Attachment 2b

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Summary of professional accomplishments

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1. Name and surname

Mikołaj Piniewski

2. Obtained degrees – name, place and year of obtaining them as well as title of the doctoral thesis.

- 2012: **PhD** degree in **technical sciences** in the domain of environmental engineering (with distinction) obtained in the Institute of Meteorology and Water Management – National Research Institute. Title of the doctoral thesis: „Impacts of natural and anthropogenic conditions on the hydrological regime of rivers: A Narew River Basin case study". Supervisor: prof. dr hab. Tomasz Okruszko. Distinction granted by the Research Council of the IMGW-PIB on the basis of the decree no. 7/2012/VII.
- 2007: **M.Sc**. title in **mathematics** in the domain of applied mathematics obtained at the Facultuy of Mathematics, Informatics and Mechanisc of the University of Warsaw. M.Sc. thesis title: „Global dynamics in double diffusive convection". Supervisor: prof. dr hab. Grzegorz Łukaszewicz.

3. Information on current employment in scientific institutions

- 1.10.2013 – today: **assistant professor** in the Department of Hydraulic Engineering of WULS-SGGW (on leave between 1.10.2014 and 30.09.2017)
- 1.10.2014 – 30.09.2017: **post-doc** in Potsdam Institute for Climate Impact Research (Germany) within the Alexander von Humboldt Foundation Fellowship Programme
- 1.10.2011-30.09.2013: **research assistant in** the Department of Hydraulic Engineering of WULS-SGGW

4. Scientific achievement

4.1. Title

Macroscale analysis of water resources in Poland under climate change

4.2. Series of articles

The scientific achievement is composed by a series of 11 articles (article codes are given in rectangular parentheses and the journal impact factor values together with my estimated percent contribution into each work are given in round parentheses):

1. [ESSD2016] Berezowski, T., Szcześniak, M., Kardel, I., Michałowski, R., Okruszko, T., Mezghani, A., **Piniewski, M**. 2016. CPLFD-GDPT5: high-resolution gridded daily precipitation and temperature data set for two largest Polish river basins. *Earth System Science Data* 8, 127-139, 2016, doi: 10.5194/essd-8-127-2016 (IF[1] 6.696, contribution 30%).
2. [ESSD2017**]** Mezghani, A., Dobler, A., Haugen, J. E., Benestad, R. E., Parding, K. M., **Piniewski, M**., Kardel, I., Kundzewicz, Z. W. 2017. CHASE-PL Climate Projection dataset over Poland – Bias adjustment of EURO-CORDEX simulations. *Earth Syst. Sci. Data.* 9, 905-925, doi: 10.5194/essd-9-905-2017 (IF 8.792, contribution 10%).
3. [MZ2017**] Piniewski, M**., Mezghani, A., Szcześniak, M., Kundzewicz, Z.W. 2017. Regional projections of temperature and precipitation changes: Robustness and uncertainty aspects. *Meteorologische Zeitschrift* 26(2), 223-234, doi: 10.1127/metz/2017/0813 (IF 1.436, contribution 60%).
4. [RRA2017] **Piniewski, M**. 2017. Classification of natural flow regimes in Poland. *River Research and Applications*, 33(7), 1205-1218, doi: 10.1002/rra.3153 (IF 2.067, contribution 100%).

[1] IF – Impact Factor for the publication year

5. [AG2018**] Piniewski, M**., Marcinkowski, P., Kundzewicz, Z.W. 2018 Trend detection in river flow indices in Poland, *Acta Geophysica* 66(3), 347-360, doi: 10.1007/s11600-018-0116-3 (IF 0.709, contribution 70%)
6. [HSJ2017**] Piniewski, M**., Szcześniak, M., Kardel, I., Berezowski, T., Okruszko, T., Srinivasan, R., Vikhamar-Schuler, D., Kundzewicz, Z.W. 2017. Hydrological modelling of the Vistula and Odra river basins using SWAT. *Hydrol. Sci. J.* 62(8), 1266-1289, doi: 10.1080/02626667.2017.1321842 (IF 2.061, contribution 50%).
7. [D2017**] Piniewski, M**., Szcześniak, M., Kardel, I. 2017. CHASE-PL—future hydrology data set: Projections of water balance and streamflow for the Vistula and Odra basins, Poland. *Data* 2(2), 14, doi: 10.3390/data2020014 (IF -, contribution 70%).
8. [HR2018**] Piniewski, M**., Szcześniak, M., Huang, S., Kundzewicz, Z.W. 2018 Projections of runoff in the Vistula and the Odra river basins with the help of the SWAT model. *Hydrology Research*, 49(2), 303-317, doi:10.2166/nh.2017.280 (IF 1.801, contribution 60%).
9. [HP2017**] Piniewski, M**., Szcześniak, M., Kundzewicz, Z.W., Mezghani, A., Hov, Ø. 2017. Changes in low and high flows in the Vistula and the Odra basins: model projections in the European-scale context. *Hydrol. Processes* 31(12), 2210–2225, doi: 10.1002/hyp.11176 (contribution 50%, IF 3.181).
10. [AG2017**] Piniewski, M**., Meresa, H.K., Romanowicz, R., Osuch, M., Szcześniak, M., Kardel, I., Okruszko, T., Mezghani, A., Kundzewicz, Z.W. 2017. What can we learn from the projections of changes of flow patterns? Results from Polish case studies. *Acta Geophysica*, doi: 10.1007/s11600-017-0061-6 (IF 0.709, contribution 40%).
11. [W2017] Marcinkowski, P., **Piniewski, M.,** Kardel, I., Szcześniak, M., Benestad, R., Srinivasan, R., Ignar, S., Okruszko, T., 2017. Effect of climate change on hydrology, sediment and nutrient losses in two lowland catchments in Poland. *Water*, 9(3) 156; doi: 10.3390/w9030156 (IF 2.069, contribution 30%).

4.3. Discussion of the scientific aim of this work as well as achieved results and ways of their potential use.

The aim of the research conducted within the described series of articles was to carry out comprehensive, macro-scale analyses of water resources of Poland under changing climatic conditions using modern mathematical modeling tools and the newest generation of climate change scenarios. The series is composed of 11 thematically and logically connected articles, published in peer-reviewed journals indexed in the Web of Science, whose relationship scheme is presented in Fig. 1. The articles are divided into four groups denoted as A, B, C and D and discussed below. The first group encompasses climatological papers and the three subsequent groups deal with hydrology. Another division of papers is into those that deal with historical period [ESSD2016, RRA2017, AG2018, HSJ2017] and those that deal with future climate change and its impacts (the remaining ones). The articles presented herein deal with different spatial domains. In the majority of cases, the Vistula and Odra basins (VOB) are the topic of investigation (Fig. 2A). Two articles concern the set of 147 near-natural catchments (Fig. 2B). One article deals with eight sub-catchments of the VOB (Fig. 2C) and one with two sub-catchments (Fig. 2D).

The description of scientific achievement follows below, starting from group A and ending with group D.

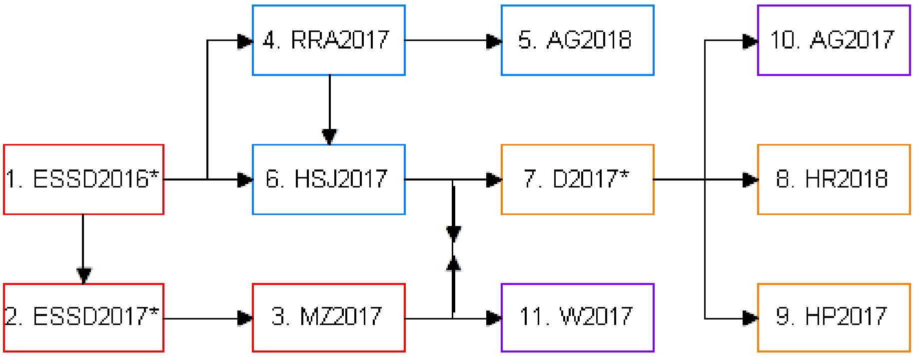

Figure 1 Flowchart illustrating logical sequence of the articles composing the scientific achievement (* denotes "data" papers). Red colour (subset A) denotes articles on climate (historical period and future scenarios), blue (subset B) denotes articles on water resources (historical period), orange (subset C) denotes articles on macro-scale assessment of water resources under climate change and violet (subset D) similar type of articles as in subset C but at the meso-scale.

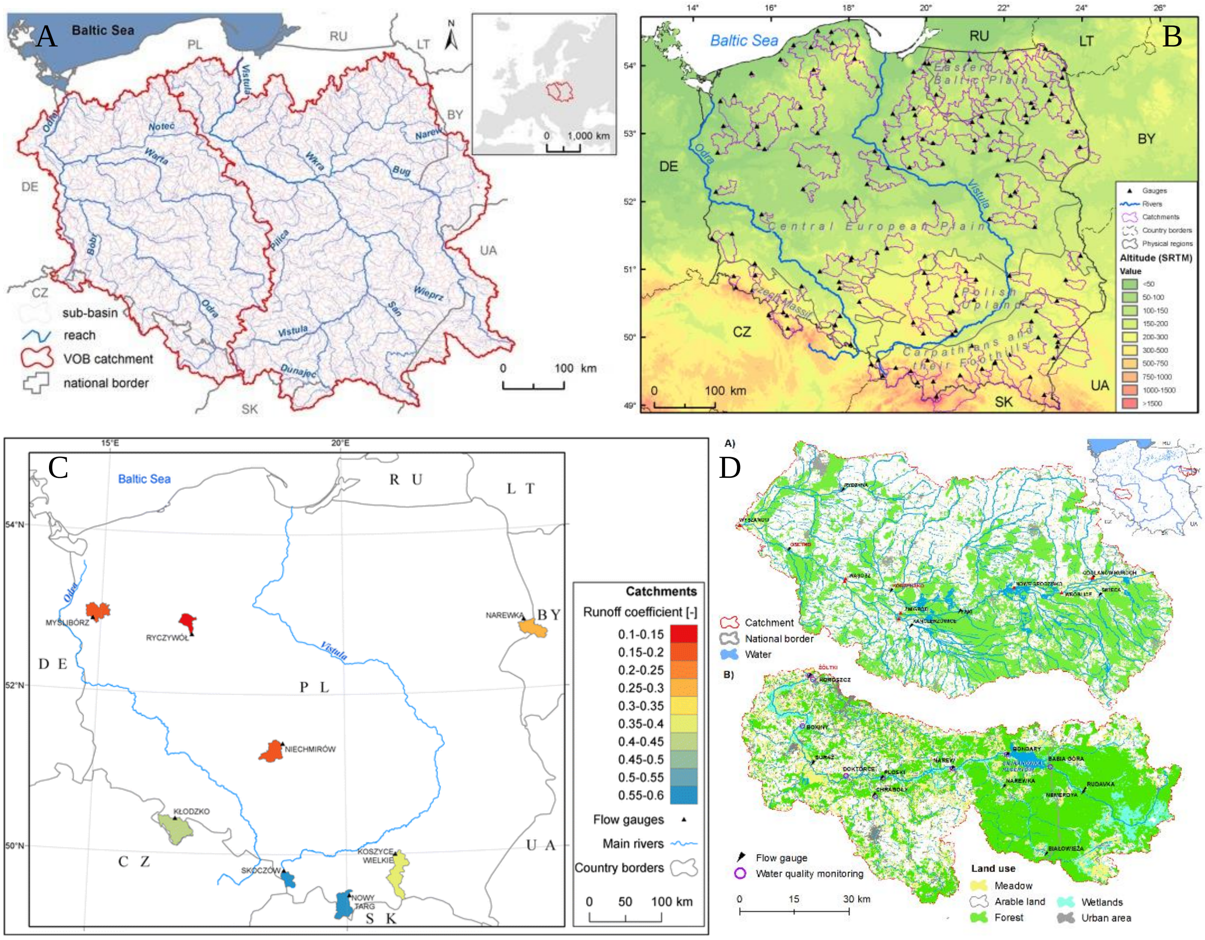

Figure 2 Spatial domains of analyses in the papers composing the scientific achievement: A. Vistula and Odra basins (VOB) and their division into sub-basins [ESSD2016, MZ2017, HSJ2017, D2017, HR2018, HP2017]; B. 147 near-natural catchments in Poland [RRA2017, AG2018]; C. Eight sub-catchments of the VOB [AG2017]; Two sub-catchments of the VOB, Barycz and Upper Narew [W2017].

A. Macro-scale, high-resolution climate forcing: observations, projections and their uncertainty

The first group of articles includes papers marked in red in Fig. 1, dealing with macro-scale climate analysis for the historical period [ESSD2016] and future horizons [ESSD2017, MZ2017].

The CHASE-PL Forcing Data–Gridded Daily Precipitation & Temperature Dataset–5 km (CPLFD-GDPT5) consists of 1951–2013 daily minimum and maximum air temperatures and precipitation totals interpolated onto a 5 km grid [ESSD2016]. The spatial domain was the union of Poland with the area of the VOB. So far, no high-resolution gridded data set exists for this territory, so the [ESSD2016] paper accompanied by a freely available data set was the one to fill this gap. For the interpolation, geostatistical techniques such as: kriging with external drift (temperature), indicator kriging and universal kriging (rainfall) were used. The CPLFD-GDPT5 data set is more fit-for-purpose as input for hydrological modeling than the readily available global data sets such as E-OBS (Haylock *et al.* 2008), due to its higher spatial resolution and denser network of stations. Thus, it is expected that lower errors in precipitation will translate into lower errors in values of simulated discharge and water balance.

Interpolation was conducted using kriging with elevation as external drift for temperature and indicator kriging combined with universal kriging for precipitation, based on daily meteorological observations from the Institute of Meteorology and Water Management (IMGW-PIB; Polish stations), Deutscher Wetterdienst (DWD, German and Czech stations), and European Climate Assessment and Dataset (ECAD) and National Oceanic and Atmosphere Administration–National Climatic Data Center (NOAA-NCDC) (Slovak, Ukrainian, and Belarusian stations). The number of available meteorological stations for precipitation and temperature varied in time from about 100 for temperature and 300 for precipitation in the 1950s up to about 180 for temperature and 700 for precipitation in the 1990s. Daily precipitation was corrected for snowfall and rainfall undercatch using the Richter method (Richter, 1995), which is important from the point of view of hydrological modelling north of 45°N latitude (Tian *et al.* 2007).

The kriging cross validation revealed low root-mean-squared errors expressed as a fraction of standard deviation (SD): 0.54 and 0.47 for minimum and maximum temperature, respectively, and 0.79 for precipitation. The correlation scores were 0.84 for minimum temperatures, 0.88 for maximum temperatures, and 0.65 for precipitation. The CPLFD-GDPT5 product is consistent with 1971–2000 climatic data published by IMGW-PIB. Its usefulness was further confirmed by its successful applications for multiple purposes: (1) as a training data set for bias correction of the regional climate models in [ESSD2017]; (2) as input data for calculation of climatological catchment characteristics in [RRA2017]; (3) as climate forcing of the Soil and Water Assessment Tool (SWAT) model of the Vistula and Odra basins [HSJ2017].

Regional climate change projections for all terrestrial regions of the globe have been made available for climate researchers in the framework of the CORDEX initiative. Within this initiative, a large ensemble of high resolution regional climate projections including Europe (EURO-CORDEX, the European branch of the CORDEX initiative) have been made available to provide climate simulations for use in climate change impact, adaptation, and mitigation studies (Giorgi *et al*., 2008). Although most of the simulations are run on a high grid resolution, systematic biases in the regional climate models are remaining due to errors related to i) imperfect model representation of the physical processes or phenomena and ii) to the parametrization and incorrect initialization of the models. Bias correction methods continue to be used in impact studies e.g. hydrology (Teutschbein *et al*., 2012) to reduce systematic bias in climate models.

Mezghani *et al.* [ESSD2017] suggested that the number of climate impact studies using the newest generation of climate models in Poland is generally low, which was a motivation for developing and publically sharing the CHASE-PL Climate Projections - Bias Corrected Daily Precipitation and Temperature dataset 5 km (CPLCP-GDPT5). The non-parametric 'Quantile Mapping` method, that has previously shown a good performance in reproducing not only the mean and the standard deviation but also other statistical properties such as quantiles (Gudmundsson et al., 2012), was used for correction of systematic biases in regional climate model (RCM) simulations. The data set covered the same spatial domain as the observations i.e. the area of Poland and parts of the Vistula and Odra basins belonging to neighbouring countries. Selected simulation ensemble consisted of the nine combinations of four general circulation models (GCMs) and four RCMs following the two representative concentration pathways RCP4.5 and RCP8.5. RCPs are plausible pathways towards reaching specific target radiative forcing trajectories as a result of climate policies – reduction of greenhouse gases emissions and increase of CO_2 sequestration (Moss *et al.* 2010). Two RCPs used in this paper, corresponding to the 4.5 W m^{-2} and 8.5 W m^{-2} levels of radiative forcing in year 2100, seemed to be the most widely used in impact studies worldwide. In [ESSD2017] as well as in subsequent papers originating from it (cf. Fig. 1) three common time slices spanning the periods 1971-2000 (control period) and two future horizons 2021-2050 (near future) and 2071-2100 (far future) were used.

The bias in annual means averaged over all raw simulations was 15.5 +/-4.39 mm/month for precipitation and 1.09 +/-0.65 ^{0}C and 1.64 +/-0.45 ^{0}C for minimum and maximum daily temperatures, respectively. For seasonal means, the largest bias was found in summer precipitation 26.4 +/-8.61 mm/month, mainly due to the convection, not well represented in the climate models. The same tendency, i.e. large bias in the summer compared to the other seasons, was also found for daily maximum temperature. In general, biases in maximum daily temperatures were 0.5 to 1 ^{0}C higher than those found in minimum daily temperatures. As shown in [ESSD2017], the bias correction method preserved both lower and higher order moments, not changing the magnitude of the climate change signal. In result, the spatial distribution of the climate change signal was consistent in all corrected simulations.

The produced bias-corrected data set was made available for use through a dedicated CHASE-PL web geo-portal http://climateimpact.sggw.pl to serve both researchers and a wider audience, including students, stakeholders and public authorities, as climate change science has not been disseminated widely in Poland to date (Kundzewicz and Matczak, 2012. The Geoportal stores in total 180 maps of projected variables (precipitation, minimum and maximum temperature) for two time horizons (near and far future), under two RCPs (4.5 and 8.5), for five temporal aggregation levels (annual and four seasonal) and three ensemble statistics types (5th percentile, median and 95th percentile). By including them, the geoportal informs end-users both about the magnitude and the spread of change (climate model uncertainty). The web-map application has the following functionalities: (1) meta-data searching; (2) searching by location; (3) identification of selected values on the map; (4) data download in NetCDF and GeoTIFF formats.

The bias-corrected climate scenarios data set constructed in [ESSD2017] was used for assessment of temperature and precipitation change in the Vistula and Odra basins in [MZ2017]. Even though an ensemble approach is now recognised as a standard in climate change science, aggregation of projections from different ensemble members, often counted in tens, into a single, informative and stakeholder-friendly map has always posed various challenges. When analysing climate projections from multiple models for a given location, two properties can be assessed: the level of agreement between models and statistical significance of change according to each model. A combination of these two properties is often referred to as robustness (Knutti and Sedláček, 2013). In [MZ2017] the robustness method of Knutti and Sedláček (2013) was adopted to Polish conditions. The proposed method holistically considers the magnitude of change, the sign, natural variability and inter-model spread. In simple terms, ensemble-based changes are assessed as robust if the majority of climate models agree on the change that is statistically significant (marked by stippling in the maps). When different models predict statistically significant change that differs substantially in terms of magnitude (and sometimes even in direction) across the ensemble, the results are assessed as "non-robust" and the corresponding areas on maps are marked in white, thus covering the ensemble mean change. When the majority of models suggest non-significant change, the areas on maps are hatched to mark "agreement on the lack of significance".

We found a robust increase in the annual mean of daily minimum and maximum temperature, by 1-1.4 ^{0}C in the near future and by 1.9-3.8 ^{0}C in the far future (areal-means of the ensemble mean values). The gradient of change went from SW to NE regions. Seasonal projections of both temperature variables reflect lower robustness and suggest a higher future increase in winter temperatures than in other seasons, notably in the far future under RCP 8.5 (by more than 1 ^{0}C). However, changes in annual means of precipitation are uncertain and not robust in any of the analysed cases, even though the climate models agree well on the increase. This increase was intensified with rising global temperatures and varies from 5.5 % in the near future under RCP 4.5 to 15.2 % in the far future under RCP 8.5. Spatial variability was substantial, although quite variable between individual climate model simulations. In the majority of cases, projected changes in mean annual and seasonal precipitation were not robust.

The ability to distinguish between robustness, inconsistency and no change in a spatially-explicit, transparent and user-friendly manner is an added value compared to all previous studies on ensemble-based projections of climate change in Poland. This method was later adopted for assessment of robustness of hydrological projections for the VOB in [HR2018] and [HP2017].

B. Macro-scale water resources analysis: historical conditions

The sub-set of papers in this group (Fig. 1) explores a wide variety of methods and tools for assessment of water resources in historical conditions: classification using clustering techniques and decision tree models [RRA2017], trend detection [AG2017] and large-scale hydrological modelling [HSJ2017].

River flow regimes vary in space and time on an extraordinary scale. The temporal scale spans from minutes (flash floods) to years (supra-seasonal droughts), while the spatial variability is controlled by catchment properties such as climate, topography, land cover, soils and geology. The goal of hydrological classifications is to simplify this huge spatio-temporal variability using strict discrimination criteria. In [RRA2017] paper the overarching methodological framework for hydrological classifications developed by Olden *et al.* (2012) was followed in order to classify semi-natural river flow regimes of Poland. The inductive reasoning approach was pursued, in which similarities among rivers are characterised according to a set of diagnostic hydrological metrics that vary spatially across the landscape. Inductive approach consists of several steps (Olden *et al.*, 2012): (1) acquisition and evaluation of hydrological data; (2) selection of hydrological metrics; (3) computation of hydrological metrics; (4) conducting the hydrological classification and (5) interpretation and spatial modelling of the developed classification.

Many countries (e.g. Canada, UK, USA) possess networks of gauges with long and uninterrupted river flow records from catchments with minimal anthropogenic activity – sometimes referred to as reference hydrometric networks, RHNs (Burn *et al.* 2012). Although Poland does not maintain its RHN, in the [RRA2017] paper an attempt was made to create a data set of gauging stations with RHN-like features. Gauging stations in river cross-sections terminating small to medium catchments with relatively unmodified flow regime were selected. Catchments were characterized by a good geographical coverage and sufficient length of the available river flow record. A comprehensive analysis of available GIS data was carried out in order to exclude catchments suspected to have a moderate or high degree of flow regime disturbance. Daily hydrographs for all gauges were inspected in order to identify dubious patterns. The final selection included 147 flow gauges, with mean catchment area of 856 km^2 (Fig. 2B). It was acknowledged that some, unavoidable, level of human-induced flow alteration was still present in most of selected catchments, however, some degree of disturbance has to be tolerated (cf. Murphy *et al*. 2013), and furthermore, the work done represented best effort to select the subset of least human-impacted gauges in Poland.

Classification was performed using k-means and k-medoids techniques. Out of seven distinguished classes, four (P1-P4) were spread across the Polish Plain, one (U5) was restricted to uplands and two (M6 and M7) to mountains. The between-class differences in hydrological metrics were generally high, although classes P1 and P3 were not easily distinguishable. Baseflow index, low flow magnitude, Colwell's flow predictability, high flow magnitude and daily coefficient of variation were among the most influential metrics. In the second stage a classification tree based on a random forest model was developed for class membership prediction based on climatic and physiographic catchment properties. Mean predictive accuracy of the developed model was 79% which was high compared to other studies of this type.

In terms of a possibility of a direct application of the results of the [RRA2017] study in water management practice, they seem to provide a solid hydrological basis for development of environmental flow framework for Polish rivers, which is currently demanded by the EU water legislation. The developed class membership prediction model could be applied across the entire network of Polish rivers, generating a high-resolution, national map of flow regime types, that would be a valuable asset in itself.

The issue of trend detection in long time series of river flow records, being a topic of the [AG2018] paper, is a very important task of vast theoretical interest and considerable practical relevance (Kundzewicz *et al*. 2005). Water management is based on the assumption of stationarity, hence it is crucial to check, on a regular basis and using updated records, whether taking this assumption is justified, i.e. whether statistical properties of the record can be regarded as approximately stationary.

River flow is the integrated result of natural factors, such as precipitation, catchment storage and evaporation, as well as catchment management practices and river engineering that alter the river conveyance system over time. This complicates the problem of detecting a climate change signature in river flow data (Kundzewicz *et al*. 2005). In order to assess climatically-forced hydrological changes, data should be taken, to the extent possible, from near-pristine drainage basins; that are not largely affected by human activities (urbanization, deforestation, reservoirs, drainage systems, water abstraction, river engineering etc.). Catchments featuring significant changes during the interval of records, related to land use and land cover or river regulation are not appropriate.

The set of 147 near-natural catchments identified in [RRA2017] was then used in [AG2018] for long-term trend detection in selected river flow indices describing annual and seasonal average conditions as well as annual extreme conditions. The special focus was on the spatial analysis of trends, carried out on a comprehensive, representative data set of flow gauges. Two separate analyses were carried out for two subsets of the original data set. One subset (A) comprised 57 gauges with daily data available for 61 years (1956-2016), while the other subset (B) comprised 144 gauges with daily river flow data available over the time interval of 36 years (1981-2016). The subset (A) was selected to maximize the duration of the time series of records, while the subset (B) was selected to maximize the station count and geographical coverage.

The non-parametric rank-based Mann-Kendall (MK) test for detection of monotonic trends (Kendall 1975) was used. The study focused on direction and magnitudes of trends and their spatial patterns rather than significance. Sen slopes (Sen 1968), which are quite robust to outliers, were calculated for estimation of trend magnitudes for each index and station.

The results suggested that there was a strong random component in the river flow process, the changes were weak and the spatial pattern was complex. Yet, the results of trend detection in different indices of river flow in Poland showed that there exists a spatial divide that seemed to hold quite generally for various indices (annual, seasonal, as well as low and high flow). The highest magnitude of decreases was noted for the low flow indicator in the shorter time period, in particular at latitude around 53°N. Decreases of river flow dominated in the northern part of the country while increases usually in the southern part. It seemed also that the magnitude of increases of river flow was generally lower than that of decreases. Stations in the central part showed mostly ‘no trend’ results. Two selected time windows demonstrated the sensitivity of the river flow process to the selection of the study period. The spatial gradient was apparent only for the data for the period 1981-2016 rather than for 1956-2016. The more recent period, however, was of more practical interest for water managers.

It was also found that some catchment properties had a fairly strong correlation with Sen slopes for different river flow indices. The strongest predictor of Sen slope was the distance from the geographical centre of the catchment from the Baltic Sea coast. In this context, one can interpret the existence of a clear divide of the country into two or three zones, depending on the latitude and distance from the coast.

The third study in this group, [HSJ2017], dealing with macro-scale modeling of water balance and streamflow in the VOB using the Soil & Water Assessment Tool (SWAT; Arnold *et al.*, 1998) also concerned water resources assessment for the historical period. SWAT is a process-based, continuous-time, semi-distributed hydrological model that has become a popular tool for dealing with water resources in large river basins and regions. The [HSJ2017] study coined a term ‘tailored calibration’ in relation to this type of models, which can be understood as a model application in which: (1) input data are not limited to free global-scale datasets, but take advantage of the country-scale or regional-scale datasets; (2) model calibration and validation involves a sufficient number of flow gauging stations to account for input heterogeneity and spatial variability in hydrological processes in the modelling domain. The literature review showed that there currently does not exist any model application that could be referred to as "tailored to the VOB". Several existing studies carried out using continental-scale models have some limitations from the point of view of using their output for evaluation of water resources and streamflow in the VOB and thus the need for a distributed process-based hydrological model tailored to the VOB seems to be well-justified.

A high resolution climate forcing dataset CPLFD-GDPT5 developed in [ESSD2016], as well as other national datasets available in Poland were used for model setup, as opposed to studies using free global and/or continental-scale datasets used so far. The model used a daily time step and the median size of modelling unit (10 km^2) was low compared to comparable studies carried out so far. The biggest challenge of large-scale modelling is however related to the model calibration process.

Calibration strategy should properly address the issue of the use of gauges impacted by water management in model calibration in the absence of water management in the model setup. Due to various reasons, e.g. lack of access to data, lack of ability in the model, etc. it is often not feasible to represent various aspects of water management altering natural streamflow in the models. Still, the observed human-influenced flow time series are often used for calibration of such models, that may lead to lower model performance and biased calibrated parameter values. To address this problem, we designed a novel approach for simulating natural (unimpaired) streamflow in the whole model domain, which can be summarised in the following steps:

1. Selection of a large and representative set of small, non-nested catchments with relatively unimpaired streamflow for spatial calibration ("benchmark" catchments). This step was similar as in [RRA2017], although the selected catchments were slightly different due to different spatial domains (Poland vs. VOB) and different additional requirements.
2. Clustering benchmark catchments based on flow regime similarity, following the approach outlined in [RRA2017] in order to derive homogeneous calibration areas.
3. Designing a regionalisation (parameter transfer) framework and selection of a large set of catchments for validation.
4. Performing model calibration in the set of derived clusters, followed by validation for a different time period.
5. Performing transfer of optimal parameter values from donor clusters to target ungauged sub-catchments using the hydrological distance approach and spatial **validation of the model** in gauges not used in calibration.

Model calibration and validation showed overall good behaviour for 80 benchmark catchments divided into eight clusters, whereas spatial validation for 30 gauges showed that the designed regionalisation scheme performed well (median value of the Kling-Gupta Efficiency KGE indicator of 0.76; cf. Gupta *et al.* 2009). The cluster-median daily KGE values were above 0.5 in both calibration and validation periods. One-to-one comparisons of model performance with studies carried out using different continental-scale models (e.g. mHM by Rakovec *et al.*, 2016; SWAT by Abbaspour *et al.*, 2015; HYPE by Donnelly *et al.*, 2016) clearly showed that the SWAT model developed in the [HSJ2017] paper outperformed them. It is expected that using a high-resolution input data, climate forcing data in particular, helped to achieve higher goodness-of-fit values than those reported in previous studies.

The SWAT model output (CHASE-PL Natural Hydrology data set – CPL-NH) was made available through a research data repository, as it can be used for a variety of purposes. First of all it is an extensive hydrological dataset that can be analysed with respect to both its spatial (e.g. regionalisation) and temporal (e.g. trend detection, flow alteration) dimensions. Baseline natural streamflow data are essential for setting environmental flows in rivers (Piniewski, 2016a). The calibrated model can be used for climate change impact assessment on water resources, which will be discussed in the following sections.

C. Macro-scale water resources analysis under climate change

In contrast to southern and northern Europe, expected changes in precipitation conditions in central and eastern Europe are less evident and more uncertain (Jacob *et al*. 2014). Mean renewable surface water resources in this part of Europe are rather low, which makes the question about the future river flows in this region particularly valid. Projections of future water balance and streamflow conditions can be obtained by forcing hydrological models with the output from climate models. Actually, mathematical modeling is the only meaningful way to establish projections of climate change impacts on freshwater resources. Physical laws and equations of mathematical physics hold true both in current and future climate, hence physically-based, distributed models hold the greatest promise for both advancing the science and achieving practically-useful information (Krysanova *et al*., 2016). Such projections are particularly important at macro-scale, such as country or large river basin level, as at these scales water policies are being planned and implemented.

In the series of three articles described in this section and depicted in orange in the diagram in Fig. 1, we employed the SWAT hydrological model [HSJ2017] driven with an ensemble of nine bias-corrected EURO-CORDEX climate simulations [MZ2017] to generate future hydrological projections for the VOB in two future horizons (2024–2050 and 2074–2100) under two Representative Concentration Pathways (RCPs). In the first, so-called data descriptor article [D2017], the data set called CHASE-PL – Future Hydrology (CPL-FH) consisting of future water balance and streamflow projections for the VOB was described. This has laid the groundwork for two subsequent original research articles, one focusing on analysis of impacts on mean annual and seasonal runoff (HR2018) and one focusing on hydrological extremes (HP2017). It should be noted that since the SWAT model developed in [HSJ2017] did not include water management in its setup, the projections discussed here present the pure effect of climate change, not damped or magnified by water management.

The CPL-FH data set builds upon three previously described, state-of-the art, high-resolution spatial hydro-meteorological data sets: climate forcing for the historical period (CPLFD-GDPT5, [ESSD2016]); hydrological simulations for the historical period (CPL-NH, [HSJ2017]; future climate forcing (CPLCP-GDPT5; [ESSD2017]. The CPL-FH data set, described in the [D2017] paper, was the last one in the chain, and closed the modelling matrix performed in CHASE-PL.

The data set consists of three parts: (1) model inputs; (2) raw model outputs; (3) aggregated model outputs. The first one allows the users to reproduce the outputs on their own or to create the new ones. The second one contains the simulated time series of 10 variables: precipitation, snow melt, potential evapotranspiration, actual evapotranspiration, soil water content, percolation, surface runoff, baseflow, water yield and streamflow, simulated by SWAT driven by climate projection data. In total, 46 different simulations being combinations of climate models, RCPs and future horizons were executed. Two types of output variables can be distinguished: sub-basin-level variables (water balance) and reach-level variables (streamflow). The former were aggregated to the monthly scale, due to a large number of variables and space limitations, and the latter were stored in the original daily scale. The third part of the data set consists of the multi-model ensemble statistics of the relative changes in mean seasonal and annual variables developed in a GIS format. The statistics include: 5-th percentiles, medians, and the 95-th percentiles of the relative changes in the multi-annual or multi-seasonal mean values of analysed variables between respective future horizons and the reference period. The statistics are calculated for all sub-basins and reaches, for two future horizons (always with respect to the reference period) under both RCPs. The aggregated model outputs can be also visually analysed in the interactive geoportal of the CHASE-PL project: http://climateimpact.sggw.pl (section Maps—Impact). This way of dissemination should be of interest of stakeholders, water managers and water-sector policy makers in the context of climate change adaptation.

In the [HR2018] paper maps of projected change in mean annual and seasonal runoff as well as monthly hydrographs of the Vistula and Odra rivers at their main outlets were elaborated based on model outputs from the [D2017] paper. The uncertainty originating from climate models was taken into account using the robustness approach previously used for temperature and precipitation projections for the VOB [MZ2017]. Annual runoff increases were found to dominate, regardless of RCP and future horizon. The multi-model ensemble mean of spatially averaged runoff increase varied between 15.8% (RCP 4.5, near future) and 41.6% (RCP 8.5, far future). The seasonal patterns showed the highest increase in winter and the lowest in spring, whereas the spatial patterns showed the highest increase in the inner, lowland part, and the lowest in the southern, mountainous, part of VOB. In general, at low warming levels the lack of statistical significance of changes dominated, hence hatching dominated throughout the projection maps. These changes were reflected in streamflow hydrographs simulated for the main outlets of the investigated rivers: advancement of maximum flows from April to March or even February, as well as a sharp increase in January/February flow were two most important characteristics. The main mechanism leading to runoff and streamflow increase was increased infiltration and sub-surface flow components (lateral flow and baseflow), whereas increases in surface runoff were low. A huge decrease in snow melt over March and April was expected to explain a decrease in surface runoff in spring.

Average annual and seasonal conditions do not reflect the full complexity of water resources. Since a number of extensive droughts and destructive floods have occurred in Poland in the last years (for example: droughts in 1992, 1994, 2006, 2008, 2015; floods in 1997, 2001, 2010), there is a well-founded presumption that future hydrological extremes hazard will increase. Hence, projections of low and high river flows are of considerable interest and importance. In the [HP2017] paper we developed projections of low and high flows in the rivers of the VOB. We calculated the low flow index QL, being the multi-annual average of 10th percentiles of daily flow, and the high flow index QH, being the multi-annual average of the 90th flow percentiles. Despite a substantial spread of flow projections, the main message of that study was that increases of both low and high flows are likely to dominate. The magnitude of increase of low flow was considerably higher (in relative terms) than that of high flow, that is, future streamflow droughts were projected to be less severe, whereas, in contrast, river floods were projected to increase. However, over large areas, projected changes were not statistically significant. The southern mountainous belt of the VOB was characterized by the lowest magnitude of change and this was particularly visible for high flows for which SWAT projections driven by different climate models agreed on the lack of a significant change for this area. In contrast, the inner, lowland, part of the VOB was subject to the highest magnitude of change.

In a broader perspective, an overall agreement of these findings for the VOB region with projections of hydrological extremes from both continental-scale models (Roudier *et al*., 2016; Papadimitriou *et al*., 2016; Alfieri *et al*., 2015) and conceptual catchment-scale models (Meresa *et al*., 2016; Osuch *et al*., 2016) forced by EURO-CORDEX results in the European-scale studies was noted in [HP2017]. It has to be noted, though, that in the case of using climate forcing data other than EURO-CORDEX, the consistency was lower.

Lower severity of droughts suggested by this study would be a good news for water management, drought risk reduction and climate change adaptation. High river flows were projected to be on the rise and this means a challenge for water management, flood risk reduction and climate change adaptation, since the presently existing flood risk reduction measures will not be sufficient. Yet, caution is needed when interpreting these results, for both low and high flows. First of all, selected indicators, QL and QH, do not represent the most extreme events, such as 100-year floods or droughts, but “average” extremes. As shown in the study of Wyżga *et al*. (2018) using the same SWAT model driven by the same set of climate projections for the Upper Vistula basin, the model spread of flood projections was correlated with the flood return period. Secondly, in the case of droughts, other types of them (e.g. groundwater or agricultural droughts) may behave differently than streamflow droughts.

D. Elaboration of water resources analyses under climate change after moving from macro-scale to meso-scale

All preceding articles dealt with either climate or water resources of Poland or VOB as viewed from macro-scale. Although this scale is highly meaningful from the water management perspective, in certain circumstances it is problematic to address some specific water resources issues. In the fourth, closing group of articles (depicted in purple in Fig. 1) we demonstrate two types of problems that at present can be more easily tackled at meso-scale than at macro-scale. The first one is the uncertainty of river flow projections due to hydrological model choice and the second one is projections of water quality. In the first case, the motivation is driven by the globally growing number of hydrological climate change impact assessments derived using different hydrological models. The present understanding of the magnitude of the effect of hydrological model choice on runoff projections is limited. Outside Poland, there have been some promising initiatives focused on model inter-comparisons such as ISI-MIP, in which several different hydrological models were driven by a consistent climate forcing in several large river basin on six continents (Eisner *et al.*, 2017). In Poland, as suggested in [HSJ2017], the SWAT application for the VOB was the first of this type at the macro-scale. Hence, the only way of carrying out the inter-comparison was to focus on a small subset of catchments within the VOB for which other hydrological models were developed and driven by consistent climate forcing. This was the case of the [AG2017] paper.

In the second case, it is evident that the future outlook of water quality might be at least as important for decision-makers as the one of the water quantity. However, application of process-based, distributed water quality models is extremely rare at the macro-scale, due to the fact that it heavily relies on human pressures data (e.g. fertilization rates, point sources) at sufficient resolution, which are often difficult to obtain. The SWAT model has an erosion and sediment transport component as well as a nutrient flow and transport component that enable for tracking sediment, nitrogen and phosphorus pollution in water bodies. However, application of this component for the entire VOB and subsequent calibration was not feasible, hence it made more sense to select sub-catchments of the VOB for studying the effect of climate change on water quality. This was the case of the [W2017] paper.

In the [AG2017] paper the analyses were based on the SWAT model output extracted from the macro-scale SWAT-VOB model for the future climate horizons (cf. [D2017]) and the output of the lumped, conceptual HBV model calibrated and validated for eight small and medium-sized catchments within the CHIHE (Climate Change Impacts on Hydrological Extremes) project (Romanowicz *et al*., 2016). Eight catchments having different physiographic and climatic conditions were analysed: four mountainous catchments Nysa Kłodzka (hereafter: Nysa), Wisła, Dunajec, and Biała Tarnowska (hereafter: Biała) and four lowland catchments Oleśnica, Myśla, Flinta and Narewka. River flow projections from these eight catchments for two future time horizons and RCP 8.5 scenario were compared. Climate projections in both studies originated from the common EURO-CORDEX dataset comprising seven RCM simulations, but they were different e.g. due to different bias-correction approaches. The main difference between the applications of SWAT and HBV was the fact that the HBV model setups were created for each catchment individually, while for SWAT, the model setup was created for two large river basins of the Vistula and the Odra. Another important difference was the climate forcing used for the historical period and for training of bias correction. In the case of SWAT, in both cases the CPLFD-GDPT5 data set [ESSD2016] was used, whereas in the case of HBV climate data from between 1 and 5 stations were interpolated for each catchment using the Thiessen polygon method.

Both hydrological models agreed on the dominating upward direction of change in the mean annual flow in all catchments and time periods, although four mountainous catchments: Biała, Dunajec, Nysa and Wisła, had variable directions of change in the near future. In general, there was a high agreement among hydrological models on the magnitude of change in the near future, whereas in the far future there was a high. Both, the magnitude of projected change, and the climate model variability grew with time for most catchments. The highest discrepancies were noted for the lowland catchments. For seasonal flows, there was also a relatively good agreement between hydrological models in the near future and a much weaker agreement in the far future. In winter season, increases were dominating throughout all combinations of catchments, models and periods. For seven out of 16 cases, SWAT flow projections are statistically higher than HBV projections in winter. Mean spring discharge in the far future was projected to increase according to the HBV model in each catchment, whereas according to SWAT it was projected to increase only in lowland catchments. Projected flow changes in summer and autumn seasons also considerably diverged in the far future. Increases in summer flow projected by SWAT were significantly lower (even two or three-fold) than the corresponding values from HBV. For the Dunajec catchment, summer flow simulated by SWAT was projected to decrease according to most of climate models, whereas changes in the opposite direction were simulated by the HBV model. On the other hand, there was a fairly good agreement among the two models on projected changes of flow in the autumn season in the mountainous catchments and the Narewka catchment. The results also showed that the lower the runoff coefficient, (1) the higher the change in mean annual flow for both models; (2) the higher the difference in mean annual flow changes between two models. A part of the difference could be attributed to generally lower precipitation increases used as future climate forcing in SWAT compared to HBV.

In summary, this study showed that future flow projections have a large spread that has its origin in different representation of hydrological processes in models, differences in temperature and, particularly, precipitation projections and their bias correction. The reasons for large differences in annual and seasonal flow projections between HBV and SWAT, frequently exceeding 100% for the Myśla, Flinta and Oleśnica catchments in the 2071-2100 horizon, remain unknown at this stage and require further investigation. It is clear that such water-limited, groundwater-dominated catchments are more challenging for hydrological modeling. Considerable differences in results of both projects create a serious interpretation issue for practitioners dealing with climate change adaptation and water management.

Modelling of climate change effects on water quality with the help of SWAT was performed in the Upper Narew and the Barycz catchments in the [W2017] paper. These two catchments were selected because they represent two types of conditions characteristic for the Polish Plain: a lower anthropopressure on water resources in the East (Upper Narew), and a higher anthropopressure in the West (Barycz). The catchments moderately differ in terms of climatic conditions and land cover, whereas they differ substantially in soil and hydrological conditions. Agriculture in the Barycz catchment is much more intensive, population density and urban pressure is much higher, and there is a large number of fish ponds in the upper catchment. Observed concentrations of total nitrogen (TN) and phosphorus (TP) in surface waters of the Barycz catchment largely surpass the Good Ecological Status thresholds. The northern part of the Barycz catchment has been designed as the Nitrate Vulnerable Zone (NVZ).

The climate forcing from [MZ2017] and some of the input data from [HSJ2017] were used in this study. The analysis were restricted to RCP4.5. Three water quality indicators were considered, i.e. catchment-averaged sediment, TN and TP losses, i.e. the amount of sediment, TN and TP that is transported from land (sub-basins) to the river network (kg ha^{-1}). An increase in mean annual sediment losses in both catchments was projected. Projections followed, to some extent, changes in surface runoff, showing an increase in sediment losses in winter and summer in the Upper Narew catchment, as well as a decrease in winter and an increase in summer in the Barycz catchment.

Mean annual TN losses in the historical period were nearly three-fold higher in the Barycz catchment (5.6 kg ha^{-1}) than in the Upper Narew catchment (1.9 kg ha^{-1}). This was likely related to different levels of human pressure in both catchments. Ensemble median increase by 35 % in TN losses was projected for the Barycz catchment in the far future, whereas an increase by 45 % was projected for the Upper Narew catchments. In both catchments, but particularly in the Barycz catchment, the highest increase was projected to occur in winter season. This may be explained by a high projected increase in percolation and baseflow in winter. The timing of maximum TN losses in the Barycz catchment was expected to be shifted from spring to winter.

The differences in present-day agricultural intensity (assumed unchanged for the climate change scenarios) were likely to explain differences in the mean annual TP losses for the reference period, i.e. values that were nearly twice as high in the Barycz catchment as in the Upper Narew catchment. Projections showed moderate increases for the Upper Narew catchment and high uncertainty for the Barycz catchment. However, seasonal patterns were slightly different. In the Barycz catchment, the most distinct signal was projected in summer, which was related to an increase in precipitation in this season. In contrast, in winter, TP losses were projected to decrease. In the Upper Narew catchment, increases were prevailing in winter and summer, whereas small decreases occured in spring. Autumn was the season with high model spread.

Even though simulations forced with RCP 8.5 were not done for water quality models, it can be expected that with a higher magnitude of increase in winter runoff associated with this RCP (discussed in [HR2018]), even higher TN losses would be projected. This is related to the fact that there is a strong correlation between runoff and TN (in particular nitrates) for Polish lowland rivers, caused mainly by high mobility of nitrates not being assimilated by plants during the dormancy season and being transported to streams via lateral and groundwater flow.

For water resources management in Poland, the message from the [W2017] paper is mixed. Increased lateral and groundwater flow is expected to trigger an increase in TN losses, particularly in the Barycz catchment characterized by a high fraction of land vulnerable to nitrate leaching. These results suggest that climate change may require additional adaptation actions on top of the "business-as-usual" actions aimed at non-point source pollution mitigation in Poland. Future studies should asses what kind of measures would help achieve the highest reduction in future TN losses, particularly in the more vulnerable Barycz catchment. Since the majority of the projected increase in TN losses occurred in winter season, it is expected that maintaining vegetative cover on agricultural fields in winter could be a good solution to prevent future TN losses (Piniewski *et al*., 2014).

Summary

As part of the presented scientific achievement, the following issues were solved:

- four unique hydrometeorological data sets with a high spatial resolution have been developed, covering the river basins of Odra and Vistula (VOB): (1) a set of climate data for the historical period; (2) a set of climate data from bias-corrected regional climate models; (3) a set of results of hydrological simulations for the historical period; (4) a set of hydrological simulation results for future time horizons.

- the first classification of semi-natural flow regimes of Polish rivers was carried out and a prediction model of class membership based on catchment parameters was developed.

- detection of trends in selected flow characteristics in a large and representative collection of Polish rivers was carried out using the most recent measurement data up to 2016.

- a distributed, process-based hydrological model for the VOB area was built, calibrated and validated, which was the first such an achievement for these river basins.

- the developed hydrological model was used to assess the impact of expected climate change on river runoff in average and extreme conditions, and on soil erosion and nitrogen and phosphorus loss (on the example of two smaller catchments).

- in the developed maps of climatic (precipitation and temperature) and hydrological (river runoff, extreme flows) projections, a *robustness* method was used on projection maps taking into account the consistency of projections obtained from a series of models included in the ensemble and statistical significance of changes.

- a comparison of hydrological projections obtained from the SWAT model with projections from the HBV model was carried out, which allowed for the first, in Poland, assessment of hydrological modelling as a source of uncertainty in determining the impact of climate change on the river flow.

A practical use of the above results can be expected, in particular by:

- use of developed data sets disseminated in publicly available scientific repositories and on web-mapping systems for various purposes, including those related to the adaptation of various sectors, especially water management, to climate change.

- using the developed, calibrated and validated SWAT model for the VOB area as a tool for assessing current and future water resources, not only in the context of climate change but also changes in land use, water management, etc.

- using the developed classification of flow regimes and the class membership prediction model to create a detailed map of the semi-natural regimes of the Polish rivers.

As regards the first of the three points mentioned above, some of the developed data sets, i.e. the results of high flow projections, are currently used in the update of the Initial Flood Risk Assessment carried out by SWECO and the Institute of Meteorology and Water Management at the request of the National Water Management Authority.

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5. Description of other scientific achievements

My scientific sensitivity and the subject matter of research have been shaped to a large extent already during my studies at the College of Inter-Faculty Individual Studies in Mathematics and Natural Sciences (MISMaP) at the University of Warsaw. From the beginning of my studies, I was most interested in the use of mathematical tools to describe natural phenomena, especially hydrological processes and systems. However, only after obtaining a master's degree and starting doctoral studies at WULS-SGGW, I was able to start a systematic and long-term work on hydrological modeling - initially as part of the European project SCENES, in which I was one of the main contractors. My first important article from that period [28], concerning the multi-site calibration and validation of the SWAT model in the Narew basin, was, as it turned out, one of the first in which the issues of appropriate model calibration for large catchments using data from a large number of flow gauges were discussed. This was reflected in a considerable number of citations in the Web of Science database (17 as of May 2018).

Hydrological modeling, especially with the use of distributed, process-based models such as SWAT, has since then remained the dominant subject of my research until today. In another work on the Narew basin [15], I analyzed the impact of the scale of the spatial model operation on the results of hydrological projections on the example of the "accurate", catchment SWAT model and "less accurate" continental WaterGAP model. The results of the simulation of the latter model were obtained thanks to cooperation with the Center for Environmental Systems Research (CESR) of the University of Kassel (Germany).

Around the same time, I started working on the setup and calibration of water quality models. In the first successful implementation of the SWAT model in this scope [49], model works were carried out in the small Reda catchment in Pomerania. The next example concerned the Pilica catchment [19], which is larger than Reda catchment, and the following were the Upper Narew and Barycz catchments [50]. In all these catchments, modelling involved at least one of the forms of nitrogen (most commonly TN, NO_3-N) and phosphorus (most commonly TP, PO_4-P). In the majority of cases, the goodness-of-fit criteria showed greater reliability of simulations of nitrogen forms than phosphorus forms, which could be interpreted by greater mobility of nitrogen (nitrates) and its higher correlation with river flow and by imperfect description of phosphorus transport in the SWAT model. The developed models were later used for various purposes, which will be discussed later in the text.

At the same time, when working with the SWAT model developed for the Pilica catchment, I took up the topic of the influence of the method of interpolation of precipitation data on modelling results. The published article [20] was an extension of the master's thesis of Mateusz Szcześniak, prepared under my supervision, which won the first place in the 6th edition of the Kazimierz Dębski competition for the best diploma thesis in hydrology in 2014. Both in the master's thesis and the article it was shown that the use of simple (Thiessen's method, IDW method) and more complex (kriging) methods of interpolation of precipitation data leads to better flow simulation results than the default method used in the SWAT model.

In the following years (2015-2017), my scientific work was mostly connected with participation in the Polish-Norwegian project CHASE-PL (cooperation with the Institute of Agricultural and Forest Environment of the Polish Academy of Sciences and Met Norway) and a parallel stay on the scholarship of the Alexander von Humboldt Foundation at the Potsdam Institute for Climate Impact Research (PIK) in Potsdam. Articles included in the series described in point 4 of this document were not the only ones that were created as part of this project and fellowship: two other articles partly related to hydrological modelling [23, 25] were published in high-rated journals, i.e. Environemtnal Science & Policy (IF 3,751) and Science of the Total Environment (IF 4.9). In the first one [23], devoted to the uncertainty in assessing the impact of climate change on the water resources, various sources of uncertainty and ways to reduce it in three areas: (1) data and information; (2) climate models and (3) hydrological models, were systematically discussed. In the second one [25], multi-thread article devoted to the holistic approach to reducing flood risks in the Upper Vistula catchment, my participation consisted of developing projections of changes in selected flood quantiles.

My experience with hydrological modeling was not limited to the Polish catchments. In 2013, I joined the bottom-up initiative of the environment of users of hydrological models dealing with the impact of climate change on the outflow under the name of Regional Model Intercomparison Project (RegMIP). This initiative, in which dozens of people from research centres around the world participated, was a part of the ISIMIP project (Intersectoral Model Intercomparison Project) coordinated by PIK. The SWAT model developed by myself with colleagues from the University of Sydney, developed for the Darling basin in Australia, was used in this project to estimate the impact of climate change on river flow. These results were used in several articles in the special issue of the journal Climatic Change (IF 3,496), and in particular in the article on flow seasonality of 12 large rivers on six continents, of which I was a co-author [22]. The mathematical model of the Darling basin itself was developed as part of a master thesis carried out under my supervision.

Concluding the topic of research using hydrological models, I would like to emphasize one particular publication, of which I am a co-author, namely the chapter in the book Handbook of Applied Hydrology, Second Edition edited by Vijay P. Singh [39]. This 1440-page and 156-chapter work is a continuation of a book considered a milestone in hydrology, i.e. the Handbook of Applied Hydrology edited by Ven Te Chow published in 1964. The chapter of which I am co-author concerns the assessment of the impact of climate change on water resources and discusses such issues as a description of the methodology of such an assessment, the choice of the appropriate tool (model), review of commonly used basin-scale or regional-scale models and methods for assessing uncertainty and ways to reduce it.

The previous description focused on the achievements closely related to the mainstream of my research interests, i.e. hydrological modelling, but these issues do not exhaust all my interests. As one can see from the list of publications (Att. 3.II), there are quite a few of these additional trends, however, two distinctive ones can be distinguished: one related to ecohydrology and the other one to agriculture.

Within the aforementioned SCENES project carried out in parallel with the period of my doctoral studies at WULS-SGGW, I dealt with the issue of environmental flows, and in particular the requirements of some fish species and riparian wetland communities regarding the characteristics of the flow regime [1]. In subsequent works (of which some of the results can be found in my doctoral dissertation) I analysed the impact of climate change on selected environmental flow indicators using SWAT and WaterGAP models [12] and the degree of meeting the needs (in terms of flow) of biota, that were treated similarly to other water users. In all these articles, I worked closely with my colleagues at the Centre for Ecology & Hydrology (CEH) in Wallingford, and the articles themselves were also created thanks to the frequent short-term research visits at CEH that I did at that time.

Thanks to the work in the Polish-Norwegian Kampinos project coordinated by SGGW in 2008-2011 and cooperation with the University of Oslo, I participated in the development of a simple GIS-based model, which aimed to assess the effectiveness of selected restoration activities against the degradation of wetlands at in the Kampinos National Park. The developed approach allowed for the prediction of the change in the state of soil and vegetation degradation with the help of conditional probabilities dependent on the depth to the groundwater table. The results were published in the form of monograph [31] and an article in the journal Ecological Engineering (IF 2.958) [14].

The issue of degradation of wetlands and their hydrological conditions was also connected to my participation in the development of the Narew National Park (NNP) Protection Plan in 2014. A simple, conceptual water balance model for the NNP wetlands was developed and the impact of possible variants related to external (climate change, change in the control of the Siemianówka reservoir) and internal (change of vegetation) factors was analysed for long-term changes in this balance. The results indicated the dominant influence of the climatic factor, which was presented in a later scientific publication [26]. Research on the impact of climate change on hydrological aspects of wetlands has been continued on a macro scale (the Odra and Vistula basin) under the Polish-Norwegian project CHASE-PL [38]. At present, a doctoral thesis devoted to these issues is being realized at SGGW, in which I act as an co-supervisor (cf. Att. 3K).

Concluding the topic of ecohydrological research, I would like to draw attention to the publication, which I consider to be the most important in this group, concerning the role of hydrological droughts and floods in shaping selected biological indicators quantifying the state of fish and invertebrates [21]. This publication was the result of my participation in the European project REFORM and continued cooperation with CEH. The systematic search of scientific databases focussed on finding articles describing in a quantitative way the impact of hydrological extreme events on fish and invertebrates in European rivers. The responses of fish and invertebrates to the events of a given type (drought or flood) were compared as well as the differences between the responses of biota to drought and floods. These studies can be considered pioneering, which was reflected in the prestigious Ignacio Rodriguez-Iturbe Publication Award given to the author team by the editors of the Ecohydrology journal (IF 2.852) for the best scientific article published in this journal in 2017.

Analysing my achievements regarding the second of the additional research topics (agriculture), it can be noted that my work initially concerned the assessment of the effectiveness of protective measures aimed in reducing nitrogen and phosphorus contamination in agricultural catchments, i.e. the Reda catchment or the Pilica catchment. Among the analysed protective measures were: avoidance of fertilization in high risk areas, application of soil cover in the autumn and winter season (catch-crops), construction of buffer zones and construction of artificial wetlands. In the case of the Reda catchment, two scenarios of the future development of agriculture in the catchment were also developed - partly as part of the Baltic COMPASS project: one based on extrapolation of historical trends and the other based on the assumption of strong intensification of agriculture following the West European model [18]. In the case of the Pilica catchment, the focus was on buffer zones (ecotons) for which field measurements were available in several transects in the catchment, performed by employees of the European Regional Center for Ecohydrology of the Polish Academy of Sciences (ERCE PAN) under the auspices of UNESCO [19]. The SWAT model developed in earlier works [20,49] was used to quantify the developed scenarios and to estimate the effectiveness of protective measures in both catchments. The results were of great practical importance, in particular they were used to develop a program of activities aimed at reducing pollution in the Pilica catchment by the Regional Water Management Authority in Warsaw.

The second aspect of the agricultural trend of my research was the topic of modelling the phenomenon of agricultural drought. The SWAT model for the DOW area, developed as part of the CHASE-PL project, was used to simulate the occurrence of extremely low levels of soil moisture under the main types of spring crops in Poland: spring cereals, potatoes and maize [39]. Simulations were verified based on the so-called crop weather indices calculated by collaborators from the Institute of Plant Cultivation and Soil Science - National Research Institute in Puławy. Projections of the occurrence of soil drought in the near future according to the RCP4.5 and 8.5 scenarios were also prepared.

The last example from the agricultural thread of my research was an article on the impact of climate change on the dates of sowing and harvesting spring barley and maize in Poland [24]. The work involved the projections of climate change developed as part of the CHASE-PL project. To assess the change in sowing and harvesting dates, the effective temperatures sum method implemented in a simplified version of the EPIC model constituting the plant growth component in the SWAT model was used. The model has been positively verified in terms of reconstructing the temporal and spatial variability of the sowing and harvesting dates of barley and maize in the historical period.

6. Summary of scientific output

6.1. Research activities

Summing up my list of scientific and research achievements, in the period 2008-2018 I published 51 scientific publications whose total number of points according to the criteria of the Ministry of Science and Higher Education is 933. I was the first author in 25 papers. As many as 43 out of 51 works worth a total of 853 points were published after obtaining the doctoral degree (November 2012). Publications included in the JCR database account for more than half of my publication output and over 90% in terms of number of points achieved (Table 1). Analysing selected bibliometric indicators according to the Web of Science database (Table 2), I would like to state that the value of the Hirsch index is currently 7, and has a strong growth potential. The total number of citations of my works by Web of Science is 154 (of which 90 are without self-citations), and the total Impact Factor has a value of 60,489. The results of my research were presented at scientific conferences in the form of 29 papers or posters, of which 23 were international events (cf. Att. 3L).

Table 1 Summary of publication activities (as of July 2018).

Publication type	Number	Number (after PhD)	MNiSW points	MNiSW points (after PhD)
Publications from the *Web of Science Core Collection*	28 (30)*	24 (26)	794	730
Publications in other journals	5	3	39	28
Monographs	1	0	25	25
Chapters in monographs (English)	9	8	45	40
Chapters in monographs (Polish)	6	6	30	30
Total	49 (51)	41 (43)	933	853

* Taking into account works published in 2018 but not included in the *Web of Science Core Collection* until 31.07.2018.

Table 2 Summary of bibliometric indices according to the *Web of Science Core Collection* (as of July 2018).

Indicator	Value
Number of publications of which: indexed in: - Science Citation Index Expanded (SCIE) - Emerging Sources Citation Index (ESCI) - Book Science Citation Index (BSCI) - Conference Proceedings Citation Index (CPCI)	28 24 1 2 1
Number of articles published or accepted in 2018 but not yet included in the WoS database as of 31.07.2018.	2
Citation number Of which: - without self-citations	154 90
Hirsch index	7
Total Impact Factor	60,489

6.2. Teaching and science popularisation activities

During the period of my employment at SGGW I was teaching 10 courses at three courses of study (cf. Att. 3I).

- Engineering hydrology, Engineering hydrology 2, Geoinformation systems at the course of study Civil Engineering (1st degree studies);

- Hydrology I, Hydrology II, Computer Foundations of Design, Spatial Information Systems, at the course of study Environmental Engineering (1st degree studies) and Modelling of water resources and Modelling in hydrology (2nd degree studies);

- Geoinformation in environmental protection at the course of studies Environemtnal Protection (1st degree studies).

I am the coordinator of the following courses: Modelling of water resources (Environmental Engineering), Modelling of diffuse pollution (Water Engineering and Management). I am also the author of the syllabuses for these courses.

In 2013 and 2015 I was a supervisor of two master thesis defended at the course of studies Environmental Protection (Att. 3J). The first theses written by M.Sc. Mateusz Szcześniak was awarded with the first prize in the 6th edition of the Kazimierz Dębski competition for the best diploma theses in hydrology organized by the Association of Polish Hydrologists in 2014. I am currently a supervisor of one more master theses at the Cnvironmental protection course of study. In 2018 I was an external reviewer in a Master theses submitted at the course of study Geospatial Information Science at Flinders University in Australia.

My science-popularization activities were related to two lectures: one given in 2010 for the students of Jan Kasprowicz High Scool in Inowrocław and the second one in 2013 during the "GIS Day – GIS in the capital. Man – Environment – Technics" Conference.

I conducted two training lectures in 2013: one during the workshop for the employees of the Łódź Agricultural Advisory Centre "Buffer zones and other measures mitigating diffuse pollution from agricultural areas"; the second one during the XXIII National School of Water Management "Modelling in planning and management of water resources".

I participated twice in round table discussions related to scientific events: once during the „French-German-Polish Conference Water and Climate Change" in 2015 in Leipzig, where the topic of discussion was protection of water resources against climate change impacts; for the second time, during the workshop „CLIPC final demonstration and evaluation workshop" in 2016 in Brussels, where the topic was future perspectives of climate services in Europe.

Within the Polish-Norwegian CHASE-PL project I was involved in the merit-based coordination of the development of the first Polish interactive mapping service (geoportal) dealing with climate change in Poland: http://climateimpact.sggw.pl. One of the aims of this service was a wish to make available for the wide public reliable data on observations, projections and impacts of climate change in Poland. The portal was awarded the second prize in the competition of the best internet map of the year 2017/2018 by the Association of Polish Cartographers.

6.3. Organizational activities

A significant part of my organizational activity during the period of employment at SGGW consisted in the organization of various types of scientific events: conferences, seminars, workshops and trainings. Together with dr hab. Jarosław Chormański, prof. SGGW and prof. Raghavan Srinivasanem from Texas A&M University I organized four editions of the Central Eastern European SWAT Workshop in 2011, 2014, 2015 and 2016. In total, about 100 people attended the workshop and it can be said that these events contributed significantly to raising qualifications of many young scientists and practitioners from Central and Eastern Europe in the field of hydrological modeling. In addition, in 2015 and 2016, I organized the International Eastern European SWAT User Seminar. In 2017, I was a co-chairman of the organizing committee of the 2017 International SWAT Conference, which took place in Warsaw and gathered over 160 participants from over 40 countries. In 2018, I was the organizer of the Collaboration for Environmental Evidence (CEE) Systematic Review Methodology Course, which was organized as part of the BONUS RETURN project.

Prior to obtaining the doctoral degree, in 2009 I was the organizer of the workshops "The Red Bog Project International Workshop" organized as part of the Czerwony Bagno project. In turn, in 2010, I was the scientific secretary of the workshop "Modeling hydrological processes in the Narew basin" organized as part of the SCENES project by the Department of Hydrology and Water Resources of the Warsaw University of Life Sciences and the Institute of Geophysics PAS. In the same year, I took part in the work of the organizing committee of the first National Hydrological Congress, in which over 200 people took part.

My organizational activities at the Faculty of Civil and Environmental Engineering of SGGW consisted of on the membership of the Development Committee in the years 2012-2016, where I was the secretary of the team responsible for strategy and development directions of the faculty. In 2013, I took part in the works of the competition commission to evaluate applications under the MNiSW targeted subsidy to conduct in 2013 scientific research or development works and related tasks for the development of young scientists and participants of doctoral studies funded under the internal competition procedure.

In 2011, I was a member of the European Geosciences Union (EGU) and since 2018 I have been a member of the International Association of Hydrological Sciences (IAHS).