Department of the Hydrology and Hydrodynamics

About

Under the framework of NHH02 the following objectives have been achieved.

1. Flood Risk Assessment Methods. The aim of this objective is to investigate:

a) hydrological projections and reconstruction of past hydrological conditions. Two methods of aggregating statistical models for estimation of flood quantiles are compared, i.e. averaging the magnitudes of quantiles of the same order from candidate distributions and averaging over the probabilities of non-exceedance of the fixed flow value from the individual models.

b) closed form expressions for asymptotic standard error of design quantiles in complex flood frequency models. Standard errors have been developed for: seasonal approach to annual maxima quantiles; two methods of model aggregation and two stage non-stationary flood frequency analysis.

c) the methods and errors of the flood estimation when there is no systematic observations and only historical floods are known, inference based on type II left side censored samples.

2. Uncertainty related to the derivation of flood inundation extent including observations based on tele-detection:

The main goal of studies undertaken is the development of a methodology for the derivation of future projections of flood inundation extent. The idea of an emulator of a flow routing model is applied to shorten the computation costs. The research is further extended towards an application of remote sensing based on unmanned aerial vehicles (UAV) for the development, calibration and validation of distributed flow routing models. The application of low-cost, well georeferenced UAV images of river shorelines is an unprecedented source of distributed observations.

3. Modelling of transport processes. The aim of this objective is to investigate:

a) water-vegetation interface in open channel flow. The results indicate that seasonality significantly affects the shear layer dynamics in vegetated channels, with implications on lateral transport of mass and momentum. We demonstrate how vegetation can be incorporated into channel designs, to improve resilience to flooding, control the transport of substances, and how the vegetation encroaches on fluvial sandbars. As far as the interactions between turbulent flow and representative flexible submerged vegetation are concerned, results showed that both morphological and biomechanical traits may cause certain flow disturbances, where water velocity and turbulence were diminished.

b) effect of water-air heat transfer and impact of initial conditions on the prediction of the spread of thermal pollution in river.

c) experimental studies on gravity currents and sedimentation of particles in complex ambient conditions. A methodology for experimental study of gravity currents and measurement methodology using image analysis methods have been developed and tested.

4. Modelling of hydrological processes. The aim of this objective is to investigate:
a) innovative metaheuristics and their application to the calibration of hydrological models. A detailed review and intercomparison of metaheuristics that belong to very successful JADA and SHADE family of methods has been given. Based on this experience, an important innovation has been added to four recent L-SHADE variants. It was shown that the modified versions outperform former algorithms on large number of optimization problems.
b) relationship between calibration time and final performance of conceptual rainfall-runoff models. Two models were tested (HBV and GR4J), each applied with or without error correction procedure, and with three calibration procedures (GLPSO, MDE_pBX and SPS-LSHADE-EIG) at five catchments Biala Tarnowska and Suprasl, Poland, Cedar River, Fanno Creek, and Irondequoit Creek, USA located in temperate climatic conditions.
c) performance of the air2stream model that relates air and stream water temperatures. In the study 12 optimization algorithms were tested for the calibration of the air2stream model with eight parameters, for hydro-meteorological daily data from six streams located in USA, Poland and Switzerland. It was shown that the performance of the air2stream model largely depends on the selected calibration procedure.
d) the hydrology of a small Arctic permafrost catchment. The overall aim of the study was to examine the relationships between temporal changes of active layer depth and hydrological model parameters, together with variation in the catchment response. The analysis was carried out for the small unglaciated catchment Fuglebekken, located in the vicinity of the Polish Polar Station Hornsund on Spitsbergen.

Personel

Head of the Department
Jarosław Napiórkowski
Professor

Paweł Rowiński
Professor

Renata Romanowicz
Professor

Marzena Osuch
Associate Professor

Krzysztof Kochanek
Associate Professor

Adam Piotrowski
Associate Professor

Ewa Bogdanowicz
Assistant

Iwona Kuptel-Markiewicz
Assistant

Monika Kalinowska
Assistant

Michael Nones
Assistant

Emilia Karamuz
Assistant

Anna Łoboda
Assistant

Joanna Doroszkiewicz
Research Assistant

Research Project

- Impact of expected climate change on water temperatures of selected Polish rivers

  Piotrowski | NCN | 2017 -2020

- Hindcasting and projections of hydro-climatic conditions of Southern Spitsbergen

  Osuch | NCN | 2018 -2021

- Hydrological research using unmanned aerial vehicles (UAV)

  Doroszkiewicz, Karamuz | MN | 2017 -2018

- Comprehensive hydrological research of the Świder basin using modern measurement techniques

  Karamuz, Osuch, Łoboda | MN | 2018 -2019

- Seaweed reaction to mechanical stresses - a lesson of biomechanics of marine plants

  Łoboda | MN | 2018 -2019

- Experimental studies on the impact of density gradient in a liquid column on settling dynamics of non-spherical particles

  Mrokowska | MN | 2018 -2020

- Relationship of permafrost with geomorphology, geology and cryospheric components based on geophysical research of the Hans glacier forefield and its surroundings. Hornsund, Spitsbergen

  Osuch | NCN | 2017 -2019

- Field experimental investigation of hydrodynamics of water flow-vegetation-sediment interactions at the scale of individual aquatic plant

  Łoboda, Przyborowski | NCN | 2015 -2019

PhD Students

Łukasz Przyborowski | Poland
supervisor: Robert Bialik

Instruments and facilities

Equipment

Model 801 Electromagnetic Open Channel Flow Meter
Model 10 Field Fluorometer au-005-ce (sn.6857)
Fluorometer: (sn.800606)
YSI Professional Plus handheld multiparameter meter
GPS LEICA gx1230gg (sn.467006)
ProODO Optical Dissolved Oxygen Instrument
A wireless weather station Pro2™ Plus including UV & Solar Radiation Sensors
ADCP - acoustic Doppler current profiler model RiverSurveyor S5 (SonTek)
Bench Top Testing Machine 5ST (Tinius Olsen)
ADV - acoustic Doppler velocimeter (Sontek)
ADV - acoustic Doppler velocimeter (Nortek) (x2)
Cameras: GoPRO HERO 3 (x1), GoPRO HERO 3+ Silver (x2), GoPRO HERO 3+ Black (x2)
Microscope model Delta optical Genetic Pro Trino (Delta Optical)

Laboratory

Main equipment in Hydrodynamic Models Laboratory:
- Sony video camera
- high-resolution macro image acquisition system
- refractometer
- two hydraulic channels

Research activity and results

Flood Risk Assessment Methods

The parametric instability of hydrological models was analysed to develop hydrological projections as well as reconstruction of past hydrological conditions. We compared the two methods of aggregating statistical models for estimation of flood quantiles i.e., averaging the magnitudes of quantiles of the same order from candidate distributions, and averaging over the probabilities of non-exceedance of the fixed flow value from the individual models. The formulas for the asymptotic standard error of design quantiles were developed for both averaging procedures. A Monte Carlo simulation was used to illustrate the coverage probability that the confidence interval contains the true value of interest. The case study of two distributions with almost equal weights is presented in Figure A1. The work resulted in developing methods of estimating flood quantiles using a multi-model approach, which gives a more accurate and robust estimates of quantiles with long return periods. This method is currently being improved and developed.

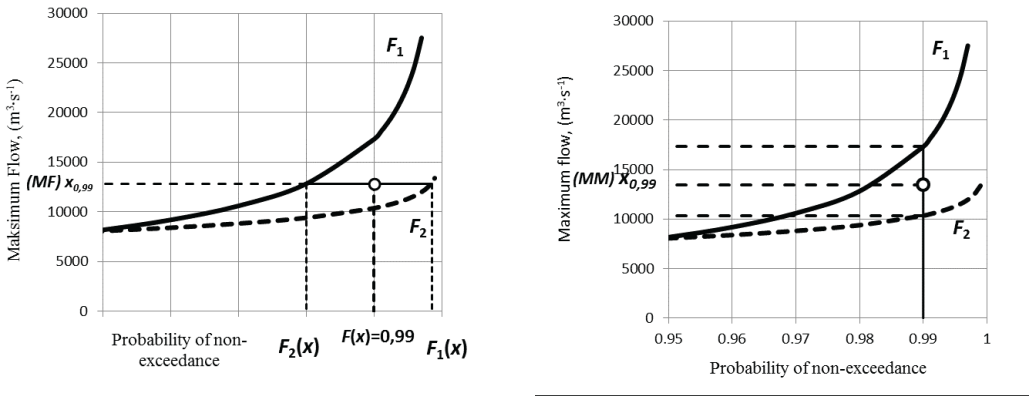


Figure A1 Two ways of aggregating/averaging distributions: a) aggregation according to magnitudes of quantiles (MM) and b) aggregation according to probability of non-exceedance (MF).

In areas where floods occur in two distinct seasons in a year a seasonal approach to estimation of annual maxima (AM) quantiles is required. The problem can be identified as an estimation of AM quantiles based on two-component distribution and assessment of accuracy/uncertainty of AM quantiles obtained in such way. The seasonal maxima distributions are estimated for each season separately using any estimation method. It is assumed that in each year seasonal maximum flow is regarded as a flood in the Flood Frequency Analysis (FFA), so its distribution is a continuous one, and moreover that seasonal maxima flood flows are mutually independent. The main subject is a derivation of a closed-form expression for accuracy of AM quantile estimated from two-component distribution. In practice seasonal statistical models can differ not only in respect of distribution types and parameters but also estimation methods used. The formula has been developed for asymptotic standard error of AM flow quantile estimate applicable for any pair of seasonal distributions commonly used in the FFA and any parameter estimation method with known variances of quantiles of the component distributions. It is the function of PDFs, CDFs and the quantile variances of both seasonal distributions. The version for dependent seasonal maxima has also been developed in the case of Archimedian copula function and

Inference Functions for Margins (IFM) method of estimation of copula parameter. AS the example Probabilities p1 and p2 for the hydrological station Sarzyna showing domination of winter or summer floods within the range of annual maximum flow Figure A2.

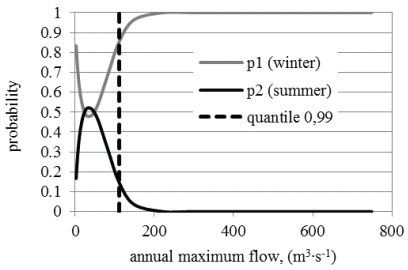


Figure A2 Probabilities showing domination of winter or summer floods within the range of annual maximum flow.

Additionally, as part of work on the analysis of the risk of flood occurrence, analytical formulae were derived to determine the confidence intervals of design quantiles for the methods used in the non-stationary analysis of the frequency of floods. In addition, software was developed to calculate the limits of confidence intervals by derived analytical formula. The results was compared with those obtained by Monte Carlo techniques. It is worth mentioning that the above-mentioned analytical elaboration of standard errors of flood quantiles is an original achievement of our team. Derived patterns were announced at the Third Congress of Polish Hydrologists, however, they are still the subject of research and testing and will soon be published in a major international journal.

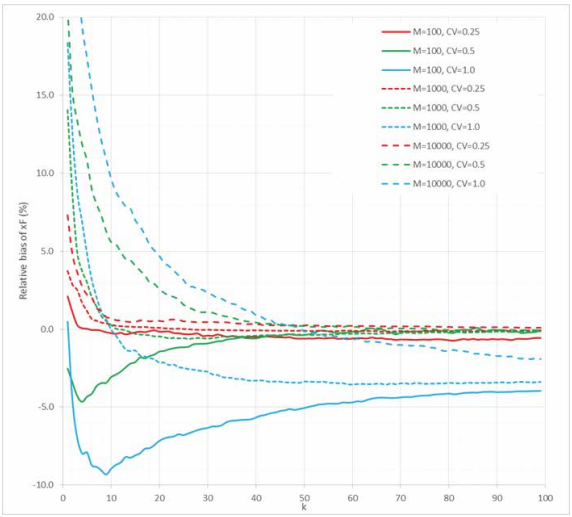


Figure A3 Bias of the upper quantile estimate by means of heavily censored dataset of historical information.

As part of the flood frequency task, research on the quality of flood estimation was also continued when only historical or prehistoric historical information about old floods is known. Such datasets are called heavily censored ones. The historical information is often incomplete, i.e. limited to the biggest floods, and culmination discharge is roughly estimated by means of high flood marks and historical logs. It is assumed that both data sets, complete and incomplete (heavily censored) historical series represent the same population. Therefore, these two sets can be combined into one sample modelled by the a statistical model whose parameters and quantiles are estimated. It turns out that using only historical information and appropriate statistical techniques, one can get a relatively accurate estimation of quantiles with a long return period - the quantiles bias is much smaller than expected. Preliminary results of the study were announced at the Congress of Polish Hydrologists. As an example we present the diagrams (Figure A3) showing the errors of estimation of quantile xT=100 years for heavy censored datasets when k elements of the historical peak flows are known within M-long historical period

for various coefficients of variation (CV). The historical data were generated by means of the Gumbel distribution function, and then the quantiles are estimated by the same model (true assumption of the distribution function). Contrary to our expectations and theoretical features of maximum likelihood method, the bias of quantile for heavily-censored sample does not disappear even for large k and M.

Uncertainty related to the derivation of flood inundation extent including observations based on tele detection

The main result of studies undertaken is the development of a methodology for the derivation of future projections of flood inundation extent until the end of 21st century. The idea of the emulator of a flow routing model was applied to shorten the computation costs of flow routing model. This idea is further explored and the review of analytical solutions to flow routing was presented and the relevance with the emulator-based flow routing model was shown. The research on flow routing in open channels was further extended towards the analysis of changes of river flow and its causes.

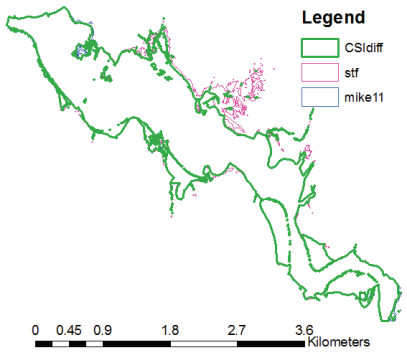


Figure B1 Maximum inundation extent of MIKE11 (blue), emulator of MIKE 11 (magenta) for the year 1997 for a part of the Tuchow meander and the CSI based difference (green)

Figure B1 presents the comparison of two maximum inundation contours at the Tuchow meander. The first contour is derived using the distributed MIKE11 model (blue line), the second (green line) presents the same maximum inundation area obtained using the MIKE11 model emulator. The results show that the differences between both contours are very small.

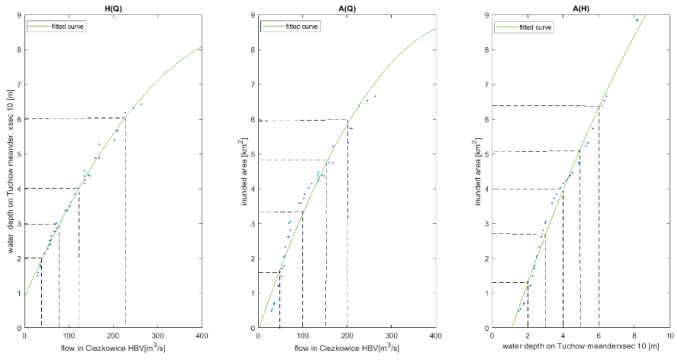


Figure B2 Dependence of hydrological input (annual maxima) and routing model predictions for Tuchow meander for the reference period 1971 - 2010; (a) water depth values on 10th cross-section of meander versus maximum annual flow, (b) inundation areas of Tuchow meander versus maximum annual flow; (c)inundation area versus maximum annual water depth at 10th cross-section of Tuchow meander, blue dots denotes the data, green lines denoted fitted curve to square polynomial.

Figure B2 presents the projected relationships between the water depth at Tuchow meander cross-section and flow in the Ciezkowice upstream (left-hand panel), relation of maximum inundation area and annual maximum flow in Ciezkowice (middle panel) and inundated area extent versus water depth at Tuchow meander (right-hand panel).

Those results may be used to derive the sensitivity of inundation area extent to changes of flow upstream related to climate changes.

In order to provide uncertainty assessment of the projections, apart from the uncertainty related to the MIKE11 emulator, also the uncertainty of MIKE11 distributed predictions is required. With this aim in mind, a series of experiments were planned using the unmanned aerial vehicles (UAV).

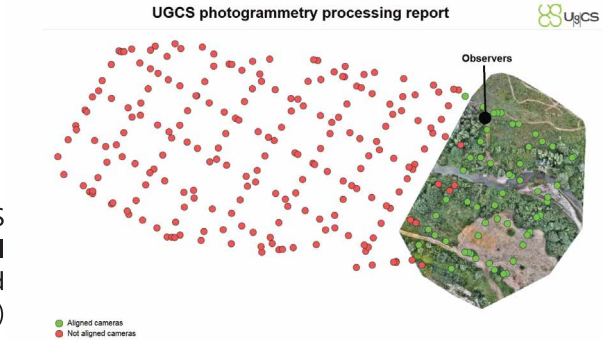


Figure B3. Report from the UGCS photogrammetry processing tool with flight pathways (red and green points)

Figure B3 presents a report from the UGCS photogrammetry processing tool obtained on the Tuchow meander subreach of the Biala Tarnowska. The aim of the experiment was providing the observations of shorelines at the meander studied in the paper of Doroszkiewicz et al. (2018) to help in the validation of a distributed model and its emulator and to derive the uncertainty bands of the predictions of inundation extent. The experiment is the first of the series planned for the future. Its results were used to improve the methods of obtaining the distributed images from the UAV.

Remote sensing based on unmanned aerial vehicles (UAV) is a novel approach and it is becoming popular due to its flexibility and fast decreasing costs. One of its most advantageous features is the possibility of acquisition of field data independently of weather conditions and a possibility of straight-forward analysis of georeferenced results nested in Geographic Information System. In particular, UAV can provide precise information about the location of a river shorelines. This information is particularly useful for the development, calibration and validation of distributed flow routing models. The application of low-cost, well georeferenced UAV images of river shorelines is an unprecedented source of distributed observations.

Further work aimed at exploring the potential for this approach to provide valuable information about the river shorelines at varying flow velocities. The River Świder, southeast of Warsaw and the Upper Narew River (Figure B4) are used as case studies. We applied DJI PHANTOM 4 unmanned quadrocopter which provides sequences of pictures. After geoprocessing they serve as a source of spatial digital data. UgCS software is used for campaign planning and post-processing of collected data. The HEC RAS 1-2-D distributed model will be used for flow routing. The calibration and validation of its roughness coefficients will be performed using vector-fitting criteria based on the comparison of modelled and observed river shorelines.

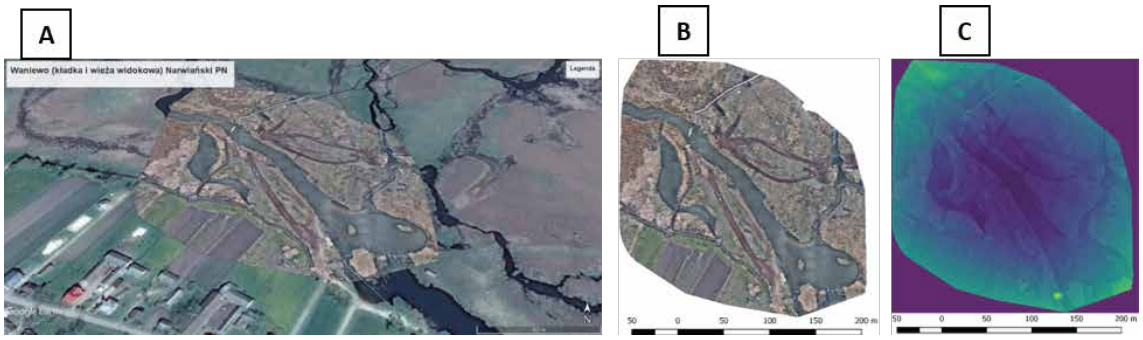
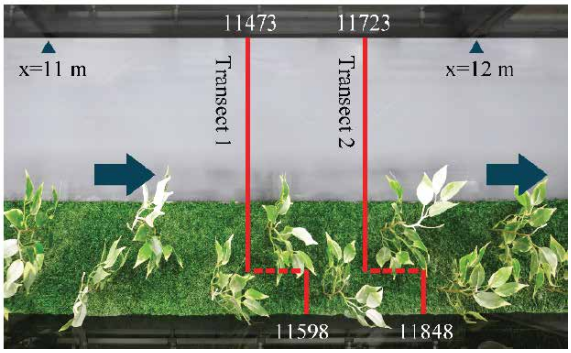


Fig B4. Orthophotomap (A, B) and DSM (C) from the UAV aerial photograph (Waniewo – Narew National Park)

Figure B4. presents orthophotomap and Digital Surface Model (DSM) of the side in the neighborhood of Waniewo in Narew National Park. The upper panel shows the general location of the area studied; the lower left panel presents detailed UAV photograph of the river reach and the right lower panel shows the DSM coverage. These images are used as a documentation of the present state of the Narew case study area.

Modelling of transport processes | **Turbulence at water-vegetation interface in open channel flow**

Riparian vegetation generally presents a complex and seasonally variable morphology that, together with its reconfiguration behaviour, deeply affects the flow in channel-vegetated bank systems. The aim of this research was to investigate the influence of foliation and flexibility-induced reconfiguration on velocity statistics, onset and coherence of turbulent structures, and turbulence anisotropy across the shear layer formed at the horizontal interface between vegetation and open water. The investigations were conducted in a laboratory flume that was partly vegetated to mimic emergent woody plants with underlying grassy understory. The natural-like vegetation exhibited a realistic reconfiguration behaviour with density and morphological characteristics comparable to those of woody riparian species. Seasonality effects were investigated using the same emergent woody vegetation under foliated and leafless conditions (see figure below).



Plan view of the Investigated transects for the foliated case

The mean and turbulent flow structure was determined with acoustic Doppler velocimetry, and dynamic plant motions were derived from video footage. The presence of morphologically complex plants, their reconfiguration behaviour and seasonal variability profoundly affected the overall characteristics of the flow. Foliation induced stronger cross section-scale mixing effects, whereas for the leafless vegetation the local effects induced by the stems were predominant. The interface coherent structures were found to be two dimensional with a characteristic frequency consistent with the canonical mixing layer theory.

Reconfiguration and dynamic plant motions affected the onset and coherence of interfacial large-scale turbulent structures by altering the vegetative drag and the drag discontinuity at the interface. Our results indicated that reconfiguration and seasonality significantly affect the shear layer dynamics in natural partly vegetated channels, with implications on lateral transport of mass and momentum through the cross section.

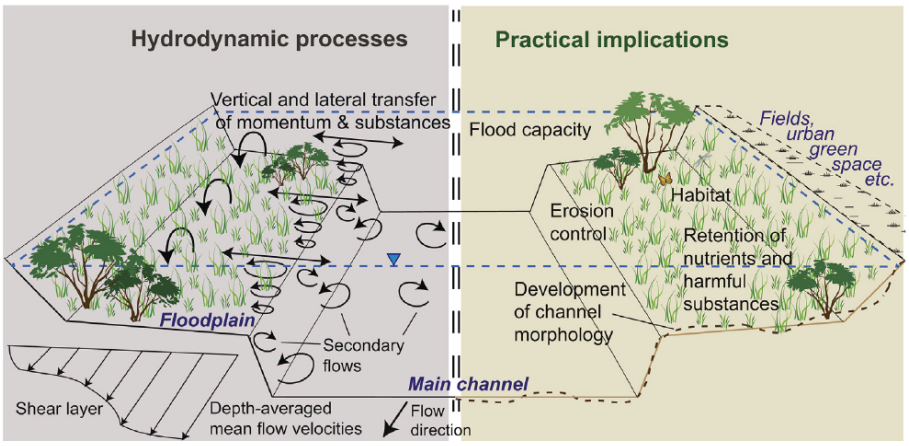
Modelling of transport processes | Flow structure through a fluvial pool-riffle sequence

Pools and riffles in gravel-bed rivers have a major effect on the variables of the flow equations. Obtaining measurements of these variables requires comprehensive research conducted in rivers. Detailed measurements were taken from one reach of the Kaj River, Iran. The subsequent results showed a phase shift for: X-component of velocity, near bed velocity in X and Z directions, and bed shear stress versus bed elevation profiles. In the riffle section, vectors of the vertical velocity component were oriented towards the bed. However, in the pool section, vectors were oriented downward close to the bed, and upward at higher levels. Quadrant analysis for the pool illustrated the dominance of ejection and sweep interactions near to the bed and near to the water surface respectively. However, in the riffle, outward interactions were dominant near the bed, and sweep interactions were dominant near the water surface. The spectral analysis revealed that flow over pool-riffle does not follow the scaling regime of Kolmogorov, used to illustrate the slope of −5/3 in inertial sub-range.

Local map of the selected reach of Kaj River

Modelling of transport processes | Vegetation as a tool for nature-based solutions (NBS) in river management

New sustainable, cost-effective solutions are urgently needed for river management since conventional practices have posed serious ecological threats on streams, rivers and the surrounding riparian areas. Besides addressing the societal needs e.g. for flood management, river management should increasingly address the ecosystem requirements for improved water quality and biodiversity. We argue that it is not feasible to solve existing and future river management challenges with intensive restoration projects. Instead, we believe that less resource-intensive solutions using natural channel processes and features, including vegetation, should be investigated. Besides directly supporting biota, aquatic and riparian vegetation traps, takes up and helps to process nutrients and harmful substances, and thus this paper emphasizes vegetation as a tool for NBS in river management. It has been shown that the fate of substances in channel systems is largely controlled by abiotic and biotic processes facilitated and modified by vegetation, including flow hydrodynamics, channel morphology, and sediment transport. Subsequently, we demonstrate how vegetation can be incorporated into channel designs, focusing on a two-stage (compound) design to improve resilience to flooding, control the transport of substances, and enhance the ecological status. As a conclusion, clever use and maintenance of vegetation present an unused potential to obtain large-scale positive environmental impacts in rivers and streams experiencing anthropogenic pressures.



Two-stage channel design offers flood capacity while floodplain vegetation controls sediment deposition and nutrient retention.

Modelling of transport processes | The vegetation encroachment on fluvial sandbars

Starting from the case study of a reach of the Po River (Italy), monitored during the last two years in collaboration with the University of Bologna, we are studying the vegetation encroachment on fluvial sandbars by means of satellite imagery, evaluating the changes of the Normalized Difference Vegetation Index (NDVI). This index can be validated against field information retrieved from a fixed video camera that operated in 2017-2018, after rectifying the images based on ground control points. The study will provide additional insights into the ongoing discussion about the oversimplification of this river because of a decrease of water/sediment discharge due to the anthropogenic pressure. Indeed, a lower variability of flow and an increase of drought periods contributed to provide optimal conditions for the vegetation growth, contributing to stabilize the existing bars and to trap suspended sediment.

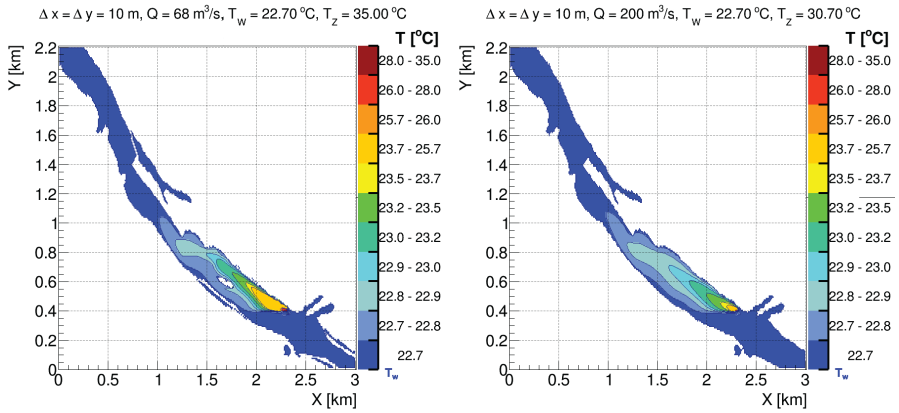
Within the same collaboration, several data were acquired regarding a tributary of the Po River, the Secchia River. In this case, our work is towards the development of a rating curve between the concentration of suspended sediments and the backscatter signal coming from a horizontal Acoustic Doppler Current Profiler. Most of the work is already done, but a comparison with similar data of the Albanian river Devoll will be done in the next months.

Thanks to the several data available for both rivers, aside from these studies some numerical simulations will be performed, aiming to provide future scenarios in response to changing hydrology (climate change) or possible management strategies. These simulations will be made using freeware codes like Hec-Ras and iRIC, as well as commercial models like CCHE2D, depending on the aims, which are still under evaluation.

Modelling of transport processes | Impact of initial conditions on the prediction of the spread of thermal pollution in rivers

Thermal pollution is a result of any unnatural process that changes ambient water temperature. It is often caused by discharged heated water used for cooling purposes. Since the increase of water temperature may be dangerous for the environment, prediction of possible increase of water temperature caused by an artificial heat source is of crucial importance. Such predictions are usually made using numerical models where the choice of initial conditions for which the prediction is made constitutes a key problem. In principle, such predictive computations should be performed for the most severe situations from the environmental point of view. But the choice of such conditions usually requires an in-depth analysis of the historical data for a particular case.

The influence of initial conditions on the prediction of the increase of river temperature below the point of release of heated water for a designed power plant has been analysed in this study. The results for different assumed values of river flow and different temperatures of the discharged heated water have been presented. The two-dimensional in-house RivMix model has been used to simulate the temperature distribution whereas the two-dimensional depth-averaged turbulent open channel flow model CCHE2D has been used to simulate the velocity fields and the water depths for the selected flows of the river.

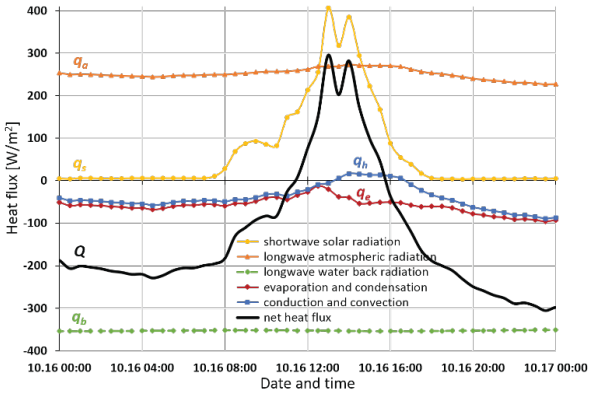


Predicted 2D temperature distributions within considered river reach for the selcted case – the worst (left) and the best (right) scenarios.

We fully realize that the influence of initial conditions on final results in boundary value problems dissipates and the temperatures of water tend to the same values no matter what initial conditions we set. However, the speed at which this influence dissipates reflects different patterns of the transport of the heated water plume. This pattern is crucial since we are extremely interested in determining in which area the temperature of heated water may pose a threat to the biological life in the stream. The study is related to a designed hydro-engineering construction in a lowland river. The focus of this study was on the choice of initial conditions, such as river flow and temperatures of ambient and released water. Those conditions influence the detailed velocity field, water depths, bed shear stresses and consequently dispersion coefficients which in turn influence the solutions of heat transfer equations and thus the temperature distributions.

Modelling of transport processes | Effect of water-air heat transfer on the spread of thermal pollution in rivers

While working on practical problems related to the spread of thermal pollution in rivers, we face difficulties related to the collection of necessary data. However, we would like to predict the increase in water temperature at the best accuracy to forecast possible threats to the environment.



Heat fluxes exemplary values calculated for a selected case over the day (Narew River, Poland, 16th of October, 2013).

In most cases in the mid-field zone, omission of all terms related to heat exchange with the environment including the heat exchange with the atmosphere is recommended. Not perfect input data may in some cases introduce much larger error to the final results than just simple omitting of the heat fluxes terms. The problem is especially important in practical cases when we deal with limited and not ideal data. We of course fully realize that in some applications it is necessary to include the heat exchange with the atmosphere and/or other heat fluxes. The situation very much depends on the considered case and time and space scale, to decide whether 1, 2 or 3D approach is appropriate and which additional heat exchange processes should be taken into account.

First, the expected outcome together with the appropriate time and space scale should be defined. Next all affecting processes should be analysed subject to their significance and the availability of necessary input data, but also taking into account all other errors that may be committed during the calculations.

In the cases where the heat exchange with the atmosphere estimation is necessary, it is important to bear in mind that its estimation is based on empirical formulae that depend on many uncertain parameters. To be precise it will be necessary to measure many parameters directly on the side taking into account their space and time dependence to adjust the applied empirical formula to the current conditions.

In most cases for various reasons, there is no enough data to perform all the necessary calculations and prediction must be done based on existing historical, often limited and incomplete, sometimes also inaccurate data, as has been shown using two case studies presented in the paper. Therefore, in practical applications, heat exchange with the atmosphere estimation is full of judgements and extremely subjective. The most problematic to estimate is the wind speed function and atmospheric emissivity formulae. The most fragile to local conditions are measured shortwave solar radiation and wind speed value.

Modelling of transport processes | Flow-biota-sediment interactions

The investigation of the hydrodynamics of water flow-vegetation interactions depends on three groups of plant characteristics: (1) plant morphology characteristics; (2) plant material characteristics; and (3) flow-plant interaction characteristics (Fig. D1a). These interplays result from the interaction of three groups of forces that control the hydrological regime, i.e., flow-induced forces (e.g., drag forces), plant-induced forces (e.g., buoyancy forces) and plant-reaction forces (e.g., bending forces) (Fig. D1b). The study of these features and their connections were the aim of the study of research group (Anna Łoboda, PhD; and Łukasz Przyborowski, MSc) from Department of Hydrology and Hydrodynamics. Measurement were conducted on different rivers, e.g. the Wilga River and the Świder River (Fig. D2).

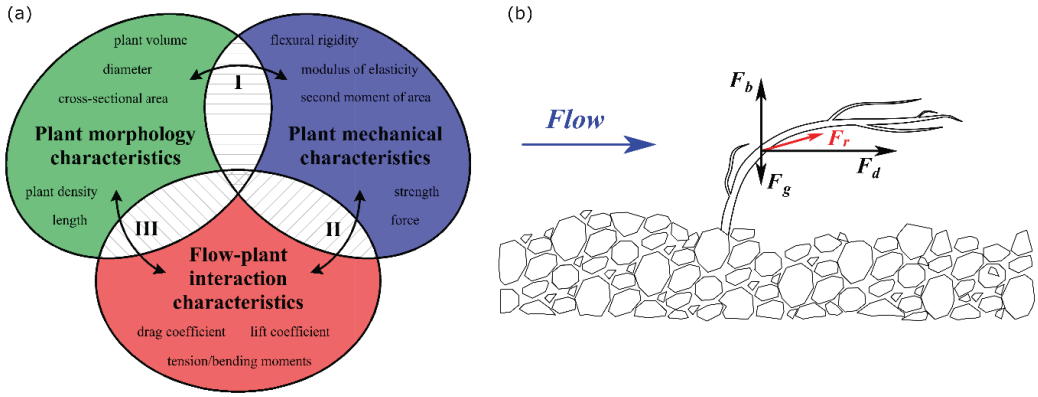


Fig. D1. A schematic of the divisions of plant characteristics (a); and the main forces acting upon a plant stem: the drag force Fd, the buoyancy force Fb, and the gravity force Fg, and the resultant force of these loads Fr (b).

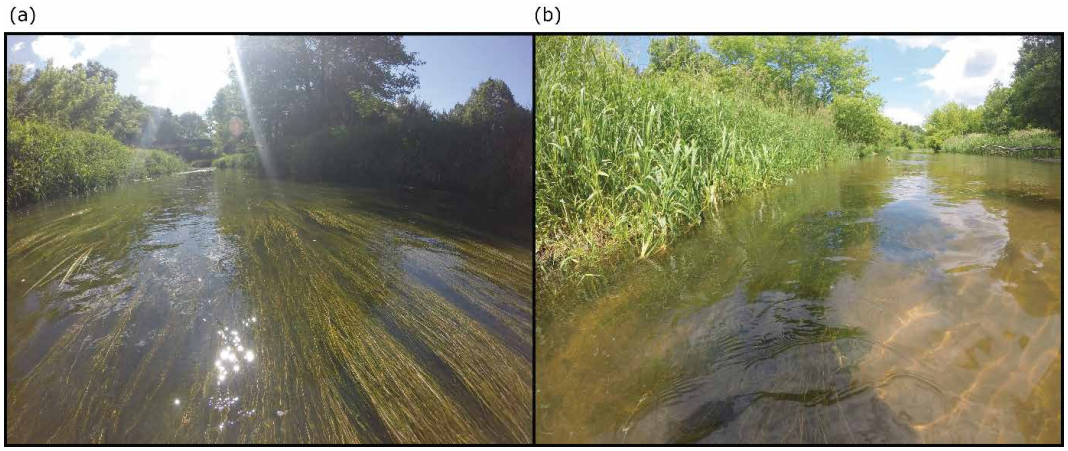


Fig. D2. The channel of the Wilga River (a) and the Świder River (b) during vegetative growth at the sampling sites.

Based on a series of biomechanical measurements of three freshwater plants, i.e. Potamogeton pectinatus L., Potamogeton crispus L. and Elodea canadensis Michx., the analysis of biomechanical properties and their seasonal variability of aquatic plants rooted in flowing waters was carried out to develop a model that shows the correlation between the diameter of the stem and its flexural rigidity, i.e., $EI = a \cdot db$, where EI is the flexural rigidity, d represents the diameter of the stem, and a and b represent the model coefficients determined using nonlinear regression. The flexural

rigidity has a meaningful impact on drag forces, as it modifies the adaptive mechanisms of the plant and the flow patterns, where a flexible plant generates much lower resistance than vegetation with rigid stems, producing eddies. The EI values can be determined using a detailed approach that includes the effect of seasonality on the flexural modulus and plant morphology, or a general approach, in which changes in the diameter of stems play a smaller role (Fig. D3). The model is the response to one of the interdisciplinary problems of aquatic ecosystems, namely, the lack of biomechanical models of river plants. The proposed formula would allow for the estimation of the flexural rigidity based on the stem morphology, which is necessary to determine the drag generated by hydrophytes in rivers.

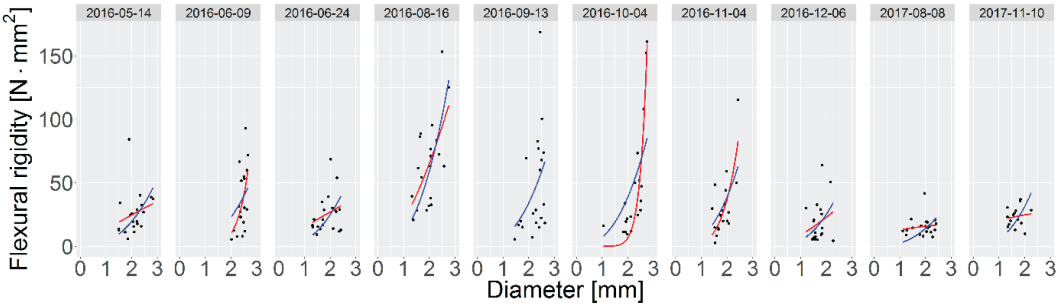


Fig. D3. Model matching for P. crispus. The red line represents case 1 (detailed approach), and the blue line represents case 2 (general approach).

The second part of the studies was the search for the interactions between turbulent flow and representative flexible submerged vegetation. It was conducted by a series of field experiments from 2017 in the Świder and Jeziorka Rivers, which are the lowland, sandy bed rivers. In the experiments, acoustic Doppler velocimeters were used as well as special platform to maintain their position in the river current. A few cases were investigated, where patches of different aquatic plant species were found, i.e., Myriophyllum spicatum L., M. alterniflorum L., P. pectinatus and P. crispus. Detailed flow field measurements (e.g., Fig. D4) were used to determine, which patch characteristics could alter the flow, and which turbulent structures could be associated. Biomechanical tests were used to give additional information about plant reconfiguration capabilities.

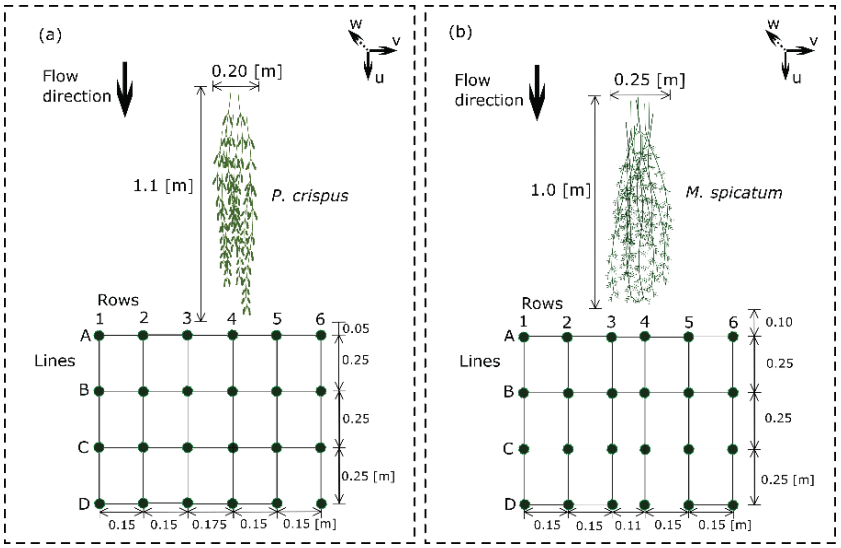


Fig. D4. Scheme of vertical profiles of velocity measurements downstream two aquatic plants in July and August 2017

Results showed that both morphological and biomechanical traits may cause certain flow disturbances, e.g., generation of a mixing layer or 'dead zone', where water velocity and turbulence were diminished. More rigid plants as well as patches of sufficient density and bed coverage are deemed to have much stronger influence on flow than the smaller and weaker ones. This proved that plant biomechanics is important factor in flow-biota interactions. All measurements and the analysis of obtained results were presented in detail in six scientific papers in 2018.

Modelling of transport processes | Experimental studies on (1) gravity currents and (2) sedimentation of particles in complex ambient conditions were carried out in Hydrodynamic Models Laboratory

A methodology for experimental study of gravity currents and measurements methodology using image analysis methods have been developed and tested. An experimental set-up was prepared (Fig. E1) and a series of experiments were conducted. A volume of denser fluid (aqueous NaCl solution) was released from a lock into a rectangular tank filled with less dense ambient fluid (water). There was a small difference between the density of a current and ambient fluid O (1%) to ensure validity of Boussinesq condition.

The aim of the study was to assess the impact of bed roughness on the propagation of gravity current. Gravity currents were released over four bed configurations – a smooth bed and three types of triangular macro-roughness elements. Image analysis methods have been applied to evaluate basic parameters describing propagation of gravity current – front velocity and contours of the current (Fig. E2). The results have demonstrated linear relationship between a current front and time (constant front velocity) indicating that the current was in a slumping phase. Moreover, decrease in front velocity with the increase in the height of roughness elements has been observed (Fig. E3). Simultaneously, a numerical model has been under development within the cooperation with an external group (IG PAS plus University of Warsaw).

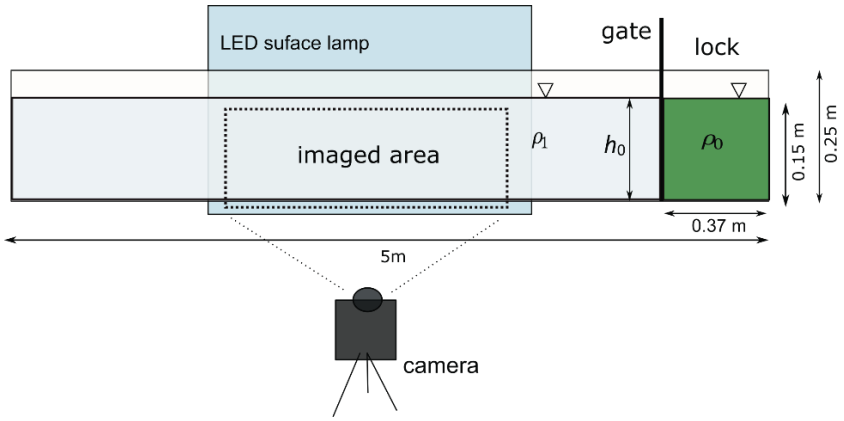


Figure E2: Scheme of experimental set-up.

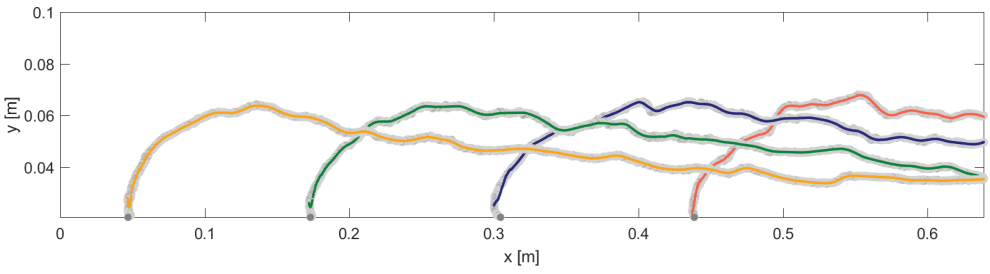


Figure E3: Evolution of gravity current (four images of gravity current with 4 s – time step). Contours of gravity current (grey) with fitted curves (colour).

Dynamics of particle settling in non-Newtonian solutions was studied experimentally. Settling experiments in a low Reynolds number regime were carried out using spherical and non-spherical particles and solutions of natural polymers. The impact of polymer content on settling velocity, drag, and orientation of settling particle was studied. This study was performed in cooperation with Warsaw University of Technology. The results were analysed along with rheological properties of solutions, i.e. viscoelastic and flow properties.

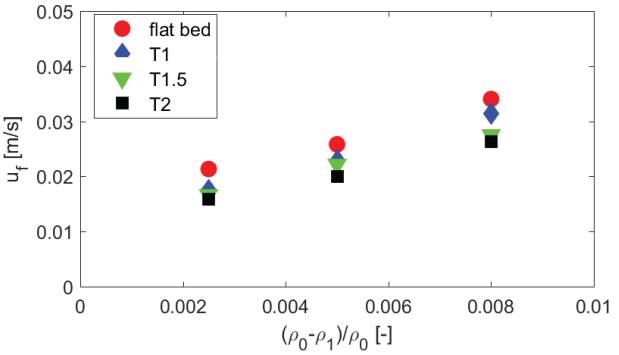


Figure E4 Gravity current front velocity for various bed configurations and density conditions.

It has been shown that rheological properties of non-Newtonian fluids modify settling behaviour of particles compared to Newtonian fluid. Drag coefficient increased with polymer content as a result of the increase in viscosity. A negative wake was identified using Particle Tracking Velocimetry method developed in the laboratory (Fig. E4). Settling velocity fluctuations were observed, which is the effect of rheological properties of a fluid. Non-spherical particles settled with the longest axis vertical, as a result of normal stresses.

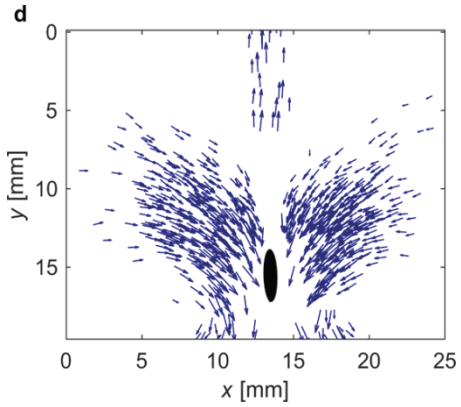


Figure E4 Negative wake behind settling particle.

Modelling of hydrological processes | Testing of innovative metaheuristics and their application to the calibration of hydrological processes models

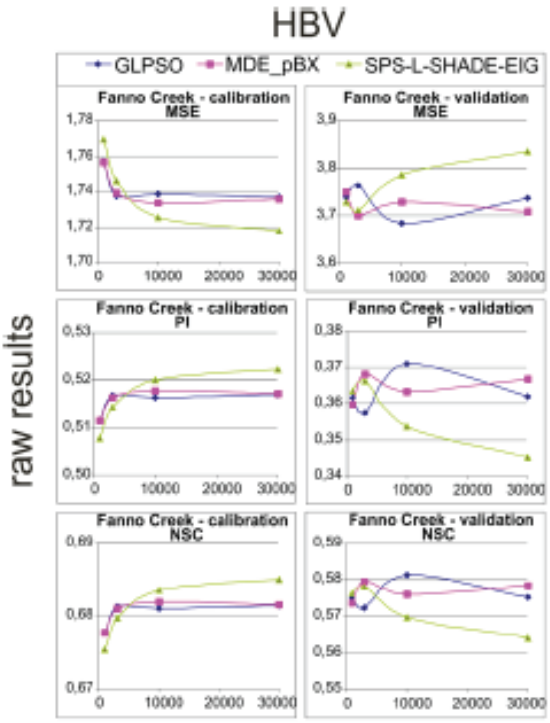
Particle Swarm Optimization (PSO) has been successfully used in versatile scientific fields, ranging from humanities, engineering, chemistry, medicine, to advanced physics. Since its introduction in 1995, the method has been widely researched, what led to the development of hundreds of PSO versions and to numerous theoretical and empirical findings on their convergence and parameterization. However, so far there is no wide-scale study on the proper choice of PSO swarm size that affects performance of metaheuristics. In most applications, authors restrict the population size to 20-50 particles. In this study, we relate the performance of eight PSO variants with swarm sizes that range from 3 up to 1000 particles. Tests are performed on sixty 10- to 100-dimensional scalable benchmarks and twenty two 1- to 216-dimensional real-world problems. Although results differ for the specific PSO variants, for the majority of considered PSO algorithms the best performance is obtained with swarms composed of 70-500 particles, indicating that the classical choice is often too small. Larger swarms frequently improve effectiveness of the method for practical applications.

Numerous Differential Evolution algorithms (DE) have been proposed during last twenty years for numerical optimization problems. Recently a number of successful history-based adaptive DE variants with linear population size reduction (L-SHADE) have been considered among the most efficient Evolutionary Algorithms. In this study we show that the performance of L-SHADE variants may be improved by adding a population-wide inertia term (PWI) to the mutation strategies. The PWI term represent an averaged direction and size of moves that were successful in the previous generation. The PWI term is implemented into four L-SHADE variants proposed during 2014–2018 period. Empirical tests are performed on 60 artificial benchmark problems from IEEE CEC'2014 and IEEE CEC'2017 test sets, and on 22 real-world problems from IEEE CEC'2011. For each considered test set every L-SHADE variant performs better with PWI term than without it.

Among plentiful DE versions proposed so far those that are based on mutation strategies and control parameter adaptation methods introduced within JADE and SHADE variants show especially encouraging performance. In this study in-deep insight into the performance of twenty two JADE/SHADE-based variants on a large sets of artificial benchmarks and real-world problems is presented. The impact of the pre-assumed maximum number of function calls and the algorithm population size on the results is verified and discussed. The main aim of the study is to point out these among recently introduced JADE or SHADE-based operators that turn out to be especially successful, and to determine conditions under which they either achieve desired results or fail.

Modelling of hydrological processes | Relationship Between Calibration Time and Final Performance of Conceptual Rainfall-Runoff Models

This paper aims at studying the impact of the assumed number of function calls to be used during calibration of the lumped conceptual rainfall-runoff model on the final performance. Tests with different numbers of function calls (1000, 3000, 10,000 and 30,000) are performed independently, hence longer calibration does not necessarily imply better results. Two models are tested (HBVand GR4J), each applied with or without error correction procedure, and with three calibration procedures (GLPSO, MDE_pBX and SPS-LSHADE-EIG) at five catchments (the mountainous Biala Tarnowska, Poland and Cedar River, WA, USA; the hilly Fanno Creek, OR, USA; the lowland Irondequoit Creek, NY, USA and Suprasl, Poland) located in temperate climatic conditions. Research is based on 14–39 years long daily data that are divided into calibration and validation parts.

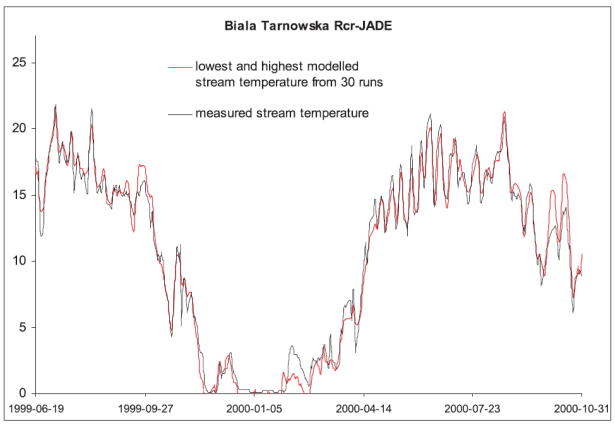


Relation between the performance of HBV model without error correction procedure for Fanno Creek

At the calibration stage, when more than 10,000 function calls is used, only marginal improvement in model performance has been found, irrespective of the catchment or calibration algorithm. For validation data, the relation between the number of function calls and model performance is even weaker, in some cases the longer calibration, the poorer modelling performance. It is also shown that the opinion on the model performance based on different popular hydrological criteria, like the Nash-Sutcliffe (NSC) coefficient or the Persistence Index (PI), may be misleading. This is because very similar, largely positive values of Nash-Sutcliffe coefficient obtained on different catchments may be accompanied by contradictory values of the Persistence Index.

Modelling of hydrological processes | Performance of the air2stream model that relates air and stream water temperatures depends on the calibration method

A number of physical or data-driven models have been proposed to evaluate stream water temperatures based on hydrological and meteorological observations. Physical models require a large amount of information that is frequently unavailable, while data-based models ignore the physical processes. Recently the air2stream model has been proposed as an intermediate alternative that is based on physical heat budget processes, but it is so simplified that the model may be applied like data-driven ones.



Biala Tarnowska River. Highest and lowest air2stream model simulations from 30 calibrations by the Rcr-JADE and cNrGA algorithms

In this study 12 optimization algorithms were tested for the calibration of the air2stream model with eight parameters, for hydro-meteorological daily data from six streams located in the temperate climatic conditions of northern USA, Poland and Switzerland. Each optimization algorithm was run 30 times to calibrate the air2stream model for every stream. It was shown that the performance of the air2stream model largely depends on the selected calibration procedure. The best and most robust results for each stream are obtained with the CoBiDE and GA-MPC methods. A number of other optimization procedures lead to less reliable results, and two out of the 12 optimization algorithms tested turned out to be inappropriate for the air2stream calibration. The wrong choice of calibration method may lead to misleading simulation of stream water temperatures.

Although the values of the Nash-Sutcliffe criterion for the air2stream model, calibrated with the best optimization procedures, range between 0.93 and 0.98 for the validation data, depending on the catchment, the forecasting skills of the model are limited, as per the Persistence Index criterion, which is often negative and never higher than 0.3. This is because the air2stream model does not have a bias correction module.

The air2stream model, calibrated by well selected optimization procedures, clearly outperforms data-based stream water temperature models that are widely used in the recent literature.

Modelling of hydrological processes | Simple modification of nonlinear regression stream temperature model for daily data

Among various stream temperature models those based on nonlinear regression frequently attract attention due to their simplicity and small number of required variables. Among such approaches the Mohseni logistic regression model developed twenty years ago for weekly data is still widely used in various scientific studies that require quick and simple calculation of streamwater temperature. The model has been modified a number of times in recent years to capture the relationship between daily stream water temperatures, air temperatures and flow. In this study, we propose further modifications of the logistic regression model that do not require any additional variables that may be hard to measure. The proposed models capture the relationship between the stream temperature and the declination of the Sun, the air temperature and the flow from a number of recent observations. The proposed approaches are tested on six rivers located in diverse orographic conditions of temperate climate zones of Europe and USA. Although the proposed models remain very simple, their performances are competitive against the performances of more advanced semi-physical or data-driven models

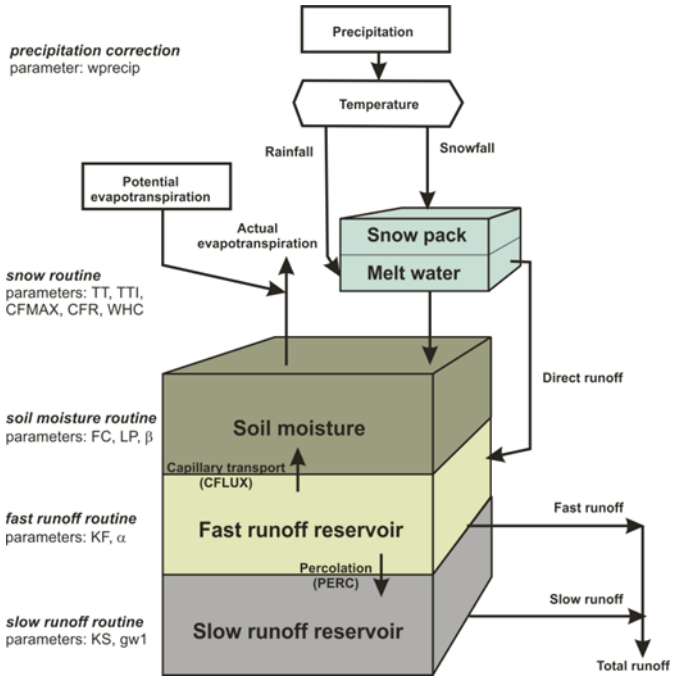
Modelling of hydrological processes | Hydrodynamic derivation of parameters of the Muskingum model

To describe the unsteady flow in rivers by means of the methods of mathematical physics, it is necessary to know with sufficient accuracy the geometrical and hydraulic characteristics of the channel reach as well as the initial and boundary conditions. The difficulties of meeting these requirements led to the development in hydrology of lumped conceptual models, in particularly Muskingum model.

There exists a direct possibility of deriving the Muskingum equations from St. Venant equations. One approach is the lumping of the hydrodynamic model under the assumption of linear changes of water level along the river reach and then linearizing it around the steady state. The second approach uses the method of inverse order. First, a state trajectory variation method is applied to the complete St. Venant equations and then the resulting equations are lumped. In both approaches the resulting equations are equivalent to the linear form of the Muskingum model. Hence the relationships between the hydraulic parameters of the St. Venant equation and the lumped parameters of the Muskingum model are derived.

Modelling of hydrological processes | The hydrology of a small Arctic permafrost catchment

The overall aim of the present study is to examine the relationships between temporal changes of active layer depth and hydrological model parameters, together with variation in the catchment response. The analysis was carried out for the small unglaciated catchment Fuglebekken, located in the vicinity of the Polish Polar Station Hornsund on Spitsbergen.



HBV catchment runoff model

For hydrological modelling, the conceptual rainfall-runoff HBV model was used. The model was calibrated and validated on runoff within subperiods. A moving window approach (3 weeks long) was applied to derive temporal variation of parameters. Model calibration, together with an estimation of parametric uncertainty, was carried out using the Shuffled Complex Evolution Metropolis algorithm. This allowed the dependence of HBV model parameters on ALT to be analysed. Also, we tested the influence of model simplification, correction of precipitation, and initial conditions on the modelling results.

The nonstationary of the parameters of the catchment runoff model has been tested in case of catchment with varying geophysical conditions (changes in the thickness of the active layer). To this end, the model has been successfully calibrated in successive time windows, enabling estimation of model parameters and their variability depending on the thickness of the active layer and other hydro-climatic indices.

Seminars and teaching

Seminars and lecture outside of the IG PAS

- Romanowicz | *Climate change impact on hydrological processes at a catchment scale* | Seminar
  University Twente | Twente, Netherlands
- Romanowicz | *Climate change impact assessment - a hydrological perspective* | Invited lecture
  EcoPol | Poznań, Poland
- Rowiński | *Polish Academia towards Climate Change Studies. Safeguarding Our Climate, Advancing Our Society event accompanying UN Climate Summit COP24* | Invited lecture
  Pontifical Academy of Science | Casina Pio IV, Vatican City
- Rowiński | *Silny Uniwersytet Badawczy – czy jest to możliwe w warunkach polskich?* | Invited lecture
  ASSECO | Warszawa, Poland
- Rowiński | *Uczelnie badawcze, czyli jakie?* | Invited lecture
  Fundacja Rozwoju Systemu Edukacji | Warszawa, Poland
- Nones | *Modelling Process in Hydroengineering Projects* | 30 hour course
  BTU Cottbus-Senftenberg | Cottbus, Germany

Completed PhD thesis defense

- A. Łoboda | *The influence of the seasonal variability of biomechanical properties of selected plant species rooted in flowing waters on flow resistance* | Supervisor: R. Bialik
- E. Karamuz | *Wpływ zmian klimatu oraz użytkowania terenu na przepływ środkowej Wisły* | Supervisor: R. Romanowicz
- H. K. Meresa | *Modelling of Hydrological Extremes under the Influence of Future Climate Change* | Supervisor: R. Romanowicz
- S. E. Debele | *Frequency analysis of extreme river flows: selected methods and their application* | Supervisor: R. Romanowicz

Visiting scientists

- J. Juha | Aalto University | Aalto , Finland
- J. Aberle | Technical University Braunschweig | Braunschweig, Germany
- V. Kaisa | Aalto University | Aalto , Finland

Meeting, workshop conferences and symposia

The International Conference on Fluvial Hydraulics, River Flow 2018 | Lyon-Villeurbanne; France
Kalinowska, Rowiński | *Impact of initial conditions on the prediction of the spread of thermal pollution in rivers* | oral

5th IAHR Europe Congress | Trento, Italy
Kalinowska | *Heat and mass transport under complex natural conditions – introduction to the special session* | oral

Przyborowski, Łoboda | *Effect of Myriophyllum Species on Downstream Turbulence in a Natural River. In New Challenges in Hydraulic Research and Engineering* | oral

Rowiński, Kalinowska | *Heat and mass transport under complex natural conditions – review* | oral

OSH2018 – Ogólnopolska Szkoła hydrauliki | Gdańsk, Poland
Kalinowska, Rowiński | *Modelowanie prędkości w kanale prostokątnym częściowo pokrytym roślinnością z użyciem modelu CCHE2D* | oral

XXXVII Sympozjum Polarne "Polar Change - Global Change" | Poznań, Poland
Osuch | *Snow Cover Development on Spitsbergen Coastal Tundra Environment – Present State and Predictions for the End of XXI Century* | oral

Konferencja Naukowo-Techniczna | Warszawa, Poland
Kochanek | *Informacja historyczna w analizie częstości występowania powodzi* | oral

Markiewicz | *Wielo-modelowe podejście do estymacji kwantyli powodziowych* | oral

III Krajowy Kongres Hydrologiczny | Warszawa, Poland
Kochanek, Bogdanowicz, Markiewicz | *Error of the estimation of the flood quantiles calculated by means of the data series of the* | oral

Markiewicz, Bogdanowicz, Kochanek | *Two ways of a multimodel approach to the estimation of seasonal and annual maxima flow distirbutions* | oral

Romanowicz | *The application of cumulants to flow routing* | oral

Bogdanowicz, Kochanek, Markiewicz | *Asymptotic standard error of annual maximum flow quantile estimated by seasonal approach*| oral

| Budapest, Hungary
Osuch | *Modelling snow water equivalent in the coastal tundra of Hornsund fiord, Towards a better harmonization of snow observations, modeling and data assimilation in Europe* | oral

9th International Plant Biomechanics Conference | Montreal, Canada
Łoboda | *To what we endeavor in the biomechanics of aquatic plants?* | poster

SIOS | Svalbard
Osuch | *Permafrost monitoring in Hornsund area, SW Spitsbergen, Permafrost thermal state in Svalbard 2016-2017 (PermaSval)* | oral

Nordic Water 2018 | Bergen, Norway
Osuch | *Water Temperature Modelling of Small High Arctic Stream (Fuglebekken, SW Spitsbergen)* | oral

8th Global Friend-Water Conference | Beijing, China
Osuch | *Projections of hydro-climatic conditions in small arctic unglaciated catchment Fuglebekken (SW Spitsbergen)* | oral

Osuch | *The influence of permafrost degradation on runoff generation in small arctic unglaciated catchment (Fuglebekken, Spitsbergen)* | oral

Warszawski Festiwal Nauki 2018 | Warszawa, Poland
Romanowicz | *Wpływ zmian klimatu na ekstremalne zjawiska hydrologiczne, Globalne ocieplenie - różne perspektywy* | oral

Rozwiązania bliskie naturze dla poprawy zasobów wodnych | Warszawa, Poland
Rowiński | *Rozwiązania bliskie naturze dla poprawy zasobów wodnych - wprowadzenie* | oral

LAHTI LAKES 2018 – Restoration of Eutrophic Lakes: Current Practices and Future Challenges | Lahti, Finland
Rowiński, Kalinowska | *Environmental two-stage channels: potential for catchment-scale reductions in nutrient transport?* | oral

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