Załącznik 2b/ Appendix 2b

Summary of professional accomplishments

(Autoreferat)

Table of Contents

1. Name and surname : **Katarzyna Ewa Weinerowska-Bords**

2. Scientific degrees

a) 1997 r. – **Master of Sciences,** Faculty of Environmental Engineering**,** Gdansk University of Technology, field of studies: Environmental Engineering, specialization: sanitary engineering (completed with a perfect result). MSc thesis title: Project of the Laundry for the Hospital for Mentally and Nervous Patients in Gdansk-Wrzeszcz, Srebrniki St., Promoter: MSc. Eng. Andrzej Nurek.

b) 1998 r. – **completing the annual Supplementary Studies in Environmental Engineering** (as a part of the PhD Study "Geotechnics and Environmental Engineering"), Faculty of Environmental Engineering**,** Gdansk University of Technology,

c) 2001 r. – completing the PhD Study "Geotechnics and Environmental Engineering", field of studies: Environmental Engineering; **Philosophy Doctor, discipline: Environmental Engineering, specialization: Hydraulics**. PhD thesis title: *Inverse problems in open channel hydraulics*. Promoter: prof. dr hab. inż. Romuald Szymkiewicz. Gdansk University of Technology, Faculty of Civil and Environmental Engineering. The PhD dissertation was awarded.

d) 2010 r. – completing the Pedagogical Course organized at the Gdansk University of Technology.

e) 2015 r. – completing the course: School of Tutors (1st degree), organized by Collegium Wratislaviense; obtaining a Tutor Certificate.

f) 2016 r. – completing the 3rd edition of the course: *Practitioner of Tutoring*, School of Tutors (2nd degree), organized by Collegium Wratislaviense, obtaining a Certificate: Practitioner of Tutoring.

3. Employment in scientific institutions

a) 1.10.1997 to 2.07.2001 r. PhD studies: „Geotechnics and Environmental Engineering", Gdansk University of Technology, Faculty of Environmental Engineering; PhD student in the Department of Hydraulics and Hydrology

b) 1.08.2001 to 30.09.2015 r. – assistant professor in the Department of Hydraulics and Hydrology (now: Department of Hydraulic Engineering), Faculty of Civil and Environmental Engineering of Gdansk University of Technology

In the period : March 2007 – March 2008 – annual break (sickness and maternity leave)

c) Since 1.10.2015 – senior lecturer in Department of Hydraulic Engineering, Faculty of Civil and Environmental Engineering of Gdansk University of Technology

4. Scientific achievement indicates as the basis for habilitation degree according to regulation dated from 14th March 2003 (Dz. U. 2016 r. poz. 882 ze zm. W Dz.U. z 2016 r. poz. 1311)

a) Title

Series of monothematic publications: **Modeling of unsteady pipe flow in water hammer conditions**

b) Publications included in the achievements

1. **Weinerowska-Bords K.** (2006): Viscoelastic model of waterhammer in single pipeline – problems and questions, Archives of Hydro-Engineering and Environmental Mechanics, vol. 53, no. 4, 331-351, **MNiSW pts = 6**; (in 2018 r. **14 pts**)

   Independent publication, 100% share

2. **Weinerowska-Bords K.** (2006): Accuracy and parameter estimation of elastic and viscoelastic models of water hammer, TASK Quaterly, vol. 11, no. 4, 383-395, **MNiSW pts** = **6** (in 2018 **10 pts**)

   Independent publication, 100% share

3. **Weinerowska-Bords K**. (2011): Space-time conservation method applied to numerical solution of water hammer equations, TASK Quaterly, vol. 15, no. 3-4, 353-368, **MNiSW pts = 9** (in 2018 **10 pts**)
   Independent publication, 100% share

4. **Weinerowska-Bords K.** (2015): Alternative approach to convolution term of viscoelasticity in equations of unsteady pipe flow, Journal of Fluid Engineering-ASME, vol. 137, no.5, doi:10.1115/1.4029573 **MNiSW pts = 30**, ***IF= 1.283***
   Independent publication, 100% share

5. Kodura A., Stefanek P., **Weinerowska-Bords K**. (2017): An experimental and numerical analysis of water hammer phenomenon in slurries, Journal of Fluid Engineering-ASME, vol. 139, no.12, FE-17-1134. doi:10.1115/1.4037678, **MNiSW= 30 pts,** ***IF= 1.915***

   My contribution to this work: development of a mathematical model of water hammer in a slurry pipeline, its numerical implementation, calculations and numerical simulations, discussion of the results and cooperation in editing the content of the article (theoretical part, section devoted to the numerical model and conclusions). I estimate my participation at 40%.

6. Kodura A., Kubrak M., Stefanek P., **Weinerowska-Bords K**. (2018): An experimental investigation of pressure wave celerity during the transient slurry flow, In: Kalinowska M., Mrokowska M., Rowiński P. (eds) Free Surface Flows and Transport Processes, GeoPlanet: Earth and Planetary Science, Springer, Cham, 259-269. doi:10.1007/978-3-319-70914-7_16, **MNiSW pts = 10**.

   My contribution to this work: participation in field measurements and the development of results. I estimate my participation at 35%

7. Kodura A., **Weinerowska-Bords K**., Artichowicz W., Kubrak M., Stefanek P., (2019): In situ verification of numerical model of water hammer in slurries, Journal of Fluid Engineering-ASME, vol. 141, no.8: 081115-081115-8. doi:10.1115/1.4042959 **MNiSW pts = 30**., ***IF= 1.915***

My contribution to this work: development of a mathematical model of water hammer in a slurry pipeline network, its numerical implementation, calculations and numerical simulations (for measured and hypothetical episodes) and co-editing of the article (the entire chapter devoted to numerical aspects) . I estimate my participation at 40%.

Tab. Summary of publications, with points and participation

No. of publ.	% share in publ.	Points (in the year of publ.)	Points (in the year of publ.) including % share	Points (acc. to 2018)	Points (acc. to 2018) including % share	Impact Factor	No. of citations in publications indexed in WoS	No. of citations acc. to WoS	No. of citations acc. to Google Scholar
Ad.1	100%	6	6	14	14	0	10		19
Ad.2	100%	6	6	10	10	0	11		13
Ad.3	100%	9	9	10	10	0			
Ad.4	100%	30	30	30	30	1.283	13	13+1*	18
Ad.5	40%	30	12	30	12	1.915	1	1+1*	3
Ad.6	35%	10	3,5	10	3,5	0			
Ad.7*	40%	30*	12*	30	12	1.915			
Suma		**121**	**78,5**	**134**	**91,5**	**5,113**	**35**	**14+2***	

* Publication from 2019, not yet indexed in WoS

My average share in publications with IF is 60% (average share in all publications Ad.1- Ad.7: 73,5%).

c) Objectives and results of the work

The analysis of transient flows in pressurized pipelines constitutes a significant and complex group of issues related to both, broadly understood environmental engineering and a number of other fields, including various branches of industry or medicine. Due to the different nature of the phenomena occurring and their potential effects, the group of flows with the most dynamic variations in time, referred to as *water hammer*, is distinguished from this group. By *water hammer* one understands the rapid pressure changes resulting from sudden changes in the velocity of the flow, moving in the pipeline at very high velocities in the form of a disturbance wave of a very high amplitude and high oscillation frequency.

Water hammer phenomena are particularly important in engineering and sanitary technology (e.g. in water distribution systems, heating networks, fire-protection installations), hydropower and industrial installations, networks for hydro-transport (transit pipelines) or drilling platforms, in agricultural irrigation networks or in solar and nuclear power plants (e.g. Samani and Khayatzadeh 2003, Wang, Jiang and Lan 2014, Cristoffanini et al. 2014, Leishear 2017 and others). Their mathematical description is also used in transport issues, e.g. for modeling sudden changes in vehicle traffic (e.g. Teodoro et al. 2018). They also play a special, though different role in issues of a medical nature (biomechanics), for example in the problems of propagation of pressure waves in the blood vessels and in voice production system (e.g. Van de Vosse and Stergiopulus 2011, Alastruey et al. 2012, Sciamarella and Artana 2009).

Despite the wide range of these areas, the phenomenon of water hammer is often considered on the one hand as "niche", on the other - as well-known, well recognized and, consequently, not worth deeper analysis. This is probably the result of a long tradition to use as computational standards the formulas developed at the turn of the 19th and 20th centuries. These include: 1) the Korteweg formula published in 1878 on the pressure wave speed in the pipeline, 2) attributed to Yukovsky (or Yukovsky and Allievi) and dated 1898, the formula for the maximum pressure increase and 3) formulated in 1913 by Allievi, and supplemented by Strickler and Gibson (in the 1920s), a "classical" mathematical description of water hammer, in the form of a system of mass balance equation and the dynamic equation, describing the unsteady flow of a compressible liquid in a homogeneous elastic conduit. Although the above-mentioned description referred only to single pipelines, in which the water hammer manifests itself in the form of pressure oscillations with a regular envelope and with the extremal values always in the first amplitude, it is still regarded as a valid canon of estimates of the main parameters of water hammer.

Meanwhile, the rapid development of technology, which began in the 20th century, caused the necessity of revising the ‘old’ views on the nature of water hammer and the possibilities of its computational modeling. The possibility of more precise experimental analysis of the phenomenon (especially in relation to the accuracy of measurement of high frequency pressures in the pipe), as well as better and more efficient computational algorithms, showed a significant inconsistency between the observations (measurements) and calculations performed with use of the "classical" description. This in turn led to the conclusion that the phenomenon of water hammer is more complex than originally assumed. Consequently, it has become necessary to modify the computational models in order to enable proper ‘reconstruction’ in calculations the impact of the factors previously not taken into account. In response to the aforementioned demand, the intense development of scientific research, aimed at improving the consistency between the results of measurements and calculations, was observed. In current considerations of water hammer, carried out simultaneously in several research centers around the world, there are several fundamental directions of research, the most important of which include, among others: analysis of energy dissipation mechanisms during water hammer (e.g. Szymkiewicz and Mitosek 2007), evaluation of the role and the possibility of describing the unsteady friction term (e.g. Brunone et al 1991, 2000, 2004, Zarzycki 1994, Pezzinga 2000, 2009, Bergant et al. 2001 and others), mathematical description of the phenomenon in viscoelastic pipelines (e.c. Covas et al 2002, 2004, 2005), analysis of the fluid-structure interactions (Tijsseling 1996, Wiggert and Tijsseling 2001, Keramat et al. 2011), analysis of water hammer in more complex systems of pipelines (with a change in diameter, change in pipeline materials, pipelines with local leak, pipeline networks, etc.; e.g. McInnis and Karney 1995 , Meniconi et al. 2012) or in the case of a mixture flow (e.g. Samson and Biello 2016, Zambrano et al. 2016). However, the complexity and diversity of the aspects related to water hammer, cause that there is still a lack of a full and systematic analysis of all problems arising at the stage of creating and applying the computational models, especially with reference to the mathematical description, the identification of its parameters and the numerical methods used to obtain the solutions.

And this very complexity and multifaceted nature of the issues accompanying the phenomenon of water hammer, while being strongly anchored in a practical context, have become one of the main reasons why - at the instigation of the then Head of my Department, prof. Romuald Szymkiewicz - I decided to undertake this research topic. In practice, this involved the extension of the range of my scientific interests to a new direction, because as part of my doctoral thesis, and within a few years immediately after obtaining the doctoral degree (until about 2005) I dealt with open-channel flows, publishing in this area about ten works and performing the research within the international program US-Poland Technology Transfer Program (**Autoreferat, point 5**).

At the beginning of the new topic research, first of all I reviewed the bibliography (over one hundred literature items of different character) to prepare the state-of–art analysis, based on which I made a systematization of various aspects related to the modeling of water hammer phenomenon. This was necessary for the purposes of clarifying the aims of the research and the research thesis formulation.

Aims of the research and thesis formulation

The recognition of the state-of-art which I performed, showed that the issue of water hammer should be analyzed from a wider perspective and the two major areas of phenomenon considerations should be distinguished - the area of practical applications and the area of theoretical considerations.

Looking at the problem from a purely **practical** point of view, the most important tasks are undoubtedly: 1) **prediction of potential maximum and minimum pressure values**, and 2) **identification of places most exposed to excessive pressure amplitudes**, which in turn allows selection of type and location of safety devices and development of the control strategies of devices operating in the system, in order to avoid exceeding the permissible pressure values (e.g. adjusting the minimum valve opening/closing time durations, switching the pumps on/off in sufficiently long time, or developing a strategy for emergency response in system operation).

Proper recognition and implementation of the above-mentioned goals in most real practical situations, however, is not a simple and trivial task. The correct solution is usually not achieved using the two basic formulas only – Korteweg's (for the pressure wave celerity in the elastic pipeline) and Yukovsky's (for the maximum pressure increase), which could be a sufficient approximation only for a single elastic pipe with a constant diameter. An example demonstrating that such simplified description is often considered to be adequate enough is the provision in the PN-EN 13480: 2012 standard, recommending the assessment of the system's safety on the basis of the two aforementioned models. However, the experimental investigations carried out for various pipe configurations show inter alia that (e.g. Covas and others 2005, Malesińska 2002 and others):

— the value of the pressure wave velocity often does not match the value obtained with use of the Korteweg formula, and what is more, is variable during the course of the phenomenon;
— the maximum pressure increase/decrease does not necessarily occur in the first amplitude, and the envelope of the pressure characteristic is not always regular;

— the value of the maximum pressure increase/decrease does not always match the value obtained from the Youkowski formula (it can be both higher or lower than the "theoretical" value, depending on the specific situation).

Moreover, the place of the most unfavorable pressure changes in the pipe networks is not always obvious, because the final pressure distributions are the result of co-existing many factors resulting from the specificity of a particular system.

Thus, while still remaining on the level of a purely practical view of the issue, in the context of the goals presented above, it is postulated to look for such computational methods that on the one hand will be relatively simple and easy to apply, and on the other enable proper reconstruction of not only the first pressure amplitude, but also full characteristics of pressure variability during transient flow. These methods should ensure acceptable compliance of the calculated pressure characteristics with their real (observed) equivalents. In other words, from a practical point of view, it is desirable to create the model that correctly reproduces the **final effect of water hammer**, without the need for full and detailed recognition and computational reconstruction of the mechanisms and factors that cause it, even with the consent of certain important simplifications in the phenomenon description, including the introduction of substitute quantities. Such approach can be compared to the "conceptual" modeling, in contrast to the "hydrodynamic" approach, in which the correct recognition of the physical basis of the analyzed processes is essential.

The **theoretical** approach constitutes a kind of opposition to the "practical" one. Considering the phenomenon from **theoretical** point of view, the most important aspects are:

— **proper mathematical description of the phenomenon,** resulting from the recognition of individual mechanisms determining its course and their correct representation in the form of equations,

— **proper identification of the parameters** characterizing the phenomenon,

— **proper solution of the equations** constituting a mathematical description of the phenomenon, related to the selection of numerical models of high accuracy, enabling the minimization of purely numerical effects,

— **compliance** of the calculated pressure characteristics with the observed ones,

— **developing a model which is characterized by a sufficient degree of universality.**

The recognition of the physical side of the mechanisms determining the course of water hammer in order to create a full and correct mathematical description is the starting point for the development of "hydrodynamic" models, which constitute the basis of the scientific approach to the analysis and an alternative to the "conceptual" approach. In turn, understanding the diversity of factors affecting the course of the phenomenon and the numerical effects modifying the solution is an element enabling the appropriate construction of a mathematical model and subsequent proper interpretation of its results.

The analysis of the current state of knowledge led me to say that despite a very large number of research works on hydraulic impact, correct solving of issues related to this phenomenon is still an open question. There are several reasons determining such situation, among which the most important are:

— **high degree of complexity of the phenomenon,** especially in the case of real pipeline systems,
— **lack of full recognition of all mechanisms** determining the course of water hammer**,**
— **a similar effect of different mechanisms** determining the course of water hammer,
— **similarity (in terms of quality) of the numerical effects** in calculation results (shape of pressure characteristics) to the effects caused by physical mechanisms (unsteady friction, viscoelasticity of the pipe walls),
— **high degree of difficulty in carrying out full and correct identification of model parameters** (among others due to the previously mentioned simultaneous coexistence of various mechanisms, and hence - a relatively large number of interacting parameters of various nature and difficulty in their "extraction"),
— **a specific "attachment" of many researchers to the classical numerical method** of solving transient equations, often without analyzing the consequences of this choice for the obtained solutions.

The calculation examples presented in the literature predominantly use the method of characteristics, in which obtaining a solution of high accuracy is difficult in practice. The compliance between computational characteristics and the results of the experiment is often considered to be sufficient proof of the correctness of the presented analyzes. In the meantime, this compliance is often the result of numerical effects and not a natural consequence of a correct description of the phenomenon. The number of parameters occurring in the equations (especially in the case of flow in polymer pipes) is relatively large, and the identification of their values is usually done for each case individually, by matching their values to obtain the consistency with measurements. A drawback of such an approach is the one-off nature of this selection, without transposition into a more universal context, which would allow to apply the presented procedures also to other cases.

At the other end of the presented scientific publications, one can find those in which the mathematical description is based on models of relatively high complexity, at least two-dimensional, using complex models of individual mechanisms (e.g. flow resistance), approximated by high-order functions. The mathematical description takes into account more factors, but additional quantities appear in it, often variable in time and space, difficult to determine in the case of real industrial systems. This results in models with a high number of parameters. These parameters usually have a diverse, often unmeasurable, nature, which causes the need of their matching by optimization, without reference to the physical side of phenomena. Experimental measurements allow to observe the final effect (e.g. resultant pressure characteristics), which is actually the result of several mechanisms operating simultaneously. The degree of complexity of the equations constituting a mathematical model constructed in this way requires the use of appropriately complex methods of solution and the correct formulation of a larger number of boundary conditions, which in turn makes such an approach difficult to apply in practical cases of a wider and more universal range.

In conclusion, the two above-mentioned perspectives of recognition of water hammer - practical and theoretical, remain in a specific opposition to each other.
By juxtaposing the above-mentioned problems resulting from the complexity of the analyzed phenomena and the consequences of this fact for computational aspects, and on the other hand their practical significance and the real need to develop an effective solution algorithm, it seemed appropriate to look for an intermediary approach. Such a "quasi-conceptual" model, constituting a specific combination of a hydrodynamic and conceptual approach, would allow obtaining satisfactory results in a relatively simple manner, while avoiding the compliance of the calculations with measurements obtained due to numerical errors or "one-off" adjustment of the values of large number of parameters not having physical interpretation.

Thesis and aims of the research

In the context of the considerations presented above, **the following thesis was put forward**:

1. The crucial aspect for the modeling of water hammer is the fact that many mechanisms determining the final solution have a qualitatively similar effect on the resultant pressure characteristics, and the unitary participation of individual processes (mechanisms) is in practice impossible to fully "isolate" from the pressure characteristics.
2. Despite the aforementioned situation, it is possible to develop a relatively simple model for water hammer simulations, allowing for a good reproduction of the course of this phenomenon in various cases. In this model, some of the mechanisms may be described in a simplified way, and some parameters may have a conceptual character. For some parameters, however, it is possible to develop identification procedures of a more universal nature than only individually applicable to each case.

The aim of the research is:

1. Identification and systematization of the issues related to the possibilities and problems arising during the mathematical modeling of water hammer in pipelines (including polymer pipes),
2. Development of a relatively simple and universal model that allows calculation of transient flows (simulation of water hammer) in single pipelines and their networks, including its application to typical engineering problems and water hammer episodes measured in laboratory installations and in real scale systems,
3. Verification of research hypotheses.

Implementation of the research goals

In the first stage of the research I developed a numerical model enabling simulation of water hammer in a single pipeline of elastic material, i.e. in the classic system "reservoir-pipeline-valve" (RPV), extended in the next stage to the case of simple networks of pipelines (enabling, among others simulation of water hammer in different pipeline configurations with various pipe characteristics, or in a pipeline with local leakage). I wrote the source code for the computer program in the FORTRAN language. As a mathematical description of the phenomenon, the classical system of transient flow equations for a compressible liquid in the elastic pipeline (e.g. Wylie and Streeter, 1978) was used in the first approach. In subsequent stages of the research I extended the model with various modifications, enabling inclusion of additional factors affecting the course of the phenomenon. In the program I made it possible to set various boundary conditions (in the form of a constant or variable value of pressure/velocity/flow rate at the boundaries of the considered system) depending on the type of boundary node (reservoir, free outflow, cross-section with a valve etc.). Steady flow was assumed as initial conditions, calculated in the program based on the set of steady-flow equations.

I used several different numerical methods to solve the system of transient flow equations (I made it possible for the user to choose the method) - a method of characteristics (commonly used by many authors), a four-point scheme of finite difference methods (with its particular form - the Preissmann scheme) and less popular, but having very good numerical properties - a space-time conservation method, previously applied by me to solve the problem of reverse flow routing in open channel (**Autoreferat, point 5**).

With use of the developed model, I performed series of numerical simulations, in which I reproduced the courses of various water hammer episodes, measured during laboratory experiments and presented by other authors in different publications. I used both the measurement results for simple cases of single pipelines, as well as for more complex systems - with a diameter change or with a local leak. At this stage of my research, I also undertook the ongoing cooperation with dr Apoloniusz Kodura from Warsaw University of Technology, who had already carried out valuable experimental research at his Faculty's Laboratory. Some of the results of the experiments were then made available to me for the purpose of assessing the possibility of their computational reproducing by means of numerical simulations. This cooperation resulted in the first few publications, not included in the main achievement (publications listed in the next part of this document - **Autoreferat, point 5** and **Appendix 3 point II.C**). In all these publications, I was responsible for all the works related to mathematical modeling (including the numerical implementation of the model, its application to a specific case, model parameters identification, simulation, evaluation and discussion of results), while dr A. Kodura was responsible for the experimental part of the research. At this stage of analysis, I applied the simplified model for water hammer simulation, based on the transient flow equations in elastic pipeline, with quasi-steady friction term. The results of our work were presented at the 2nd Congress of Environmental Engineering in Lublin (presentation by dr. A. Kodura) and the International Symposium of the WMHE in Austria (my presentation). In addition, I prepared a paper devoted to the problems occurring during water hammer modeling, which I presented at the Scientific Seminar held in 2005 at the Gdansk University of Technology, organized by the Faculty of Civil and Environmental Engineering of Gdansk University of Technology and the Section of Sanitary Engineering of the Polish Academy of Sciences (I was also one of the co-organizers).

Additionally, in 2006, the Monographic Journal of Gdansk University of Technology (Zeszyt Monograficzny Politechniki Gdańskiej) published my publication referring to the same subject (**Autoreferat, p.5** and **Appendix 3 point II.C**).

This stage of the research made it possible to pre-assess the impact of the model parameter values and the accuracy of the numerical scheme on the quality of the obtained results. The most important conclusions include, however, confirmation of the possibility of a relatively "good" mathematical representation of the course of water hammer in various simple flow variants, if this correctness of the reproduction is evaluated only in the context of the compliance of the measurements with the calculations. It has been shown that in some cases it is possible to obtain satisfactory consistency between the results of calculations and measurements even if the applied model does not correctly reflect the mechanisms occurring during the flow (e.g. when the elastic pipeline model is used to simulate water hammer in a polymer pipe, or when the ‘substitute’ value of the wave celerity is applied, and when the numerical diffusion is introduced into the solution).

The next stage of the research required the extension of the computational model in order to obtain the possibility of **reproducing the effects of viscoelastic behavior of the pipe walls**. For this purpose, I derived again known in the literature equations of water hammer in viscoelastic pipes, I analyzed the significance of the particular terms of the equations, and then implemented them in the calculation program. In order to describe the viscoelastic properties of the pipe material (more strictly - to construct the constitutive model for the material of the pipe walls), I used the Kelvin-Voigt model, commonly accepted for these purposes. **In order to solve the equations, I applied two numerical schemes – a four-point scheme of finite difference method and a space-time conservation method, and I performed a detailed**

analysis of the numerical properties of both schemes. I consider this to be my personal contribution in this field of the research. In publications referring to the cases of water hammer in viscoelastic pipelines, the method of characteristics is the one which is practically always used. The use of other computational schemes (from the group of finite difference, finite element or finite volume methods) is limited to very few works devoted to water hammer in elastic pipe. The vast majority of them do not contain any analysis of numerical properties of the applied schemes.

In order to recognize the numerical properties of the proposed schemes, I applied the method of the modified equation (Fletcher 1991)**, which enables to assess the consistency and accuracy of the numerical scheme and to determine the type of numerical error that occurs in the solution.**

The assessment of **consistency** of the scheme requires replacement of the nodal values of the functions in the approximating equation with their expansions into Taylor series around the analyzed node. As a result, the modified equations are obtained, in which in addition to the terms occurring in the original equations, additional components appear. These additional terms constitute the truncation error, determine the numerical properties of the scheme and enable to estimate the magnitude and the type of the numerical errors (numerical diffusion or dispersion) which dominate in the solution.

In order to analyze the **stability** of the numerical scheme, I applied the Neumann method. The stability of the scheme is related to its ability to suppress the random errors. In the Neumann method, errors at a given time level in the analyzed nodes are extended into a finite complex Fourier series, and then the behavior of a single component of this series during the transition from the time level n to the level $n + 1$ is examined. If as a result of such a transition the amplitude of the wave is attenuated, then the scheme is stable; otherwise the scheme is considered to be instable. For the needs of the analyzed schemes, **I have defined the forms of the so-called amplification matrixes and made a stability assessment based on the modules of their largest eigenvalues.** The comparison of the properties of numerical schemes clearly proved the influence of the type of the scheme and the adopted numerical parameters values on the obtained quality of the solution, due to the occurrence of the numerical errors of various nature and magnitude. Comparison of the analyzed schemes with the characteristics method showed that the latter is not an optimal method of solving the problem. The method of characteristics is an accurate scheme only if the Courant number equals one. The fulfillment of this condition is in practice very difficult, if only due to the inability to determine the exact value of the wave celerity. If the Courant number is not equal to one, numerical errors appear in the solution. The first component in the truncation error contains a second order derivative, which means that the scheme is of first-order accuracy, and the solution is dominated by a numerical diffusion error. If Cr < 1, the scheme is stable but dissipative, which means that it leads to excessive smoothing of the solution, which is very often misinterpreted as a result of friction or viscoelastic effects. If Cr > 1, the scheme is instable.

The space-time conservation scheme, similarly to the method of characteristics, is an explicit scheme, which in consequence determines its conditional stability (for Cr < 1). It has, however, the highest accuracy (of second order) and the smallest numerical errors among the schemes analyzed. The four-point scheme, in turn, is absolutely stable, and with properly selected values of numerical parameters, regardless of the value of the Courant number, it can also ensure high accuracy of the solution.

At this stage of the research, I carried out another series of simulations for the episodes presented in the publications by other authors, this time including viscoelastic effects. I have analyzed in detail the question of **identifying the parameters of the model**, which I considered crucial. **For my own contribution at this stage of research I consider a thorough analysis of various aspects related to the estimation of model parameters, usually ignored in publications, downplayed or reduced to issues of secondary importance, in particular the problems related to the uniqueness of the solution.** I have addressed my discussion both to the observations of the general nature and to the examples presented in the publications of other authors.

The culmination of all the previously presented stages of analysis were three articles published at that time, which are included in the achievement submitted for the evaluation. The first two of them I consider very important in my scientific achievements:

Ad. 1) „*Viscoelastic model of waterhammer in single pipeline – problems and questions*” (Archives of Hydro-Engineering and Environmental Mechanics, 2006);

Ad.2) “*Accuracy and parameter estimation of elastic and viscoelastic models of the water hammer*” (TASK QUATERLY, 2007).

Although published in the journals of a lower rank (list B), they were noticed by leading researchers dealing with the topic of water hammer (including Pezzinga, Ferrante, Brunone, Meniconi et al.) and have been relatively often cited, including the journals indexed by Web of Science (about twenty citations in WoS).

In these publications, I presented a number of conclusions from previous analyzes. The most important are those related to the question of the identification of those model parameters, which are not directly measurable, and sometimes also have no clear physical interpretation. These values include parameters describing the creep function of the pipe material, i.e. retardation times and elastic modulus related to individual elements of the Kelvin-Voigt model. If the *N*-element Kelvin-Voigt model is used to describe viscoelastic behavior (which is relatively often used in a number of publications by other authors), then only for this simple reason the number of 2**N* parameters, without physical interpretation and requiring identification, will appear in the computational model. If the identification is carried out only on the basis of matching the results of calculations with the results of measurements, a very good compatibility can be obtained, even with incorrect reproduction of all other mechanisms. These parameters are conceptual in nature, so they can be relatively easily matched by optimization or by trial and error method, but the solution obtained will not only be unambiguous, but will only refer to one specific case for which it has been developed. The values of the parameters estimated in this way can "hide" all the shortcomings of the solution method (including potential numerical errors), which prevents proper interpretation of the calculation results. In this situation, achieving consistency between measurements and calculations does not indicate a correct solution to the problem.

The second significant group of conclusions were those relating to the determination of the value of the wave velocity. It has been shown, that acquiring its value by calculating it with use of the Korteweg formula does not lead to satisfactory results. It is difficult to determine the value of the elastic modulus of the pipe material in practice, especially in the case of polymers. Research by other authors has shown that although material parameters can be determined experimentally on the basis of tests, the results obtained depend on the size of the sample and the stress history. And that means that using this type of analysis will not be an effective approach, due to the inability to refer the results obtained for small sample sizes to real-sized pipelines.

The use of elastic modulus values published in literature also turns out to be ineffective. In one of the aforementioned articles (Ad.1), I demonstrated by simple analysis that, if different values of the elastic modulus (but always within the range appropriate for a given type of material) are applied, one can obtain the difference in the calculated value of the wave velocity of even 100 m/s, which then causes differences in the maximum pressure amplitudes of 0.1 MPa. If you additionally take into account the viscoelastic effects affecting the wave celerity and the observed variation of the pressure wave velocity during the water hammer episode (even c.a. 10%), then it is clear, that the calculation of the wave celerity values on the basis of the Korteweg formula should not be treated as a reliable way to determine this parameter. They are on average 10-25% lower than the measured values. Analyzes have shown that the best way of proper identification of this parameter is to determine it based on the length of the pressure wave period observed in the measurements. This period in a general case undergoes some changes during the course of the phenomenon, but the average wave speed determined on its basis can be considered as a representative value of this parameter, because it leads to good calculation results. Obviously, the above considerations concern the case of a homogeneous pipeline. In the case when the pipe characteristics change (e.g. diameter, wall thickness or material), computationally such a system should be treated as a network of pipelines with different characteristics and thus different values of the celerity of the wave propagation.

As a result of the analyzes mentioned earlier, I also published a paper focused on one of the numerical methods used for the solution:

Ad.3) "*Space-time conservation method applied to numerical solution of water hammer equations*" (TASK Quaterly, 2011).

In this work I presented a space-time conservation method related to the problem of unsteady flow in elastic pipelines. The idea of the method was described in detail. I derived the final equations, I presented the analysis of the numerical properties of the computational scheme and the discussion of the importance of the numerical parameters. The article also includes examples of numerical tests in which the properties of the schema are illustrated. The work focuses on the role of numerical errors. The application of the scheme of higher accuracy paradoxically did not lead to satisfactory results in the context of compliance of calculations with observations. The 'improvement' was obtained by intentional introducing a numerical diffusion. This means that the effect of numerical errors in solutions can be misinterpreted as a result of physical factors. On the other hand, this confirms the inadequacy of the classical description of water hammer for reproducing the course of this phenomenon.

An important element of my experiences at the beginning of the next stage of the research was the **construction of my own experimental setup** for testing water hammer phenomenon in pipelines. I started my efforts in this area in parallel to performing the analytical and numerical simulations presented earlier. The review of publications containing the original results of water hammer measurements has shown that the number of laboratories in the world where similar research is carried out is relatively small (not more than ten, including the Laboratory of Warsaw University of Technology and the above mentioned experimental setups of dr Apoloniusz Kodura).

The crucial reasons for which it was important for me to create my own laboratory setup, were: 1) the possibility of recognizing problems during experimental investigation of the phenomenon based on my own experience, 2) the possibility of performing experiments for rare cases or not yet published in literature (including the cases of water hammer in pipes made of viscoelastic materials other than HDPE, MDPE and PVC; e.g. cross-linked polyethylene (PE-X) or multi-layer pipes, e.g. PERT-Al-PERT), and 3) performance of the measurements in the installation in which all additional elements disrupting the course of the phenomenon are eliminated (e.g. changes in flow direction (resulting from the need to connect a pipe to the tank or from a limited space), changes in diameters, construction elements of the material different than the main pipe etc.). I created a project of the experimental setup based on the analysis of the existing similar installations in other research centers, and taking into account the research experience of dr. A. Kodura, whose consulting assistance was particularly valuable to me.

In order to obtain funds for the construction of the setup and the performance of research, I twice submitted (in 2010 and 2012) research applications for co-financing (as the project manager and main contractor, and inviting dr A. Kodura from Warsaw University of Technology as the main contractor and prof. Romuald Szymkiewicz from Gdansk University of Technology as an adviser and expert). Unfortunately, the applications have not been qualified for funding. In the absence of the possibility of obtaining external financing, the creation of the experimental setup was spread over several years, and the costs of its creation were covered by means of the Department of Hydraulic Engineering (Faculty of Civil and Environmental Engineering), materials obtained free of charge from companies and own funds.

The experimental setup was created in the Laboratory of Hydraulics and Environmental Engineering of the Faculty of Civil and Environmental Engineering (Gdansk University of Technology). The scheme of the installation is shown in Fig.1. Except the sections of the analyzed pipelines, the most important elements of the setup are:

- *model supply system* (water supply pipeline, shut-off valves, pressure reservoir (capacity 500 dm^3, H = 1.7 m) with fittings enabling regulation and maintaining constant pressure in the reservoir during measurements),
- *pressure transducers* - for measuring pressure in transient flow conditions (CL-1A, range 0-2.4 MPa, sampling frequency - up to 2000 Hz, accuracy 0.2% with built-in signal amplifier),
- *data acquisition device – analog-digital card* (MicroDAQ-Lite by EAGLE),
- *PC computer* for registration, processing and graphic presentation of data,
- *electromagnetic valve with actuator* (ESM87 LECHAR; closing time 20-60 ms) / *ball valve* (interchangeable - for rapid flow closure),
- *water hammer suppressor* (in the outflow section, in order to protect the electromagnetic flow-meter from the effects of water hammer, REFLEX);
- *filter with a vent valve* (in the outflow section),
- *electromagnetic flowmeter* (MPP 6 ENKO, DN 20, measuring range 0,1-10 m/s, accuracy 0,5% for v>0,5 m/s and 1% for v<0,5 m/s)

and additional equipment (drain valve, cables, DC power supply, complementary control fittings, auxiliary elements).

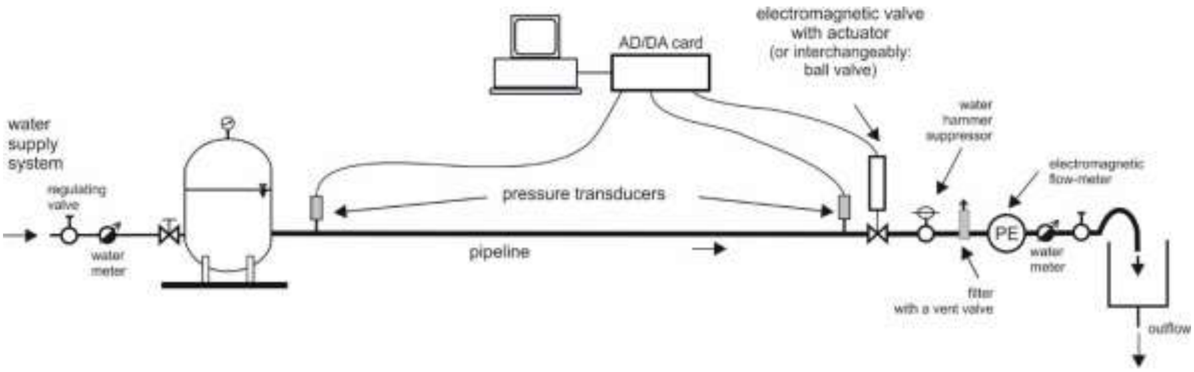

Fig.1. Scheme of the experimental setup

In order to eliminate the elements disturbing the water hammer effect, uniformity of diameters has been kept (connecting elements were adapted to the inner diameter of the analyzed pipe), the pipes were arranged horizontally in the section between the reservoir and the valve, the pipes were fixed to the wall with mounting brackets and non-invasive connection of the pressure transducers to the pipeline via three-piece mounting clamps were applied.

I performed experiments for HDPE, LDPE, PEX, PEX/Al/PEX and steel pipes in different steady flow conditions (initial pressure and velocity) before the water hammer event. The results of the measurements (unpublished materials) confirmed the significant impact of the pipe material on water hammer characteristics (both in relation to the pressure wave celerity and the oscillation frequency (duration of the oscillation period) and the rate of pressure dumping. Research has also confirmed the need to determine the pressure wave celerity based on measurements, not calculations using the Korteweg formula, because the latter does not lead to results with satisfactory accuracy. Introducing into the computational model the values of the wave celerity determined on the basis of the Korteweg formula leads to the pressure characteristics substantially different from the measured ones (both in terms of oscillation frequency and pressure amplitudes). This was particularly evident in the case of pipes with inhomogeneous wall structure (cross-linked or multi-layered), in which the reinforcing element significantly modified the properties of the material, which is not taken into account in the classical Korteweg formula.

In the next stage of research, I attempted a more thorough **analysis of the form of equations in the case of flow in viscoelastic pipelines**. This effort resulted in the publication, which I consider to be the most important in my scientific achievements:

> Ad.4) *„Alternative approach to convolution term of viscoelasticity in equations of unsteady pipe flow" (Journal of Fluids Engineering, 2015).*

In this work I presented an alternative approach to the description of viscoelastic term in continuity equation. I discussed its role, the convolution nature, the connection with the theory of a unit hydrograph and the consequences resulting from this fact. I showed that the additional term in continuity equation, representing viscoelastic effects (more precisely - the effect of retarded strain in the pipeline) in the convolution form, can be rewritten as the sum of two components - a part dependent on 'instantaneous' flow conditions and a part dependent on the "stress history" in the analyzed system. In the context of numerical calculations this means that the magnitude of this term is calculated based on the values describing the flow conditions on the current and past time levels ("history"). However, in practical applications that can be found in the literature, for simplifying the calculation procedure, this term is determined according to the procedure proposed by Covas et al. (2005), thus on the basis of the values on the current and the previous time levels only, using a linear approximation. Although such a procedure shortens the duration of calculations, it also prevents the full interpretation of the form of viscoelastic term.

In the paper I indicated that the additional terms in continuity equation has the form of a convolution in which the impulse response function demonstrates a full analogy to the instantaneous unit hydrograph (IUH) in a well-known linear reservoir model, used in hydrology and hydraulics.

The values of retardation times τ_i related to the subsequent elements of the Kelvin-Voigt model in viscoelastic term are in fact the equivalents of the *K* parameter in IUH. Thus, the interpretation of these parameters is analogous to the parameter *K*. **What is more, the form of the viscoelastic term demonstrates an analogy to the form of the unsteady friction term expressed as a convolution, which makes that both unsteady flow equations (continuity equation and dynamic equation) may be written in a coherent form, and both**

are related with the 'memory' of the described system. This explains the similarity of the influence of these two physically different mechanisms on the formation of pressure characteristics, and the difficulty in separating the individual impact of these factors on the results obtained in measurements. **Considering the form of viscoelastic term, as a consequence, I indicated that the retardation time does not have to be treated as a purely mathematical parameter and determined only by matching the results of calculations to the measurements (by 'trial and error method', or by automatic optimization).** With this approach, it is usually necessary to use a several-element Kelvin-Voigt model to obtain a sufficiently large number of parameters, so that, with their 'proper' calibration, it is possible to obtain very good consistency between the results of calculations and measurements. However, **by carrying out the numerical tests for different numbers of elements in Kelvin-Voigt model (with use of the independently prepared program using the *Controlled Random Search* procedure), I proved that the parameter τ_1 can be effectively estimated based on the analysis of system memory, and – if it is properly determined – one-element Kelvin-Voigt model becomes a sufficiently good model describing the viscoelasticity of the pipeline**. Such an approach not only significantly reduces the number of "unmeasurable" model parameters (even by 8, compared to some solutions presented by Covas et al.), but allows – at least in the case of some of them – to give them their physical interpretation.

The analysis and conclusions presented by me in the paper in my opinion are an important contribution to the general discussion regarding the possibilities of mathematical reproducing of transient flow and the role of the model parameters.

On the basis of the experiences gained from the previous stages of research, I finally developed a one-dimensional **model of transient flow in pipelines, that allows reproducing the course of water hammer in the network of pressurized pipes** (a structure of the network may be adapted each time to the specifics of the considered system).

The system of equations governing the transient flow in the pipeline network consists of continuity equations and dynamic equations for particular branches of the network, additionally the analogous balance equations for all internal junctions of pipelines and equations defining boundary conditions, the forms of which depend on the type of the node, the specifics of the layout and conditions of its operation.

The model assumes that local flow resistance in junctions (connection nodes) will be omitted. In order to take into account these resistances in calculations, one should have knowledge of the values of local resistance coefficients not only in steady conditions, but also in the case of unsteady flow (including also water hammer). At this stage of the analysis, I took into account the conclusions drawn based on the laboratory tests carried out beforehand, concerning the experimental analysis of energy loss coefficients for selected fittings, e.g. elbows, extensions and reductions of diameters and tees (tests carried out on another specially created experimental setup, described in the further part of this Summary; **Autoreferat, p.5**). These experiments clearly showed that the values of energy loss coefficients presented in the literature or the catalogues of pipe manufacturers significantly differ from those obtained due to measurements. Thus applying the 'theoretical values' from literature would not be a proper procedure for these coefficients estimation. What is more, the values of coefficients depend not only on the type and design features of the fitting, but also on the flow conditions, so they vary during the flow. On the other hand, an attempt to estimate this variability (especially in the case of more complex networks and thus a large number of elements causing local energy losses) would pose a big challenge and would become a separate research problem. The obtained model would be 'enriched' with a large number of parameters difficult to identify, which would significantly complicate calculations and interpretation of the results. Considering that in practical applications local energy losses are usually taken into account as a part of linear losses, and what is more, the computational model is purposely meant as one of the "quasi-conceptual" nature, I decided to accept the aforementioned simplification. It is worth mentioning that other authors performing unsteady flow analyzes for pipeline networks apply the same simplification in their research, although usually without a discussion on this issue.

The structure of the network in my unsteady flow model can be each time determined by defining the number of branches, the number of boundary nodes and the number and configuration of internal junctions. The pipeline sections (branches) may have variable elevation, and each of them may be individually defined by parameters describing its basic characteristics (length of the section, internal diameter, wall thickness, ordinates of the pipe axis, etc.).

The values of pressure wave velocities can be defined arbitrarily (e.g. based on measurements) or calculated inside the model based on selected formulas (Korteweg formula or other, defined depending on the specificity of the task). The parameters τ_i (retardation times in the case of viscoelastic pipelines) should be determined according to the procedure presented in (Ad.4), based on convolution approach presented before, although of course for test purposes they can also be determined in another way (presumed or obtained via optimization). The program can optionally take into account variability of liquid density and changes in the diameter of the pipe under the influence of pressure changes. One can also select the method of taking into account unsteady friction losses (e.g. quasi-steady model, increase of resistance coefficient by correction factor, model of Brunone, Vitkovski and Simpson).

In order to solve the system of equations I finally applied the four-point scheme of the finite difference method, which is characterized by high accuracy and at the same time unconditional stability, regardless of the value of Courant number. The space-time conservation scheme, previously analyzed, demonstrates even higher accuracy, but due to conditional stability it becomes less effective in the case of flow in the pipeline network, when there are pipes of different parameters (different diameters, wall thicknesses and materials) in the system. This variability of pipe characteristics causes that the pressure wave celerity is different in different places of the system (in different branches of the network). This causes that it is more difficult to choose the optimal time step to simultaneously meet the stability condition and maintain the high accuracy of the scheme.

I examined the model performance in different cases of water flow: a flow in a single straight pipe (of the constant diameter) of elastic or viscoelastic material, a flow in a pipe with one change in diameter, a flow in pipelines of different characteristics in series, and in pipeline networks. I verified the model based on literature examples and measurement experiments in laboratory conditions.

A particularly valuable test of the model's operation was the possibility of its application to the case of real pipelines that drain excess waters from the landfill site at the OWOW Żelazny Most (KGHM), implemented as part of the project (**Appendix 3, p. III.M**):

„*Analiza zjawiska uderzenia hydraulicznego w rurociągach „D" i „E" na OUOW Żelazny Most*" (for DHV Hydroprojekt).

(‘*Analysis of the phenomenon of water hammer in the "D" and "E" pipelines at OUOW Żelazny Most'*)

In this task I participated as a contractor, responsible for all calculations based on numerical modeling. The aim of the study was to examine the operation of pipelines in the conditions of a potential water hammer caused either by a gate failure or by a lack of power supply and interruption of pump operation. The model proved to be effective and the conclusions from the research were used to identify sensitive points along the pipelines and to develop a strategy for protection against water hammer (unpublished materials, rapport for the client).

A very important stage of the research work was the analysis of the possibility of **adopting the previously developed model for the case of non-homogenous liquid flow** (a slurry mixture), **both in a single pipeline and in a slurry pipeline network**.

The research was carried out on the occasion of a comprehensive research task:

„*Analiza numeryczna propagacji ciśnienia w rurociągach szlamowych podczas trwania zjawiska uderzenia hydraulicznego dla rzędnych korony OUOW od 180 m n.p.m. do 195 m n.p.m.*",

(‘*Numerical analysis of pressure wave propagation in slurry pipelines during water hammer phenomenon, for the crest elevation from 180 m. a.s.l. to 195 m a.s.*l')

implemented for KGHM Polska Miedź S.A. by Warsaw University of Technology under the supervision of dr inż. Apoloniusz Kodura, through whom I was invited to cooperation.

The project concerned a large and relatively complicated network of slurry pipelines located in Poland, transmitting a post-production mixture from three stations (ZWR) - in Polkowice, Rudna and Lubin to the OUOW "Żelazny Most" landfill.

The main goal of the analysis was to create a numerical model supporting the current operation of pipelines (in terms of the possibility of water hammer occurrence), taking into account the needs of possible future network modifications (e.g. changes in material or pipe diameters, changes of landfill crest elevation, etc.). In addition, the aim of the analysis was to identify the network points most exposed to the effects of potential water hammer occurrence and to estimate the critical pressure values in various transient scenarios (water hammer caused by pump failures or gate valve failures).

In this extensive task, I was the only author of the research work related to the development and application of the numerical model (developing a structure of the mathematical model, numerical implementation, testing, verification on the basis of obtained measurement results, performing of numerical simulations), and also I participated in study works (especially those referring to the recognition of the possibilities and limitations of modeling the flow of mixtures), in field measurements (participation in one measurement campaign), in development and interpretation of measurement results for the purpose of parameter estimation and in formulating intermediate and final conclusions, as well as preparation of the reports.

The analyzed network of slurry pipelines included transit pipelines supplying a mixture from three previously mentioned ZWR (several parallel routes from each ZWR), shorter connecting sections and a network of pipelines surrounding the landfill (three rings), allowing the mixture to be directed from any ZWR to one of over 10 point outlets or numerous outflow sections, distributed around the perimeter of the landfill. The network consists of about 380 pipeline sections with a total length of over 150 km, with a variety of characteristics (steel or polymer pipes of different diameters, exceeding 800 mm) and enables redirection of the mixture along different routes, depending on current needs.

My participation in the entire task included literature recognition in the field of mathematical modeling of transient flows of mixtures (including a review of available models and evaluation of their applicability in the analyzed case), development of a mathematical model for the purpose of simulation the course of water hammer in a slurry mixture in a laboratory installation (created for the purposes of the task at the Laboratory of Warsaw University of Technology by the team of Dr. Kodura), **participation in the analysis and evaluation of the results of laboratory measurements, considering the conclusions from laboratory analyzes for the purpose of determining the optimal configuration and identification of model parameters, performing numerical**

simulations of water hammer episodes measured in the laboratory and adopting the methodology to the case of a pipeline network, developing the simulation model of water hammer for the real slurry network, verification of the model based on in situ measurements (carried out by dr Kodura's team; in which I partly participated) **and simulation of water hammer episodes in real slurry network for various hypothetical variants of the system operation (different flow routes, different hydraulic conditions, various causes of water hammer).**

The analyzes resulted in three publications:

Ad.5) "*An Experimental and Numerical Analysis of Water Hammer Phenomenon in Slurries*" (Kodura A., Stefanek P., Weinerowska-Bords K.; *J. Fluids Eng.- ASME,* 2015); my participation: 40%);

Ad.6) "*An Experimental Investigation of Pressure Wave Celerity During the Transient Slurry Flow*" (Kodura A., Kubrak M., Stefanek P., Weinerowska-Bords K., Springer, 2018); my participation: 35%);

and:

Ad.7) "*In situ verification of numerical model of Water Hammer in Slurries*" (Kodura A., Weinerowska-Bords K., Artichowicz W., Kubrak M., Stefanek P.; *J. Fluids Eng.- ASME,* 2019; my participation: 40%).

The first of these (Ad.5) presents theoretical foundations related to mathematical modeling of the flow of mixtures, experimental investigations of water hammer in a slurry mixture carried out in laboratory conditions and all issues related to the development and implementation of a mathematical model reproducing the water hammer episodes observed in laboratory during the slurry flow in a single pressure pipe.

My participation in this publication involved co-creating of the theoretical part, with particular focus on practical discussions of the computational models functioning in literature, all the research related to the numerical analysis (model development, parameter identification, discussion of results, introduction of conceptual parameters, analysis of the obtained results) and co-editing the conclusions and the entire content of the paper.

As part of the work, I analyzed various concepts of mathematical description of unsteady flow in mixtures, as well as the possibilities and barriers to effectively identify the model parameters. The basic problems were the assessment of the practical possibilities of reflecting in the model the character of the mixture (homogeneous, quasi-homogeneous, inhomogeneous), and the role of additional phenomena accompanying the flow (e.g. deposition of the solid material, formation of bottom layer, and variability in time and space of the bottom layer thickness). Based on the results of observations and measurements carried out (by the team of dr. Kodura) during laboratory tests (including, among others, the results of suspended concentration measurements and observation of the behavior of the solid fraction during the unsteady flow in pipeline) and on the basis of preliminary numerical simulations, I decided to use the quasi-homogeneous liquid model. I also finally decided to reject the theoretical (available in the literature and presented in the paper) formulas for the pressure wave celerity and to apply the empirical value of pressure wave celerity, determined on the basis of measured pressure characteristics, individually for mixtures with different concentrations. This approach was possible due to the relatively small concentrations of the solid fraction. The mathematical model obtained in this way correctly reproduced the frequency of pressure oscillations and the rate of their damping, while it caused inaccuracies in maximum pressure amplitudes estimation, the bigger, the higher the concentration of the mixture was.

Analyzes confirmed the literature that in the case of the flow of mixtures the maximum pressure increase is greater than it would result from the calculation of Youkowski's formula, but the formulas presented in the literature did not lead to results consistent with the observations. This means that the mathematical description used, does not take into account all the mechanisms that actually modify the course of water hammer in the case of a slurry flow. An alternative would be to use a more complex model in which both phases (liquid and solid) would be described by separate balance equations, and their interaction would be taken into account in additional equations. Another approach could be computational ‘separation’ in cross-section area the ‘inactive’ bottom layer (decreasing cross-section area of the stream) and the remaining ‘active’ part of the stream.

Unfortunately, for the purposes of identification and verification of such models, more detailed measurement tests would be required to assess the variability (both in time and along the stream) of the mixture concentration (being the ‘active’ phase) and the thickness of the bottom layer resulting from the deposition of the solid fraction. In real industrial networks of slurry pipelines, in practice, such measurements cannot be carried out.

For the above-mentioned reasons, I proposed finally the apply a simplified model with modified parameters. Comparison of the results of carried out computational simulations with the results of experiments in the laboratory showed that **the resultant effect of additional factors** (not included in the mathematical description of flow in the case of quasi-homogeneous mixture) **is qualitatively similar to the effects that would occur** in this pipeline **in the case of a flow of homogeneous fluid with increased density**. This consistency applies not only to the maximum value of the pressure amplitude, but also to the entire course of the pressure oscillations. **The most important element of my own contribution in this research is to propose the introduction of a conceptual 'substitute density' parameter, which will comprehensively take into account those factors that have a significant impact on the course of water hammer, but which cannot be accurately recognized and implemented in the model due to the complexity and variability (in time and space) of processes and the inability to identify parameters describing them.** Such factors include the aforementioned formation and variability of the thickness of the bottom layer, uneven distribution of concentration in the cross-section and along the axis of the pipeline, etc.

The use of a conceptual parameter of 'substitute density' (in practice, a corresponding increase in the density of the mixture over the value resulting from the density of individual phases and their concentrations) significantly improved the quality of calculation results and enabled satisfactory (in the sense of compliant results with measurements) reproduction of the course of the recorded episodes. Finally, according to the idea of dr. A. Kodura, the substitute parameter was named the 'equivalent density'. Dr A. Kodura is also the author of the formula proposed in the paper, describing the relation between the equivalent density and the thickness of the bottom layer.

In the second of the cited publications (Ad.6), the experimental research stage was presented in more detail, both the laboratory part and preliminary results from the field part. My contribution to this publication was co-edition of the part devoted to the development and interpretation of the measurement results, as well as participation in one of the field measurement campaigns. It is worth noting that both in the case of laboratory and field measurements, the values of pressure wave velocities obtained experimentally for the same flow routes and the same concentrations of mixtures showed some variability, and what's more - non-compliance (about 10%) with results obtained by calculations using theoretical formulas (for wave celerity in the case of a mixture flow). In the context of previous considerations, this does not seem surprising. On the other hand, this is a factor hindering the identification of these parameters and confirming the previous conclusions that the best way to determine them is the experiment. Unfortunately, in the case of real objects (especially large industrial networks) it is often very difficult to carry out measurements or even - for technical reasons - it is impossible.

The last of the presented publications (Ad.7) is devoted entirely to the development of a mixture flow model in the analyzed real industrial network of KGHM pipelines. **My participation covered all the work related to the development of the mathematical model, its numerical implementation, identification and verification based on the results of field measurements and numerical tests for the situation measured in situ and future hypothetical water hammer episodes caused by a potential failure in the network.** In the paper the description of this research is presented in "Numerical calculations" chapter. Due to the limits in publication size, only a section of much broader analyzes carried out as part of the project has been presented.

The model proposed earlier proved to be effective also in the case of such a complex network of slurry pipelines. For its verification, it was necessary to determine reliable values of equivalent densities for slurry mixtures transported from various ZWR and to determine the values of pressure wave celerity (dependent on the characteristics of mixtures and the selected route of their transport, variable along the flow path). On the basis of the research carried out at this stage, the conclusions regarding the security of the analyzed network and the strategy enabling protection against potential water hammer events were drawn. A relatively flexible computational model was developed, to which the user-friendly interface was prepared by dr. Wojciech Artichowicz from the Faculty of Civil and Environmental Engineering, Gdansk University of Technology.

The research has shown that the one-dimensional unsteady flow model for a homogeneous liquid can be successfully applied to the flow of mixtures with relatively low concentrations, and thus more complex models with a larger number of parameters and the demanding calibration process can in many cases be replaced with simpler models of the quasi-conceptual nature.

Summary

The series of publications submitted for evaluation are the result of many years of research on investigating the phenomenon of water hammer in pressurized ducts. These studies included both theoretical considerations as well as computational and experimental research. The phenomenon of water hammer was analyzed on two levels - theoretical and practical, and the analysis referred to both the mathematical description itself and issues related to the possibilities and limitations of numerical implementation, parameter identification, properties of the applied numerical schemes and practical applications of the proposed solutions.

In more detailed terms:

- a broad discussion on the role and the possibility of identifying the parameters appearing in the equations constituting the mathematical description of transient flows was carried out,
- analysis of the properties of selected numerical schemes was developed and the role of numerical effects appearing in the solution was discussed,
- an alternative approach to the description and interpretation of the viscoelastic term appearing in the continuity equation of unsteady flow in polymer pipes has been proposed,
- the analogy between the viscoelasticity term to the instantaneous unit hydrograph has been demonstrated and the consequences of this fact for the purposes of parameter identification have been presented,
- similarity between the convolution forms of viscoelastic term in continuity equation and the unsteady friction term in the dynamic equation was indicated,
- an experimental setup for water hammer analysis was designed and implemented,
- on the basis of previous analyzes, a transient flow model was developed for a single pipeline and a pipeline network; in the case of modeling the flow of mixtures - a conceptual ‘equivalent density’ parameter was proposed,
- the model was verified based on laboratory tests and in situ measurements.

As a result of the analyzes, a ‘quasi-conceptual’ model was proposed with a relatively simple structure, and at the same time a wide potential spectrum of applications. The model includes the possibility of carrying out the calculations of the unsteady flow of homogeneous

or heterogeneous fluid in pipeline network of circular pipes, of any user-defined number and configuration of branches (including ring networks), made of elastic or viscoelastic materials.

The flexible possibility of defining boundary conditions (depending on the network configuration and the type of devices used) has been taken into account and the presence of valves and gate valves defined in the model by introducing additional internal boundary conditions has been included in the network. The structure of the model enables its further extension by including in the network structure other fittings and devices.

As a part of the analysis, the significance of individual parameters for reproduction of the effects of water hammer and the possibility of their identification were considered and discussed. The proposed model was verified on the basis of measurement experiments in laboratory conditions and in situ by its application for the real industrial network of slurry pipelines.

The model was able to reproduce the unsteady flow of the slurry mixture in a satisfactory manner, even in the presence of bottom layer and small amounts of air accumulated in the pipes. Thus, the model proved to be useful not only for the purposes of analyzes of a research nature, but also for practical applications – e.g. for the purposes of hazard assessment and support of decision regarding acceptable operating conditions of devices in complex industrial pipeline networks.

The analyzes allowed to confirm the thesis that many factors determining the course of water hammer, although differing significantly on the physical basis, have a similar effect on the formation of the resulting pressure characteristics, and thus can be modeled in a similar way by models of ‘quasi-conceptual’ nature, by simplifying the mathematical description of the considered mechanisms and introducing substitute parameters describing the features of the considered systems. However, in order to allow the proper interpretation of the obtained results, it is necessary to release the solution from the influence of numerical errors, and to carry out the reliable identification of the model parameters.

In my opinion, my research has both cognitive and utilitarian significance. On the one hand, it allows - at least partially - better recognizing, identification and interpretation of practical problems arising at various stages of water hammer modeling, on the other hand it provides a practical computational tool that can be used to reproduce the course of water hammer in the case of water and low-concentration mixtures flow in pressurized pipeline networks.

References

[1] Alastruey J., Parker K.H., Sherwin S.J. (2012): Arterial pulse wave haemodynamics. W: Proc. Of the 11th International Conference on Pressure Surges, Lisbon, Portugal, 24-26 October 2012, 401-442.

[2] Bergant A., Simpson A.R., Vitkovsky J. (2001): *Development in unsteady pipe flow friction modeling*. J. of Hydr. Res., vol. 39, no.3.

[3] Brunone B., Golia U.M., Greco M. (1991): *Some remarks on the momentum equation for fast transients*. Proc. Int. Meeting on Hydraulic Transients and Water Column Separation, 9th Round Table, IAHR, Valencia, Spain, 201-209.

[4] Brunone B., Karney B.W., Mecarelli M., Ferrante M. (2000). *Velocity Profiles and Unsteady Pipe Friction in Transient Flow*. J. of Water Res. Planning and Managm. Vol. 126, No.4, 236-244.

[5] Brunone B., Ferrante M., Cacciamani M. (2004): *Decay of pressure and energy dissipation in laminar transient flow*, J. of Fluid Engineering, Vol. 126, No. 6, 928-934. DOI: Covas D., Stoianov I.,Graham N., Maksimovic C., Ramos H., Butler D. (2002).*Inverse transient analysis for leak detection and calibration – a case study in a polyethylene pipe*, in: Fifth International Conference on Hydroinformatics, Cardiff, UK, 1154-1159

[6] Covas D., Stoianov I., Mano J.F., Ramos H., Graham N., Maksimovic C. (2004). *The dynamic effect of pipe-wall viscoelasticity in hydraulic transients. Part I – experimental analysis and creep characterization.* J. of Hydraul. Res., Vol. 42, No. 5., 516-530.

[7] Covas D., Stoianov I., Mano J.F., Ramos H., Graham N., Maksimovic C. (2005). *The dynamic effect of pipe-wall viscoelasticity in hydraulic transients. Part II – model development, calibration and verification*. J. of Hydraul. Res., Vol. 43, No. 1., 56-70.

[8] Cristoffanini C., Karkare M., Aceituno M. (2014), *Transient Simulation of Long Distance Tailings and Concentrate Pipelines for Operation Training*. Proc. of SME Annual Meeting/Exhibit, February 24-26, 2014, Salt Lake City, UT, USA

[9] Fletcher C.A.J. (1991): *Computational techniques for fluid dynamics*. *Part 1: Fundamental and general techniques*, Springer-Verlag Berlin Heidelberg.

[10] Keramat A., Tijsseling A.S., Hou Q., Ahmadi A. (2011): Fluid-structure interaction with pipe-wall viscoelasticity during water hammer, J. of Fluids and Structures, 28, 434-455. DOI: 10.1016/j.jfluidstructs.2011.11.001.

[11] Leishear R.A. (2017): Nuclear power plant fires and explosions, IV Water hammer explosions mechanisms, w: Proc. of the ASME 2017 Pressure vessels and piping conference, Waikoloa, HI, USA, 16-20 July 2017.

[12] Malesińska A. (2002): Rozprzestrzenianie się zaburzenia ciśnienia o skończonej amplitudzie w ciągu przewodów o różnych średnicach, rozprawa doktorska, Politechnika Warszawska, Warszawa.

[13] McInnis D., Karney B.W. (1995): Transients in Distribution Networks: Field tests and demand Models, J. of Hydraul. Eng., 121(3), 218-231.

[14] Meniconi S., Brunone B., Ferrante M. (2012) : Water-hammer pressure waves interaction at cross-section changes in series in viscoelastic pipes, J. of Fluids and Structures, vol.33, 44-58. DOI : 10.1016/j.jfluidstructs.2012.05.007.

[15] Pezzinga G. (2000): Evaluation of unsteady flow resistance by quasi-2D or 1D models, J. of Hydr. Eng., Vol. 126, No.10, 778-785.

[16] Pezzinga G. (2009): Local balance unsteady friction model, J. of Hydr. Eng., Vol. 135, No.1, 45-56. DOI: 10.1061/(ASCE)0733-9429(2009)135:1(45).

[17] Samani H.M.V., Khayatzadeh A. (2002): Transient flow in pipe networks, J. of Hydraul. Res., 40(5), 637-644.

[18] Samson, R., Biello, J.A. (2017): Longitudinal instability of slurry pipeline flow. Int. J. Multiphase Flow, 90, 57-63. DOI:10.1016/j.ijmultiphaseflow.2016.12.005.

[19] Sciamarella D., Artana G. (2009): A water hammer analysis of pressure and flow in voice production system, Speech Communications, 51, 344-351.

[20] Szymkiewicz R., Mitosek M. (2007): Numerical aspects of improvement of the unsteady pipe flow equations, Int. J. Numer. Meth. Fluids, 55, 1039-1058. DOI: 10.1002/fld.1507.

[21] Teodoro I.P., Ribeiro D.F., Botari T., Martins T.S., Santos A.A. (2018): Fast simulation of railway pneumatic brake systems, J. of Rail and Rapid Transit, online first version, DOI: 10.1177/0954409718796903

[22] Tijsseling A.S. (1996): Fluid-structure interaction in liquid-filled pipe systems: a review, Journal of Fluids and Structures, 10, 109-146.

[23] Van de Vosse F.N., Stergiopulos N. (2011): Pulse wave propagation in the arterial tree, Annu. Rev. Fluid Mech., 43, 467-499.

[24] Wang T., Jiang J., Lan G. (2014): Research on accumulator for water hammer protection of long-distance slurry transportation pipelines, Proc. of 6th Int. Symp. on Fluid Machinery and Fluid Engineering, 22 October 2014. DOI: 10.1049/cp.2014.1256

[25] Wiggert D.C., Tijsseling A.S. (2001): Fluid transients and fluid-structure interaction in flexible liquid-filled piping, ASME Appl. Mech. Rev., vol. 54, No. 5, 455-481.

[26] Wylie E.B., Streeter V.L. (1978): Fluid transients, McGraw Hill Inc., USA

[27] Zambrano, H., Sigalotti, L. D.G., Klapp, J., Pena-Polo, F. and Bencomo, A. (2017): Heavy oil slurry transportation through horizontal pipelines: Experiments and CFD simulations. Int. J. Multiphase Flow, 91, 130-141. DOI:10.1016/j.ijmultiphaseflow.2016.04.013.

[28] Zarzycki Z. (1994): Opory niestacjonarnego ruchu cieczy w przewodach zamkniętych, Prace Naukowe Politechniki Szczecińskiej, Nr 516, Szczecin.

5. Description of other scientific achievements

Looking back from the perspective of years, three different thematic paths can be distinguished in my scientific and research work:

1) analysis of free surface flows, with particular emphasis on inverse problems in open-channel hydraulics;
2) research of transient flows in pressurized pipelines, including analysis of their specific category – water hammer phenomenon,
3) scientific and practical basis for calculations of the stormwater amount in urban(ized) areas and stormwater management problems.

The diversity of the research fields presented above results, on the one hand, from the broad thematic range of my specialization (sanitary engineering) and its strong connection with practical aspects, on the other hand – is the result of changing current demand for research topics, both from my department, as well as the broadly understood industrial environment.

In the last years of my research work, these trends were implemented in parallel, which on the one hand constituted a significant difficulty due to the thematic diversity, but on the other hand it significantly influenced the broadening of research horizons and the possibility of recognizing different thematic areas. It also allowed to draw inspiration from various fields of environmental engineering and to use methods usually assigned to other areas for seemingly different applications.

Most of the scientific achievements in the field presented in point 2) (analysis of transient flows in pipelines) have been submitted for evaluation, so they are described in more detail in the previous chapter.

Below, the achievements in the scope of topics 1) and 3) will be presented in details. Additionally, the achievements in the field 2), which were not presented in the previous part of **Autoreferat**, will be also described.

a) Before obtaining PhD degree

I started my scientific and research activity on October 1, 1997, with joining the PhD Studies "Geotechnika i Inżynieria Środowiska" at the Faculty of Environmental Engineering at Gdansk University of Technology. My previous experiences were related to the activity within the Science Club: *Ekologia w Budownictwie i Inżynierii Środowiska (Ecology in Construction and Environmental Engineering)* at the Faculty of Environmental Engineering at Gdansk University of Technology.

At that time I took part in several trips organized by the Club and I presented two papers at the First National Seminar on Scientific Clubs "*Technical aspects of environmental protection*", which took place at Gdansk University of Technology.

At the beginning of my PhD Studies I started a scientific cooperation with prof. Romuald Szymkiewicz at the Department of Hydraulics and Hydrology (now: Department of Hydraulic Engineering) and I took up the research topics related to open channel flows. The subject of my PhD thesis were **inverse problems in open channel hydraulics**.

In the first period of my doctoral thesis, I reviewed the literature, developed a formal classification of the types of tasks formulated in relation to flows in open channels and I indicated the problems not yet fully recognized. In the first year of my PhD studies, I spent three-month on a doctoral stay at the University of Joseph Fourier in Grenoble, under the supervision of Jean Pierre Cholett.

The work during this period was focused on deepening the knowledge of the possibilities and limitations of the mathematical description of transient flows in open channels. As a result of the research, a study entitled "*Inverse problems in open channel hydraulics. Unsteady gradually varied flow* " was prepared, which was also a formal thesis finishing my 1-year Supplementary Studies.

In the next stage I started to deepen the subject of **numerical modeling**, with particular emphasis on the methods of **investigating the accuracy and stability of numerical schemes**.

For the needs of my research, I carried out the analysis of the basic properties of various schemes of finite difference method, including Leap-Frog, Lax, Lax-Wendroff, four-point scheme and others. I also reviewed less used methods, which due to their special properties could be applied in order to solve the demanding **task of reverse flow routing**. For the needs of the latter, I derived the system of equations describing the problem and I discussed the way the boundary conditions should be imposed. I also analyzed the practical aspects of solving the reverse flow routing problem. Finally, I chose two methods to obtain the numerical solution – a four-point scheme of the finite difference method and a less known space-time conservation method, of which the latter turned out to be optimal due to the properties of the obtained numerical scheme.

The second group of inverse problems were the tasks concerning parameter identification of steady and unsteady flow models, in the case of a single channel and for channel networks. For the purposes of these tasks, it was necessary to explore the **theory of optimization**. In this regard, I reviewed the optimization methods and the most frequently used objective functions. For various cases of identification tasks (in which the roughness coefficient and/or lateral inflow parameters were usually identified, in various channel configurations and in different flow conditions (steady/ unsteady)), I carried out a number of numerical analyzes and experiments. The results of the calculations were verified based on both, measurements carried out in laboratory and available data from field measurements.

Part of the results of my research were presented in the paper: „*Identyfikacja parametrów charakteryzujących opory ruchu w sieci kanałów otwartych*" (‘*Identification of parameters characterizing the flow resistance in open channel network*') during the XIXth National School of Hydraulics in Frombork (1999). The work I presented was awarded in the competition for the best paper of young science workers. In the same year, I also prepared both the presentation and the paper, entitled: „*Określanie parametrów charakteryzujących opory ruchu w kanałach otwartych*" (‘*Determination of parameters characterizing flow resistance in open channels*') at the 2nd National Seminar of Scientific Clubs „Techniczne aspekty ochrony środowiska" (‘*Technical aspects of environmental protection'),* organized at Gdansk University of Technology.

In order to deepen the knowledge related to the possibilities and limitations of using various optimization methods, in 1999 I took part (as an observer and listener) in the conference: „*Algorytmy Ewolucyjne i Optymalizacja Globalna*" (‘*Evolutionary Algorithms and Global Optimization*') in Potok Złoty. It resulted in my greater interest in this kind of methods, which later enabled the application of the mentioned algorithms to selected engineering tasks. Thanks to my participation in this conference I had the pleasure of being asked by dr. Jarosław Arabas (the organizer of the conference) to read the manuscript of his then-prepared book "*Wykłady z algorytmów ewolucyjnych*" ('*Lectures in evolutionary algorithms'*) and to prepare an 'informal review'. The author was so kind that he mentioned this fact in 'acknowledgements' in the book published shortly thereafter, which is a nice memento for me today.

In 2000 I started my participation in the grant of KBN (State Committee for Scientific Research) (Grant No. PO4D 032 19): '*Operational control of a flood wave in flood conditions*' in a team of contractors: prof. Romuald Szymkiewicz, Katarzyna Weinerowska and Tomasz Dysarz. Our cooperation within this research lasted till 2003 (**Appendix 3, p.III.A.3)**.

As a result of my work carried out over four years, I presented **my PhD thesis entitled** "***Zagadnienia odwrotne w hydraulice koryt otwartych***" ('***Inverse problems in open channels hydraulics***'), which was reviewed by prof. Janusz Kubrak (SGGW in Warsaw) and prof. Jerzy M. Sawicki (Gdansk University of Technology). I defended my work in July 2001. My doctoral thesis was awarded. On August 1, 2001, I was employed as an assistant professor at the Department of Hydraulics and Hydrology at the Faculty of Environmental Engineering of Gdansk University of Technology. In 2002, I received the Rector's Award of Gdansk University of Technology (individual II degree) for scientific activity in 2001.

b) After obtaining the PhD Degree

Research field 1)

In a short time after obtaining the doctoral degree, my several new publications related to open channel flow, mostly independent (100% share), appeared:

Weinerowska K. (2001): *Identyfikacja parametrów charakteryzujących opory nieustalonego przepływu w sieci kanałów otwartych*; Materiały XXI Ogólnopolskiej Szkoła Hydrauliki, Sasino, 17-21 września 2001 r., Gdańsk PAN Inst. Bud. Wodnego, 103-108.

Weinerowska K. (2002): *Procesy transformacji przepływu przez oczyszczalnię i ich praktyczne konsekwencje*, Materiały Konferencji Naukowo-Technicznej „HYDRO-MOD'2002 Hydrauliczne metody modernizacji oczyszczalni ścieków", Wydawnictwo Politechniki Gdańskiej, Gdańsk 2002 r., 23-34.

Weinerowska K. (2003): *Zastosowanie metody czasoprzestrzennych objętości skończonych do rozwiązania wybranych zagadnień nieustalonego przepływu wody* *w kanale otwartym*, w: „Problemy Hydrotechniki. Współczesne podstawy planowania i projektowania w inżynierii i gospodarce wodnej" , Dolnośląskie Wydawnictwo Edukacyjne, Wrocław 2003

Weinerowska K. (2002): *Reverse Flow Routing Problem solved by the Space-Time Conservation Method*, Archives of Hydro-Engineering and Environmental Mechanics

Szymkiewicz R., **Weinerowska K**. (2005): *Analytical-numerical approach to solve the transport equation for steady gradually varied flow in open channel*, Far East J. App. Math., 19(2), 213-228.

These works present various aspects related to flow modeling in open channels, referring both to the so-called 'conventional' problems and inverse problems. In these publications, I tried to put emphasis on the correctness of problem formulation ('well-posed'), the influence of the properties of numerical schemes on the obtained results of calculations and on the discussion of practical applications and potential problems occurring at the stage of their application.

At the same time, a publication that was the result of the work under the previously mentioned grant "*Operational control of a flood wave in flood conditions*" was published. The publication referred to three tasks within the carried out research: "*Development of channel data of Nysa Kłodzka and Odra for the transient flow model*", "*Calibration of the unsteady flow model and development of its usable version*", "*Integration of the flow model with the optimization model*":

Szymkiewicz R., **Weinerowska K**. (2003); *Simplified Unsteady Flow Routing Models for Flood Operating Systems*, w: "Modelling and control of floods", Publications of the Institute of Geophysics PAS, E-3 (365).

The analyzed section of Nysa Kłodzka was a challenge not only due to the presence of a retention reservoir system, but also to the geometric complexity of the riverbed shape, variability of roughness parameters along the channel, as well as significant temporal and spatial variability of lateral inflow intensity. On the one hand, the mathematical model required taking into account the complexity of the described system, on the other - due to the need of its integration into the flow control model of the whole system (rivers with reservoirs) - its relative simplicity was recommended in order to obtain a solution in an acceptably short time, even when multiple calculations are necessary for the needs of searching of optimal control strategies. Finally, an effective model was developed, which was then successfully applied, verified on examples of historical flood episodes in the considered area and integrated with flow control model.

During this period, I was also a co-author of the application for a research grant under the US-Poland Technology Transfer Program, entitled "*Flood control management in the river with the system of reservoirs - application for Nysa Kłodzka Reservoir System in Poland*" (project manager: Prof. Romuald Szymkiewicz, a team of performers as in the previous project). Co-financing was granted to us, and as part of ongoing work in the years 2003-2004 I worked on developing a mathematical model for the analyzed section of Nysa Kłodzka (using the American CCHE1D software) along with its verification, as well as preparing the reports. At that time, two international meetings of project participants took place (in the United States and in Poland). As a representative of our team, I presented the results of our research to the partners from the financing institutions and other project participants. Our project received a very good grade. As a result, the following publication appeared:

Dysarz T., Szymkiewicz R., **Weinerowska K.** (2005): *Application of the CCHE1D Model to the Problem of Flood Control in Nysa Klodzka Reservoir System in Poland*, in: "Computational modeling for the development of sustainable water-resources system in Poland. US-Poland Technology Transfer Program", Publications of the Institute of Geophysics PAS, E-5 (387).

Later, another my publication related to open channel flow problems was published:

Weinerowska-Bords K. (2007): *Determination of selected parameters in a 1D open channel flow model*; TASK Quarterly. Vol. 11, nr.4, s. 341-364

Around 2003, prof. Romuald Szymkiewicz, who was then the Head of the Department of Hydraulics and Hydrology in which I was employed, offered me to change the research field and to start investigations of water hammer in pressurized pipelines. Some of the analyzes mentioned above were carried out in parallel with the newly initiated scientific research.

Research field 2) (flow in pipelines)

Most of my work in this research field was presented in the previous part of the Summary (**Autoreferat**). Apart from the publications included in the achievements being evaluated, I published a few additional papers related to water hammer (briefly mentioned in the previous chapter):

Weinerowska K. (2006): *Przykłady problemów występujących przy modelowaniu uderzenia hydraulicznego*. W: Sawicki J.M., Weinerowska K. (red), Hydraulika tranzytowych systemów w inżynierii sanitarnej. Zeszyt monograficzny nr 2, PAN KILiW i PG, Gdańsk. Wydawnictwo AGNI, Pruszcz Gd., 69-78,

Kodura A., **Weinerowska K.** (2005): Oddziaływanie lokalnej nieszczelności rurociągu na właściwości uderzenia hydraulicznego", II Kongres Inżynierii Środowiska, 4-7 września 2005, materiały tom 1, Monografie Komitetu Inżynierii Środowiska PAN, vol.32, 399-407.

Kodura A., **Weinerowska K**. (2005): Some Aspects of Physical and Numerical Modelling of Water Hammer in Pipelines, W: Nachtnebel H.P., Jugovic C.J. (eds), Water Management and Hydraulic Engineering: Ninth Int. Symp. Proc, Ottenstein, Austria, 4th-7th Sept., Paper No. II.05, 125-134.

Kodura A. , **Weinerowska K**. (2007): The influence of the local pipe leak on water hammer properties. W: Pawłowski L., Dudzińska M., Pawłowski A. (eds): Environmental Engineering, Proc. of the Second National Congress of Environmental Engineering, 4-8 September, Lublin, Poland. Taylor & Francis, London, pp.239-244.

In the first of the publications listed above, I presented problems related to the correct reproduction of the water hammer phenomenon by means of numerical modeling. The material was previously presented during the Scientific Seminar organized by the Faculty of Civil and Environmental Engineering and the Section of Sanitary Engineering KILiW PAN on October 21, 2005, which I co-organized. The reviewers of the presented works were prof. Czesław Grabarczyk and dr hab. Roman Wichowski.

In subsequent works, the results of measurements and numerical simulations of selected water hammer episodes, registered during the laboratory tests at Warsaw University of Technology, were presented. My participation in each of the publications consisted in developing a numerical model of water hammer, together with performing calculations and presenting and discussion of the results of numerical simulations. I also participated in editing the content of the paper (I estimate my participation 50% in each of these publications). I presented the results of the analysis in the form of a paper during an international symposium in Austria (WMHE, 2005), while at the same time the presentation at the 2nd Congress of Environmental Engineering in Lublin was given by Dr. A. Kodura.

As part of the research topic 2), another scientific direction appeared in my analyzes.

Due to the demand reported by companies dealing in the distribution of polymer sanitary installation systems, part of my research was focused on the analysis of the **variability of the coefficients of local energy losses** during pipeline flow. The basic problem in practical hydraulic calculations lies in the fact that available in literature (and disseminated by the content of the old directive PN-76/M-34034 and numerous publications) values of energy loss coefficients had been determined based on tests of materials and fittings available in the first half of the twentieth century, and their systematization was made in the 1960s and 1970s. Therefore, they refer primarily to steel, cast iron, ceramic and concrete pipes, and have no reference to new polymer installation systems, in particular for multi-layer pipe systems and cross-linked polyethylene (PEX). Moreover, widely published and widely used tables of coefficient values present data without considering their dependence on the type of material, Reynolds number values (and hence - flow velocity), details related to the pipe connection (welded, threaded etc.) and other features of the specific case. There is therefore a need to determine the values of energy loss coefficients in experimental way, individually for each type of fittings.

Due to the great interest in this type of analysis, I applied for research funding, but it was not approved. In this situation, thanks to the available funds from the Department, sponsors supporting the project in the field of the installation systems equipment and with a partial own financial contribution, I finally managed to design, organize and implement a new laboratory setup for investigating of the energy losses in pipelines.

I performed laboratory analyses with use of different pipe fittings of several sanitary installation systems. The research resulted in the following publication:

Weinerowska-Bords K. (2014): *Eksperymentalna analiza współczynników oporów lokalnych dla wybranych kształtek i złączek w systemach rur wielowarstwowych*, Instal 6(352), s. 42-49, and also in reports, expertizes and many diploma thesis.

The research confirmed that the values of loss coefficients in the literature are much lower than the actual values obtained during flows. What is more, the values of local energy loss coefficients depend on the flow conditions (Reynolds number, the distribution of streams in the case of tees, etc.) and the structural details of the fittings, so they are not constant. It is worth noting that while in steel pipes in sanitary systems a fully developed turbulent flow was usually observed, in the newer generation pipes, especially those with smaller diameters and lower flow rates (e.g. in floor heating systems) most often the turbulent flow in hydraulically smooth pipe is observed. What is more, similar fittings (e.g. elbows DN 20 90^o) of different installation systems were characterized by significantly different values of loss coefficients, which was the result of seemingly insignificant differences in their construction. This confirmed the desirability of experimental research and the need for individual determination of these coefficients for specific elements of installation systems.

The conclusions from laboratory tests at this stage were also taken account to analyze the possibilities in modeling of transient flows in pipelines.

Research field 3) (problems of determining the amount of rainwater drained from urbanized areas).

The extension of the research subject to another area was a result of the decision of the Head of the Department to appoint me as a representative of our team at the Third National Training Conference "Rainwater – economic, technical and legal aspects", held in Toruń (10-11 April 2008). It was required to prepare a lecture related to the subject of the conference. Thus, I performed an analysis of the basic computational models used to determine the amount of rainwater for the purposes of designing and verification of sewerage and drainage networks. My research was aimed at recognizing to what extent the simplification of computational models translates into the accuracy of reproducing of actual hydrological processes in catchments. On the basis of these analyzes, I presented a lecture "*Consequences of simplifying* *assumptions in the calculations of rainwater drainage system*", and a year later the paper related to the lecture was published:

Weinerowska-Bords K. (2008): *Uproszczenia w obliczeniach kanalizacji deszczowej*, Wodociągi i kanalizacja, 5(51)/2008, 76-77.

The subject turned out to be trendy, and the presentation aroused interest, both representatives of the research centers, as well as employees of design offices and industry community. At the same time, my cooperation with prof. Ziemowit Suligowski (Gdansk University of Technology) began, who not only encouraged me to continue the research on this important topic, but also contacted me with specialists and publishers who were interested in my analyzes. As a result, I performed a further stage of research, aimed at a more thorough analysis of various aspects related to the reproduction of hydrological processes in the calculations of the outflow from the urbanized catchments. One of the questions of this study was recognition the impact of different factors on the accuracy of the calculated outflows: the degree of simplifications in the description of catchment characteristics, the accuracy of the applied precipitation characteristics, correctness and accuracy of determining the time of concentration of basin outflow, the type of the applied computational model and specific features of the computational method.

As a result of these analyzes, I took part in several seminars and conferences, where I presented my lectures:

Weinerowska-Bords K. (2009): Wykład p.t.: „*Problem umowności ustaleń przy planowaniu systemów odprowadzania wody opadowej*”, IV Ogólnopolska Konferencja Szkoleniowa „Wody opadowe – aspekty prawne, ekonomiczne i techniczne”, 6-7 kwietnia 2009 r., Włocławek

Weinerowska-Bords K. (2010): Wykład p.t.: „*Oceny ilościowe wód opadowych*”, V Ogólnopolska Konferencja Szkoleniowa „Wody opadowe – aspekty prawne, ekonomiczne i techniczne”, Gdynia 14-16.04.2010

Weinerowska-Bords K. (2011): “*Selected aspects of simplified runoff calculation in urban catchment*”, XII International Conference on Water Management and Hydraulic Engineering WMHE, 5-8 września 2011, Gdańsk.

and I published papers in scientific journals and industry magazines:

Weinerowska-Bords K. (2009): *Umowność ustaleń a wody opadowe*, Wodociągi i kanalizacja, 4(62)/2009, 38-39.

Weinerowska-Bords K. (2009): *Oceny ilościowe wód opadowych*, Wodociągi i kanalizacja, 4(74)/2010, 40-41.

Weinerowska-Bords K. (2010): *Względność ustaleń ilościowych w obliczeniach systemów odprowadzania wody opadowej*, Przegląd Komunalny: Gospodarka i Ochrona Środowiska. Zeszyty Komunalne [dodatek], 4(223)/2010, 68-73.
Publikacja samodzielna, udział 100%

Weinerowska-Bords K. (2011): *Wybrane aspekty związane z zastosowaniem równania Manninga dla potrzeb szacowania ilości ścieków sanitarnych*, Gaz Woda i Technika Sanitarna 3/2011, 98-102.

Weinerowska-Bords K. (2011): *Relativity of simplified runoff calculations for rainwater drainage systems*, In: Sawicki J.M., Weinerowska-Bords K. (eds) „Technical progress in sanitary engineering", Wydawnictwo Politechniki Gdańskiej, Gdańsk,214-224.
Publikacja samodzielna, udział 100%

Weinerowska-Bords K. (2010): *Time of concentration in simplified calculations in urban catchments*, Monografie Komitetu Inżynierii Środowiska PAN. vol 68, Warszawa, 367-377, punktacja wg MNiSW= 15 pkt. (indeksowany w bazie WoS)

Olechnowicz B., **Weinerowska-Bords K**. (2014): *Impact of Urbanization on Stormwater Runoff from a Small Urban Catchment: Gdańsk Małomiejska Basin Case Study*, Archives of Hydro-Engineering and Environmental Mechanics, Vol.61, No.3-4, 141-162, DOI: 10.1515/heem-2015-0004.

The most important publication in this field was the monography:

Weinerowska-Bords K. (2010): *Wpływ uproszczeń na obliczanie spływu deszczowego w zlewni zurbanizowanej*, Wydawnictwo Politechniki Gdańskiej, Gdańsk,

in which I presented a comprehensive synthesis of problems occurring during calculations of basin outflow (starting from formal and legal issues, through mathematical problem formulation, the question of quantity and quality of available data and the choice of calculation method) and the analysis of factors determining the accuracy of calculations when global (simplified) methods are applied. In the monography I presented a number of detailed analyzes, including a comparison of various precipitation formulas, a comparison of methods for time of runoff concentration and an analysis of basic computational models for basin outflow used in Poland (constant rainfall intensity method and limited rainfall intensity method) in the context of their compliance with hydrological processes in the catchment. **To my knowledge, this was the first study of this kind**. The book soon became a textbook in teaching thematically related subjects, and it is also used as a guide by many practitioners in project offices and institutions.

During this period also, after receiving from dr Elżbieta Wołoszyn her unfinished analysis of precipitation variability in Gdansk, I decided to complete the missing data and to carry out their full analysis. Based on this **I developed preliminary IDF-formulas** (*intensity-duration-frequency formulas*) **for the area of Gdansk-Wrzeszcz** (based on the results of rainfall measurements at the Gdansk University of Technology gauge station). **To my knowledge, this was the first such study for the area of Gdansk**. As a result, these works were created:

Weinerowska-Bords K. (2012): Lokalne formuły opadowe dla Gdańska-Wrzeszcza na podstawie dwudziestoletnich obserwacji opadów na Politechnice Gdańskiej, Inżynieria Morska i Geotechnika, Rok 33, Nr 6, 662-672

Weinerowska-Bords K. (2015): *Development of Local IDF-formula using Controlled Random Search method for Global Optimization*, Acta Geophysica, DOI:10.2478/s11600-014-0242-5, vol.63., No.1/2015, 232-274, (indeksowany w baize WoS),

the second of which **I consider to be another very important achievement of my research**. This is a comprehensive paper in which, apart from the analysis of rainfall data, there are considerations on theoretical foundations for the development of precipitation characteristics, including issues of data integrity and completeness, available computational methods and the influence of the method on the obtained results.

The paper also describes the *Controlled Random Search* method used in the analyzes, which was applied to determine the values of the parameters in IDF-functions. This method was compared with the effects of other optimization methods, including evolutionary algorithm.

During the analyzes, I took into account the experiences and conclusions from the earlier stages of my scientific work, including the previous studies on identification (optimization) of the parameters in open channel flow models.

As a continuation of this research I performed analyses of temporal and spatial variability of precipitation in other districts of Gdansk. During this period, I started cooperation with Gdanskie Melioracje (now: Gdanskie Wody), thanks to which I could use the precipitation data from several stations located in the catchment of Strzyża stream in Gdansk. As a result, subsequent relations describing the variability of rainfall intensity were developed, which resulted in the publication:

> Bielecka K., **Weinerowska-Bords K**., Szydłowski M. (2013): *Analiza czasowej i przestrzennej zmienności opadów w zlewni potoku Strzyża w Gdańsku*, Inżynieria Morska i Geotechnika, nr. 6 (2013), s.490-501,

the presentation at scientific-technical seminar:

> **Weinerowska-Bords K.** (2013): „*Analiza czasowej i przestrzennej zmienności opadów w zlewni potoku Strzyża w Gdańsku*", Seminarium naukowo-techniczne "Lokalne zagrożenia powodziowe w małych zlewniach miejskich gmin pomorskich", 24 maja 2013, Gdańsk,

and my participation in the research and development project: "*Control of stormwater and snowmelt retention and flood risk forecasting in the coastal urban basin*", financed by WFOŚiGW in Gdańsk (2015-2017). The project manager was prof. Michał Szydłowski, and the contractors were: Piotr Zima, Katarzyna Weinerowska-Bords, Patrycja Mikos-Studnicka, Jakub Hakiel and Andrzej Świerszcz. My participation in the project was connected to the task: "*Temporal and spatial distribution of precipitation in Gdansk*" (my share in the project: 10%). As a result of my work on developing the updated rainfall characteristics, an internal study was created:

> **Weinerowska-Bords K.** (2017): *Analiza opadów zarejestrowanych w wybranych stacjach pomiarowych na obszarze zlewni potoku Strzyża w Gdańsku* (opracowanie wewnętrzne Katedry Hydrotechniki WILiŚ PG),

which was used in further stages of the project work and during the preparation of the final report.

A measurable effect of the team's work was the publication of:

Szydłowski M., Mikos-Studnicka P., Zima P., **Weinerowska-Bords K**., Hakiel J., Szawurska D. (2015): *Storwater and snowmelt runoff storage control and flash flood hazard forecasting in the urbanized coastal basin*, 14th International Symposium Water Management and Hydraulic Engineering 2015/ ed. J.Riha, T.Julinek, K.Adam, Institute of Water Structures, FCE, Brno University of Technology, 2015, s.141-150 (indeksowana na WoS).

In the scope of my research work in the area of hydrological issues, there were also **analyzes of rainwater retention on green roofs**. To this end, I developed and implemented a new research and didactic setup for the purpose of investigating the changeability of rainwater retention on the green roof model. I also prepared a conceptual project and I supervised the implementation of a second research and didactic setup, designed for investigations of the impact of plant substrate retention and extensive plant species on intensity of rainwater retention. The results of these studies have not been published yet (intermediate stages have been partially implemented and described in the framework of three MA theses).

As part of the hydrological research field, I also made several expertizes and studies related usually to basin runoff calculations (urban and non-urbanized).

A list of all studies, including those not mentioned in the detailed description, can be found in **Appendix 3 p. II.D. and III.M.**

6. Summary of the scientific achievements

My scientific achievements are thematically located in three different fields, described in the previous parts of the film. Most of the publications are individual works or performed in small teams (usually two or three people). Many of the topics have a large impact on practical aspects and are often a response to the needs of the industry. This situation, on the one hand, made it difficult to obtain higher parameterization parameters, but on the other hand it significantly influenced the diversity of works and my scientific and professional experience, which could be transposed into didactic and popularizing activities described in the following part of **Autoreferat**. The following is a detailed summary of the scientific activity.

Before obtaining PhD degree

In the years 1997-2001 I wrote one thesis after the first year of the Doctoral Studies and I published four papers, all in peer-reviewed materials. I participated in five conferences, delivering four papers (Annex 3, point II.C). For one of them I received the award for young researchers (1999) (Annex 3, point II.I). I participated in one research project as a contractor (Annex 3, point II.H). I completed one foreign internship (Annex 3, point III.L).

After obtaining PhD degree

In the years 2001-2019, I published a total of 33 scientific papers, including 6 in materials indexed on the Web of Science (of which four have Impact Factor), one monograph (in national language), 5 chapters in monographs (of which 4 international), 11 papers in peer-reviewed journals (with not IF), 6 peer-reviewed conference materials, and 4 papers in industry magazines and non-reviewed conference materials (Annex 3, points IB, II.A and C).

I attended 16 conferences and seminars, I presented papers at ten of them (Annex 3, point II.J and III.B). I have written 2 reviews of manuscripts for journals indexed in the JCR (Annex 3, point III.P).

I was a contractor in three research projects, including one international (Annex 3, point III.A). I participated in the implementation of 16 expert opinions and design/conceptual works (Annex 3, points II.C and III.M).

I received two awards for my scientific activity (Annex 3, point II.I).

The total impact factor of my publications (according to the JCR list with respect to the year of publication) is 6,058. Hirsch index according to WoS is 2, according to Scopus database 3, and according to Google Scholar 6. Total number of citations according to WoS 18 (+ 3 *), according to Scopus database 34, according to Google Scholar 111. Total number of MNiSW points of all scientific publications (in accordance with the year of publication) is 191, while according to 2018, it is 237 points.

*) *At the end of the work on this summary, one of the publications (Annex 3, item I.B. item 7) has not yet been indexed to WoS, therefore some of the citations are not visible. Another publication (Annex 3, item II.A. item 3) is indexed to WoS, but it is not assigned to authors' profiles. The citation has not been indexed. Both problems were reported to WoS administrators, they are undergoing correction.*

7. Didactic activity

I have been involved in the broadly understood didactic activity since the beginning of my professional career at the Gdańsk University of Technology (1998).

I have been **teaching** since 1998, initially as a participant of the PhD Study "*Geotechnics and Environmental Engineering*" at the Faculty of Environmental Engineering (now: the Faculty of Civil and Environmental Engineering), and from 2001 up till now - as an employee of Gdansk University of Technology (initially assistant professor, currently senior lecturer). In the first years of my work I led tutorials, project and laboratory classes in *Hydraulics and Hydrology* at the Faculty of Civil and Environmental Engineering. In the following years, the list of my subjects was extended by *Fluid mechanics and hydraulics*, *Hydrology of urban basins* and *Urban hydrology* (in English), and episodically also *Water management*, *Technical aspects of water management facilities* and *Land drainage*.

Since the beginning of doctoral studies until now, I have been holding all forms of classes (lectures, tutorials, project, seminar, laboratories, and apprenticeships) as part of full-time and part-time studies (originally uniform, and after the change of teaching programs - first and second degree), in Polish and English, at your home department (in *Inżynieria Środowiska*, *Budownictwo* and *Environmental Engineering* specializations). In addition, since 2009 I have been holding classes for students of the Faculty of Chemistry of Gdansk University of Technology (in the years 2009-2016 in the subject *Hydrology and water management* for the field of Environmental Protection Technologies, and from 2017 - the hydrological part of the subject *Geology and hydrology* for the field of Green Technologies and Monitoring). Since 2005, every year I participate in SOCRATES / ERASMUS programs, under which I teach foreign students (in English).

Due to the several changes of **study programs**, including the change of the education system (transition to two-level studies), in the mentioned period I developed and implemented the new study programs in *Hydrology of the urban catchment* and *Urban hydrology* (for which I am the person responsible for the subject and I hold all classes) and in the hydrological part of the subject *Geology and hydrology*.

In addition, I co-created new study programs in the subject of *Hydraulics and Hydrology* (tutorials, laboratory and project classes), modified several times over the past period. In addition, for the needs of opening in the academic year 2015/2016 **Postgraduate Study "*Modern methods of engineering hydrology in water management*"** at WILiŚ PG I developed the study program of two subjects: *Fundamentals of mathematical modeling in hydrology* and *Modeling of urban basin runoff*, which I implemented in 2015 / 2016 and 2016/2017.

I also gave **guest lectures in English** *Flood control system in the river with systems of reservoirs* for students of the Faculty of Civil and Geodetic Engineering at the University of Ljubljana (in May 2005).

In the student questionnaires assessing the didactic work of the teacher, I obtained an average score of 4.85 (on a scale from 2.0 to 5.0).

The detailed scope of my classes is presented in **Annex 3, point III. I.d) and e).**

For the needs of didactic classes I have developed myself or co-created a number of various **didactic materials**. In 2004, I was an editor and co-author of collective work (textbook): „*Laboratorium z mechaniki płynów i hydrauliki*", published in digital form by Gdansk University of Technology Publishing House (my share in this publication about 60%). In 2008, I published a book: „*Od Pitota do Reynoldsa. Dziewięć historii o tych, którzy tworzyli hydraulikę*" (Gdansk University of Technology Publishing House), which in 2013 was released in the next edition. In 2010, my next book appeared: „*Wpływ uproszczeń na obliczanie spływu deszczowego w zlewni zurbanizowanej*", which became the basic textbook for the subject *Hydrologia zlewni zurbanizowanej* and was used as an auxiliary textbook for other subjects. In 2017 and 2018, two editions of the next book: „*Hydraulika do poćwiczenia. Przepływy w przewodach ciśnieniowych*", were published. The book is a didactic material for tutorials in *Hydraulics*. In addition to the mentioned books, I also developed auxiliary teaching materials in the form of descriptions or instructions.

In 2013, for the needs of the City Office in Gdynia, I prepared **training materials** entitled "*Calculation of the amount of rainwater and sanitary sewage in urban areas*", which have been made available to the employees of the Office.

Since 2001, I have been the **supervisor of 63 completed diploma theses, including 35 BA and 28 MA theses.** Many of the aforementioned works were carried out in cooperation with the local industry community and companies involved in environmental engineering.

Three of these master's theses were carried out in English as part of the international exchange of students of the ERASMUS program (two students from Gdansk University of Technology - Agnieszka Lorbiecka (2005), Wigna Kwapisz (2016) and one student from the University of Ljubljana - Marko Zibret (2005)). During this period, I was also entrusted with writing 23 reviews of theses, including 8 BA theses and 15 master theses.

Seven of my graduates have received ***awards and prizes***:

- *scholarships of Wojewódzki Fundusz Ochrony Środowiska i Gospodarki Wodnej in Gdansk, as part of competitions for MA studies (three people):*

  Katarzyna Rzeszutek: „Analiza czasowej zmienności opadów w Gdańsku na podstawie 20-letnich obserwacji opadów w ogródku meteorologicznym Politechniki Gdańskiej" (2010)

  Borys Olechnowicz: „Analiza możliwości alternatywnego zagospodarowania wód opadowych dla wybranego obszaru osiedla Gdańsk Orunia Górna" (2011)

  Danuta Hering: „Analiza odpływu wód deszczowych ze zlewni zurbanizowanej na terenie Gdyni na przykładzie Potoku Chylońskiego i rzeki Chylonki" (2011),

- *awards for the best master thesis at Faculty of Civil and Environmental Engineering*:

  Agnieszka Lorbiecka (Thesis: Zastosowanie metody chwilowego hydrogramu jednostkowego do określania odpływu ze zlewni niekontrolowanej") 2005

  Natalia Gietka (Thesis:"Doświadczalna i teoretyczna analiza współczynników oporów lokalnych na kolankach w systemach przewodów wielowarstwowych") 2013

- *award in the competition organized by PZITS for the best master thesis:*

  Wioleta Szultka and Aleksandra Zelma for the thesis: „Eksperymentalna analiza wartości współczynników oporów lokalnych przy przepływie przez trójnik dla wybranych systemów rur wielowarstwowych". Money prize and participation in the workshops for the laureates and an invitation to the workshops for the promoter (September 2016)

- *distinction in the competition of Pomorska Okręgowa Izba Inżynierów Budownictwa 2014-2018 for the best master thesis*:

  Wioleta Szultka and Aleksandra Zelma, thesis: „Eksperymentalna analiza wartości współczynników oporów lokalnych przy przepływie przez trójnik dla wybranych systemów rur wielowarstwowych".

Currently, there are 9 master's theses and one BA thesis in progress under my supervision.

Since 2013 I have been the **assistant supervisor of one PhD dissertation** (PhD student: Natalia Gietka, *The impact of pipe material heterogeneity on the propagation of pressure wave during transient flow*), opening date: 26/10/2016, supervisor: prof. Romuald Szymkiewicz).

Since 2001, I have been responsible for the **Individual Studies of students**: Wacław Grzywacz (year 2008 in Environmental Engineering), Magdalena Prabucka (year 2009 in Environmental Engineering) and Aneta Senk (year 2009, Environmental Engineering). I was also the guardian of students of Environmental Engineering 2009.

In the years 2014-2015 I participated in the works on the foundation, and then I was the **first co-patron of the "Konfuzor" Scientific Club** at the Department of Hydraulic Engineering, Faculty of Civil and Environmental Engineering. I developed the framework of the scientific activity of the Scientific Club, I was also the initiator and co-author of the series of open lectures for students delivered by employees of the Department of Hydraulic Engineering of the Faculty of Civil and Environmental Engineering of the Gdansk University of Technology, connected thematically with hydraulics, hydrology and water management, but going beyond the scope included in the study program.

In addition, I was the originator of a series of presentations prepared by students for students, as well as a co-organizer of workshops devoted to communication skills and teamwork (co-organized and run by students of the Faculty of Social Sciences of the University of Gdansk).

In the following years, I cooperated with the Scientific Club, leading individual academic care for several students, which resulted in the presentation of papers and posters at conferences and seminars and the publication of papers in journals, industry magazines or conference materials. They were:

- inż. Wioleta Szultka, inż. Aleksandra Zelma: „Eksperymentalna analiza wartości współczynników oporów lokalnych przy przepływie przez trójnik dla wybranych systemów rur wielowarstwowych", wystąpienie: V Międzynarodowa Studencka Konferencja Naukowa „Inżynieria Środowiska Młodym Okiem" , Białystok 2016; (publikacja: Inżynieria Środowiska – Młodym Okiem, tom 20, 2016)
- Artur Groth: „Analiza zmienności opadów na obszarze zlewni Strzyży w Gdańsku" , wystąpienie: V Międzynarodowa Studencka Konferencja Naukowa „Inżynieria Środowiska Młodym Okiem" , Białystok 2016; (publikacja: Inżynieria Środowiska – Młodym Okiem, tom 20, 2016);
- inż. Weronika Łykowska, inż. Przemysław Kłos: „Eksperymentalna analiza wartości współczynników oporów lokalnych na nagłym zwężeniu przewodu i złączce prostej dla wybranych systemów rur wielowarstwowych", - poster na I Interdyscyplinarnej Akademickiej Konferencji Ochrony Środowiska 2016
- inż. Weronika Łykowska, inż. Adrianna Necel: „Doświadczalne wyznaczanie retencyjności na modelach zielonych dachów" - poster na II Interdyscyplinarnej Akademickiej Konferencji Ochrony Środowiska, Gdańsk 2017.
- Marek Pobłocki: „Eksperymentalna analiza współczynników oporów lokalnych przy przepływie przez wybrane trójniki systemu rur wielowarstwowych", wystąpienie: VI Międzynarodowa Studencka

Konferencja Naukowa „Inżynieria Środowiska Młodym Okiem", Białystok, maj 2017 (publikacja: Rynek Instalacyjny Nr10/2017)

One of the mentioned persons, Artur Groth, received the award for the best paper at the 5th International Student Conference: Environmental Engineering *Młodym Okiem*.

As part of my didactic activity, for a long time I have been trying to introduce activating methods of teaching, including work with a project method, *case study*, and individual work with the *tutee* using methods of *tutoring*. I am gradually **improving my professional qualifications**.

In 2010, I graduated from the Pedagogy Course organized by Gdansk University of Technology. In 2015, I graduated from the Collegium Wratislaviense course "*Tutors* I grade" (under which I took classes in the field of personalized education, scientific and development tutoring and the use of selected coaching tools in working with students). In 2016 I graduated the next degree of the course - "*Tutoring Practice*", obtaining both certificates.

In 2016, I also participated in the *3rd National Congress of Tutoring in Warsaw* and I participated in the workshops. In addition, in 2018 I took part in the training workshop "*Effective communication and cooperation with students for the teaching staff of the Gdansk University of Technology*", implemented as part of Module III of the "Integrated Program of Development of Gdansk University of Technology" POWER 3.5 (currently I am still involved in this project; I am updating and modifying selected didactic materials).

Acquired didactic competences allow for continuous improvement of classes. They also resulted in the initiation and implementation (in 2015) of a two-semester **Pilot Tutoring Program in the field of Environmental Engineering** at our Faculty.

I am also the **author of four didactic papers** and **a chapter in a peer-reviewed scientific monograph devoted to tutoring** ("Tutoring as a meeting: Stories of individual cases", ed. By: Karpińska-Musiał, Magdalena Panońko, Wolters Kluwer, Warsaw 2018).

I have received four Rector's Awards from Gdansk University of Technology for my didactic activity (including three individual II-level prizes and one third-class collective award), two awards of a Dean of the Faculty of Civil and Environmental Engineering for outstanding teaching and two awards and one honorable mention of the students of our Faculty for the best lecturer. In 2013, I received the Medal of the National Education Commission.

8. Organizational activity

In the years 2000-2017 I took part in **three research projects**, including one international in the framework of the US-Poland Technology Transfer Program, cooperating with the National Center for Computational Hydroscience and Engineering, University of Mississippi. As part of my work, I actively participated in research and took part in meetings of project participants in Poland and the United States (Oxford, Mississippi, 2004).

As part of international cooperation, I am also a long-term **participant in the SOCRATES / ERASMUS programs.** In addition to didactic activities related to this program, I also took part in working meetings devoted to cooperation between the Department of Civil and Geodetic Engineering at the University of Ljubljana and the Department of Hydraulic Engineering of the Faculty of Civil and Environmental Engineering, Gdansk University of Technology, at which I presented the Faculty and agreed on the details of student exchange and care of diplomas, and I holt guest lectures. Currently, I participate in the "**Integrated Development Program of the Gdansk University of Technology**" financed by the European Social Fund under the Operational Program Knowledge Education Development.

In total, I participated or was included as a contractor in six submitted grant applications, including three times as project manager.

I was a **co-organizer of three scientific seminars and one scientific and technical conference** (Annex 3, point III.C). I was also **a member of the editorial committees** of “Zeszyty Monograficzne” of Gdansk University of Technology and the monograph "Technical progress in sanitary engineering", as well as an independent editor of one collective work (textbook) (Annex 3, point III.I).

I actively contributed to the development of my Faculty's didactic and research base. In 2010-2017 I developed, co-organized and implemented five research and teaching setups in laboratory (Annex 3, point III.Ie2). I have repeatedly undertaken cooperation with representatives of companies from the environmental engineering sector in order to co-organize teaching aids, equip research facilities, enable scientific and professional contacts between students and representatives of companies, organize guest lectures, presentations of a selected topic.

I have actively promoted topics related to the safe drainage of rainwater from urbanized areas, by giving lectures to representatives of scientific, design and executive environments (as part of conferences and seminars), holding training meetings and preparation of training materials (e.g. for employees of city offices) and popularization scientific literature. For this purpose, among others, over 120 copies of the prepared monograph (Weinerowska-Bords, 2010) have been distributed to project offices and private individuals. To my knowledge, in many cases this book has become an important textbook supporting the work of designers and officials. In addition, I am also the author of the chapter in *Poradnik kierownika budowy i inspektora nadzoru* (Wyd. Dashoffer Verlag).

On the other hand, I was concerned about **engaging students** in getting to know and propagating the subject of **green roofs**. I co-organized the scientific events with them as part of the Baltic Festival of Festivals and the Pomeranian Science Festival, I involved them in research. Many of my mentees have found work in important institutions and leading companies in the field of sanitary engineering.

I also took part in other popularizing activities, including " *Dziewczyny na Politechniki* " action, or was I involved in the preparation of the presentation of our department in the industry environment.

I was also involved in other **organizational work for my Faculty or my Department**, e.g. twice I was a member of the Qualification Committee during the recruitment for studies, for many years I have been responsible for settlement of didactic hours at the Department. I am currently a department coordinator of ‘*karty przedmiotów*” and ECTS credits. I participated in the preparation of modifications to the learning outcomes of the subjects conducted by our Department. I was also involved in updating the topics of the diploma theses proposed in the department, and I took part in the preparation of exam questions for the engineering and master degree exams. I participated in the diploma examination commissions many times. In the year 2017/2018, at the request of the Head of the Department, I observed the classes conducted by PhD students at our Department.

For 4 years, I was a member of the Faculty Council.

Since 2011 I am a member of the Polish Hydrologists Association. Until March 2018, I was also a member of the Polish Association "Green Roofs".

For all my work, I was awarded the Bronze Medal for the Long Service (2011)

9. Summary of the achievements

Pos.	Type of the achievement	Number	
		Before obtaining PHD degree	After obtaining PHD degree
1	**Scientific publications, including:**	**4**	**33**
	- indexed in WoS (in journals with Impact Factor)		6 (4)
	- monographs in national language		1
	- chapters in monographs in language of international range		4
	- chapters in monographs in national language		1
	- reviewed papers in journals		11
	- reviewed publications in proceedings of conferences	4	6
	- journals and proceedings not reviewed		4
2	**Didactic and popularizing publications, including**		**9**
	- books and monographs in national language		3
	- chapters in monographs in national language		1
	- didactic and popularizing papers		5
3	**Research projects, including:**		**3**
	- international		1
	- national		2
4	**Author and co-author of presentations at conferences and seminars, including:**	**4**	**10**
	- international		2
	- national	4	8
5	**Creative professional works, including:**		**21**
	- new research setups		5
	- opinions and expertizes		4
	- project and conceptual works		12
6	**Prizes and awards, including:**		**13**
	- for scientific activity	1	2
	- for didactic activity		10
	- for the entirety of work		1
7	**Assistant promoter in the doctoral dissertation**		**1**
8	**Promoter of diploma thesis, including:**		**63**
	- BA thesis		35
	- MA thesis		28
9	**Reviewer of diploma thesis, including:**		**23**
	- BA thesis		8
	- MA thesis		15
10	**Citations**		**111**
11	**Hirsch Index**		**2**
12	**Impact Factor**		**6,058**
13	**Total number of MNiSW points (acc. to 2018), including:**		**238(297)**
	- scientific publications		191 (237)
	- didactic and popularizing publications		47(60)