1. Research objective

The scientific problem of the project is the recognition of the influence of emergent aquatic macrophytes on water temperature in a small natural lowland agriculture river. This research problem still remains an open issue and has not been examined yet. The subject of our research is also the recognition of temporal and spatial variability of water temperature in this type of river, quantitative analysis of the factors shaping water temperature and quantitative description of these factors' impact on water temperature. The stream water temperature and its fluctuations is one of the main factors determining the course of physical, chemical and biological processes in water, regulating the functioning of aquatic ecosystems (Caissie, 2006). A wide range of biological parameters is determining by water temperature (Demars et al., 2011). In lowland agricultural landscapes, dominating in Poland, small low-dynamic rivers constitute the largest percentage of all water bodies. Their characteristic feature is the intensive overgrowth of the bottom and banks by aquatic macrophytes. Managing these rivers is of the critical importance for local biodiversity and novel tools are required to describe elements of these ecosystems for future management setup (Grygoruk & Acreman, 2015). The intensive overgrowth creates riverine canopies, that shades river surface. So far, the issue of influence of the riparian vegetation shading in small river on water temperature has been analysed in detail in research (Kalny et al., 2017). In contrast, the influence of emergent aquatic macrophytes on water temperature in small low dynamic lowland rivers still remains an open issue (Willis et al., 2017).

The most common tools for the prediction of water temperature are: 1) deterministic models (Hebert et al., 2011; Kalny et al., 2017), whose applicability is restricted by the requirement of the number of qualitative and quantitative analyses, long measurement datasets and parameters, often difficult or impossible to carry out, measure and/or identify; 2) statistical models analysing correlations between a relatively small number of input environmental variables (usually the air temperature is used) in different time scale and water temperature (Benyahya et al., 2007; Laanaya et al., 2017). In small lowland river the air temperature is not dominant factor for water temperature, therefore water temperature predicted only by means of the air temperature is far from being accurate (Ericson & Stefan, 2000; Łaszewski, 2018).

Research hypothesises: 1) Water temperature in small lowland agriculture river can be predicted with satisfactory accuracy in different time scale by statistical models determined by the key predictants stemming from the meteorological, hydro-morphological and riverine vegetation factors. 2) Hydraulic and shade features of aquatic macrophytes influence seasonal water temperatures in small lowland agriculture rivers.

The scientific aim of the project is to verify the research hypothesises through:

1) Learning about the temporal (annual, with and without vegetation) and spatial (along the river course) variations of water temperature in a small lowland river through automatic monitoring of the temperature on a selected section of the river; **2)** Collecting the dataset of predictors related to hydromorphological, meteorological and aquatic macrophytes as a result of automatic monitoring and field survey as well as applying of hydrodynamic river flow model including riverine vegetation influence on hydraulic features; **3)** Employing the hierarchical regression methodology to find crucial environmental predictors for the dependent variable – river water temperature and development of regression models in different time scale for selected river reach; **4)** Formulating the answer to the question about influence of the riverine vegetation into the temperature in the small agriculture river through implementation in the model parameters referring to the biomass, shading and coefficient of cross-section cover by aquatic macrophytes by applying two main scenarios – one concerning the river with the vegetation and other in which vegetation will be removed in 1 km segment of the river.

2. Significance of the project

The stream temperature and its fluctuations is one of the main factors determining the course of physical, chemical and biological processes in water, regulating the functioning of aquatic ecosystems (Caissie, 2006). Water temperature in rivers determines multiple elements of riverine ecosystems of both physical (biotopic) and biological (biocoenological) features (Demars et al., 2011). The above mentioned issues indicate the importance of research related to the analysis of the temporal and spatial variability of river water temperature.

The characteristic feature of small low-dynamic rivers in the lowland agricultural landscapes is the intensive overgrowth of the bottom and banks by the aquatic macrophyte which occur also in-stream. Currently, little literature is available that mention the quantitative assessment of aquatic plants on water temperatures in the local scale. A few studies on the influence of aquatic vegetation on water temperature provide some insights, i.e., that although stream-water temperatures typically increase during late summer, some species of macrophytes are able reduce maximum water temperatures by an average of 5.1°C (Willis et al., 2017). Some studies explain these effects and quantify the influence of shading effects of riparian vegetation on water temperature of small and medium-sized rivers (Kalny et al. 2017). Most of the reports show that shading effect successfully decreases water temperature, especially in the critical periods of mid-summer droughts. It is therefore expected, that the shading effects of emergent, large-leaf aquatic macrophytes, due to their dense canopy in some lowland slow-running rivers, will influence water temperatures in a similar manner. However, these topics have not been studied so far, therefore, we will examine these issues in detail in our project. Predicting riverine water temperatures over the space and time is traditionally considered either in deterministic or in statistic approaches (Cole et al., 2014). Deterministic (physical) models tackle processes of heat exchange between the river and the surrounding environment (heat transfer and mass-transfer from advection and dispersion) (Hebert et al., 2011). Some of these models can also explain thermal interactions between the shading effects of riparian vegetation (Kalny et al., 2017). Despite this successful investigations, one has to bear in mind that the deterministic models require the number of qualitative and quantitative analyses, long measurement datasets and parameters, often difficult or impossible to carry out, measure and/or identify. Even though such measurements are possible and the estimation of the parameters is feasible, the cost of such actions is high. So, the complexity of the hydro-ecological systems and the random character of the hydrological and ecological phenomena seriously limits the use of deterministic modelling.

Statistical models require fewer parameters than deterministic models and base on correlations between a relatively small number of input environmental variables (usually air temperature) and water temperature (Benyahya et al., 2007; Laanaya et al., 2017). As far as the temporal distribution is concerned, statistical models are said to be more effective at weekly and monthly scales than daily scale, because of the lower daily variation of the water temperatures and greater autocorrelation between the days (Caissie, 2006). The nonlinear parametric regression models, that constitute the majority of such solutions, link water temperature to air temperature by means of the logistic approach (Benyahya et al., 2007). Such logistic models relatively well predict weekly data, but when it comes to the data of higher temporal accuracies, they do not reveal a good fit (Mohseni et al., 1998). Up to 95% of variations of stream water temperature can be predicted on the basis of air temperature, if the catchment is large enough to assure air-water interaction (Ericson & Stefan, 2000). Although atmospheric heat fluxes are known to be significant in small lowland rivers, air temperature is insufficient to quantify all heat transfer processes through a water surface (Łaszewski, 2018). Bearing in mind weaknesses of statistical models limited only to water-air temperature relation and degree of complexity of data for deterministic or physical models we propose to examine in statistical model (the hierarchical regression methodology (HM)) for small lowland river the relationships in different time scales among stream temperature (measured by sensors in the river) and selected variables including atmospheric conditions, hydromorphology characteristic and aquatic macrophyte features (biomass, degree of cross-section overlap by the plants and shading coefficient). Predictors associated with aquatic macrophyte indicators will also be considered as the time-dependent (growing season) ones and spatially distributed (location of temperature measurements). In the approach presented in this proposal, variability of stream water temperature will be analysed along the pilot 6 km stretch of the River Biebrza – the exemplary lowland river in its upper reach between the villages Rogożyn Nowy and Rogożynek, the river is there up to 5 m wide. The maximum depth reaches 1.5 m.. River flows through the valley (average width is 1 km), where organic soils dominate over the mineral. The research site was formed during the Riss glaciation and peat developed in the Holocene. On this stretch, the River Biebrza remains only under the influence of catchment (agriculture) factors and is not exposed to any other river management measures. Such an experimental setup allows to examine the processes of macrophyte-induced temperature variability with no risk of disruption originating from unexpected channel maintenance works. Flow velocities in this reach do not exceed 0.15 m/s during the average annual river discharge transfer. In this flow condition water is well mixed and results in stable temperature in a given cross-section, both with the river's width and depth (the above thesis is justified with the results of measurements carried out under the former National Science Centre (Pol.: NCN) project (UMO-2016/21/B/ST10/03042)). It means that it is enough to measure the temperature along the river course in one selected point per a cross-section to obtain valuable dataset of temperatures in line with the current of the river. In consequence, we will install one monitoring sensor per representative cross-section. Automatic temperature recorded every 15-minute at 22 locations along the analysed section of the river combined with the automatic recording of meteorological parameters (with the same time step) by a weather station will provide sufficient data in terms of their temporal and spatial variability. In order to obtain data related to hydromorphology of the same time and spatial resolution, a one dimensional channel flow model will be developed based on Saint-Venant equations. Contrary to the previously used models of surface water flow in the Biebrza Valley, in which the influence of aquatic vegetation on river hydraulic was considered in a simplified manner (Miroslaw-Swiatek et al., 2008), in the flow model for the resistance term a two layer approach, proposed by Västilä and Järvelä (2017) will be used. It is a process-based description of the effect of the flexible and immerse vegetation on flow, based on a detailed parameterization of vegetation properties, including i.e.: blockage factor, frontal projected areas of plant stems and leafs. The proposed research, apart from analysis of the temporal and spatial variability of temperature in a small river

in an agricultural landscape, may play an important role in the environmental management. In case of small rivers where the efficiency of agricultural production is growing, the maintenance works such as sludging and mowing plants from the bottom and banks, are regularly and systematically carried out. While the impact of these actions on the decline in the quality of ecosystems measured by the loss of biodiversity and morphological diversity is widely discussed in the literature, their effect in relation to changes in the temperature field is not recognized.
The HM models developed for the Upper River Biebrza can be easily adopted to other similar rivers by applying predictors characteristic for these rivers and can be used in the development of hydrological models. The proposed statistical model can be used to determine the water temperature in surface water quality models in catchment areas used for agricultural purposes.

3. Work plan

The project will consist of five Work Packages divided into research tasks. The interdependence of the tasks is shown in Fig.1.

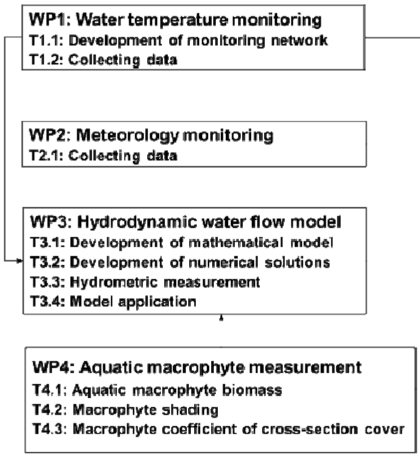

Fig. 1. Project structure.

WP1: Water temperature monitoring

Obtaining data on water temperature and its time and space variability in the analysed section of the river. These data will be used as the dependent data of the statistical model (T5.1). The sensors will be planted in the cross-sections where the properties of the river are to some extent characteristic. This will give us a full spectrum of the variability of the river's parameters for the models which will be prone to react to the input of the wider range of parameters' values.
Expected outcomes: Dataset of spatial and temporal variability of water temperature in sensors locations.

WP2: Meteorology monitoring

Identification of the meteorological predictors to statistical model (T5.2). The data will be collected by means of the weather station installed in the location that guarantees the representativeness of measurements for the 6 km section of the river and security of the equipment.
Expected outcomes: Dataset of temporal variability of meteorological factors in the weather station location.

WP3: Hydrodynamic water flow model

Development a one - dimensional (1D) channel flow model that will consider the seasonal and spatial impact of aquatic macrophyte on stream flow. The model will be used to generate predictors for a statistical models with a time resolution compatible with the temperature measurements by automatic sensors (T5.3).
Expected outcomes: Dataset of spatial and temporal variability of hydromorphology factors in sensors locations.

WP4 Aquatic macrophyte survey

Analysis of the aquatic macrophytes due to its changes over time and in the space of the river channel. This WP will consist of three tasks (T4.1-T4.3) that deal with individual features of aquatic vegetation.
Expected outcomes: Spatial and temporal variability of % cross-section cover by macrophyte in sampling location; identified vegetation properties for the resistance formula in the one-dimensional model.

WP5: Statistical models of the Stream Temperature

Collecting the datasets of predictors (WP1-WP4) and applying them in the development of statistical models.
Expected outcomes: The water temperature, meteorological, hydromorphological and the aquatic macrophyte data of the assumed temporal distribution. The tested and calibrated regression models for the selected river reach.
We considered all precautions related to the following elements of risks: 1) Weather or water conditions that unable carrying out the field work; 2) Purchase of the equipment fails or is late; 3) Measurement sensors fail; 4) Measurement sensors are destroyed; 5) Our measurement devices planned to be applied during the project

are used by the other project at the same time; 6) Scientific papers prepared in the framework of the project are not accepted for publication.

4. Methods of research

The general research plan includes two main components: 1) the development of the methodology of statistical approach to modelling of stream temperature and 2) the experimental study – based on meteorological, hydrological field measurements and aquatic macrophyte survey as well as water temperature measurement that are aimed to generate the predictors for water temperature and model validation. In addition, in the study a 1D hydrodynamic model will be developed considering the impact of aquatic vegetation on stream flow. Model parameters will be identified using quasi-Bayesian estimation, what will allow for an uncertainty estimation. Calculations made with this model will allow to obtain predictors describing hydromorphology. The predictor associated with the groundwater inflow will be determined by simulations of integrated hybrid surface-groundwater flow model developed in the former National Science Centre (Pol.: NCN) project (UMO-2016/21/B/ST10/03042).

In this project, we are going to develop the methodology of the statistical approach to modelling of temperature of various temporal distribution and employ the hierarchical regression methodology (Daraio et al, 2017). Hierarchical models (HM), aka multilevel models, are particularly appropriate for research designs where data are organized at more than one level, i.e. one builds subsequent regression models by adding variables to a previous model at each step; later models always include (nest) models previous steps. Bearing in mind that the number of potential parameters influencing the temperature in small low-land rivers is significant and yet not exhausted, the selection of the controlling predictors may prove necessary. The HM allows for determination whether newly added variables show a significant improvement in R^2 (the proportion of explained variance in the dependent variable by the model). The predictors that we are going to consider are: 1) atmospheric conditions, i.e.: solar radiation, relative humidity, wind velocity; air temperature; 2) hydro-morphological and hydrological conditions: water depth, stream discharge, flow velocity, flow area, ground water inflow; 3) aquatic macrophytes indicators: biomass, shading effect, coefficient of cross-section cover. We also intend to distinguish the predictors playing crucial (dominating) role in the control over the dependent variable(s) of the model, which is easier when applying the HM. Moreover, the hierarchical structure of the model allows to reveal connection (relations) between the model's parameters, eliminating the predictors which are highly correlated and thus blur the results of the modelling but not necessary carry extra information for the sake of the quality of modelling results. All these will lead to noteworthy simplification of the modelling structure without loss of the results accuracy, which cater for the 'parsimony principle' in modelling of hydrological systems. Another advantage of the suggested statistical approach is its computing time, regardless the number of predictors employed to calculate the temperature in the river. This means, that we will be able to build and (re-)calculate technically every combination of parameters for different hydrological, hydromorphological, meteorological and riverine vegetation conditions for various cross-sections and river depths within the reasonable time and then select the most suitable models of water temperature. This also allows for analysis of trends in water temperature with regard to the variability of the predictors. Our model is supposed to be universal for the whole of the monitored river reach. However, since the predictors may be particularly characteristic for a certain fragment of the river and may change along the river course, so one model cannot cope with this variability to provide reliable outcomes. Therefore, separate model should be prepared for those river profiles that distinguishably stand out from other cross-sections. The regression models will be built for several temporal distributions. We are perfectly aware that, due to the other conditions (different predictors or at least their actual values), the mean daily temperature requires different approach in modelling that the weekly average temperature or hourly temperature. Therefore, we plan to develop several models for various time spans, namely hourly temperature, mean daily temperature (for 24 hours), mean weekly temperature (7 days), mean monthly temperature. We would like also to build HM for maximum daily temperature, because these extreme conditions play a crucial role for the river's biota. The set of predictors, of course, as well as the modelling approach will be different for each of these variants of the regression models, which determines also the methodology of data collection and pre-processing.

The functions of the aquatic vegetation (referring to the shaded effect generated by riverine canopy) will be the crucial predictor of the hydrodynamic and the regression model. We also plan to implement into the model parameters referring to the biomass and coefficient of cross-section cover by aquatic macrophytes. This will allow us to formulate the answer to the question about the influence of riverine vegetation into the temperature in the small agriculture river. In other words: we will recognise two main scenarios – one concerning the river with the vegetation and other without the vegetation (in segment 1 km of the river vegetation will be removed), both in a various time of the year. The comparison of the models' results carried out for both scenarios will give the answer about the influence of aquatic macrophytes on the water temperature. It is important to note that the developed models will be prepared for one monitored reach in the

River Biebrza. We assume, however, that the regression models developed for the Upper River Biebrza can be easily adopted to other similar rivers by applying predictors characteristic for these rivers.

In the development of the statistical models, the STATISTICA program and the R (or Fortran) calculation package will be used. The source code of the hydrodynamic model will be written in the C ++ programming language. In the hydrometric measurements, the Valeport M 801 with accessories electromagnetic flow meter will be used. The water temperature will be measured at 22 measuring points along the analysed 6 km section of The Upper River Biebrza by automatic measuring sensors with an accuracy of ca. 0.1 ºC every 15 minutes. These sensors will also automatically record the position of the water table level. The covering of cross-section by aquatic macrophytes will be recorded with a digital camera using a UAV (DJI Phantom 4 Pro), and submerged vegetation will be recorded with an underwater camera. In the macrophyte shading measurements, a pyranometer will be used. Meteorological data will be automatically recorded by the weather station. Geodetic data will be obtained as a result of the use of GPS RTK and the leveller.

As a research output we are planning to publish five papers in journals with impact factors. Two papers in high profile hydrological journals (on statistical model water temperature prediction) and ecohydrological journals (aquatic macrophytes role in regulating stream temperatures and hydraulic effects of its riverine canopy). The research material should allow for publishing 2-3 papers on particular methods and results of river surveys in lower cited journals as well as to prepare the Ph.D. thesis preliminarily entitled: 'Implications of aquatic macrophytes in regulating physical features of mesohabitats in small lowland agricultural rivers'.

5. Literature

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