Attachment 3b

SUMMARY
OF PROFESSIONAL ACCOMPLISHMENTS

Dr. Mariola KĘDRA

Cracow, March 2019

1. Full name

Mariola Urszula Kędra

2. Academic diplomas and degrees

1987 **M. Sc. in Computer Science, specialty: software and IT methods**

Cracow, Jagiellonian University, Faculty of Mathematics and Physics

2003 **Certificate confirming pedagogical preparation**

Cracow University of Technology, Pedagogy and Psychology Centre, completed Pedagogical Studies for Graduates of Universities

2008 **Ph. D. in Environmental Engineering**

Cracow University of Technology, Faculty of Environmental Engineering
Ph. D. dissertation: „*Deterministic chaos in river flows of the selected mountain catchment*" (in Polish).
Supervisor: dr. hab. eng. Andrzej Prystaj
Reviewers: prof. dr. hab. Zbigniew Kundzewicz,
prof. dr. hab. eng. Elżbieta Nachlik.

3. Information on employment in scientific institutions

Employment

Cracow University of Technology
Faculty of Environmental Engineering
Department of Engineering and Water Management
24 Warszawska street
31-155 Cracow

The course of employment

1987–1992	Computer specialist at Division of Hydraulics and Hydromechanics, Institute of Engineering and Water Management, Cracow University of Technology
1992–2018	Research and teaching assistant at Department of Engineering and Water Management, Faculty of Environmental Engineering, Cracow University of Technology
2018–present	Research and teaching assistant professor at Department of Engineering and Water Management, Faculty of Environmental Engineering, Cracow University of Technology
1990, 1992	Maternity leaves
1994–2001	Maternity leaves and parental leaves

4. Scientific accomplishment according to article 16 section 2 of the Act of 14th March 2003 on Academic Degrees, Academic Title and Degrees and Title in Arts (Dz. U. nr 65, p. 595, as amended)

A) Title of scientific accomplishment:

River flow in the mountain catchment: selected aspects and conditions

B) Publications included in the scientific accomplishment (Author/Authors, year of publication, title, publisher – in order of publication)

[B1] **Kędra M.** (2014) Deterministic chaotic dynamics of Raba River flow (Polish Carpathian Mountains). Journal of Hydrology, 509: 474–503 (Att. 3.1)

IF (2014): 3.053; MNiSW* (2014): 45 pt; contribution: 100%; citations (WoS): 7
**MNiSW stands for Polish Ministry of Science and Higher Education*

[B2] **Kędra M.** (2016) Analysis of hydrological processes with non-linear methods. Proceedings of the Institution of Civil Engineers – Water Management, 169(5): 212–220 (Att. 3.2)

IF (2016): 0.547; MNiSW (2016): 25 pt; contribution: 100%; citations (WoS): 1

[B3] **Kędra M.**, Wiejaczka Ł., Wesoły K. (2016) The role of reservoirs in shaping the dominant cyclicity and energy of mountain river flows. River Research and Applications, 32(4): 561–571 (Att. 3.3)

IF (2016): 2.274; MNiSW (2016): 30 pt; contribution: 60%; citations (WoS): 5

[B4] **Kędra M.**, Wiejaczka Ł. (2016) Disturbance of water-air temperature synchronisation by dam reservoirs. Water and Environment Journal, 30(1–2): 31–39 (Att. 3.4)

IF (2016): 1.063; MNiSW (2016): 20 pt; contribution: 70%; citations (WoS): 6

[B5] **Kędra M.** (2016) Reservoir-induced changes in dynamics and synchrony of river water temperature revealed by RQA and CRQA. In: Recurrence Plots and Their Quantifications: Expanding Horizons, Proceedings of the 6th International Symposium on Recurrence Plots, Springer Proceedings in Physics vol. 180, 289–300, Springer, Switzerland (Att. 3.5)

Indexed in WoS, MNiSW (2016): 15 pt; contribution: 100%; citations (WoS): 3

[B6] **Kędra M.** (2017) Altered precipitation and flow patterns in the Dunajec River Basin. Water, 9(1): 22, DOI: 10.3390/w9010022 (Att. 3.6)

IF (2017): 2.069; MNiSW (2017): 30 pt; contribution: 100%; citations (WoS): 3

[B7] **Kędra M.** (2017) Altered precipitation characteristics in two Polish Carpathian basins, with implications for water resources. Climate Research, 72(3): 251–265 (Att. 3.7)

IF (2017): 1.859; MNiSW (2017): 35 pt; contribution: 100%; citations (WoS): 4

[B8] **Kędra M.**, Wiejaczka Ł. (2018) Climatic and dam-induced impacts on river water temperature: Assessment and management implications. Science of the Total Environment, 626(3): 1474–1483 (Att. 3.8)

IF (2017*): 4.610; MNiSW (2018): 40 pt; contribution: 90-95%; citations (WoS): 7
* *current IF applies to 2017; (IF for 2018 not yet published)*

Average contribution in publications included in the scientific accomplishment: **90.3%**

Total IF of publications included in the scientific accomplishment according to JCR: **15.477**, with the own percentage contribution: **13.901**

Sum of MNiSW points for publications included in the scientific accomplishment: **240**

Number of citations of publications included in the scientific accomplishment according to WoS (as on 18.03.2019): **36**

Hirsch index according to WoS: **4**, Scopus: **5**

Statements of co-authors of the aforementioned publications, together with the determination of their individual contribution are provided in Attachment 6.

C) Presentation of the scientific objectives of the above publications and the obtained results with discussion of potential applications

Physical processes and phenomena occurring in the area of mountain catchments are characterised by high time-space variability and a significant degree of complexity. The dynamics of these processes reflect direct and indirect interactions and feedbacks between climate and mountain topography, geological and soil conditions, and existing vegetation. One of such processes is water runoff in the riverbed, which constitutes an integrated response of the mountain catchment to the input created by precipitation, solar radiation, wind direction and speed, air temperature and humidity, and other atmospheric factors.

Publications included in the scientific accomplishment entitled "*River flow in the mountain catchment: selected aspects and conditions*" focus on the analysis and description of selected dynamic aspects of the process of water runoff in the riverbed in mountain catchments—taking into account anthropogenic conditions (the impact of dam reservoirs) and climate change (global/regional warming). **The research goal** was to analyse the dynamic features of the runoff process, including the following aspects:

- the characteristics of the daily dynamics of river flow [B2] with dynamic and static measures [B1];
- the dominant cyclicity of the daily flow dynamics and the impact of dam reservoirs on the dominant cyclicity and energy of flow [B3];
- variability and repeatability of monthly flow as well as change of long-term flow pattern in relation to changes in climatic conditions [B6], [B7]; and
- daily dynamics of river water temperatures in interaction with air temperature—cyclicity and synchronisation of temperatures and changes caused by dam reservoirs [B4], [B5], and climatic trends [B8].

The analysed aspects are important for broadening the methodological and analytical base used in the verification of simulation and forecasting methods in the field of water resources dynamics, which in turn should facilitate adaptive management of water resources under progressing urbanisation and forecasted climate change. The aspects considered concern the following issues:

- daily dynamics of river flow,
- the impact of dam reservoirs on dynamic features of river flow,
- variability of the river flow dynamics under climate change.

For research, I used modern and complementary methods of analysis, including non-linear methods, spectral analysis and recurrence plots, and statistical tests (parametric and non-parametric). They enabled obtaining new, scientifically and cognitively valuable information about the studied aspects and conditions of the river flow process in mountain catchments, with the possibility of using this information in the simulation modelling and process prediction, and in water resources management.

The study area was located in the southern part of Poland, in the Carpathian catchments of the upper Vistula Basin; in particular, it covers the basins of the rivers Skawa, Raba, Dunajec and Wisłok. The data used in analyses were made available by the Polish Institute of Meteorology and Water Management–National Research Institute (IMGW–PIB), Regional Water Management Board in Krakow, Research Station in Szymbark belonging to Institute of Geography and Spatial Organisation of the Polish Academy of Sciences, and Water Power Group Niedzica SA.

Daily dynamics of river flow

The B1 and B2 articles are the result of the second stage of research on the dynamics of the runoff process in the riverbed, carried out by me in the years 2009–2013 (after receiving Ph.D.). In the first stage of the work, I undertook the problem of examining the existence and size of deterministic chaos in the dynamic natural system, which is the catchment with its river network. This stage of work, ending with the doctoral dissertation[1], covered the daily series of measured values of the flow rate in the Raba River and its major tributaries from the hydrological years 1961–2002 and allowed positive verification of the thesis that: „the natural process of water runoff in the riverbed, deterministic in its essence, is sensitive to a small change in the initial conditions and thus carries the features of deterministic chaos". After receiving Ph.D, aware of the desirability of further, detailed research in this topic, for the two selected cross-sections (at Mszana Dolna and Proszówki on the Raba River), I expanded the range of daily flow dynamics analyses by additional tests (determinism test[2], non-linearity test[3], stationarity test[4]) and methods (FNN[5], space-time separation plot[6], Eckmann method[7]), which fully confirmed the validity of the conclusions from the first stage of the work up to the Ph.D. and allowed obtaining new, comprehensive information on the quantitative characteristics of chaos—the spectrum of Lyapunov exponents[8] for the studied river flow process. On the basis of the spectrum of the Lyapunov

[1] **Kędra M.** (2007) Deterministic chaos in river flows of the selected mountain basin. PhD Dissertation, Kraków 2007, pp. 127, http://suw.biblos.pk.edu.pl/resourceDetailsRPK&rId=3414

[2] Kaplan D.T., Glass M. (1992) Direct test for determinism in a time series. Physical Review Letters, 68: 427–430.

[3] Nakamura T., Luo X., Small M. (2005) Testing for nonlinearity in time series without the Fourier transform. Physical Review E, 72: 055201.

[4] Schreiber T. (1997) Detecting and analysing nonstationarity in a time series using nonlinear cross predictions. Physical Review Letters, 78: 843–846.

[5] Kennel M., Brown R., Abarbanel H.D.L. (1992) Determining embedding dimension for phase-space reconstruction using a geometrical construction. Physical Review A, 45: 3403–3411.

[6] Provenzale A., Smith L.A., Vio R., Murante G. (1992) Distinguishing between low-dimensional dynamics and randomness in measured time series. Physica D, 58(1): 31–49.

[7] Eckmann J.-P., Oliffson Kamphorst S., Ruelle D., Ciliberto S. (1986) Liapunov exponents from time series. Physical Review A, 34: 4971–4979.

[8] Eckmann J.-P., Ruelle D. (1985) Ergodic theory of chaos and strange attractors. Reviews of Modern Physics, 57: 617–656.

exponents, I have calculated Kolmogorov-Sinai entropy[9,10] (KS), which is the most important dynamic measure characterising the chaotic system. KS, equal to the sum of the positive Lyapunov exponents, measures the average rate at which information about the state of the chaotic dynamic system is lost[9]. In addition, based on the spectrum of the Lyapunov exponents, I have also calculated the Kaplan-Yorke dimension[11] (D_{KY}) of the attractor, a static measure of chaos. From the estimated D_{KY} one can assess the number of 'active modes' in the system, or the 'effective number of degrees of freedom' of the dynamic system under study[12]. The results of qualitative and quantitative analyses obtained in 2009–2013 are consistent and clearly indicate that the studied process of river flow is non-linear, deterministic and chaotic. Moreover, **the globally unique results concerning the Lyapunov spectrum for the river flow process** [B1] **provide further important information**:

- The sum of all Lyapunov exponents is negative; it shows that the studied process is dissipative (during the movement the energy is lost/dissipated);
- One of the Lyapunov exponents is zero; it means that the underlying dynamics studied is governed by a differential equation;
- For the river system closed by the cross-section at Mszana Dolna (covering the upper part of the Raba catchment with an area of 158 km^2), the largest Lyapunov exponent (λ_1) is positive, equal to the KS entropy, KS = λ_1 = 0.02822 1/day;
- For the river system closed by the cross-section at Proszówki (covering the Raba catchment with an area of 1470 km^2), the two largest Lyapunov exponents are positive (λ_1 = 0.03632 1/day, λ_2 = 0.01361 1/day), and KS = $\lambda_1 + \lambda_2$ = 0.04993 1/day;
- For the river system of Raba closed by the cross-section at Mszana Dolna, D_{KY} = 3.158; it means that the effective number of degrees of freedom of the studied river dynamics is 4;
- For the river system of Raba closed by the cross-section at Proszówki, D_{KY} = 5.155; it means that the effective number of degrees of freedom of the studied river dynamics is 6.

[9] Schuster H.G. (1995) Deterministic chaos: An introduction, 3rd ed. New York: Wiley, p. 112, p. 124.
[10] Ott E. (1993) Chaos in dynamical systems. New York: Cambridge University Press, p. 138.
[11] Kaplan J.L., Yorke J.A. (1979) Chaotic behaviour of multidimensional difference equations. In: Peiten H.O., Walther H.O. (eds.) Functional differential equations and approximation of fixed points. Lecture Notes in Mathematics, vol. 730. Springer, Berlin, Heidelberg, pp. 204–227.
[12] Theiler J. (1986) Spurious dimension from correlation algorithms applied to limited time-series data. Physical Review A, 34: 2427–2432.

As expected from theoretical considerations, the obtained values of invariants (D_{KY}, λ_1, KS) vary with position, increasing downstream. Both positive Lyapunov exponents, KS-entropy and D_{KY} are greater at Proszówki cross-section than at Mszana Dolna cross-section, which implies that the Raba flow dynamics at Proszówki is more chaotic and complex than at Mszana Dolna. Because KS entropy is inversely proportional to the time interval in which the state of the chaotic system can be predicted[9], the calculated values of entropy KS indicate that this time is up to 35 days for the Raba flow at Mszana Dolna and up to 20 days at Proszówki.

Regardless of the quantitative and qualitative results obtained, the B1 publication also presents a detailed methodology for the analysis of chaotic processes, including new, complementary methods supported by non-parametric statistical tests. Moreover, the resulting selection of non-linear methods useful in the analysis of the nature (deterministic/random) of hydrological processes is presented in the next publication [B2]. Non-linearity is an important feature of hydrological processes[13,14,15]; it opens the possibility of complex behaviours, which are not possible in linear systems, although not all non-linear systems are complex[16].

In the B2 paper, on the example of: (1) the river flow process of the Krzyworzeka Stream (a tributary of the Raba River) for the 12 years (1971–1982)[17], (2) the periodic process with measurement noise, (3) an autoregressive random process of order 1, so-called red noise, and (4) an uncorrelated random process with zero mean and constant variance, so-called white noise, I have presented an additional information benefit resulting from the application of two non-linear methods combined (AFN method[18,19] and 0–1 test[20,21,22]) in

[13] Amorocho J. (1967) The nonlinear prediction problem in the study of the runoff cycle. Water Resources Research, 3(3): 861–880.

[14] Kundzewicz Z.W., Napiórkowski J.J. (1986) Nonlinear models of dynamic hydrology. Hydrological Sciences Journal, 31(2): 163–185.

[15] Sivakumar B., Singh V.P. (2012) Hydrologic system complexity and nonlinear dynamic concepts for a catchment classification framework. Hydrology and Earth System Sciences, 16(11): 4119–4131.

[16] Phillips J.D. (2003) Sources of nonlinearity and complexity in geomorphic systems. Progress in Physical Geography, 27(1): 1–23.

[17] In my doctoral dissertation, the data from the Marwin station on the Krzyworzeka concerned a longer period of 16 years (1971–1986).

[18] Cao L. (1997) Practical method for determining the minimum embedding dimension of a scalar time series. Physica D, 110: 43–50.

[19] Cao L., Mees A., Judd K., Froyland G. (1998) Determining the minimum embedding dimension of input-output time series data. International Journal of Bifurcation and Chaos, 8: 1491–1504.

[20] Gottwald G.A., Melbourne I. (2004) A new test for chaos in deterministic systems. Proceedings of the Royal Society of London A, 460(2042): 603–611.

[21] Gottwald G.A., Melbourne I. (2005) Testing for chaos in deterministic systems with noise. Physica D, 212: 100–110.

relation to two standard linear methods (linear autocorrelation function and spectrograms) used to study the internal structure of hydrological processes based on measuring sequences from an appropriate time period. The linear methods used allowed correct recognition of process (2) as periodic and process (4) as random, but did not distinguish between the river flow process (1) and red noise (3). Thanks to the non-linear methods employed (AFN[18,19] and 0–1 test[20,21,22]), processes (3) and (4) were correctly identified as random, and processes (1) and (2) as deterministic, and the chaotic behaviour of the flow process (1) was distinguished from the periodic behaviour with random noise in the case of process (2). As a result of the analyses carried out in the B2 article, the daily dynamics of the studied hydrological process (the river flow process) was identified as deterministic chaotic, which in turn allows proper understanding of the behaviour of the studied process and its correct description as well as the selection of appropriate modelling and prediction methods. The B2 paper indicates also the possibility of conducting a similar analysis for other geophysical processes, which besides random features show deterministic behaviour and are characterized by non-linear relationships.

The impact of dam reservoirs on dynamic features of river flow

Papers B3, B4, B5 and B8 are the result of research on the influence of dam reservoirs on the disturbance of the flow dynamics and energy exchange characteristics. The B3 paper focuses on the role of dam reservoirs in shaping the cyclicity and energy of mountain river flows. The impact of dams and reservoirs on the cyclicity of river flows has been under-researched so far and is barely present in literature. One of the few papers on the topic analyses the Colorado River[23] and shows a drastic disruption of river flow dynamics after the construction of the dam, resulting in the disappearance of the annual cycle of river flows—one of the most fundamental natural cycles on Earth. In the B3 paper, the analysis focuses on comparing changes in cyclicity and flow energy induced by reservoirs with significantly different parameters and functions that were built on rivers with a different hydrological regime. A large complex composed of two reservoirs (Czorsztyn-Sromowce Wyżne)

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[22] Gottwald G.A., Melbourne I. (2009) On the implementation of the 0–1 test for chaos. SIAM Journal on Applied Dynamical Systems, 8(1): 129–145.

[23] White M.A., Schmidt J.C., Topping D. (2005) Application of wavelet analysis for monitoring the hydrologic effects of dam operation: Glen Canyon Dam and the Colorado River at Lees Ferry. River Research and Applications, 21: 551–565.

performing flood control, energy generation and compensatory functions[24] was compared with the smaller Besko Reservoir built on the Wisłok River in order to increase low flows and reduce flood waves in the upper reaches of the river[25]. Spectral analysis of daily series of measurements from the period of 15 years (1998–2012) reveals that the dynamics of inflow and outflow of water from the Czorsztyn-Sromowce Wyżne reservoir complex is dominated by annual cyclicity. The spectral energy of the annual cycle undergoes only a marginal increase (from 10.04% do 10.41%) in the outflow of water from the reservoirs as compared to the inflow. This shows that the Czorsztyn-Sromowce Wyżne reservoirs have a slight, positive impact on the strengthening of annual cyclicity of water flow in the upper course of the Dunajec. Spectral analysis of daily series of measurements at Krościenko on the Dunajec (22.2 km below the Czorsztyn-Sromowce Wyżne complex) corroborates the existence of a dominant annual flow cycle for the Dunajec River; however, it can be noticed that at Krościenko—along with the increase of the catchment area there is a slight weakening of the annual flow cyclicity (to 9.89% of the spectral energy in the annual cycle).

In the B3 paper, spectral analysis of daily series of measurements from the period of 15 years (1998–2012) shows that the dynamics of inflow and outflow of water from the Besko Reservoir is also dominated by annual cyclicity, but the spectral energy of this cycle is about 2–3 times lower compared to the annual cycle of the Dunajec River flow. The spectral energy of the annual cycle is 1.4 times higher in the outflow (4.03%) of water from the reservoir compared to the inflow (2.86%); this means that the operation of the Besko Reservoir strengthens the annual repeatability of the dynamics of the Wisłok flows below this reservoir.

Moreover, in paper B3, the energy of the signal was compared before and after the water flows through the reservoir. The changes of signal energy for the river flow show changes in the river's energy potential, that is, an increase/decrease of water flow results in a corresponding change to its kinetic and potential energy value. When comparing the signal energy for inflow and outflow, a clear drop in the outflow is noticeable: by 40% in the case of the Czorsztyn-Sromowce Wyżne reservoir complex and by 30% in the case of the Besko Reservoir. Given the fact that water flowing out of the reservoirs does not carry material,

[24] Kloss A. (Red.) (2003) The Czorsztyn-Niedzica and Sromowce Wyżne Reservoir Complex named after Gabriel Narutowicz. RZGW in Krakow. Monograph. Hydroprojekt Warszawa: IMGW. Warszawa.
[25] Hennig J., Hennig I., Roszkowski A. (1991) Retention reservoirs. In: I. Dynowska, M. Maciejewski (Eds.) The Upper Vistula Basin, Part II. Warszawa-Kraków. PWN, pp. 121–143.

a weaker signal energy after the water passes through the reservoir appears to be beneficial, because lower energy potential of the river water translates into its lower erosive force.

Summarising, the results of B3 publication indicate that in the period 1998–2012, the functioning of dam reservoirs in the upper reaches of the Carpathian rivers (Dunajec and Wisłok) introduces changes in the cyclicity and energy of flows that are highly similar. The considered dam reservoirs reinforce the regularity of the natural annual cycle of the flow dynamics and reduce the energy of the rivers on which they are built. However, the relatively small reservoir Besko has a greater impact on strengthening the regularity of the annual cycle in the Wisłok than the large complex of Czorsztyn-Sromowce Wyżne reservoirs for the regularity of the Dunajec flows. This is due to the relatively strong annual cyclicity observed in the dynamics of the Dunajec flows, in contrast to the relatively low annual cyclicity observed in the dynamics of the Wisłok flow as well as the retention size in relation to the outflow and water exchange rate per year in the reservoirs.

Using independent methods, articles B4 and B5 aimed at determining the role of dam reservoirs built on mountain rivers in the disturbance of naturalny shaped synchronous behaviour between air temperature and river water temperature. River water temperature, a key environmental factor for aquatic ecosystems, is the result of energy transport processes in the river and heat exchange between the river and its surrounding at the air-water interface and at the riverbed[26,27]. In the course of flow, baseline stream temperature shaped by groundwater recharge tends towards ambient air temperature, with the rate of change dependent on insulating and buffering processes operating inside the riparian zone[28]. Strong correlations between air and water temperatures[29] at daily, weekly, or monthly time scales are commonly used in linear or non-linear regression type modelling[30] developed to predict changes in stream temperature from air temperature. As water temperature responds to air temperature with a time lag caused by thermal inertia of water, using the lag (2–3 days for

[26] Caissie D. (2006) The thermal regime of rivers: a review. Freshwater Biology, 51: 1389–1406.
[27] Sinokrot B.A., Stefan H.G. (1993) Stream temperature dynamics: measurements and modeling. Water Resources Research, 29(7): 2299–2312.
[28] Poole G.C., Berman C.H. (2001) An ecological perspective on in-stream temperature: natural heat dynamics and mechanism of human-caused thermal degradation. Environmental Management, 27(6): 787–802.
[29] Caissie D., El-Jabi N., Satish M.G. (2001) Modelling of maximum daily water temperatures in a small stream using air temperatures. Journal of Hydrology, 251(1): 14–28.
[30] Mohseni O., Stefan H.G., Erickson T.R. (1998) A nonlinear regression model for weekly stream temperatures. Water Resources Research, 34: 2685–2692.

most medium-sized rivers) improved daily water temperature estimates[31]. Dam reservoirs thermally stratified cause changes in natural thermal conditions in the downstream river reaches, weakening correlations between air and water temperatures[32]. The impact of dammed reservoirs on changes in thermal conditions may extend downstream for tens to hundreds of km[33], while the range and scale of thermal changes depends, among others, on the parameters of the reservoir—its depth and places of water outflow (from the surface/bottom zone of the reservoir)[34], the magnitude of releases and local characteristics of the natural environment[35].

In order to determine the role of dam reservoirs built on mountain rivers in the disturbance of naturally shaped synchronous behaviour (in-phase time course) between air and water temperatures, wavelet analysis was used in paper B4, while cross-recurrence plots (CRP) and CRQA[36] were used in paper B5. The use of independent methods (wavelet transform and CRQA) made it possible to verify the observed synchrony between the daily values of river water and air temperatures from the point of view of the non-linear phenomenon of phase synchronisation. Synchronisation is one of the basic physical phenomena discerned in the 17th century by a Dutch researcher Christiaan Huygens[37]. In the classical sense, synchronisation is understood as an adjustment of rhythms (frequencies) of oscillating objects due to their weak interaction[38]. In the twentieth century, the notion of classic synchronisation of periodic oscillators has been generalized to the case of non-linear oscillators[39,40]. Synchronisation as a complex, dynamic process occurs, among others, in

[31] Stefan H.G., Preud'homme E.B. (1993) Stream temperature estimation from air temperature. Journal of the American Water Resources Association, 29(1): 27–45.
[32] Erickson T.R., Stefan H.G. (2000) Linear air/water temperature correlations for streams during open periods. Journal of Hydrologic Engineering, 5: 317–321.
[33] Todd C.R., Ryan T., Nicol S.J., Bearlin A.R. (2005) The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (Maccullochella Peelii Peelii): a case study of the Mitta Mitta River, southeastern Australia. River Research and Applications, 21: 1035–1052.
[34] Poff N.L., Hart D.D. (2002) How dams vary and why it matters for the emerging science of dam removal. BioScience, 52(8): 659–668.
[35] Olden J.D., Naiman R.J. (2010) Incorporating thermal regimes into environmental flows assessment: modifying dam operations to restore freshwater integrity. Freshwater Biology, 55: 86–107.
[36] Marwan N., Thiel M., Nowaczyk N.R. (2002) Cross recurrence plot based synchronization of time series. Nonlinear Processes in Geophysics, 9: 325–331.
[37] Huygens C. (1673) Horologium Oscillatorium. Apud F. Muguet, Paris, France.
[38] Pikovsky A.S., Rosenblum M.G., Kurths J. (2001) Synchronization: A universal concept in nonlinear sciences. Cambrigde University Press, Cambridge.
[39] Pikovsky A.S., Rosenblum M.G., Osipov G., Kurths J. (1997) Phase synchronization of chaotic oscillators by external driving. Physica D: Nonlinear Phenomena, 104: 219–238.
[40] Pecora L.M., Carroll T.L. (19990) Synchronization in chaotic systems. Physical Review Letters, 64: 821–824.

mechanical, electronic, biological, chemical and ecological systems[38,41,42]. For dynamic systems interacting with each other, phase synchronisation refers to a state when there is a relationship between the phases of these systems, while their amplitudes may remain almost uncorrelated[38].

The main purpose of the research published in papers B4 and B5 is to determine the role of the Czorsztyn-Sromowce Wyżne reservoir complex built in the years 1994–1997 on the Dunajec River[24,25] in the disturbance of naturally shaped, synchronous behaviour of water temperature in the Dunajec and ambient air temperature. The analysis was carried out for sequences of daily measurements of air and water temperatures from the hydrological years 1978–2012 (35 years) made at 6^{00} UTC in Krościenko, located 22.2 km below the Czorsztyn-Sromowce Wyżne reservoir complex. The S-shaped dependence between water and air temperatures[43], observed also in Krościenko, results from complex interactions between two dynamic subsystems that these temperatures are associated with, that is, the river system with its specific characteristics (Dunajec River sub-catchment) and the local weather system at Krościenko [B5]. The shape of this relationship is also determined by the fact that these temperatures relate to different media (water and air); hence, water temperature, unlike air temperature, cannot be lower than 0 °C in the winter or arbitrarily high in the summer[43]. However, for the postdam period 1998–2012 (15 years), in comparison with the predam period 1978–1992 (15 years), the slope of the S-shaped curve has changed [B5], while correlations (measured by the Pearson's cross-correlation coefficient) weakened in the summer half-year (on average from 0.82 to 0.66), and increased in the winter half-year (from 0.62 to 0.71 on average) [B4]. Fourier and wavelet analyses show [B4] that the dominant frequency in the temperature dynamics corresponds to the annual cycle and contains the majority of spectral energy (90% for water temperature and 68% for air temperature for 35 years 1978–2012). In the period of 15 years (1998–2012) after the construction of the studied reservoirs complex, compared to 15 years in the predam period (1978–1992), annual cyclicity in the dynamics of air temperature was strengthened by 3%, and in the dynamics of water temperature by 5%. Eliminating the 3% strengthening of the annual cycle by air temperature, <u>it can be assumed that the functioning of the Czorsztyn-Sromowce Wyżne reservoir complex</u>

[41] Glass L. (2001) Synchronization and rhythmic processes in physiology. Nature, 410: 277–284.
[42] Blasius B., Huppert A., Stone L. (1999) Complex dynamics and phase synchronization in spatially extended ecological systems. Nature, 399: 354–359.
[43] Mohseni O., Stefan H.G. (1999) Stream temperature/air temperature relationship: a physical interpretation. Journal of Hydrology, 218(3): 14–28.

caused about 2% strengthening of the annual cyclicity (repeatability) in the water temperature dynamics of the Dunajec River in Krościenko [B4]. These results are in line with the results of B5, in which I analysed changes in water temperature dynamics of the Dunajec River caused by the Czorsztyn-Sromowce Wyżne complex using recurrence plots RP[44] and RQA[45,46,47]. The results of B5 article, based on non-linear RQA measures, indicate an increase in regularity of the dynamics and a greater predictability of water temperature values in the Dunajec River at Krościenko after the construction of the Czorsztyn-Sromowce Wyżne reservoir complex.

In paper B4, based on the Morlet complex wavelet[48,49], I analysed instantaneous phases for the dominant frequency in the dynamics of air and water temperatures in Krościenko, corresponding to the annual cycle. For the predam period (1978–1992), the phase delay of water temperatures in relation to air temperatures was on average 0.049 radians (2.85 days), and for the postdam period (1998–2012), it increased more than fivefold, on average up to 0.253 radians (14.71 days). This means that the naturally shaped synchronous behaviour of the interacting air and water temperatures has been apparently distorted, although not completely destroyed. The obtained value (2.85 days) of the time delay in the predam period is fully consistent with the generalised results (1.5–3 days) derived from the heat budget equation[50]. The results of article B4 indicate that in the modelling and prediction of water temperatures in the Dunajec River at Krościenko based on daily or weekly air temperature values, in the period after the construction of the Czorsztyn-Sromowce Wyżne reservoirs (1998–2012), a 14–15-day delay should be considered.

In paper B5, based on recurrence plots[44] I calculated the generalised autocorrelation function RR[51] for each temperature series and the CPR correlation coefficient for these

[44] Eckmann J.P., Kamphorst S.O., Ruelle D. (1987) Recurrence plots of dynamical systems. Europhysics Letters, 4(9): 973–977.
[45] Trulla L.L., Giuliani A., Zbilut J.P., Webber C.L. Jr (1996) Recurrence quantification analysis of the logistic equation with transients. Physics Letters A, 223(4): 255–260.
[46] Webber C.W. Jr, Zbilut J.P. (1994) Dynamical assessment of physiological systems and states using recurrence plot strategies. Journal of Applied Physiology, 76: 965–973.
[47] Zbilut J.P., Webber C.L. Jr, (1992) Embeddings and delays as derived from quantification of recurrence plots. Physics Letters A, 171(3-4): 199–203.
[48] Morlet J., Arens G., Fourgeau E., Giard D. (1982) Wave propagation and sampling theory – Part II: Sampling theory and complex waves. Geophysics, 41: 222–236.
[49] Torrence C., Compo G.P. (1998) A practical guide to wavelet analysis. Bulletin of the American Meteorological Society, 79: 61–78.
[50] Bogan T., Mohseni O., Stefan H.G. (2003) Stream temperature-equilibrium temperature relationship. Water Resources Research, 39: 1245–1256.
[51] Romano M.C., Thiel M., Kurthz J., Kiss I.Z., Hudson J. (2005) Detection of synchronization for non-phase coherent and non-stationary data. Europhysics Letters, 71(3): 466–472.

functions[51], which allow identifying phase synchronisation between the analysed variables. The obtained graphs of the RR function and the value of CPR close to 1 (CPR = 0.87 for the data from the predam period 1978–1992, while CPR = 0.82 for the postdam period 1998–2012) clearly indicate phase synchronisation between the two temperature studied; however, in the period after the construction of the Czorsztyn-Sromowce Wyżne reservoirs, the strength of phase synchronisation was reduced.

Moreover, the cross-recurrence plots (CRP)[36] used in article B5 allow identifying and studying the synchronous behaviour of two variables (air and water temperature series) in the same phase-space reconstructed by the time delay embedding[52,53]. On the basis of the synchronisation line forming the main diagonal of the CRP[36], information on frequencies and phase shift between the studied temperature series was obtained. The results of CRQA indicate that in the predam period (1978–1992), the phase difference between water temperature and air temperature was 2.72 days on average, and after the construction of dam reservoirs (1998–2012), it increased more than 6-fold, to 17.00 days, on average. The results obtained in paper B5, in line with the results of paper B4, confirm that the functioning of the considered reservoirs caused a change (weakening) in synchronous behaviour of water and air temperatures on at least 22 km section of the Dunajec River below the Czorsztyn-Sromowce Wyżne complex. These results confirm the possibility of a relatively precise determination of the spatial scale of the disturbances of this process by dam reservoirs with developed thermal stratification built on a mountain river.

Paper B8 results from the continuation of research into the dynamics of water temperatures in mountain rivers, taking into account anthropogenic conditions and climate change. The main objective of the conducted research was to assess the impact of regional warming[54] and the functioning of dam reservoirs built on mountain rivers on changes in water temperature compared to the largely natural thermal conditions in the predam period. Research analysis focuses here on the comparison of changes in river water temperature below dam reservoirs with considerably different parameters and functions. A large complex of two reservoirs Czorsztyn–Sromowce Wyżne built in the years 1994–1997 on the upper course of the Dunajec River[24], the medium-sized Klimkówka Reservoir constructed in 1994 on the Ropa, and the smaller Besko Reservoir built in 1978 on the Wisłok River[25] were

[52] Packard N.H., Crutchfield J.P., Farmer J.D. Shaw R.S. (1980) Geometry from a time series. Physical Review Letters, 45(9): 712–716.

[53] Takens F. (1981) Detecting strange attractors in turbulence. In: Rand D.A, Young L.S. (eds.) Dynamical systems and turbulence, Lecture Notes in Mathematics, vol. 898. Springer-Verlag, Berlin, pp. 366–381.

selected for analyses. The analysis was based on long-term daily water temperature and air temperature data collected at the same locality for time periods before and after the construction of the studied reservoirs. The data were measured: (a) at Krościenko, 22.2 km downstream of the Czorsztyn-Sromowce Wyżne reservoirs for the years 1977–2013 (37 yr), (b) at Szymbark, 16 km downstream of the Klimkówka Reservoir for the years 1982–2009 (28 yr), and (c) at Krosno, 32.6 km downstream of the Besko Reservoir for the periods 1970–1977 and 1986–2009 (8 and 24 yr, respectively). The data for Krościenko and Krosno were taken at 6^{00} UTC, and for Szymbark were collected at 13^{00} UTC.

In B8, on the basis of linear regression, a significant ($p = 0.0000$) positive trend in long-term (24–37 year period) daily air temperature series was identified, ranging from 0.036 °C/year at Krościenko (1977–2013) to 0.079 °C/year at Szymbark (1982–2009) and 0.096 °C/year at Krosno (1986–2009). Simultaneous water temperature series show similar but slightly weaker tendencies, with significant ($p = 0.0000$) increases between 0.029 °C/year at Krościenko to 0.077 °C/year at Krosno, while an increase in water temperature at Szymbark is insignificant. All shorter temperature series (8–16 years) from the predam or postdam periods exhibit significant ($p < 0.005$) consistent warming trends as well, which are typically stronger than long-term trends. It can be noticed that <u>the relative strength of trends in water temperature in relation to trends in air temperature is weaker for postdam periods than for predam periods, by 29% and 41% for Krościenko and Szymbark, respectively, contrary to what is observed at Krosno</u>.

<u>In B8, the air and water temperature for a year differ for the predam and postdam periods studied</u>. For Krościenko, on the common plot the annual cycle of water temperature (from 6^{00} UTC) is found above the air temperature cycle for the predam period (1977–1992), while for the postdam period (1998–2013), it is shifted to the right, intersecting the air temperature cycle. For Szymbark, the water temperature cycle (from 13^{00} UTC) is generally slightly below the air temperature cycle for the predam period, but for the postdam period, it is well below the air temperature cycle (except for winter), with a slight rightward shift. For Krosno, the water temperature cycle (from 6^{00} UTC) is slightly above the air temperature cycle for both periods, but for the postdam period (1986–2009), it is somewhat shifted to the right with respect to the air temperature cycle. <u>The identified downward shift of the water temperature cycle confirms the recognised cooling effect</u> (<u>mainly in summer</u>)[34,54,55], <u>caused</u>

[54] Wiejaczka Ł., Kijowska-Strugała M., Pierwoła P., Nowak M. (2015) Influence of the Czorsztyn-Sromowce Wyżne Reservoir complex on the Dunajec River thermal regime. Geographia Polonica, 88: 467–482.

by dam reservoirs with developed thermal stratification and hypolimnetic releases. The observed rightward shifts of the water temperature cycle with respect to the air temperature cycle for the studied postdam periods point to the changes in synchronous behaviour between the analysed temperatures.

In B8, after removing significant linear trends or means from the appropriate data series, on the basis of the Morlet complex wavelet[48,49] I analysed the instantaneous phases for the dominant frequency in the dynamics of air and water temperatures corresponding to the annual cycle. For Krościenko, the phase difference between air temperature and water temperature is below 0.30 rad (17.4 days) over the entire study period (1977–2013), while for the postdam period (1998–2013), this difference increases more than fivefold in comparison with the predam period (1977–1992), on average from 0.050 rad to 0.258 rad. For Szymbark, the phase difference is less than 0.24 rad (14.00 days) overall (1982–2009), and increases over fourfold for the postdam period, on average from 0.044 rad in 1982–1993 to 0.190 rad in 1994–2009. For Krosno, the phase difference between air temperature and water temperature is generally below 0.11 rad (6.4 days), and this difference is two times greater for the postdam period (1986–2009, on average 0.068 rad) in comparison with the predam period (1970–1977, on average 0.031 rad).

The analyses included in B8 showed distinct changes in river water temperature, related to the changing climatic conditions and functioning of the considered dam reservoirs. Identified, significant positive trends in long-term air temperature series are accompanied by positive trends in river water temperature, with differences in strength. This result is in line with a number of studies regarding climate change impact on water temperature[56,57], implying progressive heating of water in mountain rivers [B8]. The identified weakening of trends in water temperature relative to air temperature for the postdam periods point to the role each dam reservoir plays in this regard. The relative weakening of warming trends in river water temperature for the postdam period is considerable at Szymbark (by 41%), fairy close (16 km) to the Klimkówka Reservoir; slightly lower weakening of the trend strength (by 29%) was identified at Krościenko, 22.2 km below the Czorsztyn-Sromowce Wyżne reservoir

[55] Soja R., Wiejaczka Ł. (2014) The impact of a reservoir on the physiochemical properties of water in a mountain river. Water and Environment Journal, 28: 473–482.

[56] Hari R.E., Livingstone D.M., Siber R., Burkhardt-Holm P., Güttinger H. (2006) Consequences of climatic change for water temperature and brown trout populations in Alpine rivers and streams. Global Change Biology, 12: 10–26.

[57] Morrill J.C., Bales R.C., Conklin M.H. (2005). Estimating stream temperature from air temperature: implications for future water quality. Journal of Environmental Engineering, 131: 139–146.

complex, while such an effect is not visible at Krosno, presumably due to a much larger distance (32.6 km) from the relatively small Besko Reservoir and a discernible increase in the flow rate in the Wisłok River, from an average of 3.4 m^3/s at Besko up to 6 m^3/s at Krosno. At the same time, the studies[54,55,58] confirm that noticeable thermal changes in the longitudinal profile caused by individual dam reservoirs include measurement profiles at Szymbark and Krościenko, but they are negligible at Krosno. The results obtained in B8 indicate that the Czorsztyn-Sromowce Wyżne reservoir complex and the Klimkówka Reservoir markedly influenced the interaction between the air and water temperature on the considered river sections, reducing the degree of their natural synchronisation and increasing the response time of water temperature to changes in air temperature dynamics. As a result, the maximum water temperature values (at Krościenko and Szymbark) decreased (by 3.2 °C and 2.3 °C, respectively) for the postdam periods, in contrast to the maximums of air temperatures, which increased (by 1.5 °C and 1.3 °C, respectively). On the other hand, according to the study[58], simultaneous increases in air and water temperatures observed at Krosno again point to the negligible impact of the Besko Reservoir on river thermal conditions 33 km downstream. Consequently, existing thermal conditions created by progressive heating of water at Krosno are likely unsuitable for coldwater species. Historically, the reaches of the Dunajec, Ropa and Wisłok rivers have long been inhabited by native cold and coolwater fish fauna, mainly salmonids and cyprinids[59]. The identified, increasing trends in air and water temperatures in the study area will likely induce adverse changes in river habitats, resulting from their thermal degradation [B8]. This shows the need for adaptive management of the thermal regime of the mountain rivers studied in order to sustain its heterogeneity and fitness[28], with particular attention focused on coldwater species. The presented examples [B8] show that even without targeted management of the river thermal regime, dams with hypolimnetic releases weaken the strength of warming trends in water temperature, and reduce and delay the summer peak of water temperature for an approximately 20 km downstream section of river. Such a reduction in summer peak for water temperature downstream of large dams has been well documented[60,61,62,63]. The study

[58] Wiejaczka Ł., Wesoły K. (2017) Effect of a small dam reservoir on the water temperature in a Carpathian river. Geographia Polonica, 90(4): 481–491.
[59] Bieniarz K., Epler P. (1991) Ichthyofauna. In: I. Dynowska, M. Maciejewski (Eds.) The Upper Vistula Basin, Part II. Warszawa-Kraków. PWN, pp. 69–81.
[60] Baxter R.M. (1977) Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics, 8: 255–283.

highlights that such dams have the potential to weaken warming trends in water temperature as well, by reducing the degree of natural phase synchronisation between air and water temperatures. This creates an opportunity for establishing appropriate management practices focused on dam operations, which can mitigate both an increasing water temperature trend and cold water releases in order to yield more favourable (near natural) thermal conditions for native aquatic biota in impounded rivers, at least along some part of the downstream river section (tailwater). This is also in line with previous studies[64,65] suggesting adaptive management strategies that may be used in dam re-operations designed to restore environmental flows involving a thermal regime. Adaptive management combined with monitoring of outflow and water temperature as well as changes in climatic conditions in individual catchments would facilitate future modelling of water outflow using realistic volumes and temperatures [B8]. As a practical application, hypolimnetic dams managed adaptively for changing climate conditions can provide tailwaters for coldwater fisheries, with spawning channels used for natural fish reproduction [B8].

Variability of the river flow dynamics under climate change

Papers B6 and B7 are the result of research carried out by me as part of the statutory activities of the Institute of Engineering and Water Management of the Cracow University of Technology, aimed at assessing the variability of the flow dynamics of the Carpathian rivers. In papers B6 and B7, based on series of monthly observations, changes in long-term characteristics of orographic precipitation and river flow were analysed in the area of the Dunajec high-mountain basin [B6] and in two Beskid catchments of the Skawa and Raba Rivers [B7]. The aim of the analyses was to assess: (a) to what extent the regional warming identified in the entire Carpathian region—with the rising air temperature trend on average of 0.27 °C per decade[66] in 1961–2010, which is *not* accompanied by statistically significant

[61] Graf W.L. (2006) Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology, 79: 336–360.
[62] Kondolf G.M. (1997) Hungry water: effects of dams and gravel mining on river channels. Environmental Management, 21(4): 533–551.
[63] Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E., Stromberg J.C. (1997) The natural flow regime: a paradigm for river conservation and restoration. BioScience, 47: 769–784.
[64] Gu R., McCutcheon S., Chen C.-J. (1999) Development of weather dependent flow requirements for river temperature control. Environmental Management 24, 529–540.
[65] Richter B.D., Thomas G.A. (2007) Restoring environmental flows by modifying dam operations. Ecology and Society 12(1), 12.
[66] Spinoni J., Szalai S., Szentimrey T., Lakatos M., Bihari Z., Nagy A., Nemeth A., Kovacs T., Mihic D., Dacic M., Petrovic P., Krzic A., Hiebi J., Auer I., Milkovic J., Stepanek P., Zahradnicek P., Kilar P., Limanowka D., Pyrc R.,

trends in the annual/seasonal areal precipitation[66]—translates into changes in the characteristics of orographic precipitation, and (b) to what extent changes in climatic conditions are reflected in river flow characteristics in the high-mountain basin and in two Beskid catchments. The homogeneity of individual measuring series was tested by Alexandersson test[67]. The non-parametric, 2-sided Wilcoxon signed-rank test[68], with the Bonferroni correction[69] was used to assess the significance of the detected changes.

First, in paper B6, monthly time series of precipitation measured at nine precipitation stations in the Dunajec Basin were compared for two 30-year periods (1986–2015 versus 1956–1985). Statistically significant ($p = 0.0039$) changes in the long-term precipitation pattern involve 6 individual months, mainly from the summer half-year. In the 30 years 1986–2015, compared to the previous 30 years (1956–1985), there was a significant median increase in precipitation in the Dunajec Basin for March (7.7 mm), May (16.3 mm) and September (14.7 mm), but a decrease in precipitation for June (–16.1 mm), August (–12.3 mm) and December (–6.6 mm). It can be noticed that the changes in the precipitation pattern are largely compensating, with shifts in precipitation between particular months: from June to May, from August to September, from December to March (from the beginning of the winter period to its end). As a result of these and other less significant changes, the long-term annual precipitation in the analysed area of the Dunajec Basin did not changed significantly for the 30 years 1986–2015 compared to the previous 30 years (1956–1985). Changes in the dynamics of long-term variability of precipitation in the years 1986–2015, measured by the coefficient of variation, include a statistically significant ($p = 0.0039$) reduction in the precipitation variability for January and February, and the increase of precipitation variability for July and September.

Moreover, in paper B6, monthly flow rate series observed at nine different sites in the sub-catchments of the Dunajec River were compared for the 30-year period 1986–2015 against the previous period 1961–1985. In 1986–2015, statistically significant ($p = 0.0039$)

Cheval S., Birsan M-V., Dumitrescu A., Deak G., Matei M., Antolovic I., Nejedlik P., Stastny P., Kajaba P., Bochnicek O., Galo D., Mikulova K., Nabyvanets Y., Skrynyk O., Krakovska S., Gnatiuk N., Tolasz R., Antofie T., Vogt J. (2015) Climate of the Carpathian Region in the period 1961–2010: climatologies and trends of 10 variables. International Journal of Climatology, 35: 1322–1341.

[67] Alexandersson H. (1986) A homogeneity test applied to precipitation data. International Journal of Climatology, 6: 661–675.

[68] Wilcoxon F. (1945) Individual comparisons by ranking methods. Biometrics, 1: 80–83.

[69] Bonferroni C.E. (1936) Teoria statistica delle classi e calcolo delle probabilità. Pubblicazioni del R Istituto Superiore di Scienze Economiche e Commerciali di Firenze, 8: 3–62.

changes in the long-term pattern of river flow in the Dunajec Basin involve 3 individual months and include a median increase in flow rates for February (0.80 m^3/s), May (2.96 m^3/s) and September (3.30 m^3/s). The underlying changes, pertaining to the increase in flow for May and September, are in line with the change direction (increase) in precipitation observed for these months. It can also be noted that the decrease in flow for June and August, although less significant ($p = 0.0742$ and $p = 0.0195$, respectively), is in line with a change direction (decrease) in precipitation for these months. The observed significant increase in the flow rate for February and the less significant ($p = 0.0078$) increase in the flow for January is probably related to higher air temperatures in January–February causing increased melting of snow. Changes in the long-term dynamics of the flow variability in the period of 30 years 1986–2015, measured by the coefficient of variation, include a statistically significant ($p = 0.0039$) increase in the flow variability for September, but a decrease in variability for October. Thus, it can be seen that for September the increase in flow and its increased variability refer to the direction of change in the dynamics of precipitation.

In article B7, to assess the repeatability of the *precipitation* process, I proposed to use the repeatability coefficient[70], used so far to assess the repeatability of the *river flow* process based on multi-annual monthly flow rates[70] from 1961–1995. The coefficient of repeatability, understood as a relative change in variability[70], was then used in papers B6 and B7 to study changes in the multi-annual repeatability of precipitation and river flow in the considered catchments. Article B6 shows that in the years 1986–2015, compared to the previous 30 years (1956–1985), 72% repeatability of the precipitation process in the Dunajec Basin decreased significantly ($p = 0.0039$) by a median of 6.6%. At the same time, the exceptionally high 75% repeatability of the river flow process observed in 1961–1985 was significantly ($p = 0.0039$) reduced in the years 1986–2015 by a median of 6.7%. Thus, it can be seen that in the 30 years 1986–2015, the repeatability of both precipitation and river flow decreased significantly by the median value close to 7% in the studied area of the Dunajec Basin.

In paper B7, the series of monthly and seasonal precipitation from nine sites located in the Beskid catchments of Skawa and Raba were compared for two 30-year periods: 1985–2014 versus 1955–1984. Statistically significant ($p = 0.0039$) changes in the long-term precipitation pattern concern 5 months and 3 seasons. In the period from 1985 to 2014, compared to the previous 30 years, in the studied catchments there was a significant median

[70] Chełmicki W., Skąpski R., Soja R. (1998–1999) The flow regime of Poland's Carpathian rivers. In: Chełmicki W., Soja R. (Eds.) Carpathian hydrology from the perspective of the end of the 20th century. Folia Geographica, series Geographica-Physica, no. 29/30, pp. 67–80.

increase in precipitation for March (11.4 mm), May (20.3 mm) and September (15.9 mm), but a median decrease in precipitation for July (–19.4 mm) and August (–9.0 mm). The percentage change in precipitation is higher for March, May and September (22.8–23.8%), and lower for July and August (–13.5% and –7.5%, respectively). Seasonal changes, combining changes occurring in particular months of that season, include a significant median increase in precipitation for spring (31.3 mm) and autumn (15.6 mm), but a median decrease for summer (–40.6 mm). As the combined increase of precipitation in the spring and autumn compensates completely for its decline in the summer, the multi-year annual precipitation in the Skawa and Raba catchments did not change significantly in the years 1985–2014 in comparison with the previous 30 years.

In article B7, the series of monthly and seasonal flow rates from nine sites located in the Skawa and Raba catchments were compared; comparisons were made for the 30-year period 1985–2014 against the previous period 1961–1984. In 1985–2014, statistically significant ($p = 0.0039$) changes in the long-term river flow pattern concern 6 months and 3 seasons. These changes include a median increase in flow for May (1.29 m^3/s) and September (1.64 m^3/s), but a median decrease in June (–1.02 m^3/s), July (–0.98 m^3/s), August (–1.16 m^3/s) and October (–0.49 m^3/s). The percentage change in flow is the highest for September (42.2%), smaller in May and August (respectively 23.1% and –22.1%), and the smallest in June, July and October (between –14.8% and –16.8%). The major changes, including a significant increase in river flow for May and September but a reduction in flow for July and August, are consistent with the change direction in precipitation observed for these months. In addition, a statistically significant ($p = 0.0039$) reduction in flow for June is in line with the slightly less significant ($p = 0.0078$) decrease in precipitation for this month. Seasonal changes, including a significant increase in flow for spring and autumn but a decrease for summer, just like for precipitation are compensating, which is why the long-term annual flow in the Skawa and Raba catchments did not change significantly in the years 1985–2014 compared to the previous period. Simultaneously, 71% repeatability of precipitation in the Skawa and Raba catchments for the years 1955–1984, decreased significantly ($p = 0.0039$) in the next 30 years by a median of 8.6%. Similarly, the repeatability of flow at 49% in the years 1961–1984, decreased significantly ($p = 0.0039$) in the next 30 years by a median of 6.2%. Therefore, in the period from 1985 to 2014, the repeatability of both precipitation and river flow in the Skawa and Raba catchments decreased significantly by a median of 6–9%.

The results presented in papers B6 i B7 are new, important information about changes in orographic precipitation that accompany regional warming[66]; these results also show the extent to which changes in climatic conditions have been reflected in river flow characteristics in the high-mountain basin and two Beskid catchments. Despite the lack of statistically significant trends in the annual and seasonal series of areal precipitation for the entire Carpathian region[66], the main results of the analyses carried out in B6 i B7 indicate a change in the precipitation pattern in the period from 1985 to 2015, which includes shifting the sum of precipitation between several (5–6) months, combined with lowering precipitation in the summer, as well as a few percent (7–9%) reduction of the long-term repeatability of the precipitation process in the studied Carpathian catchments. The identified changes in river flow refer to changes in the precipitation pattern, but the magnitude of change depends on local physiographic conditions. Changes in flow characteristics for the last 30 years relate to several (3–6) months, and in the Skawa and Raba catchments they include an increase in flow for spring and autumn but a decrease in the summer season. Moreover, a few percent (6–7%) reduction in the long-term repeatability of the river flow process was identified in the Dunajec Basin and in the two Beskid catchments studied.

The research results presented in B6 and B7 not only broaden the scope of possible analyses on the impact of local (regional) climate change on the change in hydrological characteristics; they also provide opportunity to confront the results of simulation modelling and prediction of the dynamics of hydrological processes in quantitative terms. This will allow correct verification of the performance of the simulation models based on real changes observed. The results of B6 and B7 obtained on the basis of mothly data may provide information useful in water management in the studied region. Changes in river flow characteristics, largely consistent with changes in precipitation characteristics [B6], [B7], imply the necessity to develop appropriate strategies for managing available water resources in the catchments under consideration, with particular reference to potential water shortages in the summer. One should also pay attention to the observed decrease in repeatability of precipitation and river flow processes [B6], [B7], which may additionally impede the implementation of the adopted adaptation strategies in the area of the analysed Carpathian catchments.

5. Presentation of other scientific accomplishments

After receiving Ph.D., my research activity focuses on the dynamics of environmental processes in the Carpathian catchments, taking into account changes in climatic conditions and anthropogenic factors (changes in land use and land management, construction of dam reservoirs, etc.). As in the case of the previously presented scientific accomplishment, the aim of the study is to identify the temporal and spatial dynamics of changes in the characteristics of the physical processes in mountain catchments in the Carpathian area. The results of this study are aimed at supporting on adaptive approach to water resources management in the conditions of progressive urbanisation and changes in climatic conditions. In my research, I use advanced, modern methods of process analysis, including non-linear methods, recurrence plots, Fourier and wavelet analyses, the CEEMDAN[71] method (Complete Ensemble Empirical Mode Decomposition with Adaptive Noise), and parametric and non-parametric statistical tests.

In the years 2013–2017, as part of the statutory activity of the Institute of Engineering and Water Management at the Cracow University of Technology, I conducted research in the project "Contemporary methods of design and management in engineering and water management", <u>being the manager of a task related to the assessment of the variability of river flow in the Carpathian catchments</u>. The main purpose of the multi-year theme was to characterise changes in the hydrological regime of the rivers of the Carpathian region in Poland and to verify the sustainability of the tendency to regime change. It was also aimed at identifying spatio-temporal relationships between the observed changes in the hydrological regime and the conditions prevailing in the catchment, in order to identify and indicate the main factors causing a change in the river regime for the considered Carpathian catchments and to define the boundaries of the area of observed changes. Since 2018, as part of the statutory activity of the Department of Engineering and Water Management at the Cracow University of Technology <u>I have been carrying out a research project</u> devoted to the assessment of flow variability in the area of Mała Wisła, <u>being the manager of this project</u>. The results of the project have been published so far in the article:

- **Kędra M.**, Szczepanek R. (2019) Land cover transitions and changing climate conditions in the Polish Carpathians: Assessment and management implications. Land

[71] Torres M.E., Colominas M.A., Schlotthauer G., Flandrin P. (2011) A complete ensemble empirical mode decomposition with adaptive noise. IEEE ICASSP, Praque, pp. 4144-4147.

Degradation & Development, DOI: 10.1002/ldr.3291; IF (2017): 7,270; MNiSW (2018): 50 pt; contribution 65%; citations (WoS): 0.

Moreover, as the head of the research project in the **MINIATURA 2** competition funded by the National Science Centre, I started the implementation of a single scientific activity including participation in an international conference, date of completion: 15.10.2019.

Since 2013, every year I present my research results at scientific conferences, which are an opportunity for me to discuss research issues in an international group of scientists and develop cooperation with scientists from Poland and abroad (e.g., IGiPZ PAN in Cracow; Department of Hydrology and Climatology, Vilnius University, Lithuania; National Institute of Hydrology and Water Management, Romania).

After receiving Ph.D., I actively participated in 11 international scientific conferences, presenting the results of my research work in research centres in Poland and abroad in the form of 12 oral presentations i 2 poster presentations:

1. International Carpatho-Balcan-Dinaric Conference on Geomorphology, Slovak Academy of Sciences, Stara Lesna, **Slovakia**, 2013; oral presentation;
2. 15th Biennial Conference of the Euromediterranean Network of Experimental and Representative Basins ERB2014: "Advances in Hydrologic Research on Pristine, Rural and Urban Small Basins", the Civil Engineering Department of the University of Coimbra, Coimbra, **Portugal**, 2014; 2 oral presentations;
3. International Scientific Conference: "Geomorphology and Environmental Challenges", Slovak Academy of Sciences, Snina, **Slovakia**, 2014; oral presentation;
4. 6th International Symposium on Recurrence Plots, Grenoble Institute of Technology, Grenoble, **France**, 2015; oral presentation;
5. The World Multidisciplinary Earth Sciences Symposium "WMESS 2015, Prague, **Czech Republic**, 2015; oral presentation;
6. 16th Biennial Conference of the Euromediterranean Network of Experimental and Representative Basins ERB2016: "Hydrological Behaviour in Small Basins Under Changing Conditions", National Institute of Hydrology and Water Management, Bucharest, **Romania**, 2016; oral presentation;
7. International Conference: "Towards the Best Practice of River Restoration and Maintenance", Cracow University of Technology, Cracow, **Poland**, 2016; oral presentation;

8. International Conference Energy, Environment and Material Systems (EEMS'2017), Opole University of Technology, Polanica-Zdrój, **Poland**, 2017; oral presentation and poster presentation;
9. 2nd International Conference on the Sustainable Energy and Environmental Development – SEED'17, AGH University of Science and Technology, Cracow, **Poland**, 2017; oral presentation;
10. 1st International Scientific Conference: Hydrology in Natural and Anthropogenic Environments (HYDRO2018), University of Agriculture in Cracow, Cracow, **Poland**, 2018; 2 oral presentations;
11. 17th Biennial Conference of the Euromediterranean Network of Experimental and Representative Basins ERB2018: "Innovative Monitoring Techniques and Modeling Approaches for Analysing Hydrological Processes in Small Basins", Technical University Darmstadt, Darmstadt, **Germany**, 2018; poster presentation.

In 2015, I was the co-chair of the session of Hydro-Hydrogeological Sciences II at the international conference: The World Multidisciplinary Earth Sciences Symposium "WMESS 2015" in Prague, Czech Republic.

The results of my research work presented at the international conference: Energy, Environment and Material Systems (EEMS'2017) were published in the journal E3S Web of Conferences in two research articles indexed in the Journal Citation Reports (JCR) database:

- **Kędra M.** (2017) Long-term trends in river flow: a case study of the Soła River (Polish Carpathians), E3S Web of Conferences, vol. 19, art. 02012; DOI: 10.1051/e3sconf/20171902012; MNiSW (2017): 15 pt; contribution 100%; citations (WoS): 1;
- **Kędra M.** (2017) Long-term trends in river water temperature: a case study of the Raba River (Polish Carpathians), E3S Web of Conferences, vol. 19, 02016; DOI: 10.1051/e3sconf/20171902016; MNiSW (2017): 15 pt; contribution 100%; citations (WoS): 0.

The results of my research work presented at the international conference: 2nd International Conference on the Sustainable Energy and Environmental Development – SEED'17 were published in the research article (indexed in Scopus, and under indexing in WoS):

- **Kędra M.** (2019) Multi-annual hydro-climatic trends in the Dunajec Basin (Polish Carpathians), IOP Conference Series: Earth and Environmental Science, vol. 214, 012067; DOI: 10.1088/1755-1315/214/012067; MNiSW (2018): 15 pt; contribution 100%; citations (WoS): 0.

The main indicators of my scientific achievements are presented in the table below.

Major bibliographic indicators		Before Ph.D.	**After Ph.D.**	**Total**
Total IF according to JCR (according to publication year), with the own percentage contribution		- -	**22.747** **18.626**	**22.747** **18.626**
Number of citations (*as on 18.03.2019*)	WoS Scopus	- -	**37** 42	**37** 42
Hirsh index (*as on 18.03.2019*)	WoS Scopus	- -	**4** 5	**4** 5
Sum of MNiSW points (according to publication year)		**8**	**348**	**356**

In 2013, I took a short research internship (4-day study trip) in Switzerland, at Institute F.-A. Forel, University of Geneva, (prof. V. Slaveykova), devoted to the subject of water quality in Lake Geneva and to research methods and equipment for monitoring water quality.

As part of my activities for science, I have made 11 reviews for the following international journals:

1. Proceedings of the Institution of Civil Engineers – Water Management (2014): 1 manuscript;
2. Springer Proceedings in Physics (2015): 1 manuscript;
3. Applied Mechanics and Materials (2015): 1 manuscript;
4. Water (Switzerland) (2017–2019): 6 manuscripts;
5. Science of the Total Environment (2018): 1 manuscript;
6. River Research and Applications (2019): 1 manuscript.

My research work from the years 2016–2018 was appreciated by **HM Rector of the Cracow University of Technology**; in the years 2018 and 2019 I received an award for academic employees in research and research-teaching positions for outstanding scientific achievements. In 2018, I was also awarded in the competition for the best oral presentation during the 1st International Scientific Conference: Hydrology in Natural and Anthropogenic Environments (HYDRO2018), University of Agriculture in Cracow, Poland.

A detailed list of my research achievements together with a list of published research works can be found in Attachment 4.

18 marca 2019

Mariola Kędra