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Flow simulations in the Porąbka Lake with the FESWMS model

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- Characteristics of the Porąbka lake
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Characteristics of the Soła Cascade

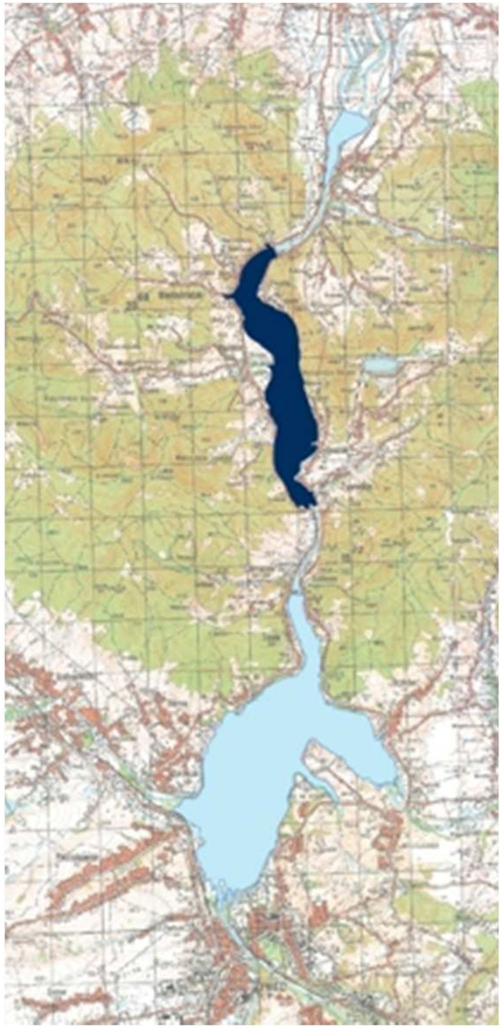
- system of three reservoirs: Tresna, Porąbka, Czaniec,
- located on Soła river in the southern Poland,
- the main function – providing drinking water for Silesia, Bielsko-Biała, Oświęcim, Kęty and also industrial water to factories,
- hydroelectric power production,
- flood flows reduction.

Characteristics of the Porąbka lake

- second reservoir in the system,
- the oldest in the system (built in 1936),
- has two hydroelectric power plants:

– the first located on the dam,

– the second located on the eastern shore,



Porąbka-Żar hydroelectric power plant

- the second biggest pumped-storage hydroelectric power plant in Poland,
- Porąbka's reservoir is its lower tank,
- upper tank located on the top of the Żar hill,
- reservoirs connected with tunnels carved into the rock,
- reservoirs water level difference – 440m,
- use for low and high electrical demands balance,
- turbine power – 500 MW,
- turbines work as water pumps or energy generators.

FESWMS model

- Included in the SMS package
- Based on the Gelarkin Finite Element Method
- Used for modeling: rivers behavior, contaminate transport, sediment transport, rural and urban flooding, coastal circulation, inlet and wave modeling,
- Supports both steady-state and dynamic simulations,
- 2.5 D – uses depth-averaged two dimensional equations,
- The calculations are carried out on grids constructed on the basis of maps.
- Boundary conditions: inflows, outflows, and the water surface elevation.
- To ensure the model to be well-conditioned the numerical grid must be properly constructed.

FESWMS model

Simplified dynamic water flow equation along the x direction has the following form:

$$\frac{\partial q_x}{\partial t} + gH\frac{\partial z_0}{\partial x} + \frac{\partial}{\partial x}\left(\frac{q_x^{\,2}}{H} + \frac{gH^2}{2}\right) + \frac{\partial}{\partial y}\left(\frac{q_x q_y}{H}\right) + \frac{1}{\rho}\left(\tau_{bx} - \frac{\partial H\tau_{xx}}{\partial x} - \frac{\partial H\tau_{xy}}{\partial y}\right) = 0$$

where:

H – water depth at a given point;

$q_x = V_x H$ – unitary flow rate in the x direction;

$q_y = V_y H$ – unit flow rate in the y direction;

z_0 –bed elevation;

g – gravitational acceleration;

ρ – density of water;

τ_{bx}, τ_{by} – bed shear-stresses in the *x* and *y* direction, respectively;

τ_{xx}, τ_{xy}, τ_{yx}, τ_{yy} – directional components of lateral shear stress caused by turbulence.

Simulations

- Two different values of total flow:

- 22 m^3/s: 20 m^3/s from Soła and two left bank tributaries, 1 m^3/s each,

- 9.1 m^3/s: 8.7 m^3/s from Soła and two left bank tributaries, 0.2 m^3/s each,

- Types of simulation:

- steady state,

- dynamic.

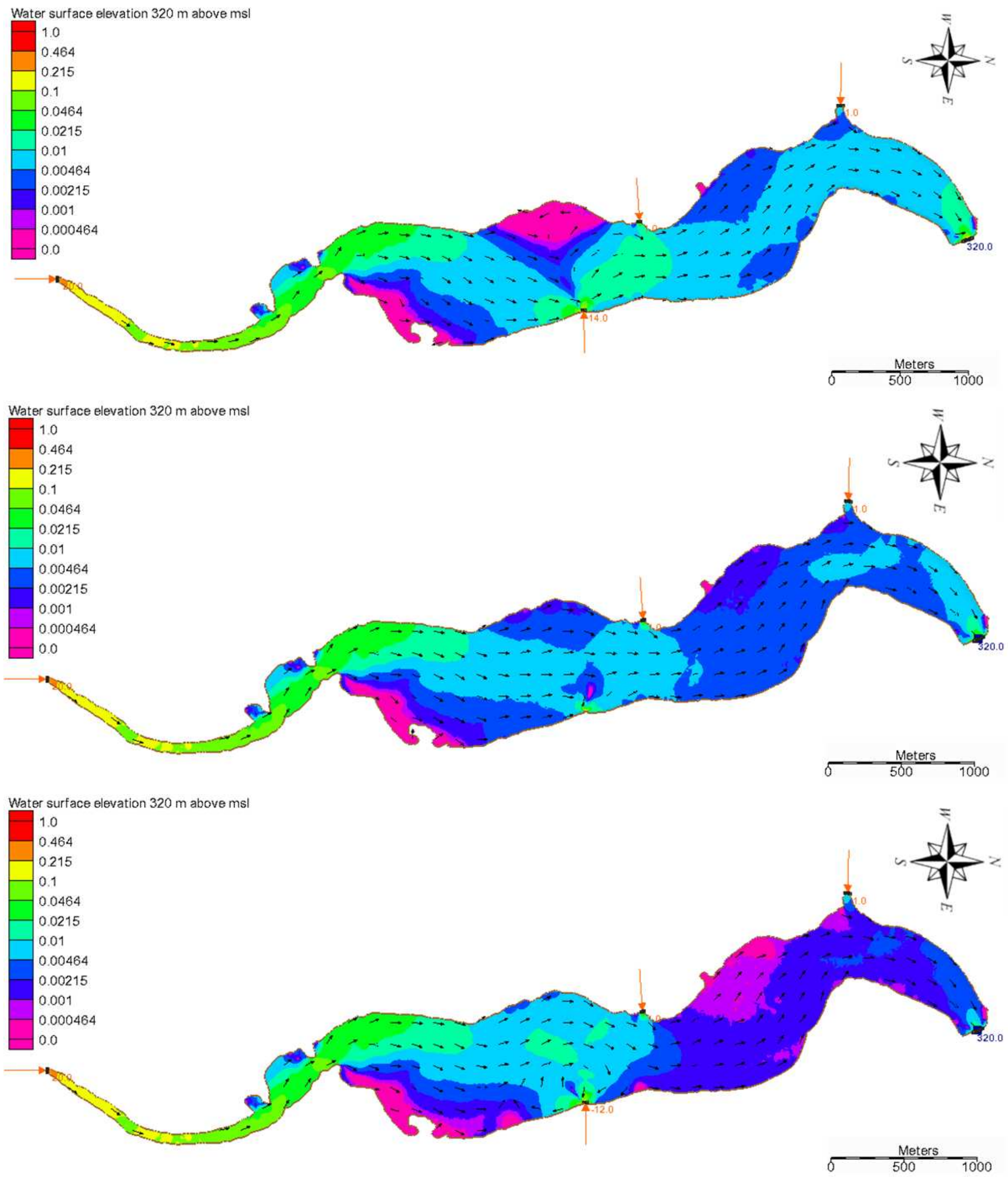
- Scenarios:

- the power plant does not work;

- the power plant generates energy injecting additional 14 m^3/s into the lake;

- the power plant pumps water into its upper tank at the rate of -12 m^3/s.

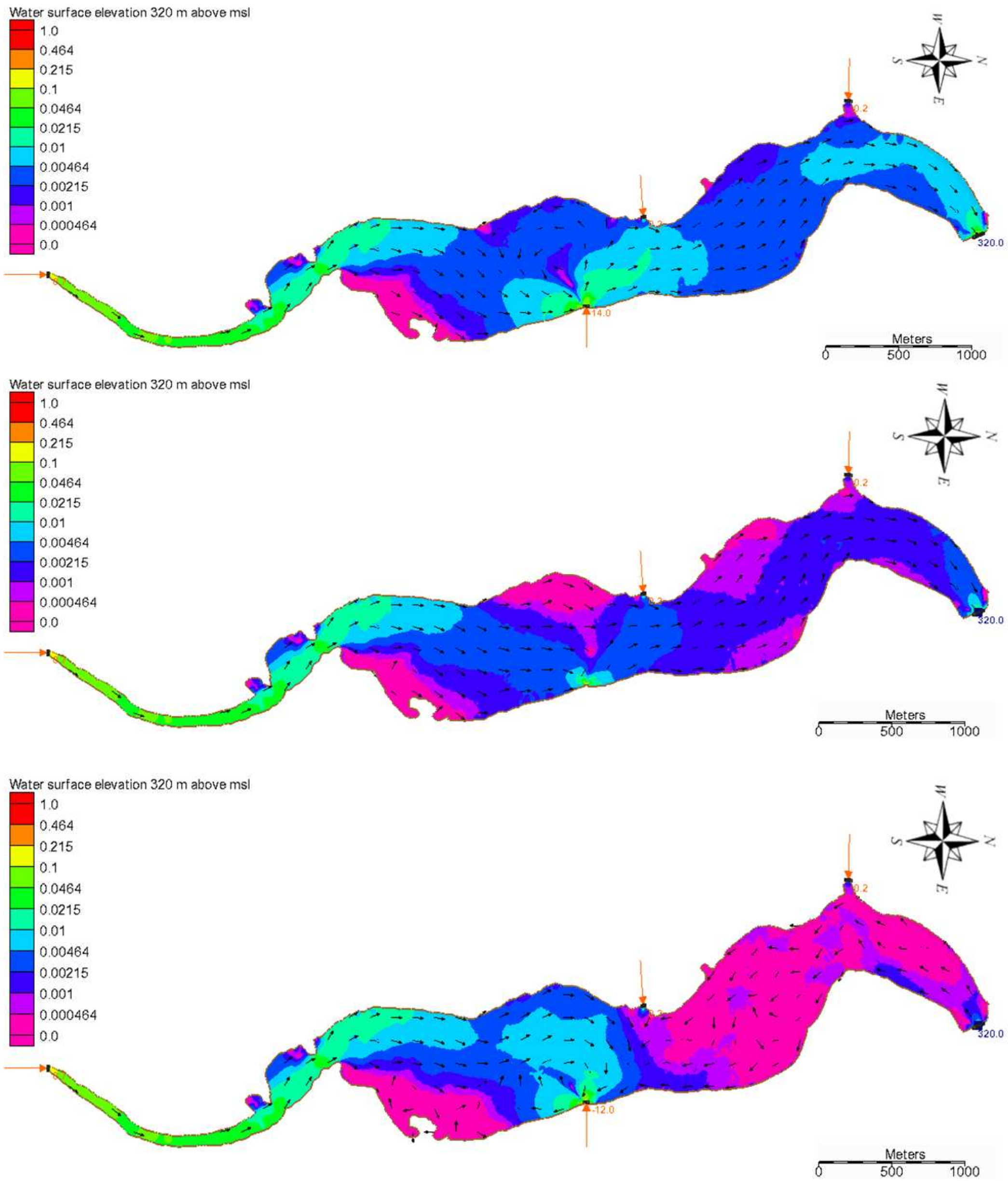
Steady-state simulations



Planar velocity fields resulting from steady state simulations for 20 m^3/s main inflow:

- the power plant dumps water into the reservoir at 14 m^3/s (upper frame);
- the power plant does not work (middle frame);
- the power plant takes water from the lake at 12 m^3/s (lower frame).

Steady-state simulations



Planar velocity fields resulting from steady state simulations for 8.7 m^3/s main inflow:

- the power plant dumps water into the reservoir at 14 m^3/s (upper frame);
- the power plant does not work (middle frame);
- the power plant takes water from the lake at 12 m^3/s (lower frame).

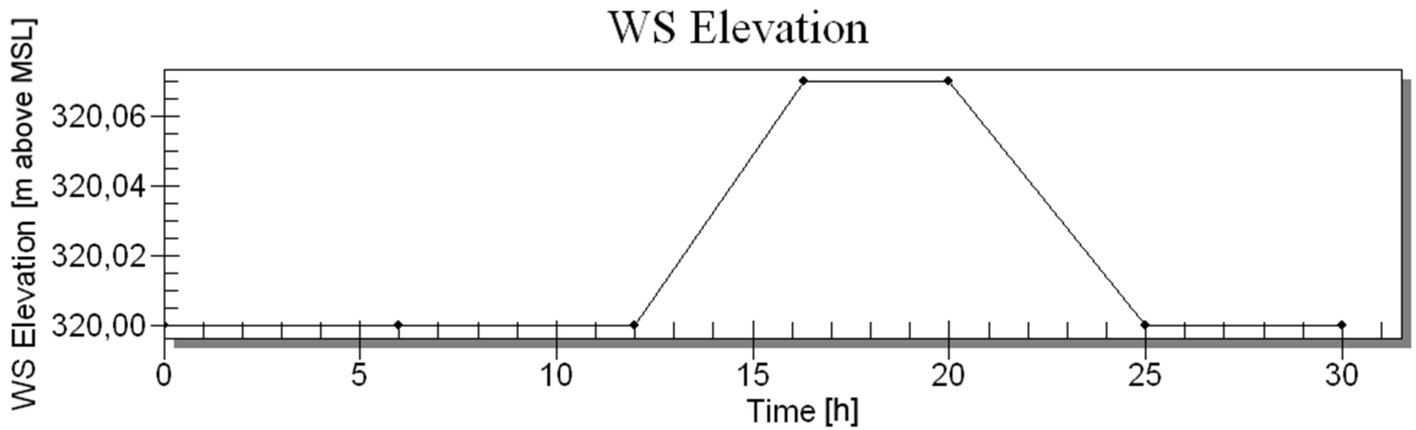
Dynamic simulations

- The dynamic simulations conducted for 30 hours of the model time.
- The first six hours used to let the model get a steady-state,
- The next 24 hours represent the daily cycle of the lake:

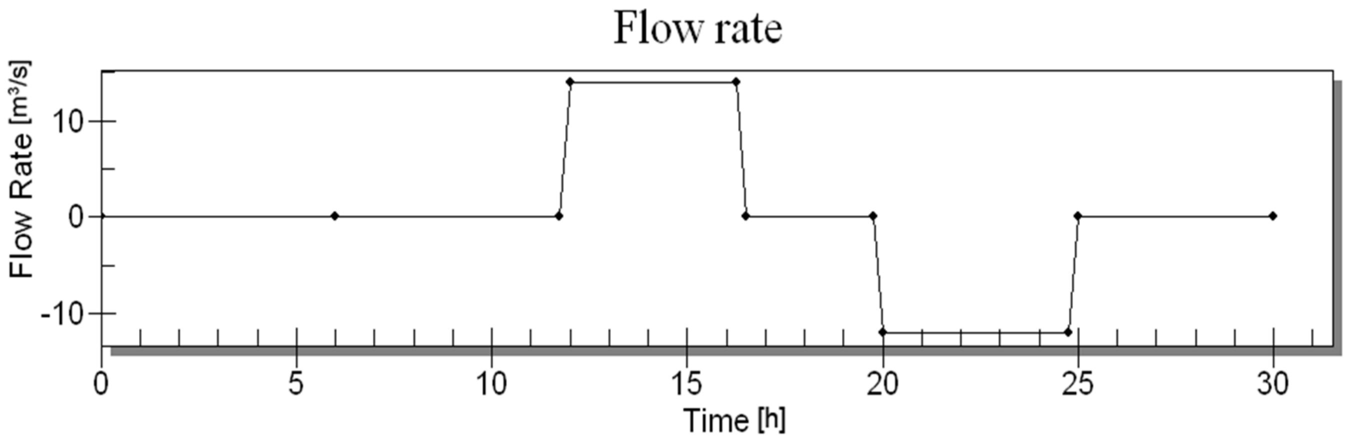
  - The power plant is inactive from noon to 6PM, from 10:30PM to 2AM, and from 7AM to noon;
  - the power plant generates electricity from 6PM to 10:30PM;
  - the power plant stores water from 2AM to 7AM.

Dynamic simulations

Dynamic boundary conditions



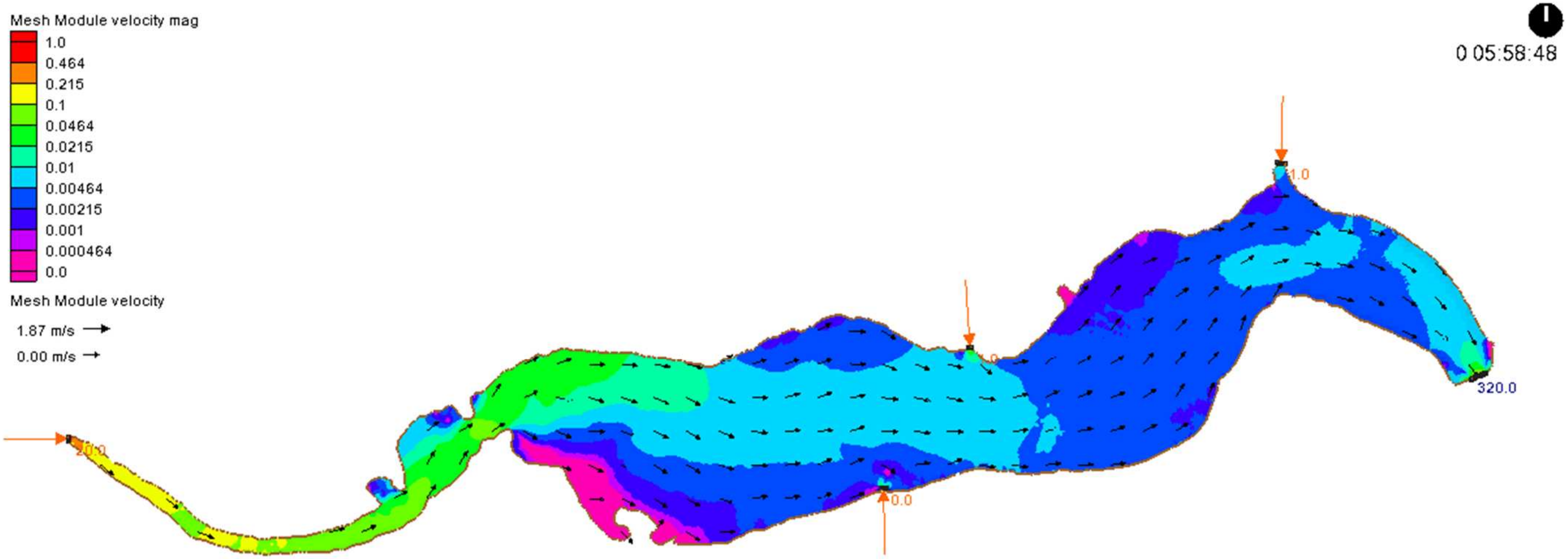
Water surface boundary condition for dynamic simulations. Damping water from the upper tank causes a 7 cm WSE rise in the lower tank.



Power plant outlet discharge rate boundary condition for dynamic simulations. Pumping water upwards takes a longer time as the discharge value is lower.

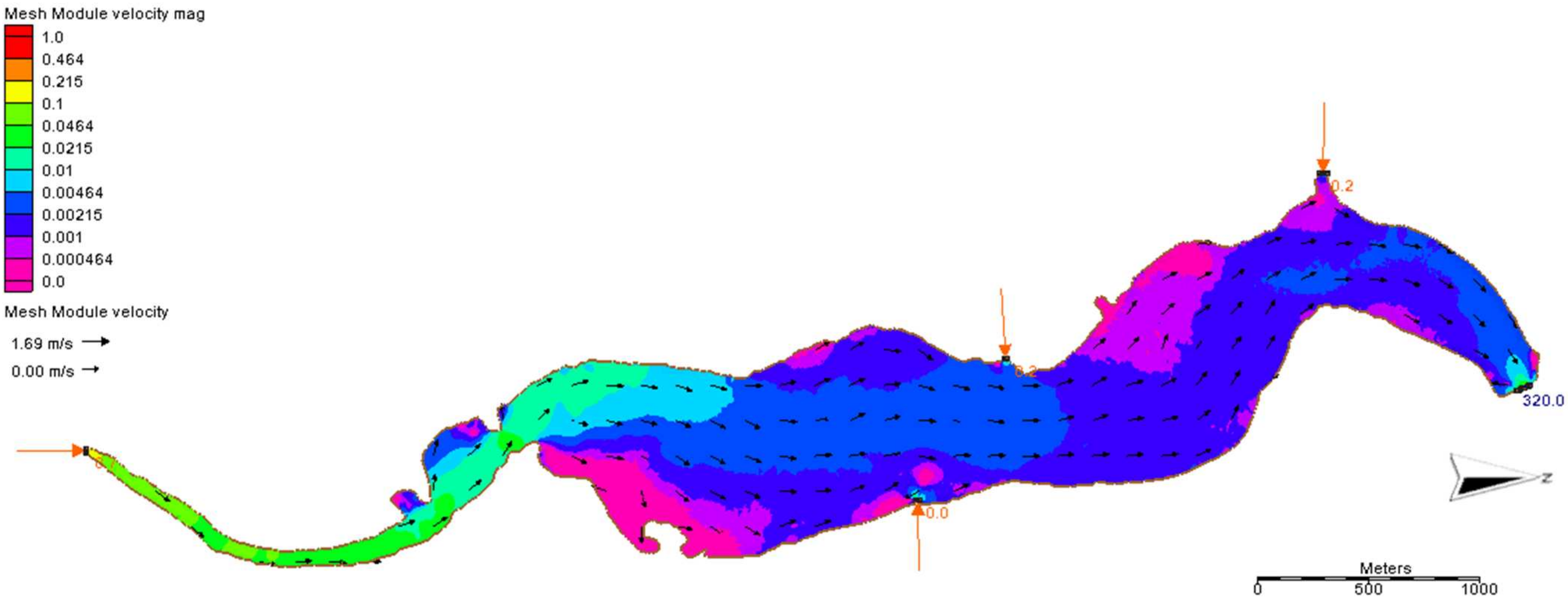
Dynamic simulations

Main inflow: 20 m^3/s



Dynamic simulations

Main inflow: 8.7 m^3/s



Summary

- Porąbka has very complicated flow structure due to the outlet of pumped-storage power station located inside the lake.
- Prepared models are very complex.
- Steady-state and dynamic simulations were performed.
- Results of simulations are physically reasonable and can be compared with field measurements.
- Model solutions are stable and ready for calibrations.
- Prepared models can be helpful for testing different reservoir scenarios.

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Thank you for your attention