing forming of groundwater resources in young glacial areas is **perched water occurrence**. Even two or three levels of perched water were found above the first aquifer and water table of perched water was elevated few dozen of meters above groundwater table of the first aquifer (locally, even more than 80 m above). Owing to this phenomenon, perched water seepage to lower aquifers is observed. The results of regional and local investigations have proved that suspended water horizons play alimental role for deeper aquifers.

3. Another typical feature of young glacial areas is common occurrence of **endorheic areas.** On absorptive endorheic areas, intensive infiltration from precipitation takes place, because a part of water from surface runoff recharges groundwater; the water accumulates in depressions and slowly infiltrates to an aquifer. In the central part of the Kashubian Lake District endorheic area constitute even up to 40% of its surface. Complex studies of endorheic areas have been conducted and they served to define recharging infiltration in model calculations. As a result I have obtained value of average infiltration in recharge area of the Gdańsk hydrogeological system as 147 mm, which constitute about 22,5% of the measured precipitation.

4. **Mutual interactions between groundwater and surface water** are considerably influenced by height denivelations occurring in young glacial areas. Based on regional investigations I have distinguished characteristic types of lakes by the kind of their contact with groundwater (I.B.1, I.B.4 zał. 4 & zał. 7.1, 7.4). Besides typical gaining lakes occurring usually in subglacial and meltwater valleys I have identified quite often surface waters of losing type. They can be found across moraine uplands and more rarely on highly elevated outwash plains. Usually they fill depression hollows of an evapotranspirative type, where surface and subsurface runoff recharges surface water reservoir located in the center of such a depression hollow and next groundwater is recharged in an indirect way. Gaining lakes are characterized by elevated mineralization, over 250 mg/dm^3 on the other hand losing lakes show low mineralization – below 100 mg/dm^3. I have also distinguished two more types among losing lakes, displaying elevated mineralization (od 130 do 300 mg/dm^3) which is caused either by indirect contact with an aquifer or by drainage of local perched water. I have also indicated flow through lakes of a mineralization range 170-200 mg/dm^3. Detailed survey of the Szymbarskie Hills confirmed the proposed distinction of surface water types and

they also proved that springs and rivers of a gaining type usually show higher mineralization than gaining surface water reservoirs (about 250-420 mg/dm^3 up to 615 mg/dm^3).

I have also performed analysis of the impact of projected climate changes on groundwater resources (I.B.1, I.B.3 zał. 4 & zał. 7.1, 7.3). Trend analysis of changes in temperature and precipitation for a six-decade period of meteorological measurements history in Kościerzyna meteorological station has shown a steady, consistent trend in temperature increase of on average +0,0182°C/year. Based on the temperature analysis in Kościerzyna it may be assumed that an average annual temperature will probably increase by 0,9 °C over the next 50 years if current trends continue. The analysis of the average monthly and annual precipitation also shows a growing trend of an average 1,8472 mm/year. In the context of groundwater resources forming, it may be assumed that the mentioned above trends may contribute to an increase in groundwater recharge, especially considering that precipitation increases in a non-growing season. If current trends continue, the sum of precipitation involved in groundwater recharge will probably increase by 36 mm (5,5%) over the next 50 years, which is consistent with the projected trends in the IPCC reports for this region [14,15]. Additional factor contributing to increased infiltration is projected temperature rise in winter months [14,15] which is consistent with trends observed in the meteorological station in Kościerzyna. In the light of the above projections I have simulated increased annual recharge from precipitation by 5,5 % and I have analyzed its impact on groundwater resources and on flow structure. The simulation results have proved that the projected climate changes will influence flow rates in the whole Quaternary aquifer system. However, the changes are most visible in the first horizon and the highest percentage increase of flow concerns the spring runoff and the descend to deeper aquifers. Groundwater table in shallow aquifers will rise by an average of 1 m.

The results of my investigations may be adopted to other young glacial areas with similar hydrogeological conditions, mainly in North America and in Europe. Many interesting regional research were conducted in Canada and in north states of United States of America. They concern mainly permeability parameters of aquitards [5,7,10,11,22,23] or recharging infiltration [5,6,8]. Also many regional model based analysis were carried out [12,18,21] however they usually didn't concern multiaquifer systems excluding few studies [9,13,17]. My analysis of recharge structure of multiaquifer system and also of the role of surface water and vertical flows constitute a complement to current knowledge on hydrogeology of young glacial areas. It also allows to form conclusions on further research necessary to even more precise recognition of the analyzed issue. I have proved that the role of endorheic absorptive areas in recharge zones of multiaquifer systems is an especially interesting research issue. It will be interesting to continue investigations in this field. Another research issue is to further detail the index method determining recharging infiltration, especially separation of additional infiltration indexes for semi-permeable sediments e.g. sandy moraine clays.

5. Description of other scientific achievements

a. Before obtaining PhD degree

In 1998 I graduated from the Faculty of Environmental Engineering of the Gdańsk University of Technology with a Master of Environmental Engineering degree, specializing in water management. I prepared my Master thesis entitled: *The evaluation of groundwater quality changes in Quaternary aquifer of pommeranian voivodeship in the light of monitoring studies,* under the direction of prof. Bohdan Kozerski and I defended my thesis in June 1998. I have received an award from “Clear Water” Foundation for the thesis. In my dissertation I have assessed changes in chemical composition of groundwater from Quaternary aquifer, based on data from the National Environmental Monitoring. I have analyzed points of national and regional net. Monitoring in national net was carried out from 1991 including 26 observation wells. Groundwater was analyzed for 49 quality parameters. As to regional net, observations were carried out from 1995 in 34 observation wells and the range of analysis included 40 quality parameters. In my dissertation I have assessed the groundwater as HCO_3-Ca and HCO_3-SO_4-Ca hydrogeochemical types, which is typical for infiltration water of young glacial uplands. I have also determined hydrogeochemical background and evaluated the quality of the monitoring analysis. In 18% of water samples I have detected ionic balance error higher than maximum permissible error (II.1 zał. 4). As an effect I have reached conclusions concerning proper funcioning of the monitoring system and my remarks were used in groundwater monitoring project for pommeranian voivodeship in 1991, elaborated with me as a co-author.

After obtaining Master of science degree in engineering, I continued my education from October 1998, as a student of doctoral studies “Geotechnics and Environmental Engineering” at the Faculty of Hydro and Environmental Engineering, Gdańsk University of Technology. In 1999 I attended a 3 months doctoral internship at the Joseph Fourier

University in France on the theme of modeling in water managemet, focused in particular on numerical modeling of groundwater flow.

In 2000 I started work on my PhD dissertation entitled: *The influence of aquifer aggregation on the precision of groundwater flow model analysis on the basis of the gdańsk aquifer stystem,* under supervision of Prof. Bohdan Kozerski. The project was supported by Ministry of Science and Higher Education as No KBN 6 P04D 086 19 grant project. Based on the research carried out within my doctoral dissertation I have created groundwater flow model for a part of the gdańsk aquifer system, covering an area of 594 km^2. The model included the area of the upland edge, zones of groundwater discharge and also a small part of the recharge zone. It has been the first groundwater flow model developed for the Gdańsk region. The initial model projected 5 aquifers: upper Quaternary, lower Quaternary, Miocene, Oligocene and Cretaceous. In next stages I simplified schematization of the aquifer system by aggregation of water bearing horizons. As a result, three further models have been built. Two of them included aggregated strata of similar hydrodynamic conditions, staying in a local contact. Model of the first aggregation consisted of four water aquifers: upper Quaternary, lower Quaternary together with Miocene, Oligocene and Cretaceous. Such a schematization was consistent with the natural hydrogeological conditions of the gdańsk aquifer system, because the Miocene horizon usually stays in a hydraulic contact with the lower Quaternary and both create main usable aquifer. Model of the second aggregation consisted of three aquifers: Quaternary-Miocene, Oligocene and Cretaceous. The third aggregation concerned separate layers differing in piezometric pressure; two Tertiary aquifers were joined together (Miocene and Oligocene), which apart from the stratigraphic similarity they differed as to hydrodynamics. As a result, the model consisted of four aquifers: upper Quaternary, lower Quaternary, Miocene together with Oligocene and Cretaceous.

The performed calculations have proved that aggregation of water bearing strata with similar hydrodynamic parameters, has a little impact on the balance of the whole aquifer system; the changes haven't exceeded 0,2-0,6%. However, flow conditions inside the system were influenced more distinctly; particular components of water balance changed from 0 to 4,2%. On the other hand, aggregation of aquifers which differ in filtration parameters and in hydrodynamic conditions leads to bigger divergence in the balance of the whole system (about 4%) and also to bigger divergence in particular components of the balance (up to 4,8%). Based on those calculations I have concluded, that fidelity in simulation of hydrogeological structures extent and geometry is less important than precise simulation of their hydrodynamic and filtration parameters.

The research carried out in my doctoral thesis involved directly the issue of groundwater flow modeling, which became the subject of my interest in subsequent years. I have built the models with the use of the MODFLOW program, widely used in the World, but in Poland only in a few centers of hydrogeological studies. In 2001 I have developed my first model for commercial purposes. The aim was to assess groundwater resources for agriculture purposes in the catchment area of the Łupawa river (II.2 zał. 4).

On 29 November 2002, in accordance with the resolution of the Scientific Council of the Hydro and Environmental Faculty, Gdańsk University of Technology I was awarded scientific degree of Doctor of Technical Sciences, discipline – Environmental Engineering, specialty – hydrogeology.

b. After obtaining PhD degree

After obtaining PhD degree I have worked as an Assistant Professor (Adjunct) in the Department of Hydrogeology and Engineering Geology at the Faculty of Hydro and Environmental Engineering of the Gdańsk University of Technology (currently named the Department of Geotechnics, Geology and Maritime Engineering)

In October 2002, shortly before obtaining PhD degree, I began a 4 semester post-graduate studies in Geology at the Faculty of Geographical and Geological Sciences of the University of Adam Mickiewicz in Poznań. I have completed the studies in June 2004. In my final thesis I worked under scientific supervision of professor W. Stankowski on the issue of the Tertiary stratygraphy in the Gdańsk region. Based on new stratygraphic data I have elaborated stratygraphic profile of Tertiary sediments (Neogene and Paleogene) in the Polish Lowlands with particular reference to the Gdańsk Pomerania. In the light of new views on Tertiary stratygraphy I have analyzed nomenclature of water bearing horizons, which was used unchanged since the beginning of the XXth century. Owing to documented Eocene sediments I have proposed that lower Tertiary layer should be named Oligocene-Eocene instead of Oligocene, or using more general nomenclature - Paleogene (of upper and middle Paleogene) (II.E.4 zał. 4).

I continued research on groundwater flow modeling and on schematization of groundwater conditions. I have developed the model of the gdańsk aquifer system edge zone and performed additional calculations of groundwater resources for separated balance areas. The results of my research have been presented in a few publications which included a part of my doctoral dissertation (II.A.1, II.E.1, II.E.3, II.E.24, II.E.25 zał. 4).

I continued my research on credibility of hydrogeological models still in 2010 (II.E.10 zał. 4). But from 2004 my scientific interests focused on calculations of groundwater resources both on regional and local scale. At that time research began within the framework of KBN (Committee for Scientific Research) grant (no KBN 4T12B 06026), under scientific supervision of prof. Bohdan Kozerski. Within this project entiitled *The Gdańsk Aquifer System* I have delimited the borders of the Gdańsk Aquifer System and of particular aquifers; besides I have created regional groundwater flow model (II.E.2 zał. 4). Over subsequent years I have completed the model investigations and analysis of resources in a regional approach, implementing new aspects connected with the concept of sustainable yield and introducing new approach to renewable resources assessment. The results have been presented above as a part of my documented scientific achievements.

From 2003 till now, I have developed numerous groundwater flow models, which were the basis for the assessment of groundwater resources and for establishing protection zones of groundwater intakes. The studies were performed in cooperation with Gdańsk geological enterprises and usually they constituted separated parts of hydrogeological documentation. These were groundwater flow models for the following intakes:

- in 2003, groundwater intake "Bitwy pod Płowcami" in Sopot (with cooperation with Geological Enterprise POLGEOL)
- in 2004, groundwater intake Wiczlino in Gdynia (with cooperation with Hydrogeological Enterprise in Gdańsk)
- in 2006, groundwater intakes Głobino and Westerplatte in Słupsk (with cooperation with Establisment of Hydrogeological Services Zygmunt Kliński)
- in 2006, groundwater intake in Suwałki (with cooperation with Geological Enterprise POLGEOL)
- in 2006, groundwater intake Wielki Kack in Gdynia (with cooperation with Hydrogeological Enterprise in Gdańsk)
- in 2008, groundwater intake Krzywe Błota in Włocławek (with cooperation with Geological Enterprise POLGEOL)
- in 2009, groundwater intake Wrzosy in Toruń (with cooperation with Geological Enterprise POLGEOL)
- in 2009, groundwater intake Morsk in Świecie (with cooperation with Geological Enterprise POLGEOL)

- in 2010, groundwater intake Cedron in Wejherowo (with cooperation with Geological Enterprise POLGEOL)
- in 2012, aggregate regional model for the Gdynia intakes: Wielki Kack Wiczlino, Sieradzka and Kolibki (with cooperation with Hydrogeological Enterprise in Gdańsk)
- in 2015, groundwater intake Bąkowo in the Kolbudy municipality (with cooperation with Establisment of Hydrogeological Services Zygmunt Kliński)

The above groundwater flow model investigations resulted in study on possibility of Tri-city intakes exploitation in conditions of their intensive interaction (II.E.5, II.E.6, II.E.7, II.E.8, II.E.27 zał. 4), also simulations of groundwater yield in the sea shore zone, considering projected rise of the sea level (II.E.26 zał. 4). I have also performed analysis of optimum groundwater abstraction for other groundwater intakes located in North Poland (II.E.9, II.E.29 zał. 4).

I also took part in the assessment of groundwater resources and protection areas of Main Groundwater Bodies (MGWB). In 2011 I have developed regional groundwater flow model for the MGWB 208 – Biskupiec (II.E.13 zał. 4) (with cooperation with Hydrogeological Enterprise in Gdańsk) and in 2015 – for MGWB 133 Młotkowo (together with A. Gumuła-Kawęcka and in cooperation with Hydrogeological Enterprise in Gdańsk, II.E.18 zał. 4)

In the years 2002 – 2010 my research was carried out together with B. Kozerski, M. Pruszkowska-Caceres and M. Przewłócka, and was aimed to assess groundwater quality and changes of its chemical composition in the Gdańsk region. The investigations conducted in the years 2002 – 2004 in cooperation with Technical University of Stokholm (Kungliga Tekniska Högskolan), focused on assessing of groundwater quality on the marine terrace; the investigations included also geophysical survey of apparent specific resistance. As a result we succeeded to observe salt water previously intruded to the aquifer, retreating towards the Gdańsk Bay (II.E.23, II.E.30 zał. 4). The other research on groundwater quality in the Gdańsk region included analysis of anthropogenic changes of its chemical composition (II.E.31, II.E.33 zał. 4), natural processes of groundwater resources recovery and of quality improvement including groundwater salinity changes (II.E.21, II.E.22, II.E.28, II.E.32 zał. 4). The most visible changes of groundwater quality were caused by overexploitation with maximum output in the years 1980 – 1985, inducing salt water intrusion from the Dead Vistula River (Martwa Wisła) and from the Gdańsk Bay. Our scientific team has proved, that since the 1990s when groundwater exploitation had been reduced, chloride ion decrease has been observed. It leads to groundwater desalinization and recovery of resources.

In 2010 I have created groundwater flow model in the area of the designed tunnel under the Dead Vistula at the request of the Gdańsk Municipal Investments. I have analyzed the impact of the tunnel (designed at that time) on groundwater. Simulations carried out by me have proved a very limited impact of the tunnel on groundwater flow; groundwater level would change from 0 to 3 cm and in any case wouldn't influence the water balance. The calculation results were confirmed by further observations of groundwater level carried out in piezometers during the tunnel construction. I have proved that there were no threats to quantitative groundwater resources of the Pleistocene-Holocene aquifer in the vicinity of the tunnel construction (II.E.11, II.E.12 zał. 4). Later, in the years 2011 – 2014 I was a member of the Scientific Consultants Team appointed by a decree of the President of the Gdańsk Municipal Investments. Together with eng. B. Buca we requested to implement groundwater quality monitoring in the vicinity of the investment (II.E.15 zał. 4). Monitoring of groundwater salinity in the vicinity of the tunnel allowed to recognize spatial and temporal variability of the chloride ion concentration. It was especially important for the process of ground freezing and in the construction of horizontal cross-connections between tunnel tubes. Recognition of the problem helped to adjust the freezing process to environmental conditions. Observations of groundwater level fluctuations have proved on the other hand that groundwater level is greatly influenced by the level of water in the Dead Vistula River. Groundwater exploitation or drainage conducted in the vicinity of the tunnel has a smaller impact, however it influences the balance between fresh groundwater and salt water from the Dead Vistula, leading to periodical salt water infiltration to the aquifer on the western bank of the river (II.E.16 zał. 4).

In the years 2010 – 2013 I participated in research carried out within the project of Polish Ministry of Science and Higher Education: *Local groundwater systems of young glacial uplands on the basis of the szymbarskie hills in the Kashubian Lake District* (no NN 307404538), under scientific supervision of prof. B. Kozerski. The investigations focused on shallow groundwater and surface water. Many of the obtained results were used by me in analysis of groundwater resources forming in areas of young glacial uplands, which is described in the above chapter as a part of my documented scientific achievements. The investigations included also analysis of chemical composition of groundwater. On the basis of the obtained results, our research team (B. Jaworska-Szulc, M. Pruszkowska-Caceres and M. Przewłócka) has assessed chemical and isotopic composition of groundwater from the Quaternary aquifer in the central part of the Kashubian Lake District and also forming conditions of chemical composition of groundwater and surface water (II.E.14, II.E.20 zał. 4).

In 2015 I have performed model simulations of pollutant migration in the area of the Szadółki landfill, together with A. Gumuła-Kawęcka. Our calculations allowed to determine both the direction and the rate of leachate migration from the landfill in a multilayered hydrogeological system. Based on distribution of pollutant concentration and on chlorine ion mass balance, we have concluded that contamination migrates in south –eastern direction and is being transported to surface water. Leachate migration from the landfill takes place in the first and the second Quaternary water bearing horizon and pollutant transport to the second layer occurs mainly through hydrogeological windows. We haven't identified any threat of the third horizon contamination, constituting the main usable aquifer in the investigated area (II.E.19 zał. 4).

In 2015, together with M. Pruszkowska-Caceres and M. Lidzbarski I participated in elaboration of the history of hydrogeological research development conducted by scientific and scientific and research centers in Gdańsk (II.E.17 zał. 4).

Currently, one of the objects of my scientific interests is to specify the index method for the assessment of recharging infiltration, especially to determine additional infiltration indexes for semi permeable sediments e.g. sandy moraine tills. Over my long-term practice in groundwater flow model construction I have recognized the need to verify and improve the index method, which I attempted to perform in my numerous flow model developments. For example, in the documented achievement (I.B.1 zał. 4 & zał. 7.1 Chapter 3.6.1) I have proposed new specification for the indexes according to Pazdro, Kozerski [19] , on the basis of own experiences and literature studies on young glacial areas - infiltration coefficient 0,12 for sandy moraine tills. Currently I am a co-author of the research project of the Ministry of Science and Higher Education (financially supported from 2016): *Infiltration recharge in an outwash plain area,* under supervision of prof. A. Szymkiewicz . Within the project, doctoral research leading to specify infiltration coefficient in outwash areas will be performed, which is to a certain extent at my initiative.

After obtaining PhD degree I have published 42 publications. Total sum of MNiSW points for publications, having considered my share is 270,7 (or 344,4 according to the MNiSW list from 2015), including publications constituting series of single issue scientific achievement 134,4 (or 191,6 according to the MNiSW list from 2015). Total IF is 4,961 and HI is 3.

Beata Jaworska-Szulc

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Papers authored/coauthored by me are listed in Załącznik / Appendix 5.

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