XLII International School of Hydraulics
20-23 May 2025, Radocza, Poland

GDAŃSK UNIVERSITY OF TECHNOLOGY

Wind surge modeling in the Vistula Lagoon using HEC-RAS 2D

Today's and tomorrow's perspective

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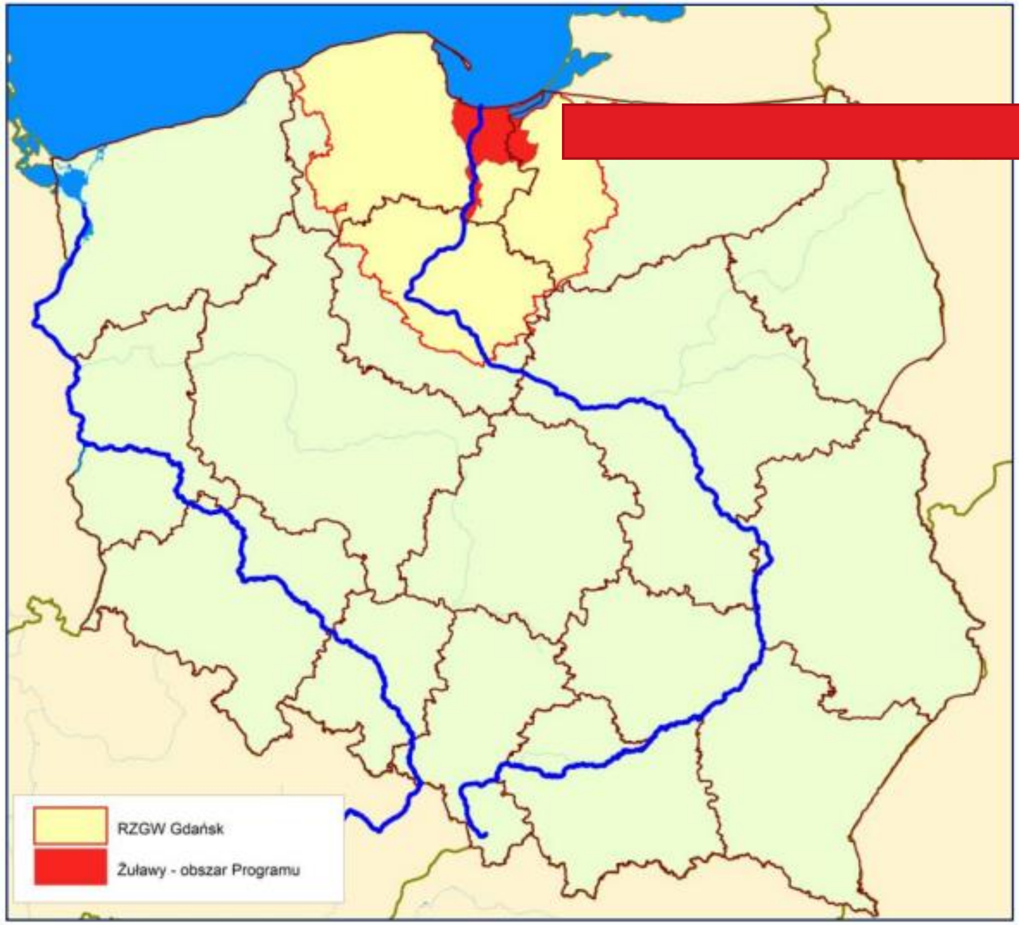
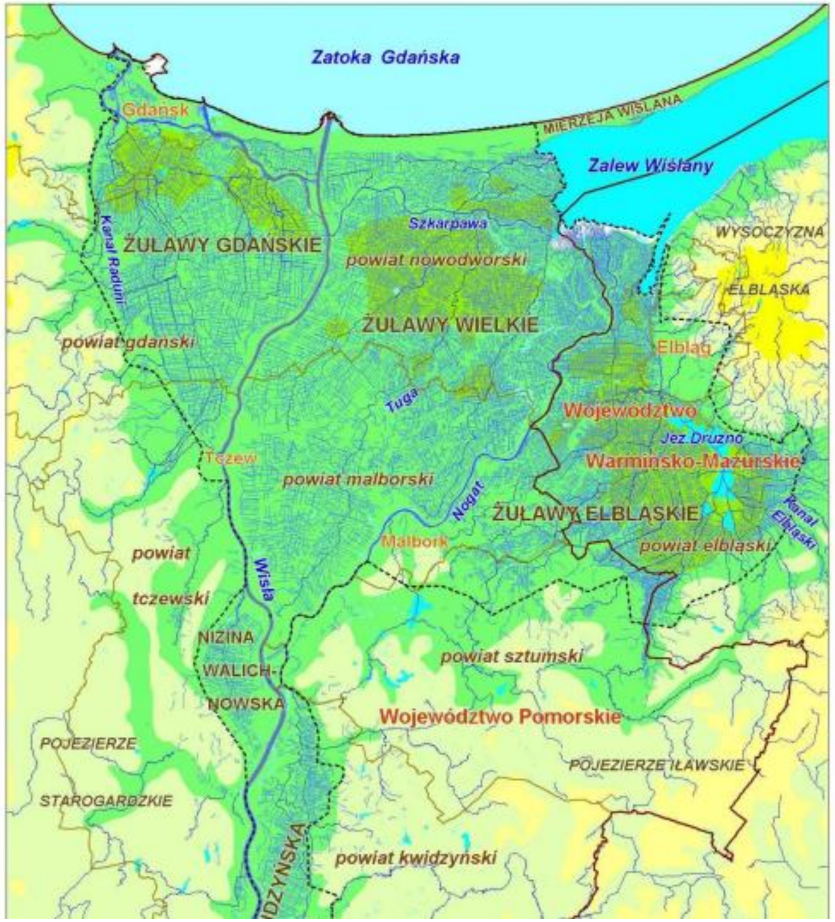
Two main research goals

- Assessment of the feasibility of using the HEC-RAS 2D (version 6.6) to simulate wind surges in the shallow coastal lagoon
- Preliminary assessment of the impact of potential wind speed changes in the Vistula Lagoon region on the increase in water levels in the southwestern (Polish) part of the lagoon

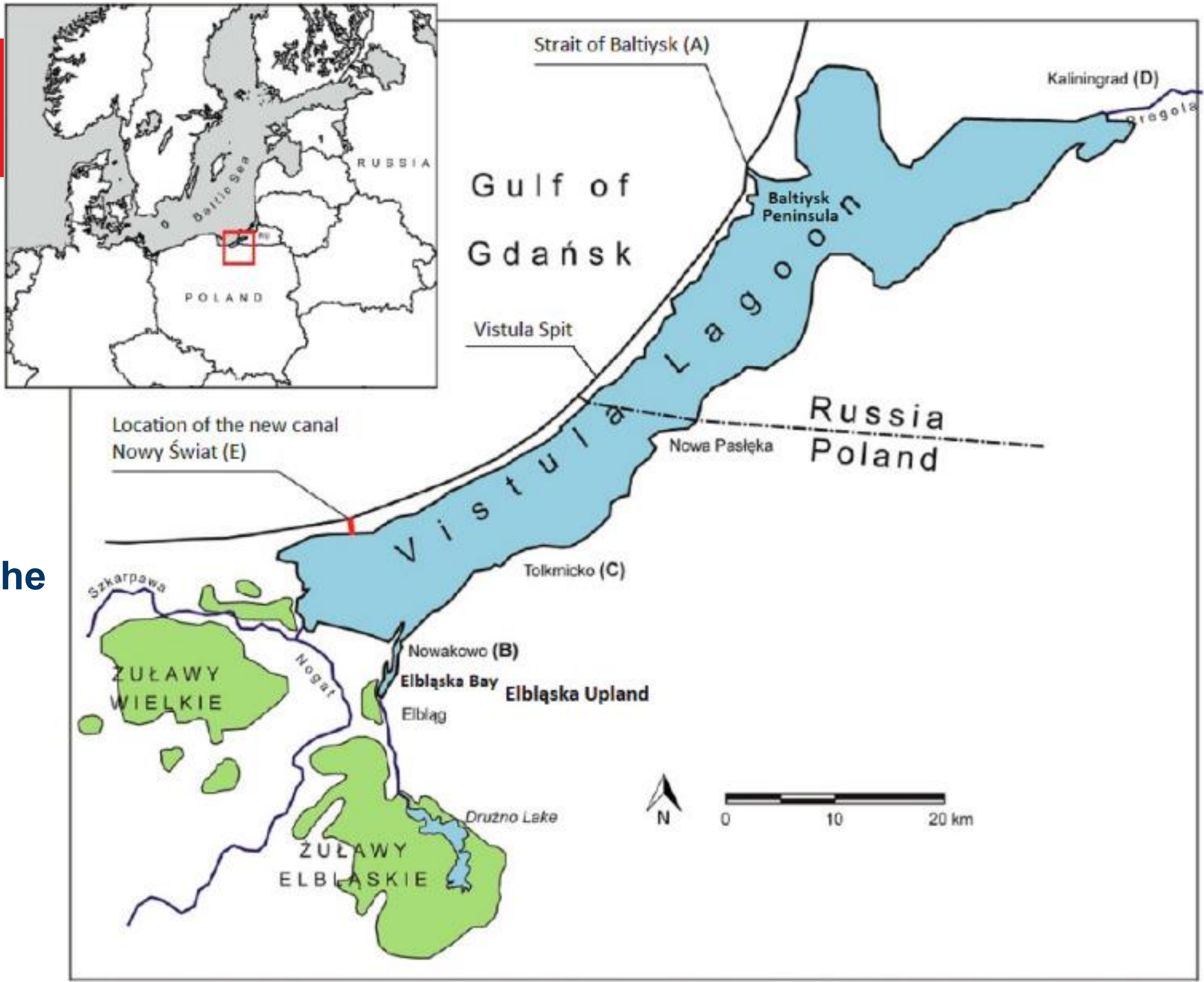
Żuławy (lowland) and Vistula Lagoon





Vistula Lagoon

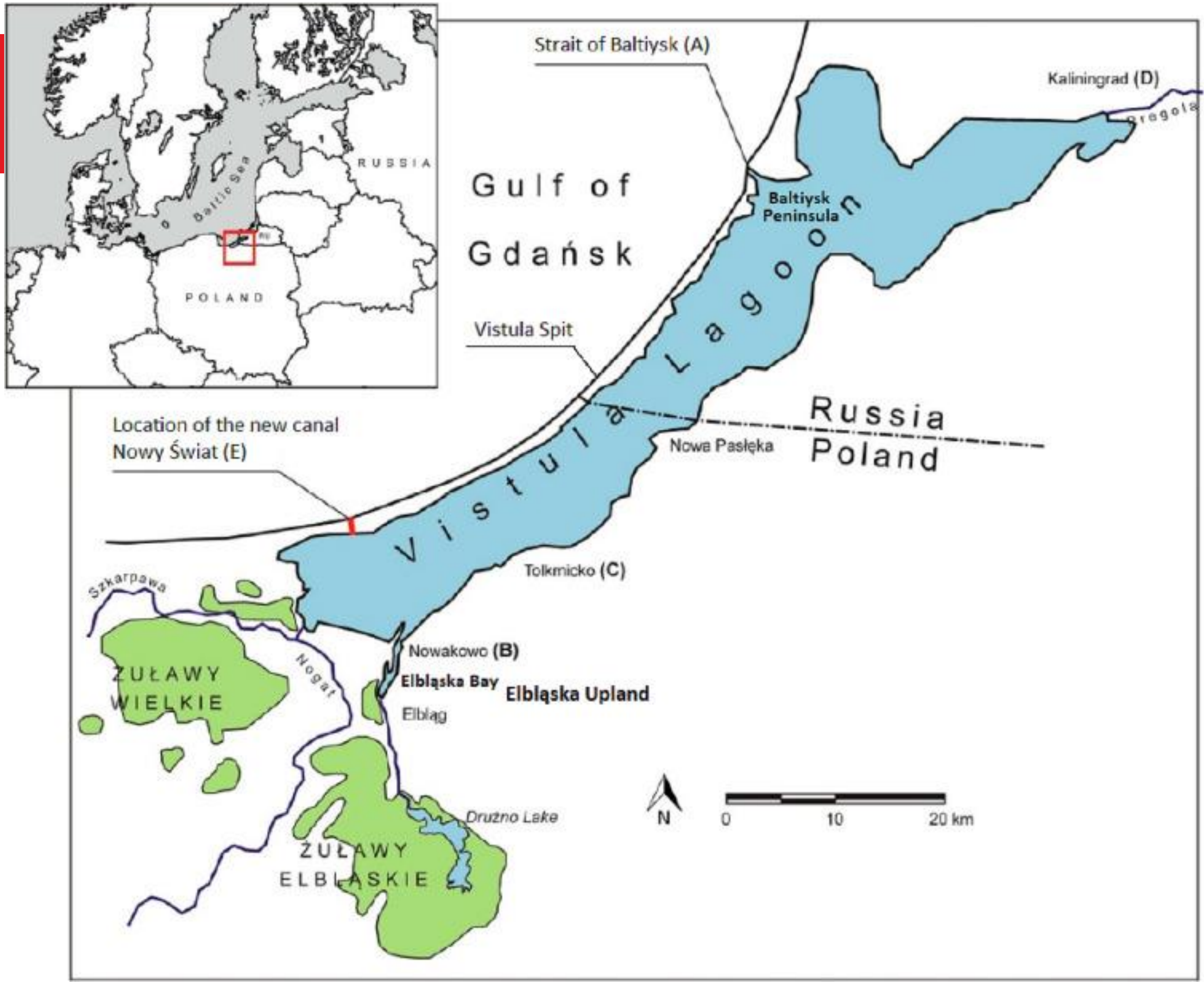
- The length of the lagoon is 90.7 km and its width varies from almost 6 km up to 13 km
- The lagoon is a shallow basin with a mean depth of about 2.75 m
- It is separated from the Gulf of Gdańsk by the Vistula Spit. The length of the spit is 65 km
- Till 2022, the only connection between the Vistula Lagoon and the Baltic Sea was through the Strait of Baltiysk (Russia)



Vistula Lagoon

- **Hydraulic conditions in the Vistula Lagoon are usually the result of variations in the sea level in the Gulf of Gdańsk and the wind action on the water surface of the lagoon**

- **The long-lasting rising of water in the southern part of the lagoon can be a cause of flood risk for the lowland areas of Żuławy Elbląskie**



Flood conditions – Elbląg, January 2019

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Flood conditions – Elbląg, January 2019

Mathematical model

- A two-dimensional shallow water equation model was adapted to simulate free surface water flow in the lagoon driven by the wind and storm surges.

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+g\frac{\partial h}{\partial x}+\frac{gn^2}{H^{4/3}}U|W|-\nu_o\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right)-\frac{T_x}{H}=0$$

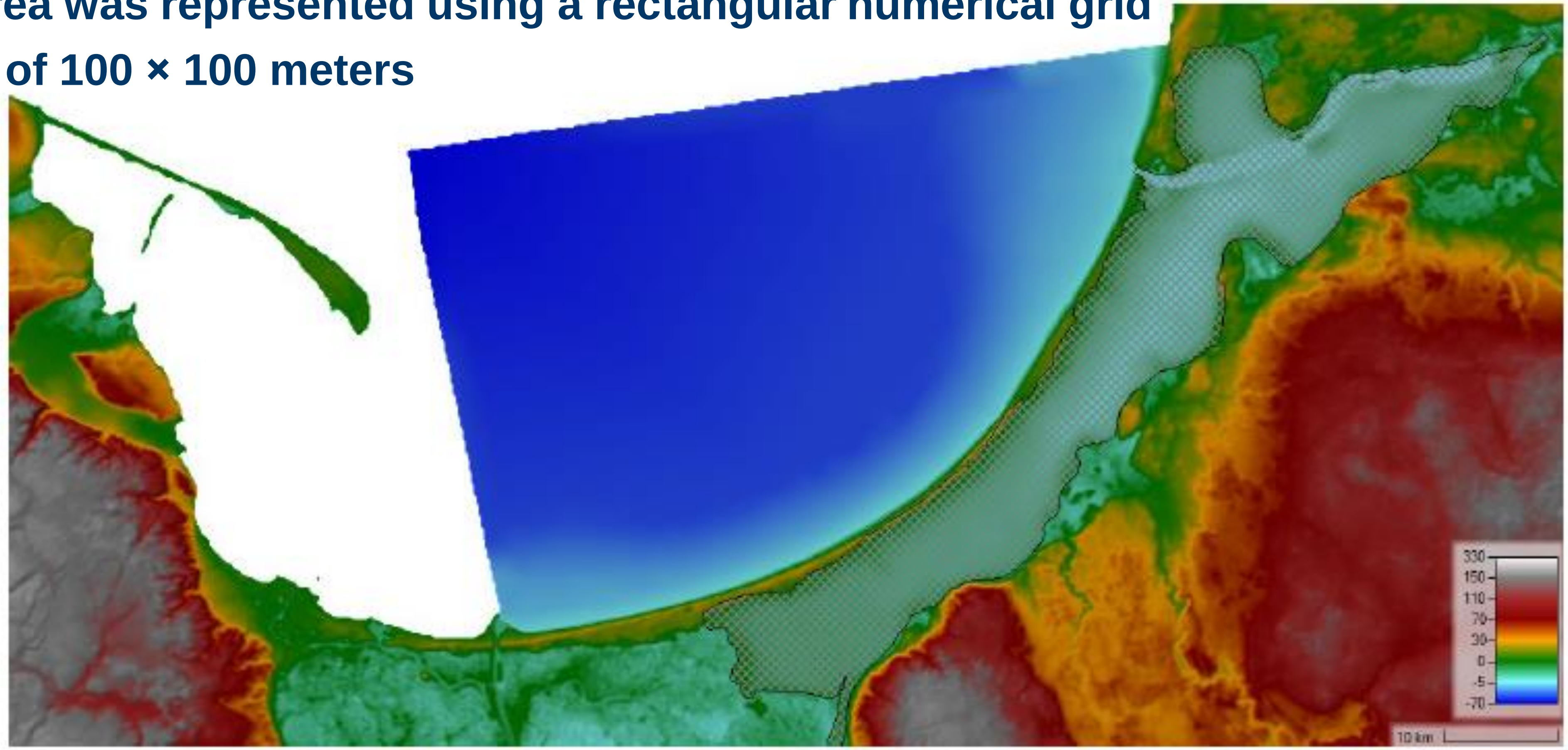
$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+g\frac{\partial h}{\partial y}+\frac{gn^2}{H^{4/3}}V|W|-\nu_o\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}\right)-\frac{T_y}{H}=0$$

$$\frac{\partial h}{\partial t}+\frac{\partial (UH)}{\partial x}+\frac{\partial (VH)}{\partial y}=0$$

- where: x, y – spatial coordinates; t – time; U, V – depth-averaged components of velocity in x and y direction;
- $|W|=(U2+V2)^{0.5}$ – modulus of the velocity vector; h – water surface elevation; H – water depth;
- g – acceleration due to gravity; n – Manning roughness coefficient; v_0 - coefficient of turbulent viscosity;
- T_x – wind stresses in x direction; T_y – wind stresses in y direction.

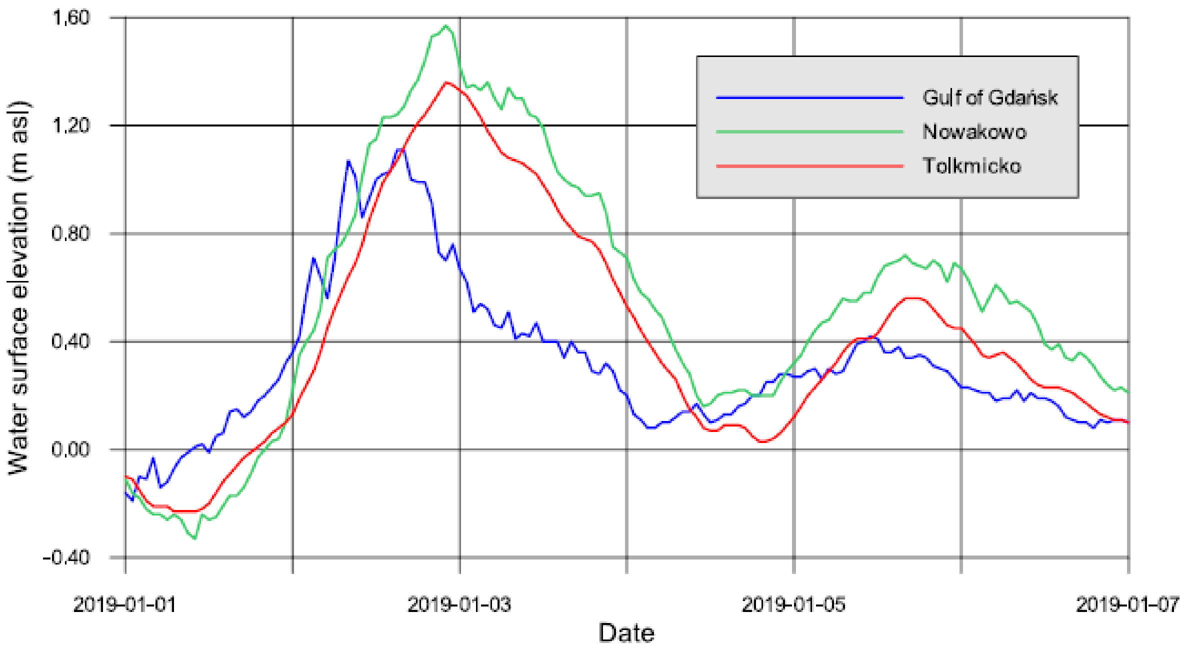
Vistula Lagoon HEC-RAS model - geometry

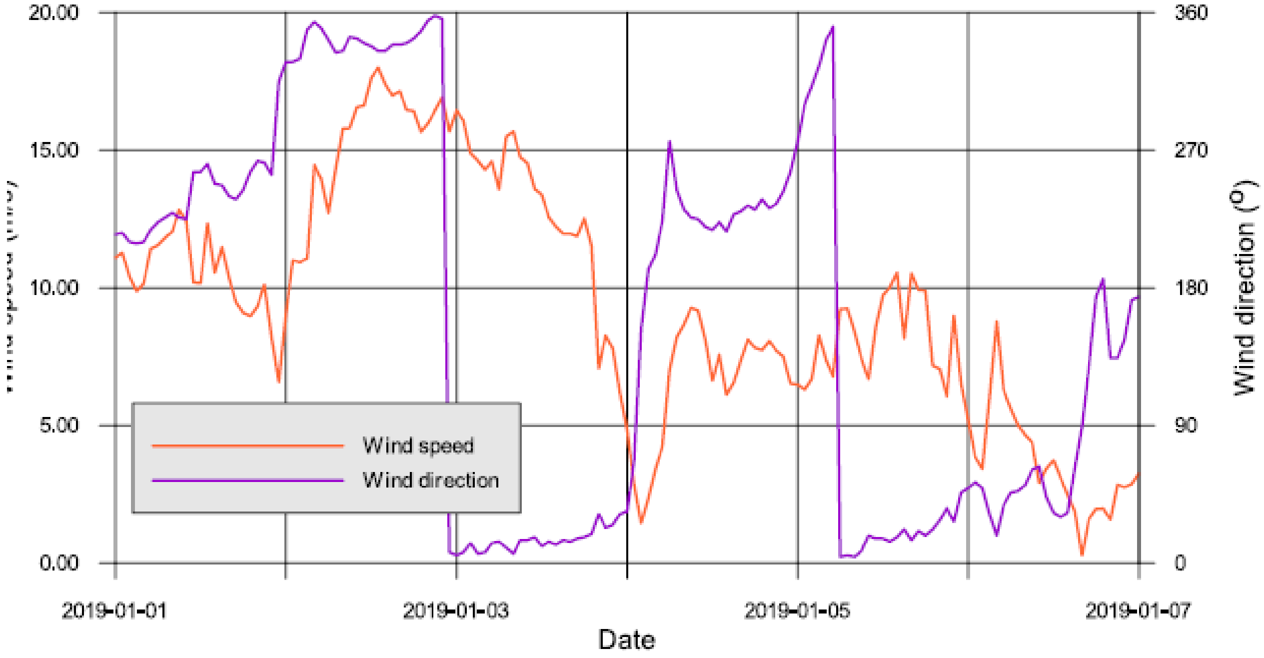
- the flow area was represented using a rectangular numerical grid
- mesh size of 100 × 100 meters



Model validation

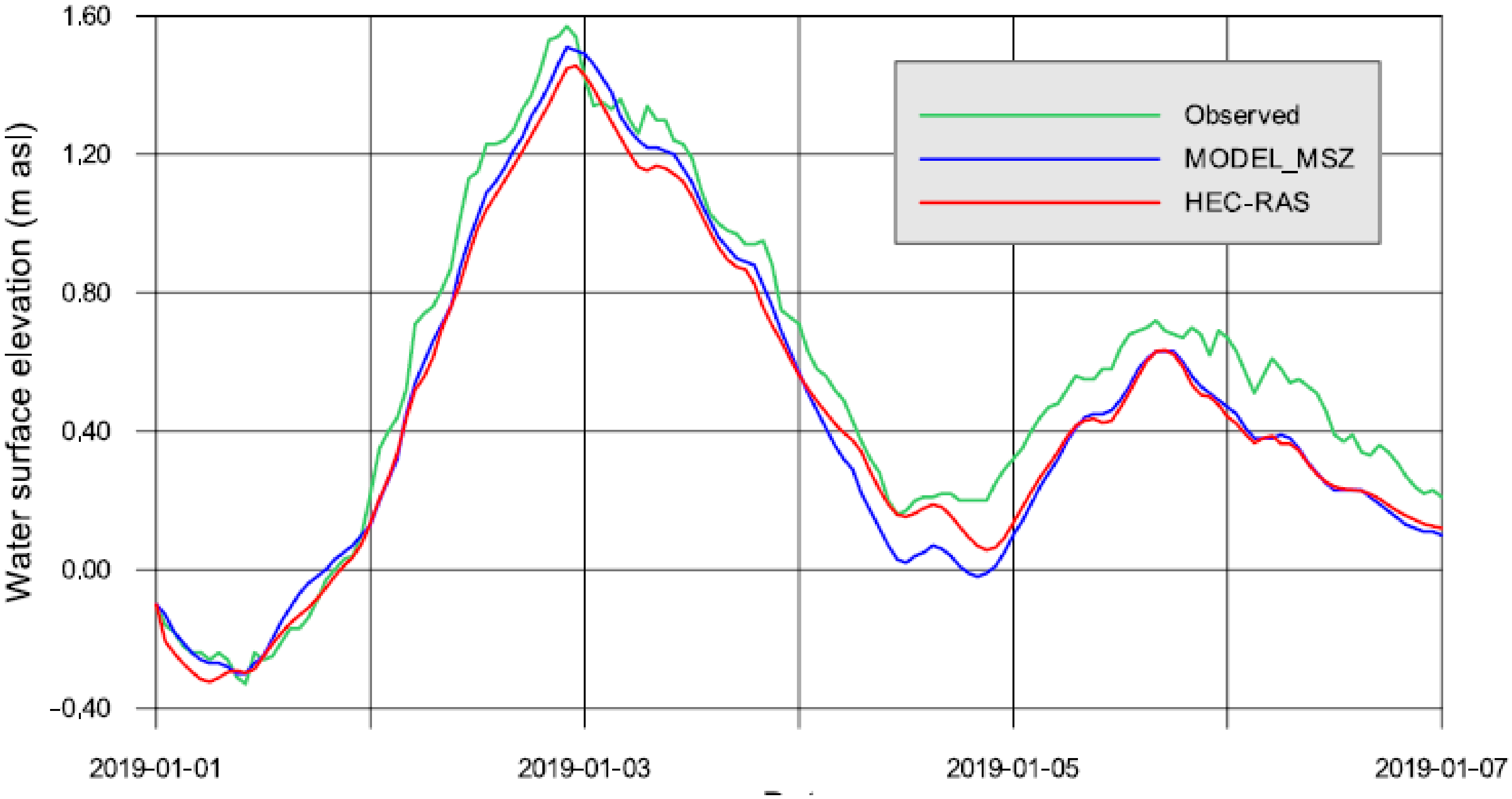
- **In order to validate the results of modeling the storm surge using the HEC-RAS 2D, a numerical simulation of the historical episode (2019 January) was performed**



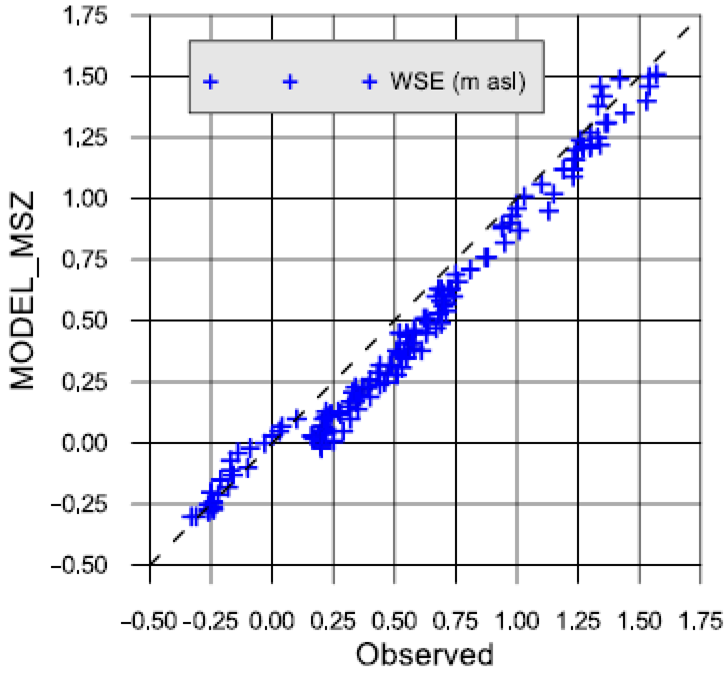


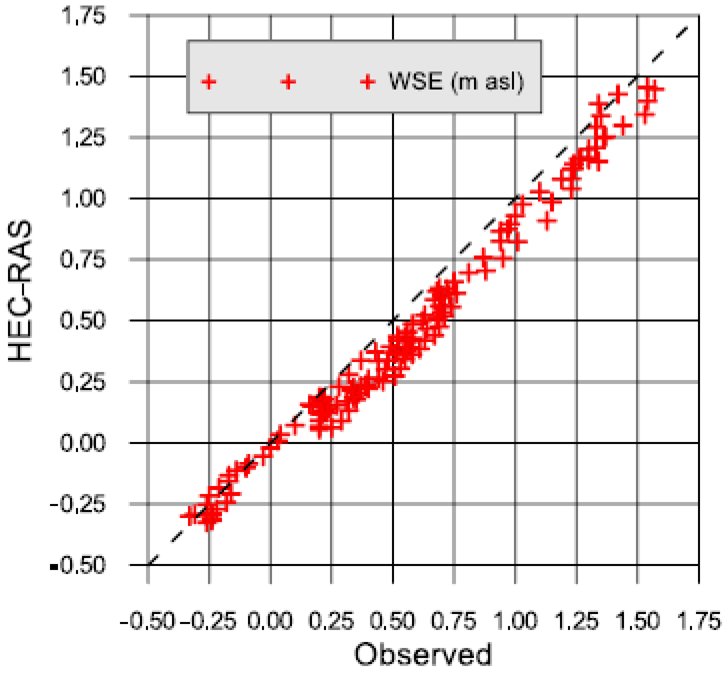
Model validation – Nowakowo station

- **Comparison of the calculated water stages at Nowakowo gauging station with IMGW PIB observations and earlier own numerical simulations (SWE)**



Model validation - statistical performance metrics



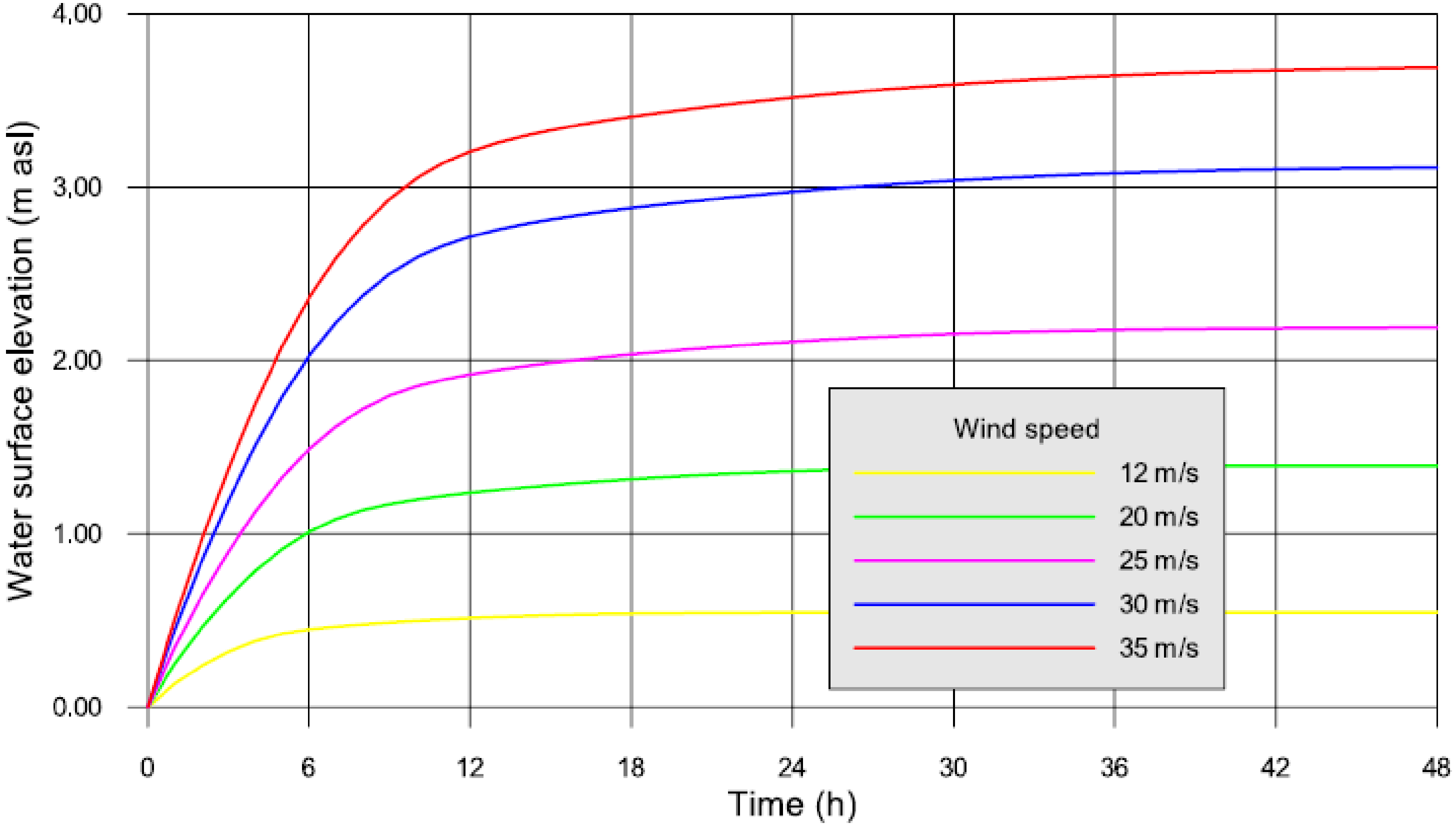


Metric	Model_MSZ	Model_HEC_RAS
MAE (m)	0.1126	0.1088
RMSE (m)	0.1283	0.1243
NSE	0.9300	0.9343
Bias (m)	-0.0994	-0.1051

Synthetic wind surge epizodes – duration 48 hours

- **Warning** water surface elevation at Nowakowo 0.81 m asl
- **Alarm** water surface elevation at Nowakowo 1.22 m asl

Speed of NE wind (ms^{-1})	12	20	25	30	35
Water stage elevation (m asl)	0.55	1.40	2.19	3.12	3.69



Conlusions

The historical event was successfully reproduced using the HEC-RAS 2D model, validating its applicability for simulating wind-induced water level changes in shallow lagoons

The numerical simulations of synthetic extreme wind scenarios showed that water levels in the lagoon could exceed 3 m asl when wind speeds reach 35 m/s

A non-linear relationship was observed between wind speed and water accumulation

The results highlight the potential increasing of flood hazard in Elbląg and the surrounding Żuławy Elbląskie polder areas

There is a need for enhanced flood risk management strategies in the region

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HISTORY IS WISDOM
FUTURE IS CHALLENGE