Załącznik 3

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Summary of professional accomplishments

containing information about the achievements in research, didactic and organizational activity, elements of the biography and the description of publications constituting the scientific achievement

Table of contents:

1. Education and academics degrees

July 4th, 1996 - **BEng in Environmental Engineering** in the field of **Protection and Development of Rural Environment**, Faculty of Land Improvement and Environmental Engineering, Warsaw University of Life Sciences. Title of the thesis: „Wastewater treatment on irrigated fields". Supervisor: dr inż. Henryk Multan.

July 16th 1998 – **MSc in Environmental Engineering** in the field of **Water and Land Reclamation Engineering**, Faculty of Land Improvement and Environmental Engineering, Warsaw University of Life Sciences. Title of the thesis: „The assessment of purification and environmental effect of irrigation with the effluent from Lodz WWTP". Supervisor: prof. dr hab. inż. Józef Mosiej.

November 19th 2003 – **PhD in Environmental Development**, Faculty of Engineering and Environmental Sciences, Warsaw University of Life Sciences. Title of the thesis: „The efficiency of sorbent filters for phosphorus reduction in on-site wastewater treatment". Supervisor: prof. dr hab. inż. Józef Mosiej. Work carried out from the 1st of November 1998, as a part of doctoral program at the Faculty of Engineering and Environmental Sciences, Warsaw University of Life Sciences in the discipline: Environmental Development, specialty: Development of the Environment of Non-urbanized Areas.

August 6th 2005 – **Postgraduate studies in Pedagogical Improvement** at the Faculty of Economics, Warsaw University of Life Sciences.

2. Employment in scientific entities

From December 31, 2003 to June 30, 2004 – **assistant** at the Department of Environmental Improvement, Faculty of Engineering and Environmental Sciences, Warsaw University of Life Sciences.

From July 1st 2004 till now – **assistant professor** at the Department of Environmental Improvement, Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences.

3. Scientific achievement resulting from the Article 16, § 2 of the Act of 14 March, 2003 on Academic degrees, academic title and on degrees and title in the field of art (Journal of Laws no. 65, item 595 as amended)

3.1. Title of the scientific achievement

The use of reactive materials to limit water polution with phosphates

3.2. Articles included in the scientific achievement

3.2.1. Karczmarczyk A., Bus A., Baryła A., 2016: *Filtration curtains for phosphorus harvesting from small water bodies*. Ecological Engineering 86, 69-74; doi:10.1016/j.ecoleng.2015.10.026 **30 p., IF 2.914**

3.2.2. Karczmarczyk A., Bus A., 2017: *Removal of phosphorus using suspended reactive filters (SRFs) – efficiency and potential applications*. Water Science and Technology 76 (5), 1104-1111; doi:10.2166/wst.2017.295 **20 p., IF 1.197**

3.2.3.Karczmarczyk A., Baryła A., Charazińska P., Bus A., Frąk M., 2012: *Influence of the green roof substrate on runoff quality*. Infrastructure and Ecology of Rural Areas 3/III, 7-15 **5 p., IF 0**

3.2.4. Karczmarczyk A., Bus A., Baryła A., 2018: *Phosphate Leaching from Green Roof Substrates - Can Green Roofs Pollute Urban Water Bodies?* Water 10 (2), 199; doi:10.3390/w10020199 **30 p., IF 1.832**

3.2.5. Karczmarczyk A., Baryła A., Bus A., 2014: *Effect of P-Reactive Drainage Aggregates on Green Roof Runoff Quality*. Water 6 (9), 2575-2589; doi:10.3390/w6092575 **25 p., IF 1.291**

3.2.6. Karczmarczyk A., Kocik A., 2017: *Influence of the thickness of the P-reactive drainage layer on phosphate content in green roof runoff.* Scientific Review – Engineering and Environmental Sciences 26 (4), 448-457; doi: 10.22630/PNIKS.2017.26.4.43 **10 p., IF 0**

3.2.7. Karczmarczyk A., Baryła A., Kożuchowski P., 2017: *Design and development of low P-emission substrate for the protection of urban water bodies collecting green roof runoff.* Sustainability 9 (10), 1795; doi:10.3390/su9101795 **20 p., IF 1.789**

3.3. List of publications with points and Impact Factor (according to the year of publication) and individual author contribution

Item	Year of publication	Points	Individual contribution [%]	Points (including individual contribution)	Impact Factor
3.2.1	2016	30	60	18	2.914
3.2.2	2017	20	70	14	1.197
3.2.3	2012	5	50	2.5	0
3.2.4	2018	30	60	18	1.832
3.2.5	2014	25	60	15	1.291
3.2.6	2017	10	50	5	0
3.2.7	2017	20	70	14	1.789
together	-	**140**	**60**	**86.5**	**9.023**

My contribution into publications listed in scientific achievement is 60%, including:

- 64% in articles indexed in Web of Science
- 50% in articles indexed by Ministry of Science and Higher Education (list B)

3.4. Introduction

Main sources of biogens (nitrogen and phosphorus) reaching the Baltic Sea are the loads transported by rivers (95% of the phosphorus load) and direct discharges from the coast. Within the sources of biogens transported by the rivers, the main important are dispersed sources, mainly agriculture (45% of the phosphorus load) and point sources, mostly municipal wastewater (20% of the phosphorus load) (ETO UE 2016).

In case of municipal wastewater management, positive changes are observed as a result of implementation of National Program of Municipal Wastewater Treatment (KPOŚK 2003, and updates from 2005, 2009, 2010, 2015 and 2017) and the access of local governments to UE financial support. An environmental effect of National Program of Municipal Wastewater Treatment predicted for years 2005-2015 (for agglomerations with PE 2000 and more) is the reduction of phosphorus discharged to the water environment of 89% (Sumisławski 2013). The positive phenomenon of phosphorus load reduction in surface water is also observed in the EU scale. In the years 1992-2011, the content of phosphorus in EU rivers decreased by 57% (EEA 2015).

Urban areas, with sealed surfaces generating significant surface runoff, are a source of phosphorus pollution of a growing importance. Urban ecosystems are reach in phosphorus (Song et al. 2015), and progressive urbanization leads to increased phosphorus concentration in surface waters (Paul and Meyer 2001, Barałkiewicz et al. 2014). Load of phosphorus discharged to the receiver from stormwater drainage system amounts 1.5 $kg \cdot ha^{-1}$ of sealed area (Pluta and Mrowiec 2015). The main sources are: precipitation, droppings of domestic and wild animals, fertilizers and decaying plants (RZGW Gliwice 2014). In 2012, stormwater systems were responsible for 1401 thousand tons of phosphorus, what reflects 9.2% of total phosphorus load discharged to Baltic Sea (IMGW 2014). In order to limit the negative effects of sealing the surfaces in urban areas, sustainable urban drainage systems are introduced. Within those measures, green roofs are very popular. The main role of green roofs is to retain the rainwater and delay the runoff. However, despite the reduced runoff, green roofs can pollute receivers with phosphorus. Amount of phosphorus discharged from green roof with the runoff depends on the quality of the structural elements of the green roof. Composition of green roof substrate that forms the basis for vegetation is the most important. Time of operation and the maintaince of the roof also influences runof quality. Concentration of phosphorus in green roof runoff can exceed 1 $mg \cdot dm^{-3}$ (Moran et al. 2005, Czemiel Berndtsson et al. 2006, Hathaway et al. 2008).

The outflow of phosphorus from agriculture to inland waters in many areas of Europe exceeded 0.1 $kg \cdot ha^{-1}$ annually, an in the most exposed areas reached 1.0 $kg \cdot ha^{-1} \cdot rok^{-1}$ (EEA 2010). As a consequence, many marine and coastal waters in EU is characterized by high or very high phosphorus concentration. Over 400 coastal areas in the global scale suffers from the oxygen deficiency due to excess of nitrogen and phosphorus (Diaz and Rosenberg 2008), and 60% of medium and large lakes and reservoirs was considered as eutrophic (Sayers et al. 2015). Carpenter and Bennett (2011) pointed out, that global limits of phosphorus contamination of freshwater were exceeded. Load of phosphorus in inland waters vary in the range of 32 - 115 Tg, what corresponds to a concentration of 0.180-0.665 $mg \cdot dm^{-3}$. The quality of over 40% of rivers and coastal waters is under the negative influence of the non-point sources of pollution (EEA 2015). As a consequence, concentration of phosphorus in inland waters increased by 75% in last half-century (Bryant et al. 2012). Eutrophication significantly limits the usefulness of water for various purposes, reduces biodiversity and fish stocks, what is observed in the Baltic Sea areas, e.g. Gulf of Finland, Gulf of Riga and the Baltic Proper (ETO UE 2016).

According to the findings of the Copenhagen Ministerial Declaration (HELCOM 2013a), the expected reduction of the total phosphorus load to Baltic Sea by 2021 is 7,480 Mg (HELCOM 2013b). As a consequence, annual load of phosphorus discharged to the Baltic Sea from the area of Poland should be reduced to 4,400 Mg in 2021 (IMGW 2014). With an average outflow from Poland, amounting to approximately 61.5 $km^3 \cdot year^{-1}$, to achieve this goal, the concentration of phosphorus in estuaries cannot exceed 0.072 $mg \cdot dm^{-3}$, which is the level similar to hydro-chemical background and is equal to no possibility of any discharges of phosphorus into the rivers (ETO UE 2016).

The validity of the research towards limiting phosphorus losses, protection of water quality and recovery of phosphorus from water and wastewater, is confirmed by documents and reports released on regional, European and global level. The Convention on the Protection of the Marine Environment of the Baltic Sea Area was already signed in 1974 (re-signed in 1992, OJ 2000/28/346). The quality of the EU's marine waters is the subject of the Marine Strategy Framework Directive from 2008, which aims to ensure the achievement of good environmental status of the EU's marine waters by 2020 (OJ L 164, 25.06.2008). In 2009, the European Council adopted the EU Strategy for the Baltic Sea Region (COM/2009/248). In the working document (SEC/2009/712/2), in the area "To Make the Baltic Sea Region an Environmentally Sustainable Place" "To reduce nutrient inputs to the sea to acceptable levels", the objectives set out in the Baltic Sea Action Plan with regard to reducing the inflow of nutrients were included. **The quality of rivers entering the sea is considered as a crucial for the protection and achievement of good status of the Baltic Sea.** Improvement of inland water quality is the objective of the implementation of the Water Framework Directive 2000/60/EC (OJ L 327 of 22.12.2000), the Urban Waste Water Treatment Directive 91/271/EEC (OJ L 135, 30.5.1991) and the Nitrates Directive 91/676/EEC (OJ L 375, 31.12.1991). The HELCOM declaration (2013a) expressed also concerns about the future supply of nutrients, in particular phosphorus, on the background of water and soil pollution due to phosphorus losses on the subsequent stages of its life cycle. It also indicates the need to increase the level of phosphorus recycling, especially in agriculture and wastewater treatment. The Roadmap to a Resource Efficient Europe (COM/2011/571) addresses the problem of sustainable supply of phosphorus and limiting the EU's dependence on phosphorus mined, especially in the aspect of food safety. In this approach, phosphorus is also a resource listed as the twelfth Sustainable Development Goal (UN 2015). The Consultative Communication on the Sustainable Use of Phosphorus (COM/2013/517) broadly discusses the state and risks associated with resources, environmental risks and the potential for effective use of phosphorus in the future.

Increasing requirements for the quality of inland and marine waters, together with potential limitation of the availability of phosphorus resources in the future, forces the need of the development of the new ways of phosphorus removal and recovery from the sources, which till now not been considered priority. The example of such, can be urbanized areas, with the scope other than effluents from municipal wastewater treatment plants. The area of future activities is also a place of generation of non-point and dispersed pollution. Innovative, but simple solutions to be implemented on the place of pollution generation will be preferred. Measures to control phosphorus pollution in the small scales, but introduced as a system of measures can efficiently protect water bodies against pollution. Those measures should include both, minimizing phosphorus outflow to water as well as removal of phosphorus from polluted water bodies. The use of reactive materials is of a great oportunity here.

Reactive materials are referred to as adsorbents or sorbents and specifically interact with targeted chemical species (Cucarella and Renman 2009). They are often use in the form of filters, and so sorption capacity is usually tested together with physical properties of the materials which influence its filtration ability. P-reactive materials can be divided into two groups: (1) materials based on iron (Fe) or aluminum (Al), and (2) materials based on calcium (Ca) or magnesium (Mg) (Sibrell et al. 2009). Main process of phosphorus removal by Al and Fe based materials is adsorption, while in case of Ca-based materials precipitation is dominant (Sibrell et al. 2009, Christianson et al. 2017). P-reactive materials can be also categorized due to the origin of the material (natural materials, industrial waste materials and man-made products). Regardless of the origin, materials are often modified before the application. Researches on reactive materials for the removal of phosphorus have been carried out for many years, but the significant increase in the number of publications in this field is observed from the beginning of XXI century. The most popular applications of P-reactive materials cover domestic and municipal wastewater treatment (Baker et al. 1998, Søvik and Kløve 2005, Shilton et al. 2006, Renman and Renman 2010, Yin et al. 2011, Jia et al. 2013, Kholoma et al. 2016, Jóźwiakowski et al. 2017), pollutants removal from non-point sources (McDowell et al. 2007, Penn et al. 2007, Ballantine and Tanner 2010, Wang et al. 2014, Klimeski et al. 2015, Uusitalo et al. 2015), stormwater treatment (Wium-Andersen et al. 2012, Sønderup et al. 2015) and improvement of the quality of eutrophicated streams and water reservoirs (Berg et al. 2004, Hussain et al. 2014, Yin and Kong 2014, Ge et al. 2016). Also the idea of implementation of P-reactive materials as the support of constructed wetlands for wastewater, stormwater, and agricultural runoff treatment developes (Korkusuz et al. 2005, Prochaska and Zouboulis 2006, Rosenquist et al. 2011, Saaremäe et al. 2014, Vohla et al. 2011, Xu et al. 2006, Žibiene et al. 2015).

3.5. Description of the scientific objectives and achieved results of the work listed in chapter 3.2

Base on my experience in testing of phosphorus reactive materials, the analysis of the need of limiting of phosphorus outflow from different sources and existing methods of phosphorus removal from water bodies, I formulated the following **goals of research:**

- **3.5.1. development of the method and determination of the efficiency of the use of reactive materials in the form of suspended reactive filters (SRF) for phosphates removal from small watercourses,**
- **3.5.2. determination of application forms and assessment of the efficiency of reactive materials in reduction of phosphates runoff from green roofs.**

Ad. 3.5.1. Small watercourses and water reservoirs are often the receivers of pollutants from non-point sources. Specificity of non-point sources of pollution, enforces application of other than end-of-pipe methods of treatment. At present, for the reduction of phosphorus from agricultural runoff buffer zones and constructed wetlands are most often used, and in case of reactive materials: (1) geochemical barriers in the form of permeable walls filled with reactive material, located below the surface and on the way of the potential migration (Frątczak et al. 2012, Kirkkala et al. 2012), (2) wells filled with reactive material fed with polluted water from drainage systems (Ulen et al. 2013), and (3) box filters located on watercourses (Penn i in. 2016). Current solutions have a number of advantages, however they also have some disadvantages connected with construction and operation. In case of solutions implemented on watercourses (box filters) main problems are: (1) the need to direct the flow to the filter, (2) the need to evenly distribute the water on the filter bed, (3) the need of selection of fraction of filtration material adequate to the flow conditions, (4) significant volume of the filter required in relation to the volume of treated water, (5) significant weight of the filter (heavy equipment is required for the filter installation, risk of disturbance of the structure of the watercourse, location of the filter installation is determined by the possibility of the heavy equipment accessibility), (6) replacement of filtration material requires filter de-installation, and the technical difficulties listed in (5). In case of geochemical barriers, the replacement of the reactive material is associated with the need of construction of the new barrier.

The result of my research is **the development of an alternative method of implementation of reactive materials**. The method named „Filter for removing of pollutants, especially from small watercourses and reservoirs" is protected by patent (application P. 403571 from April 17, 2013; author's contribution: Karczmarczyk Agnieszka 50%, Bus Agnieszka 50%). The method allows the application of reactive material in the form of suspended filters (**Suspended Reactive Filter, SRFs**) and enables removal of pollutants, eg. phosphorus from polluted water. The system can be used on small natural watercourses, drainage ditches, canals and small water reservoirs as well as an additional filter for phosphorus removal, e.g. in constructed wetlands treating stormwater or agricultural runoff. Filtration curtains consisting of SRFs can be used in the form of modules, i.e. many curtains based on the banks distributed along the length of the watercourse. In case of water reservoirs, floating curtains can be used (**fig. 1, 3.2.2**). The SRFs method allows the use of any reactive material with a fraction above 2 mm. The advantages of the method over the previously used forms of application of reactive materials are: simple installation and de-installation of the filters, easy replacing of the reactive material after it become saturated, no interference into the structure of banks of the watercourse, possibility of adjusting to water level and the possibility of periodic use. The use of reactive material in the form of SRFs favors direct contact of water with the material, without the risk of creating privileged flow paths. With the proper parameters of the filters, all of implemented material would take part in water purification. Suspended reactive filters are designed to retain pollutants at the place of their formation, and they can provide effective protection for larger watercourses and the Baltic Sea.

The goal 3.5.1. „development of the method and determination of the efficiency of the use of reactive materials in the form of suspended reactive filters (SRF) for phosphates removal from small watercourses" was achieved in specially designed experiment, which results were published in two articles (**3.2.1** and **3.2.2**). The efficiency of suspended filters has been confirmed by using two reactive materials: Polonite® (**3.2.1**) and autoclaved aerated concrete (AAC) (**3.2.2**).

Autoclaved aerated concrete (AAC) and Polonite® are the examples of calcium based reactive materials of different origin. Polonite® is thermally modified calciferous bedrock (opoka). The characteristic feature of the material is it heterogeneity related to the composition of the natural material and the applied thermal treatment process (**C.3.19, annex**

4). AAC is an anthropogenic material, commonly used as a construction material in the form of blocks (bricks). As an reactive material, it is used in crushed form. Waste material from demolition process can be also used. Chemical composition and physical properties of the material are homogenous. Both, homogeneity and possibility of using of waste material makes AAC more advantageous than Polonite®. Both materials are classified as materials with very high P sorption capacity (Cucarella and Renman 2009).

The experiment was designed to simulate a system of SRFs curtains distributed along the watercourse. In the variant with Polonite® (**3.2.1**) four different initial concentrations of solutions were used (1.439; 1.852; 2.384 i 3.012 mg $P\text{-}PO_4^{3-}\cdot dm^{-3}$), whereas in the variant with AAC one initial concentration of 1.335 mg $P\text{-}PO_4^{3-}\cdot dm^{-3}$ was used. These concentrations correspond to the values for polluted surface waters (Skwierawski et al. 2008, Uusitalo et al. 2015, Mosiej and Bus 2015). In the variant with AAC, the experiment was carried out longer, therefore the comparison of the results with the second variant (Polonite®) is possible only in the first phase of AAC experiment (**fig. 3, 3.2.2**). In case of both reactive materials, a successive reduction of $P\text{-}PO_4^{3-}$ from solution together with passing through filtration curtains was observed. The relationship was linear with good and very good fit (correlation coefficients ranging from 0.8904 to 0.9758, $p <0.001$). As the result of experiment, $P\text{-}PO_4^{3-}$ load was reduced by 18.0-34.6% for Polonite® and 50% in the comparable time and number of cutrains passed for AAC. Unit sorption of $P\text{-}PO_4^{3-}$ in the variant with Polonite® at different initial concentrations ranged between 0.166 and 0.181 $mg\cdot g^{-1}$, and in the comparable period for AAC amounted 0.192 $mg\cdot g^{-1}$. Despite the greater efficiency of $P\text{-}PO_4^{3-}$ removal observed for AAC, both materials confirmed their efficiency in phosphates removal from water in the form of suspended reactive filters. Thus, they also confirmed the usability and effectiveness of the developed method of reactive materials implementation.

Base on the results obtained from the experiment carried out using Polonite®, I developed **the nomogram for the estimation of the mass of this reactive material needed to decrease the concentration $P\text{-}PO_4^{3-}$ from the actual to expected** (**rys. 5, 3.2.1**). I proposed three values of expected concentration (0.25, 0.10 and 0.01 mg $P\text{-}PO_4^{3-}\cdot dm^{-3}$). Total mass of reactive material (Polonite®) determined from the nomogram, base on the actual and expected $P\text{-}PO_4^{3-}$ concentration, should be divided into individual filtration curtains (considering the width and filling of the watercourse), and then placed along the length of the watercourse. However, the nomogram gives only a theoretical guidelines, as it was developed bese on the results of experiment carried out in laboratory conditions. In fresh river water, there may be a number of factors that will affect the efficiency of P reactive material. Reactive materials usually have high porosity and surface area, which can accelerate the development of biofilm on the material grains. According Herrmann et al. (2013), biofilm may negatively affect sorption capacity of reactive material. This may be particularly important for the filters suspended in the water permanently. The risk of biofilm influence on phosphate sorption efficiency of reactive material can be limited by implementation of SRFs in watercourses with periodic flow or by drying the material. Periodical use of the material and its drying prolongs effective phosphate removal (unpublished data).

The tests of phosphate removal efficiency by reactive materials in the form of SRFs were conducted with the use of two reactive materials, which proved to be P-reactive in other laboratory scale tests (**B.1, B.3, B.6, C.1.3, C.3.18-19**). In SRFs, however, other reactive materials can also be used, but in case of P, the material phosphate removal efficiency from water with low phosphate concentration have to be first confirmed. It is not recommended to use of reactive materials with confirmed removal efficiency from wastewater or highly P polluted water uncritically, as they can be a source of phosphorus in case of contact with water with low phosphate concentrations.

The universality of the SRFs method gives wide possibilities of its implementation. In my research so far, I have concentrated mostly on application of SRFs to surface waters that are the receivers of non-point or dispersed sources of pollution, but it can be also use in stormwater retention systems, on site wastewater treatment, backyard ponds or swimming ponds, etc.

Possibility of reuse of phosphorus sorbed by reactive material eg. for fertilization was not the subject of my research, but it was proved by other researchers (Hylander and Siman 2001, Hylander et al. 2006, Cucarella et al. 2008). The use of reactive materials in the innovative form of suspended filters gives an opportunity of easy removal of the material, and as a consequence creates the potential to introduce recovered phosphorus into a biological cycle. It increases the attractiveness of SRFs method in the aspect of achieving the objective of reducing the EU's dependency on phosphorus from non-renewable sources.

Ad. 3.5.2. The field of my research covers both rural and urbanized areas. In urban areas, increasing pollution of waters with phosphorus is the result of population migration to cities, progressive urbanization and assimilation of surrounding areas, what results in progressive sealing the surface and increasing surface runoff of rainwater. Recovering of biologically active surfaces in such areas is necessary to limit negative effect of urbanization. One of popular solution is the construction of green roofs. The advantages of green roofs include limiting the urban island effect, increasing the energy efficiency of buildings, improving air quality, and retention and delaying of rainwater runoff to urban drainage or storm sewer systems. Sometimes the runoff quality is also mentioned between green roofs benefits, however, in this case, the scientific community is not consistent (Wang et al. 2017). The positive aspect in terms of runoff quality may be, for example, increase of pH of the effluent in relation to the pH of precipitation, which is advantageous in case of the occurrence of acid rains (Long et al. 2006). However, many studies indicate an increase of concentration and loads of heavy metals (Aslup et al. 2011, Malcolm et al. 2014, Vijayaraghavan et al. 2012) and phosphorus (Aitkenhead-Peterson et al. 2011, Buffam et al. 2016, Harper et al. 2015) in green roof runoff in relation to precipitation. Among the factors affecting the quality of green roof runoff are: type and the composition of the substrate, thickness of the substrate, type of drainage, type of the roof, ege of the roof, maintenance, roof location (rainfall quality) and climatic conditions (Czemiel Berndtson 2010). The majority of the phosphorus released from the green roof substrates occurs in the form of phosphates (Czemiel Berndtston et al. 2006) and concentrations vary within a wide range from 0 to 1.4 mg $P\text{-}PO_4^{3-}\cdot dm^{-3}$ (**tab. 2, 3.2.4**) or higher.

The aim of the research **3.5.2.** „**determination of application forms and assessment of the efficiency of reactive materials in reduction of phosphates runoff from green roofs**" was realized in several stages. In the first stage, I confirmed that **substrates used in green roofs construction are the source of phosphates in runoff** (**3.2.3-4**). Then, I proposed **underlying the substrate with the drainage layer made of reactive material** (**3.2.5**) and assessed the efficiency of this solution. In another experiment, I determined the optimal thickness of the drainage layer (Polonite®, **3.2.6**) to retain phosphates releasing from substrate. I the last stage, **I developed a procedure for selection and testing of materials to be used in the composition of low P emission substrate** and I **prepared and tested substrate** according to proposed procedure (**3.2.7**).

Two commercially available green roof substrates, intensive and extensive type, were tested in column experiment (**3.2.3**). As the result, $P\text{-}PO_4^{3-}$ concentrations in leachate were obtained in amount of 0.064-0.387 $mg\cdot dm^{-3}$ (intensive roof substrate) and 0.023-0.284 $mg\cdot dm^{-3}$ (extensive roof substrate) and the total load of $P\text{-}PO_4^{3-}$ discharged from columns in the time of experiment amounted 1.69 $mg\cdot kg^{-1}$ d.m. (intensive) and 1.90 $mg\cdot kg^{-1}$ d.m. (extensive). Substrates predicted for construction of intensive green roofs usually contain larger amounts of organics than substrates for extensive green roofs. Main organic compounds used in substrates composition are: bark, peat and compost, with amount of up to several dozen percent of the volume. According to Czemiel Berndtson (2010) and Gregoire and Clausen (2011) the share of compost and use of fertilizers are the main source of biogenic compounds in leachate. Observations of the leachate quality from performed column experiment (similar load of phosphates in leachate from both substrates) suggest, that **mineral compounds of substrate may be a source of phosphorus**. I confirmed this assumption in later studies, which showed that the majority of mineral aggregates commonly used in substrates are a potential source of phosphorus in green roof runoff (**tab. 3, 3.2.7**) and the load of phosphates were not correlated with organic matter content (**3.2.4**). The column experiment with the use of five fresh green roof substrates collected from the market (**3.2.4**), showed that unit loads of phosphates lechad from the substrates as a result of simulation of precipitation during first vegetation period, were lower in case of extensive than in case of intensive substrates. Organic matter content in all tested substrates was similar (**tab. 1, 3.2.4**). Long term monitoring of the container filled with intensive substrate showed, that at the begiening of operation (1st and 2nd vegetation period) more phosphates were observed in leachate than in precipitation. In the 5th year of experiment green roof substrate acted as a net sink of phosphorus (**tab. 4, 3.2.4**). As the result of this stage of research it can be concluded that **green roof substrates are the source of phosphorus in green roof runoff, especially at the beginning of operation**. I also confirmed, that hydrochloric acid extraction can be usefull tool for the comparison of different substrates base on potential phosphate leaching. For five fresh substrates described in **3.2.4** high correlation was obtained ($r=0.9930$, $p=0.002$) between the results of HCl extraction and column leaching experiment.

In the next stage of the research, extensive green roof substrate (**3.2.3**) was underlined with reactive material with the thickness of 2 cm (**3.2.5**). This solution proved to be very effective both in terms of the quality of the leachate and its quantity. In 90 days long experiment with AAC (**3.2.5**) 13 precipitation events were simulated in doses sinilar to reference experiment (**3.2.3**). High water absorption of AAC (83.74%, **tab. 5, 3.2.5**) resulted in reduction in the number and volume of leachates (from 13 in reference (**3.2.3**) experiment to 6 (**3.2.5**)), of which only 3 were polluted with phosphates, and $P\text{-}PO_4^{3-}$ concentration did not exceeded 0.01 $mg \cdot dm^{-3}$ (**3.2.4**, **fig. 6**). The similar experiment with the use of Polonite® (water absorption of 56%) has been described in **C.1.4**. In 90 days of experiment, 23 precipitation events were simulated and 12 leachates observed, of wich 7 were polluted with phosphates. Concentration of $P\text{-}PO_4^{3-}$ did not exceed 0.005 $mg \cdot dm^{-3}$ (**fig. 2, C.1.4**). **Obtained**

results confirmed the efficiency of reactive drainage layer in limiting the outflow of phosphates from extensive green roof substrate. Potential environmental effect, in the form of decreased P-PO_4^{3-} load discharged to environment from the extensive green roof substrate with typical parameters underlined with AAC was estimated at 1 $kg \cdot ha^{-1} \cdot yr^{-1}$.

Positive results of the previous experiment led me to a more through analysis, aimed **to determine whether the thickness of the reactive drainage layer underlying green roof substrate affects the amount of leaching phosphates** (**3.2.6**). The experiment was conducted with the use of intensive substrate and the reactive material Polonite®. Three thicknesses of reactive material were used: 1 cm, 2 cm and 5 cm which underlined substrate with the thickness of 10 cm. In this experiment the columns were irrigated with the tap water in the doses and schedule determined on the basis of rainfall recorded at WULS meteorological station in Warsaw in 2013. As in case described in **3.2.3**, the increased phosphate outflow from the columns was observed in the initial phase of the experiment. What was also noted, that in case of a significant load of P-PO_4^{3-} in simulated precipitation, the substrate itself may retain this contamination, and the use of reactive material thickness of 1 cm did not improved the quality of the effluent. As the result of the implemetnation of a reactive material with the thickness of 2 and 5 cm, reduction of P-PO_4^{3-} amounted 89.6% and 93.7%. The results of described experiments confirmed that **the use of reactive drainage layer of 2 cm thickness can be considered as an optimal solution for green roofs**.

Underlying green roof substrate with reactive material is effective, however it may cause significant increase in investment costs. The dynamic development of green roofs in Poland in recent years, resulted in increase in a number of commercially available substrates offered on the market. The majority of them are made of materials with a significant content of phosphorus (**3.2.7, tab. 3**). It was the reason why I decided to prepare a **low P emission green roof substrate**. Based on my own experience, I proposed **a five-step procedure for material selection, substrate mix preparation and testing** (**3.2.7, fig. 1**). I used this procedure to develop a substrate composition from locally available materials for use in extensive roofs covered with *Sedum* mate. The effect of limiting the outflow of phosphates was obtained through the use of the limestone with a sorption capacity of 4.66 mg P-$PO_4^{3-} \cdot g^{-1}$ as an one of the substrate components. Developed substrate was tested in a 319 day long open air experiment, and the results confirmed, that the appropriate share of mineral components (including reactive material) allows **to compose the substrate with limited emission of phosphates**. I also found, that **the period of spring related to snow melting may be critical in the aspect of phosphate outflow from green roof**. Base on this observation I formulated an operational guideline, which suggests that the spring outflow connected with the snow melting should be additionally treated. It would be extremely important in residential areas, where the outflow from green roof often supplies retention reservoir performing also recreational functions.

As the construction of green roofs without any P release protection measure can strongly contribute to eutrophication of urban water bodies, sustainable use of green roof technology can be achieved by: (i) selection of the substrate mix with limited P content and release potential **(3.2.7)**, (ii) underlying the substrate with the P reactive material (**3.2.5-6**), or (iii) in already existing green roofs or to support newly constructed roofs implementation of P-reactive filtration system for the effluent treatment is recommended.

3.6. The most important scientific achievements

As the most important scientific achievements, I consider:

a. development of the method of application of reactive materials (the method of suspended reactive filters – the invention protected by patent protection from 17.04.2013, **I.1, annex 4**) enabling phosphates removal from various water bodies, including that receiving surface runoff which is difficult to control. Due to its universality, this method can be used in watercourses and reservoirs located in both rural and urban areas. Additional advantage of this method is easy replacement of saturated material and its further use for recovering of sorbed phosphorus;

b. development of the nomogram enabling the assessment of the mass of the reactive material, to be implemented in the form of suspended reactive filters, required to reduce phosphate concentration in water from the real to expected value;

c. demonstration, that some of reactive materials being effective in phosphate removal from wastewater, may be a source of phosphorus in case of water treatment. Standard tests of sorption isotherms do not allow to state this fact, so it is recommended to extend the tests with leaching tests;

d. demonstration, that mineral aggregates used as substrates components are an important source of phosphates in outflows from green roofs. So far, as the most important factor affected the outflow of phosphates from green roofs, content of organic components and green roof maintenance were considered;

e. development of the method of reducing phosphate runoff from green roof substrate by underlying substrate with the layer of P reactive material. The results of experiments confirmed, that the use of reactive materials in green roof construction significantly reduces the amount of phosphates discharged to receivers;

f. development of a five-step procedure for the selection of materials for preparation of green roofs substrates to reduce the outflow of phosphates and protect the water bodies in urban areas;

g. demonstration, that properly selected proportions (share) of mineral materials and reactive material, can significantly reduce the outflow of phosphates from green roof;

h. demonstration, that snow melting is a critical moment in the aspect of phosphate outflow from the green roof. Therefore, it is recommended to separate and treat the outflow connected with melting of snow, especially in case of connecting green roof with stormwater retention reservoir.

3.7. The potential of application of the results of the research

Application potential of my research is best demonstrated by cooperation with business entities. Particularly high application potential has the concept of reduction phosphates in the outflow from green roofs in the aspect of rainwater management in the scale of residential areas. There are two main trends here: the construction of reactive drainage layers and use of reactive materials in the composition of substrate mix. This idea was noticed by two Warsaw companies (**Ł.1 and Ł.2, annex 4**). In the frame of cooperation agreement with **Ł.1** join research project was carried out, which results were implemented in the form of covering roofs with low P emission substrate (**application sheet I.2, annex 4**). We are currently running the project „Investigation of leachate from extensive green roofs in terms of the amount of water and phosphate content" (**G.2.7 annex 4**). The company **Ł.2** appreciated the results of my research by inviting to the project „ Saving of water resources and air quality improvement through the use of rain water retention" (**G.2.6. annex 4**). I also cooperate with entity **Ł.3 (annex 4)** in the scope of the use of reactive materials for phosphorus removal from swimming ponds, where the goal is to maintain phosphorus below 0.01 $mg \cdot dm^{-3}$. Currently, we are running the project „The impact of biofilm on phosphate removal by flow controlled mineral filters" (**G.2.8. annex 4**). The results from the first season of research were presented in the form of a commissioned presentation at the international congress (**E.2.63, annex4**).

Another direction of potential application of research results is the use of reactive materials to remove phosphates from small watercourses and reservoirs. The developed method of suspended reactive filters (**I.1, annex 4**) allows the removal of phosphates from waters that are a polluted from various sources, including non-point sources that are difficult to control. The developed method advantages from the fact that the reactive material in the form of suspended filters is easy to remove and replace with new material, and sorbed phosphorus can be reused in plant production. This solution has been created for use in watercourses and water reservoirs suffering from non-point pollution, but it has a wider application potential e.g. in maintaining water quality in garden or residential ponds, which due to the growing number of such facilities may also cause interest from business entities.

Another direction in which reactive materials are and will be used are on-site and local wastewater treatment systems. These issues were partly the subject of research in my doctoral thesis and are still being developed. The application potential is wide, but it is not supported by appropriate legal requirements forcing the owners of such installations to apply solutions limiting the outflow of phosphates to the environment. Dispersed buildings are responsible for over 12% of phosphorus discharged from Poland to the Baltic Sea (IMGW 2014) and therefore it is expected that the legal requirements will be tightened in this respect. At the same time, taking into account the fact that this applies to individual investors, solutions in this area must be simple and cheap. The application potential for the results of my research can be seen in the replacement or supporting of traditional filter materials with reactive materials, e.g. in filling beds of constructed wetlands, sand filters or under the infiltration systems distributing wastewater to the soil. Research in this field is the subject of publication (**C.3.27, annex 4**).

4. Other scientific achievements

4.1. Before obtaining a doctoral degree

Protection of water quality through natural or semi-natural systems of wastewater treatment and the idea of nutrient recycling were my interests from the beginning of scientific work. In doctoral dissertation, preliminary I wanted to continue with the subject of wastewater treatment and nutrient recycling via irrigation and constructed wetlands technology. This idea, initiated by the supervisor of my MSc thesis prof. Józef Mosiej, evolved as a result of cooperation with prof. Gunno Renman (KTH in Stockholm) and prof. Zygmunt Brogowski (WULS-SGGW), who at that time dealt with the use of sorbent prepared on the basis of limestone-silica rock opoka, for removal of phosphorus from wastewater. Through to participation in international projects led by prof. Renman, i.e. „Recycling of phosphorus in wastewater using reactive filter media" (**G.1.2, annex 4)** and „Sustainable development of rural areas through implementation of environmental technology" (**G.1.1, annex 4**), I noticed the potential of using this material for upgrading efficiency of phosphorus removal in small scale wastewater treatment systems. Thanks to the support of my supervisor, prof. Józef Mosiej, I've obtained founding of research in the form of KBN grant „Research on the efficiency of phosphorus removal by the filters in small scale wastewater treatment plants" (**G.1.3, annex 4**). Field research were carried out on the municipal wastewater treatment plants (Brańszczyk and Bolimów), and the results of these research and the series of laboratory scale experiments were used to propose the options of sorbent application for upgrading the efficiency of horizontal subsurface flow constructed wetland. Partial results of the research were the subject of publications (**B.1, B.3. B.5-7, annex 4**) and a doctoral thesis „Assessment of the suitability of natural sorbents for phosphorus removal in local wastewater treatment systems" was defended 19 of November 2003.

4.2. After obtaining a doctoral degree

From the time of obtaining doctoral degree, I was employed as an assistant (from December 31, 2003), and from the July 1, 2004 as an assistant professor at the Department of Environmental Improvement, Warsaw University of Life Sciences - SGGW. Since then, my **research topics covered the following issues**:

- Assessment of efficiency and longevity of treatment beds in subsurface flow constructed wetlands (4.2.1)
- Aspects of the reuse of wastewater treatment plant effluent for energy biomass production (4.2.2)

- The use of reactive materials in water filtration systems for backyard and swimming ponds (4.2.3)
- Wastewater management at the areas with dispersed population (4.2.4)

4.2.1. Assessment of efficiency and longevity of treatment beds in subsurface flow constructed wetlands

After obtaining the doctoral degree, I continued research at constructed wetland in Bolimów and established new cooperation with constructed wetland in Sadowa. Both plants were constructed in the 90’s on the basis of the Kickuth technology, that in the treatment bed filling use the site soil. Both of systems were based on horizontal subsurface flow of wastewater. The treatment beds were made of fine particles materials, thus they were sensitive to colmatation, and their treatment efficiency decreased with the time of operation. Research articles in this field (10 publications) were published in years 2004-2013. They cover: efficiency of wastewater treatment, in particular organics and phosphorus, changes in treatment efficiency in the time of operation, and assessment of longevity of treatment beds (**C.3.1-3, C.3.7-8, C.3.11, C.3.14, C.4.4**). In one of monitored constructed wetlands (Sadowa), I got the permission to sample filtration material from the one of parallel treatment beds. The aim of this research was to assess of phosphorus accumulation in filtration material and to determine the potential of filtration material in further phosphorus sorption from wastewater. Samples of filtration material were collected in a grid of 20 points at two depths. The results showed a significant unevenness of the wastewater flow through the bed and thus uneven horizontal and vertical distribution of phosphorus in the treatment bed **C.2.2 (annex 4)**. The last work I carried out at this facility was research on the effectiveness of wastewater treatment in low temperatures, and assessment of the temperature distribution in the reed canopy over the treatment bed, using the thermovision method (**C.1.2, annex 4**).

4.2.2. Aspects of the reuse of wastewater treatment plant effluent for energy biomass production

In the first year of my work at the Department of Environmental Improvement, I also started to work under the 6 FP EU project „Monitoring and control system for wastewater irrigated energy plantations” (**G.2.1, annex 4**). It was a CRAFT project, focused on cooperation between SMEs and universities. The aim of the project was to develop a prototype of a monitoring and control system steering wastewater irrigation on short rotation plantation (SRP). The subject of the project was for me a continuation of the issues covered in my diploma theses, in which I dealt with wastewater treatment through irrigation. The start of the project with the Poland entry into European Union, caused increasing interest in biomass production for energy purposes. In our project, the main goal was to achieve effective biomass grow by wastewater irrigation, without negative environmental effect. The prototype created by the consortium was based on moisture sensors distributed in the soil and the NPK balance. Base on water and nutrient needs of the plants and the control of soil moisture, irrigation with wastewater or water was steered in the terms and amounts safe for the environment (no leaching of nutrients into a groundwater was allowed). The prototype was tested on two SRPs: willow plantation in Estonia and poplar plantation in Spain. The effect of the project was increased annual biomass of plants comparing to reference site. The composition and the caloric value of the biomass was also analyzed with the focus on pellet production. The subject of the project was the theme of 9 publications (**C.2.1, C.3.5, C.3.6, C.3.12, C.4.1-2, C.4.5-6, C.6.5, annex 4**). In parallel with the **G.2.1 project,** SPB and internal grant were also implemented **(G.2.2-3, annex 4).**

4.2.3. The use of reactive materials in water filtration systems for backyard and swimming ponds

From 2013, I'm conducting the research on the possibility of using reactive materials in filtration systems for backyard ponds. Backyard ponds are usually of a small surface and volume and, what is often, with disturbed biological balance through excessive amounts of fishes, plants etc., while in the same time high expectation of the visual quality of water. In 2013, the monitoring of water quality in pond was run, and from 2014 filtration system was introduced. In following years different filtration system configurations with the use of reactive material are tested. Preliminary results of research were presented as a conference presentation (**E.2.46-47, E.2.53**). The experiment is continued. I also performed a series of laoratory tests on reactive materials with the focus on the possibility of their application in case of water with low phosphorus concentrations (**C.1.3, C.3.18-19, C.3.21, C.3.23, annex 4**). It should be noted, that some of reactive materials successfully used to remove phosphorus from wastewater, are not efficient in low phosphorus concentrations, and in such application may even be the source of phosphorus pollution (**A.4, annex 4**). My publications on reactive materials for phosphorus removal from years 2012-2014 resulted in interest from **Ł.3 i Ł.4 (annex 4)**. In swimming ponds, chemical methods of maintaining the water quality are minimized in favor of biological methods, such as filtration through root zone of aquatic plants, zooplankton and mineral filters. In this field, I performed a series of laboratory test of materials used in regeneration zones of natural swimming pools. The tests focused on (1) the assessment of phosphorus leaching from materials and (2) assessment of their phosphorus sorption capacity. One of the effect of this research is an article **C.1.3**. The problem of the maintenance of water quality in the swimming ponds or backyard ponds is complex, and requires the work in interdisciplinary team. Research in this field will be continued in the future. At the moment, within the cooperation with **Ł.3** and **Ł.4** (**annex 4**) join research project „Influence of the biofilm on phosphate removal by mineral filters" is running **G.2.8** (**annex 4**). The results of the research obtained in this topic can be also implemented in stormwater reservoirs in urban areas.

4.2.4. Wastewater management at the areas with dispersed population

Simultaneously with the above-mentioned topics, during the entire period of my scientific work, I used part of my time for the research connected with wastewater management in areas with dispersed population. In this research area, apart of the articles included in **4.2.1** of the Summary, I published also 4 scientific papers (**C.3.13, C.3.17, C.3.25-27, annex 4)** and 3 didactic publications (**C.6.2-3, C.6.7, annex 4**). This issue is also one of the main topic of didactic activity, carried out in the form of lectures (**N.4.2.1, N.4.3, annex 4**) and the promotion of diploma theses.

4.3. Contribution of research to the development of the scientific discipline Environmental Engineering

The issues I dealt in my research fit in the area of scientific discipline environmental engineering. Environmental engineering covers work related to researching and understanding of the impact of economic activity on natural environment, creates and develops the scientific basis needed to solve environmental problems (pollution of air, water and soil) and uses tools typical for engineerng like analysis, synthesis and design (Radczuk i Markowska 2008). Branch of environmental engineering is ecological engineering (Kowalik 2004), which like environmental engineering deals with environmental problems, eg. obtaining clean water, energy, protection of natural resources, cleaning the environment, restoring of degraded ecosystems and developing of new environmental technologies (Radczuk i Markowska 2008). The product of ecological engineering is the technology incorporated in natural cycles, so that the energy incurred was minimal, and benefits include both the society and the natural environment (Mitsh i Jorgensen 1989). Ecological engineering promotes the solutions, in which energy from external sources is relative small and only stimulates the process, but it is sufficient to obtain a significant effect resulting from natural processes and natural energy sources (Odum 1962). The role of human is only the initiation of natural processes, associated usually with a minimal contribution of energy comparing to predicted effect. The basis for the created ecosystem operation are natural sources of energy: sun, wind, soil and plants. The use of non-renewable resources, energy from non-renevable sources are important in ecological engineering, as well as limited production of waste. Logical consequence of ecological thinking is recycling and creation of loops of water and nutrients in local and time scale, and achieving the assumed effects should not cause losses in the environment.

The principles of ecological engineering as a branch of environmental engineering found application in: restoration of rivers and prevention of erosion; recultivation of degraded areas, rainwater harvesting, stormwater treatment, grounwater recharge, retention and delying of stormwater runoff (green roofs); composting of organic wastes and toilet wastes (composting toilets); use of plants in water purification (biofilters, buffer zones); use of **constructed wetlands for wastewater treatment**; wastewater treatment connected with nutrient recycling (hydroponics, **irrigation with wastewater**, **reactive filters**, source separation of wastewater); use of plants and grenhouse technology for sludge dewatering and compensation of damages casued in natural ecosystems and their restoration.

I believe that the most important achievements of my research mentioned in point **3.6** of this summary represent an important contribution to the development of the environmental engineering discipline.

5. Synthesis of scientific achievements

5.1. Authorship or co-authorship of scientific publications in journals indexed in the Journal Citation Reports (JCR) database

At the moment of preparing this summary, I was co-author of 13 publications indexed in Web of Science, including 10 with Impact Factor in the year of publication. Articles with IF were published in: *Ecological Engineering* (2016); *Water Science and Technology* (2016, 2017), *Fresenius Environmental Biulletin* (2013, 2015), *Water* (2014, 2018), *Sustainability* (2017), *Journal of Environmental Engineering and Landscape Management* (2013), and the rest indexed in Web of Science in *Acta Scientiarum Polonorum – Formatio Circumiectus* (2017), *Water* (2011) and *Journal of Environmental Engineering and Landscape Management* (2007) (**A.1-2, A.4-5, A.7, C.1.1-5, C.2.1-3, annex 4**). **Total IF** of my publications acording JCR, consistent with the year of publication is **13.048** and HI according to WoS amounts 3. Number of citations according to WoS is 31, without self-citations 20. Detailed data are summarised in **annex 4, C.1-2** and **D.1-2**.

5.2. Authorship or co-authorship of scientific publications in journals not indexed in the Journal Citation Reports (JCR) database

I have published 37 scientific articles in journals indexed on the list B Ministry of Science and Higher Education, including 7 articles from the period before obtaining the doctoral degree, and 11 chapters in monographs and reviewed conference proceedings. I am also an author and co-author of popular 5 publications and 8 didactic publications. Set up of publications ranked by year of publication is presented in **C.3-6 annex 4**. The number of citations according to Google Scholar database is 174, and Hirsch index according to this database is 7 (**annex 4, D.1**).

5.3. Authorship or co-authorship of collective studies and expert opinions

I participated in the preparation of 8 expert opinions, in various authors teams. Most of these works are developed concepts for solving problems related to water management in reservoirs, including water quality. I also took part in the work of the team developing recommendations for the national water-environmental program (**annex 4, M.1-8**).

5.4. Presentations of research results at international and national conferences and sessions chairing at international conferences

Since 2004 (after obtaining a doctoral degree) the results of my research have been presented in the form of 17 oral presentations and 46 poster presentations (**E.2.1-63, annex 4**) in the frame of 25 international conferences (Austria, Czech Republic, Netherlands, Lithuania, Germany, Poland, Russia, Slovakia and Sweden) and 18 national conferences. In total, it was 63 original and co-authored presentations, of which 31 in english. I also had the honor and pleasure of chairing sessions at two international conferences (**F.1-2, annex 4**).

5.5. Managing or participating in international or national research projects

I participated in the implementation of 12 research projects, including 3 before obtaining the doctoral degree. Six of the research projects were international projects.

During the PhD research I had the pleasure of being a participant in two international projects **G.1.1** and **G.1.2**, which had a significant influence on me and gave the initial shape to my doctoral thesis. Thanks to the support of my scientific supervisor, Prof. Józef Mosiej, I was also implementing a supervisory grant, KBN (**annex 4, G1.3**).

After obtaining the doctoral degree, and at the beginning of my work at the Department of Environmental Improvement, I participated in the implementation of an international research project under the 6th EU Framework Program. Project **G.2.1** was a CRAFT project, focused on cooperation between representatives of universities and SMEs. In parallel with the project in FP6, I was also implementing the SPB **G.2.2** project (both under the direction of Professor Józef Mosiej) and an internal grant, which I was the manager (**annex 4, G.2.3**). In the following years, I took part in two international projects financed by Swedish Institute (**annex 4, G.2.4-5**). Both projects were focused on cooperation in the field of eco-technology developed to improve the quality of inland waters in the aspect of the protection of Baltic Sea.

Currently I carry out two national research projects. The first **G.2.7 (annex 4)** is carried out jointly with dr inż. Anna Baryła and **Ł.1 (annex 4)** at the area of Water Center WULS-SGGW. In the frame of the project we are running the research on the composition of the substrates for extensive green roofs with the focus on their water retention and phosphorus emission. The second project **G.2.8 (annex 4)** is carried out together with dr inż. Agnieszka Bus and **Ł.3-4 (annex 4)**. In the frame of this project we are testing the phosphorus removal by mineral filters with controlled water flow. The experiment is running at the partner's property **Ł.4 (annex 4)**. Currently, I am also participating in the implementation of the one international research project **G.2.9 (annex 4).**

5.6. Internships in foreign research centers

During my doctoral studies I completed an internship at the Royal Institute of Technology (KTH) in Sweden in 1999-2000 (3 months in total). These included both a training internship at the Department of Land and Water Resources Engineering, the Royal

Institute of Technology (KTH), as well as study visits and fieldwork. Scholarships were funded under the **G.1.2** project under the management of prof. Gunno Renman (KTH) funded by Svenska Institute (SI). This internship was for me the first contact with the idea of ecological engineering, it allowed me to understand both theoretical (access to an unlimited base of publications) and practically (through study visits) its assumptions and applications. KTH was also the goal of my later visits as part of the Erasmus exchange program. In 2006 (May 23-28) and 2008 (June15-20) I visited KTH twice as a lecturer. In the frame of the Erasmus program, I hosted lectures at Vilnius Polytechnic (VGTU) in Lithuania in 2008 (May 20-25) and 2011 (May 15-21). I also delivered lectures abroad as part of TEMPUS projects (**annex 4, N.1.3 and N.1.6**), and as part of summer schools (**N.2.10, annex 4**). I also received an individual scholarship from the Swedish Institute (SI) for a presentation of my research at international seminar in Russia in 2009 (**E.2.26, annex 4**). In March 2010, I had the opportunity to re-sit a week-long scientific internship at the Royal Institute of Technology (Sweden, March 8-13) as part of a project funded by the SI. I devoted this time to the preparation of a scientific publication, which appeared in 2011 (**C.2.2, annex 4**). In 2014, I completed a week-long scientific internship in Neubranderburg and Berlin (Germany, April 7-13). The scientific supervisor was prof. Manfred Köhler from the Green Roof Center of Excellence at the Faculty of Landscape Architecture at the University of Applied Sciences in Neubrandenburg (Hochschule Neubrandenburg, University of Applied Science). I completed the internship as part of the project **N.1.5 (annex 4)**.

5.7. Reviews of scientific articles made for foreign journals and opinions of doctoral dissertations

I prepared 19 revisions of manuscripts at the request of international scientific journals (**annex 4, H.1-16**) ie. *Journal Ekologija, Environmental Engineering Science, International Research Journal of Pure and Applied Chemistry, British Journal of Applied Science & Technology, Journal of Water Supply: Research and Technology – AQUA, Desalination and Water Treatment, International Journal of Ecology and Ecosolution (IJEE), Chemosphere, Environmental Science and Pollution Research, Ecological Engineering, Journal of Applied Chemical Science International, Science of the Total Environment, Journal of Environmental Engineering and Landscape Management, Sustainability* and *Journal of Water Process Engineering.*

I also prepared 5 opinions on doctoral dissertations made at foreign universities, including 4 in Lithuania (Vilnius Gediminas Technological University) and one in Pakistan (University of Sindh) (**annex 4, J.1-5**).

5.8. Developing skills and extending knowledge within training and workshops

Throughout the entire period of my scientific work I am developing my skills and broading my knowledge in the area related to research and teaching. Prior to obtaining the doctoral degree, I completed 8 trainings, courses and workshops on a wide variety of topics (**annex 4, L.1.1-8**). After obtaining a degree, I also broadened my knowledge in the framework of 8 trainings and workshops completed with a diploma or certificate in the following areas: pedagogical improvement, laboratory management, management of international research projects, writing scientific articles, calculation of water and carbon footprint and green roofs (**annex 4, L.2.1-8**). In addition, I regularly participate in open conferences and seminars on subjects similar to my scientific and didactic interests (**annex 4, L.3.1-16**).

5.9. Awards for scientific activity

I was awarded with the Rector's Award of the Warsaw University of Life Sciences - Team III Degree for scientific achievements in 2014, Team II Degree for scientific achievements in 2015 and 2016, Team III Degree for scientific achievements in 2017.

6. Didactic and popularizing achievements and international cooperation

6.1. Participation in international didactic programs

I participated in the implementation of 6 international didactic projects, including three under the TEMPUS program (**annex 4, N.1.2-3, N.1.6**), two under the Leonardo da Vinci program (**annex 4, N.1.1, N.1.5**) and one within the framework of the Norwegian Financial Mechanism of the European Economic Area (**annex 4, N.1.4**). In these projects, with the exception of one Leonardo da Vinci in which I was a beneficiary (**annex 4, N.1.5**), I was a lecturer or author of didactic materials in the form of an e-learning course or textbook.

6.2. Achievements in the field of popularization of knowledge

Popularization of the knowledge is carried out through: trainings outside the university (**annex 4, N.2**), publications promoting knowledge (**annex 4, C.5**) and didactic publications (**annex 4, C.6**), engaging students in research and cooperation with companies (**annex 4, L**). In the period after obtaining the doctoral degree, I conducted trainings for sanitary engineers, farmers, water and drainage engineers, entrepreneurs from the mining sector, developers, the army dministration and representatives of local government. Publications promoting knowledge are directed to the journal Ekonatura, whose readers include educational institutions. I also systematically include students in research, resulting in joint publications (**A.3, A.5., C.3.7, C.3.12**) and presentations at scientific conferences (**E.2.7, E.2.54, E.2.61**).

6.2.1. Achievements in didactic activity and popularization of knowledge at international scale

As an achievements in didactic activity at international scale I consider: diploma theses prepared under my supervision by students from Spain (**N.3.2.1, N.3.2.4, annex 4**) and Indonesia (**N.3.2.2, annex 4**), supervision of the scientific scholarship of PhD student from VGTU in Lithuania, lectures given at the summer schools and trainings of academic teachers within TEMPUS project (**N.1.2, N.1.3, N.1.6, annex 4**) given both in Poland and abroad (Russia, Ukraine and Uzbekistan), co-authored chapters in textbooks (**C.6.5-8, annex4**), e-training courses (**C.6.1-2)** and courses run at SGGW in english (**N.4.3, annex 4**).

6.2.2. Achievements in didactic activity and popularization of knowledge at national scale

As an achievements in didactic activity at national scale I consider: diploma theses prepared under my supervision (**N.3, annex 4**), chapters: **C.6.3-4** (**annex 4)** in the „Eco-innovations in Mazovia Region”, e-learning course „ Good practices in wastewater treatment in rural areas”, articles (**C.5.1-5, annex 4**) and conducted trainings (**N.2.1-8, annex4**).

6.3. Supervision of diploma theses

Since obtaining the doctoral degree, I have been the promoter of 80 diploma theses, including 46 engineer and 34 master's theses. Most of the work I carried out in the field of Environmental Engineering and Environmental Protection. Five of Master's theses have been carried out in English, of which two are in the field of Environmental Protection (specialization: Restoration and Management of Environment) and three Master's theses under the Erasmus and Erasmus Mundus program. Detailed information on the promoted diploma theses is summarized in **annex 4 (N.3)**.

6.4. Didactic activity

The number of teaching hours is 240 (+ 20%) per year. Most of teaching is done in the form of lectures at Environmental Engineering, Environmental Protection and Civil Engineering study directions, including courses in english run for specialization of Restoration and Management of Environment (RME) and Erasmus+ program (**N.4.3, annex 4**). I am usually well rated in student surveys (score above 4). In my work I had the opportunity to conduct classes in 8 fields of study (**annex 4, N.4.1**). Currently conducted classes are implemented by me according to author's and co-author's programs. I conduct classes as part of full-time and external studies, first (engineer) and second (master) stage.

6.5. Received awards for didactic activity

I was awarded with the Rector's Award of the Warsaw University of Life Sciences – Team I degree in 2013 and The Bronze Medal for long service No 460-2014-55 in 2014 (**N.5, annex 4**).

7. Organizational activity

Since the beginning of doctoral studies I have been actively participating in the life of the Faculty. Initially, I was involved in promotional activities presenting the scientific and didactic activities of the Department of Environmental Improvement as part of the SGGW Days or the Science Picnic. After obtaining a degree and employment at WULS-SGGW in 2004-2006, I was responsible for preparing the annual reports of the Department scientific and research activities. In the academic year 2005/2006 I was the Secretary of the Scientific Board of the Inter-faculty Study of Environmental Protection (MSOŚ). Since 2005 I have been actively involved in the implementation of the WULS-SGGW Water Center project. My role was creating scientific and didactic stands, equipping and organizing the work of the Laboratory of Ecotechnology. From 2010 to the present I am responsible for this laboratory.

In the years 2005-2008 I was a member of the Faculty Science Committee (the team for international cooperation and the EU projects). In 2008, I was a member of the Faculty

Commission for the accreditation of Environmental Engineering. In years 2008-2012 and 2012-2016, I was a member of the Faculty Science Committee (research team and the international cooperation team). I was also appointed to the Science Committee for the international cooperation team for the 2016-2020.

From October 2009 I was the Coordinator for International Cooperation (coordination of international cooperation of employees and students). I performed this function until the end of the 2008-2012. From September 1, 2012, I was appointed to act as a Dean's Attorney for International Cooperation and European research programs (until December 31, 2016).

In the years 2004 - 2013 I was a member of the District Commission to carry out written and practical elimination in the thematic block of the Environmental Protection and Engineering of the Agricultural Knowledge and Skills Olympiad.

I also organized and co-organized a number of scientific seminars as part of research projects in which I was a contractor, as well as meetings, seminars, didactic internships and visits of foreign guests in three projects in the TEMPUS program. I also conducted all administrative work within of these projects. In years 2012-2016, I was a member of the Board of the Faculty of Civil and Environmental Engineering. I was also elected to perform this function in 2016-2020. A list of the functions of election and assignment is given in **annex 4 (O.1-2)**.

I was awarded twice with the Rector's Award of the Warsaw University of Life Sciences – Team I degree for organizational achievements in 2011 and 2012. (**O.3, annex 4**).

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