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Flow between the sub-basins of Charzykowskie Lake – modelling and measurements

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ABSTRACT

One of the problems in the studies of the deep ribbon lakes fed and drained by the rivers is the calculation of the water inflow and outflow as well as internal circulation. The flow between separated basins of the lake may be difficult to estimate using only mass balance of inflow and outflow rivers discharge measurements. With the improvement of hydrodynamic models it is possible to approach that problem using CFD methods. In this study for showing the flow between the sub-basins of Lake Charzykowskie we apply 2D hydrodynamic numerical model *CCHE2D* developed at the *National Center for Computational Hydroscience and Engineering (NCCHE) at University of Mississippi, USA*. The model solves the depth-averaged Navier-Stokes equations utilizing the control volume approach and the efficient element method.

Charzykowskie Lake is a flow-through glacial ribbon lake located in the Tuchola Forest Biosphere Reserve in North-West part of Poland. Main river supplying lake is Brda River there are also tree smaller rivers with their mouths in the lake. There are underwater sills separating the whole lake in to the following sub-basins: Northern-1, Northern-2, Central and Southern. Bathymetry data for creating DTM of the lake bottom had been taken from *EULAKES* research project accomplished by *IMGW-PIB*.

The data to prepare the computing mesh was DTM of 20 x 20 m resolution containing 108035 (x, y, z) coordinates. Computing mesh had i=100 by j=100 lines, and average spacing of lines creating computing mesh 20x40 m. Upper boundary condition were steady discharges measured in the field, lower boundary condition was a water level at the Brda outflow z=120.3 m a.s.l. During field measurements was a calm weather with no wind, so this force was not specified in the model.

In this study to get the reference data for hydrodynamic model verification it was used *ADCP RiverPro* doppler-profiler made by *Teledyne*. Comparison of the *ADCP* profile No. 9003 and *CCHE2D* model results is shown at Fig. 1. *ADCP* measurements shows a main flux with the direction to the North (Brda outflow) located in the deepest centre of the cross section and above shallow area close to Eastern bank. *CCHE2D* model shows reverse flow near the Western bank and this pattern is confirmed by *ADCP* measurements by lower magnitude of velocity and directions of flow toward South. Reverse flow can be explained by the expansion of the cross section and return of the flow near lake banks in circulation induced by the main stream. Measurements of vertical temperature profiles in the Charzykowskie Lake had shown that there is no thermal stratification of the water in Northern-1 and Northern-2 sub-basins, but thermal stratification occurs in Central and Southern sub-basins with the thermocline at 6 m. Water velocity distribution at *ADCP* profile do not indicate the vertical differences which probably could occur at the profile with thermal stratification.

The distance between inflow leaving the delta cone and outflow of Brda river in Northern-1 sub-basin is only 1300 m. For the verification of the *CCHE2D* model results showing circulation pattern it was designed a pattern of 8 points for velocity measurements in a section by section mode. To localize the measurement points their geographical coordinates were given and boat was positioned on a two anchors bow and aft. In given points average velocity in vertical was measured. The *ADCP* instrument makes

possible also to measure the velocity vector direc-tion, but in the low flow velocities we could not obtain a reliable value of current direction. The average difference of performed *ADCP* measurements and *CCHE2D* results is only 0.002 m s^{-1}, which confirms the proper estimation of model calculated velocities.

Performed modelling and *ADCP* verification of flow pattern of Charzykowskie Lake had confirmed a water flux between the sub-basins. Fact that Northern-1 and Northern-2 sub-basins are not thermally stratified confirms the existence of flows and make possible application of *CCHE2D* model where water properties are uniform in a whole computing domain. In a moving boat method *ADCP* instrument shows properly the magnitude of velocities and the pattern of reverse flow. This property of *ADCP* instrument make possible to use the measurements results for hydrodynamic model verification and helps to understand complex pattern of flow in lake with separated sub-basins.

CCHE2D flow modeling in sub-basin Northern-1 had proved a circulation of river stream leaving delta of Brda inflow. The comparison of modeling results with *ADCP* measurements shows similar velocities magnitude, but it was impossible to measure the velocity direction. The pattern of circular flow of Brda River inflow and additional flux of water from Central and Southern sub-basins explain high concentration of organic matter in the bottom sediments at Northern-1 sub-basin. Both fluxes bring nutrients in organic and mineral form and circulation pat-tern improves a sedimentation conditions and increase the time of water residence.

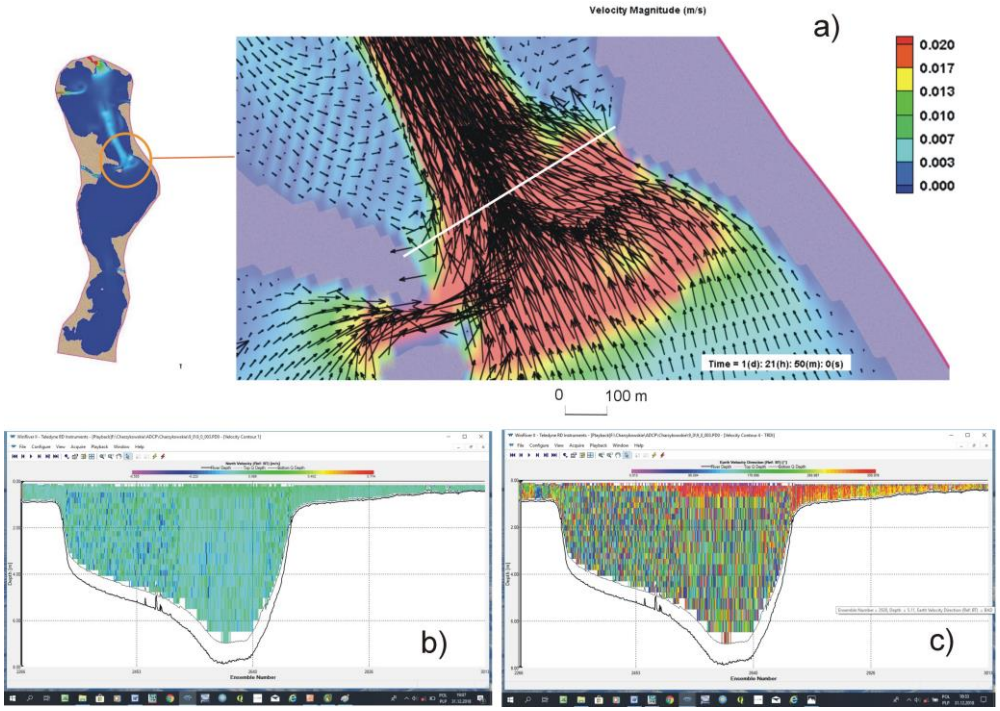

Fig. 1. Selected *ADCP* profile No. 9003 at sill separating sub-basins Central and Northern-2 compared to: a) velocity field calculated by *CCHE2D* model, b) velocity magnitude by *ADCP* measurement in geographic N direction, c) geographic flow directions by *ADCP* measurement