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# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

**Oscar Herrera-Granados**

**Wrocław University of Science and Technology (Poland)**
Faculty of Civil Engineering,
Chair of Geotechnics, Hydrotechnics, underground construction and hydro-engineering

**Brunel University London (England, UK)**
College of Engineering, Design and Physical Sciences,
Department of Civil and Environmental Engineering.

Contact: Oscar.Herrera-Granados@pwr.edu.pl

**Anna Uciechowska-Grakowicz**
Wrocław University of Environmental and Life Sciences

**Marta Kiraga**
Warsaw University of Life Sciences

Brunel University London

unite! University Network for Innovation, Technology and Engineering

Wrocław University of Science and Technology

# Presentation outline

- Introduction (case study)
- Model set-up
- Results and discussion
- Summary and conclusions

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- **Introduction (case study)**
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# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

Inland water transport is a viable alternative or addition to road and rail transport on European corridors. Nonetheless, it remains largely under-exploited in Europe (CSWD, 2018).

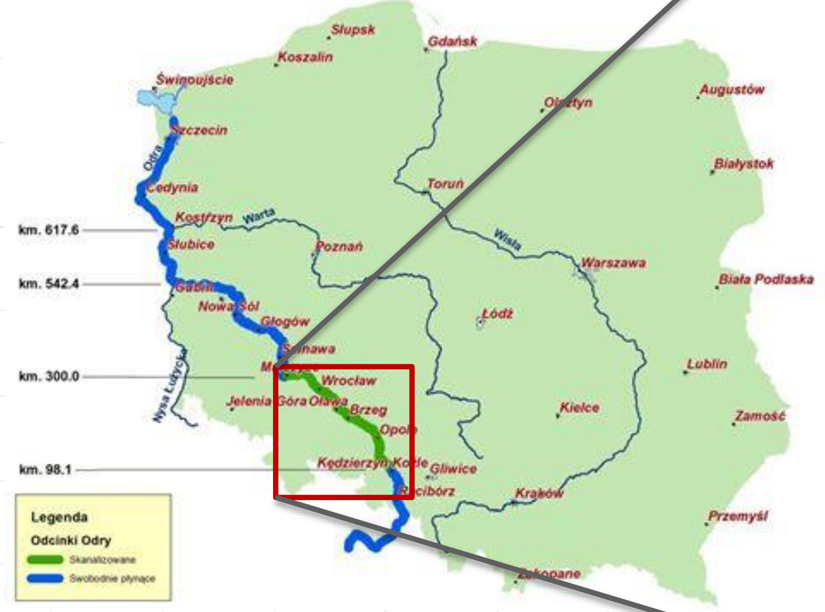


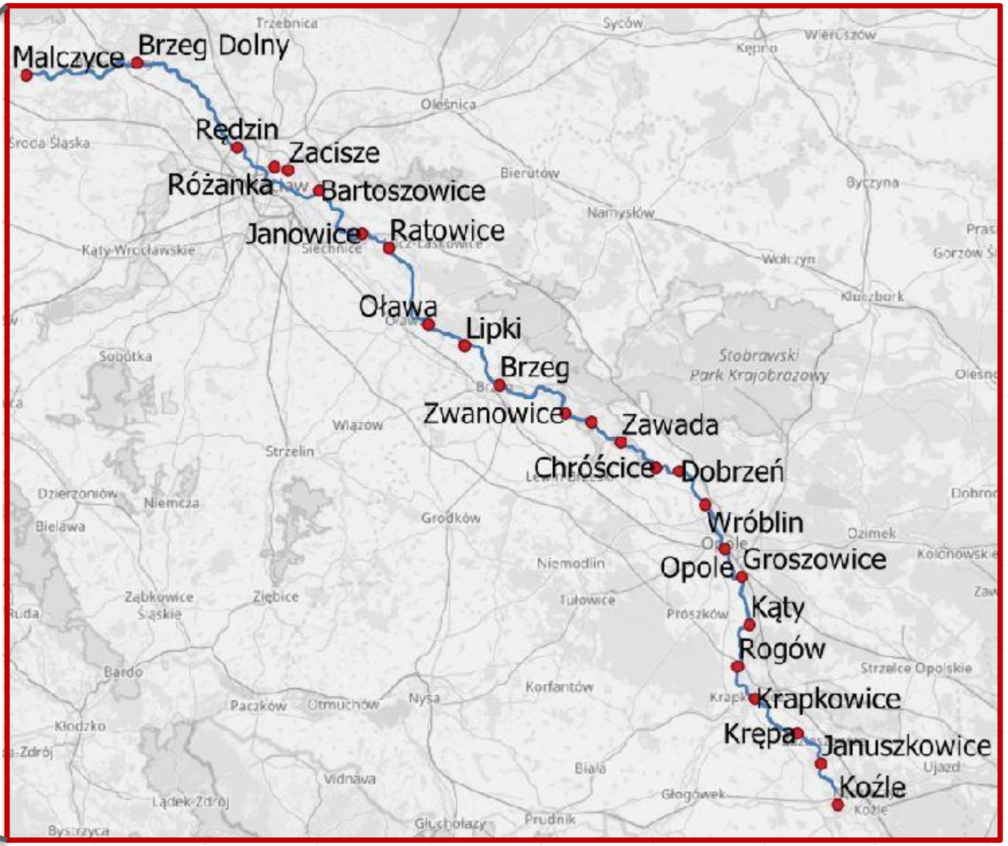

Herrera-Granados, O. *et-al* (2023).

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

During the years 2018-2019, the Wrocław University of Science and Technology carried out the project “*Research and Development Conception on the modernization of the canalized reach of the Odra River to a navigable waterway of class Va*”. Different enhancement works (river training, reconstruction, etc.) on the canalized reach of the Odra river were proposed.

The Odra is planned to be part of the E-30 European waterway linking the Baltic sea to the Danube river in Bratislava. Thus, the modernization of the Odra river is the main priority for Polish inland navigation purposes.



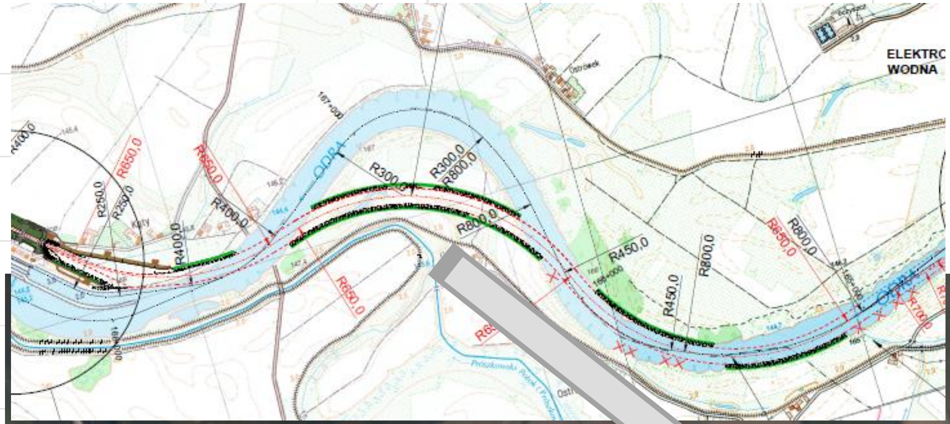



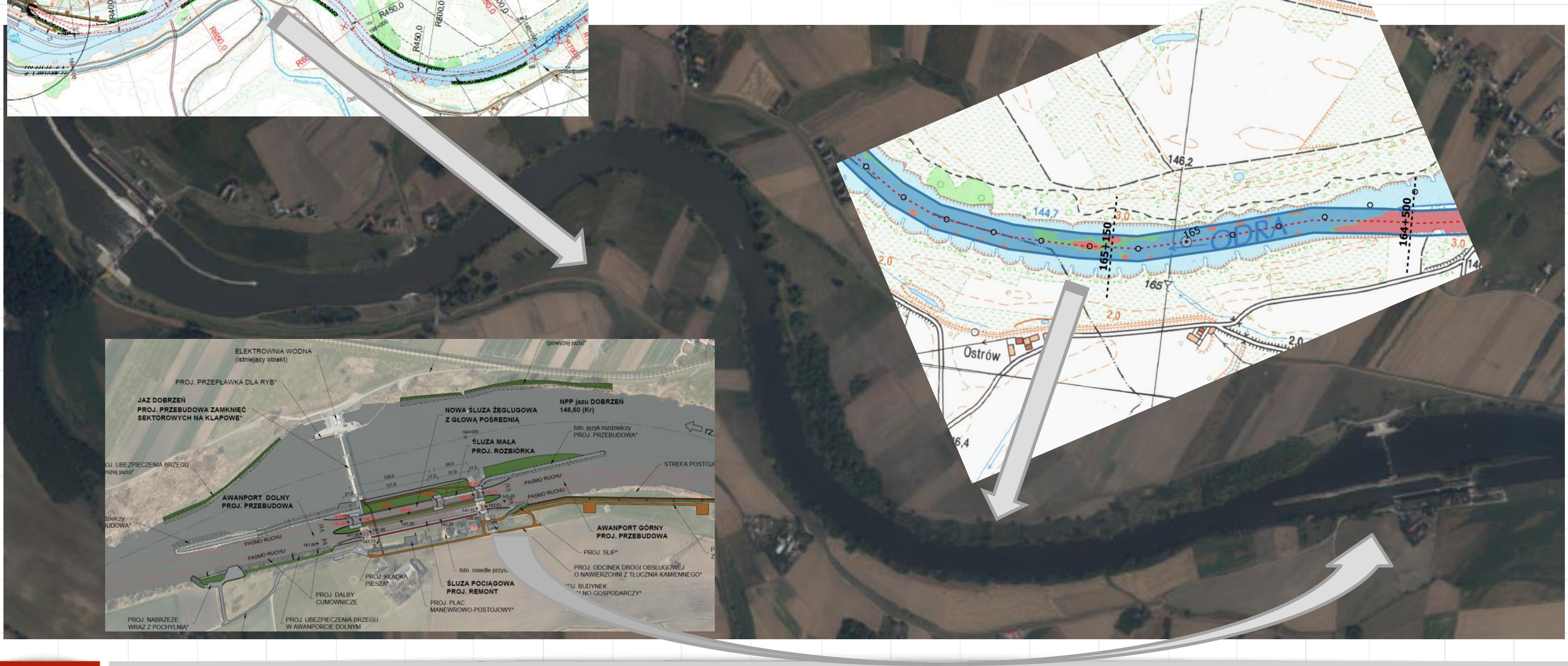

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

Herrera-Granados, O. *et-al* (2023). All photos taken by Oscar Herrera-Granados

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

## Case study – modernization proposals (Kostecki, et-al., 2019)






Aerial photo source: ArcGIS world imagery

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# Model set-up

Five simple steps to accurate analyse (numerically) any phenomenon related to water flow (Herrera-Granados, 2022):

TIME DEMANDING
EXPENSIVE

1. Data retrieval and geometry construction of the computing domain
2. Choosing the mathematical model to analyse the natural phenomenon
3. Choosing an adequate numerical method to discretize the mathematical model
4. Defining the boundary and initial conditions of the problem
5. Calibrating and validating the model

Essential for a good prediction of the natural phenomenon

Sometimes very difficult (almost always), but a must to make our numerical models reliable

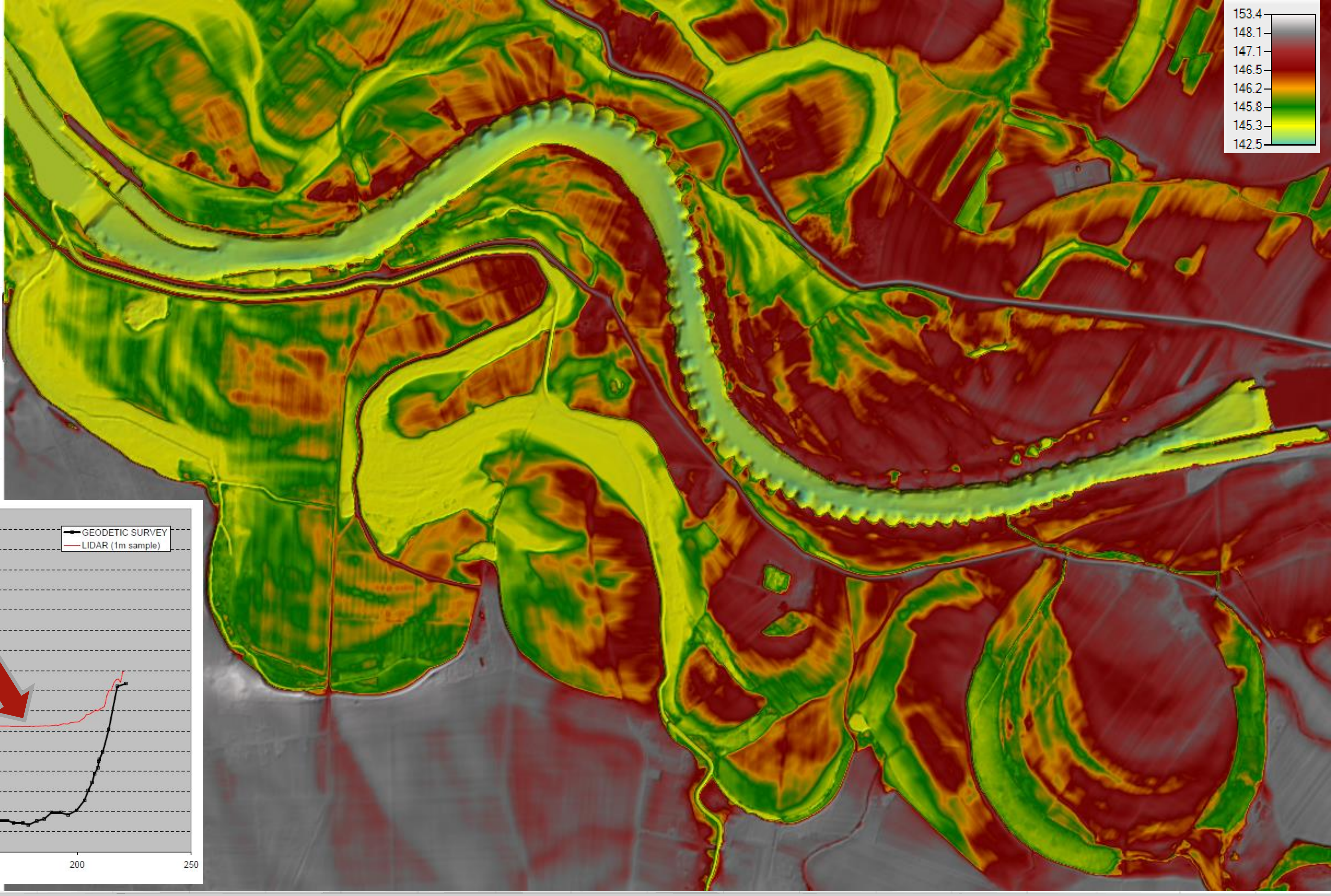
Normally the end-user (the modeler) does not face this problem as there are plenty of computer programs that makes these steps easier (HEC-RAS)

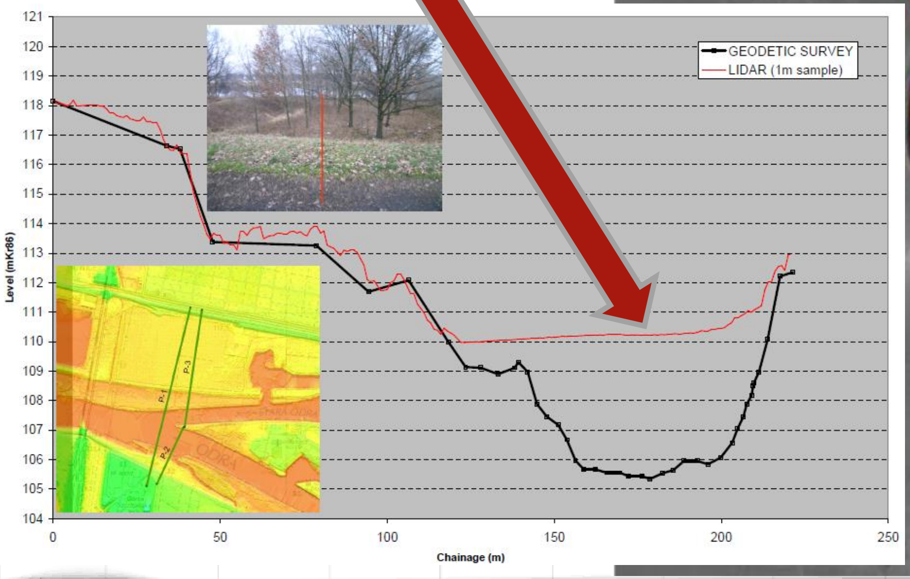
However, it is necessary to avoid the black-box dilemma, or even worst, to fall in the black box error

# Geometry: Setting up the computational domain

An accurate Digital Elevation Model (DEM) from LIDAR data (ISOK project) was facilitated. The first problem arose:

The ISOK's DEM did not include information about the bathymetry.

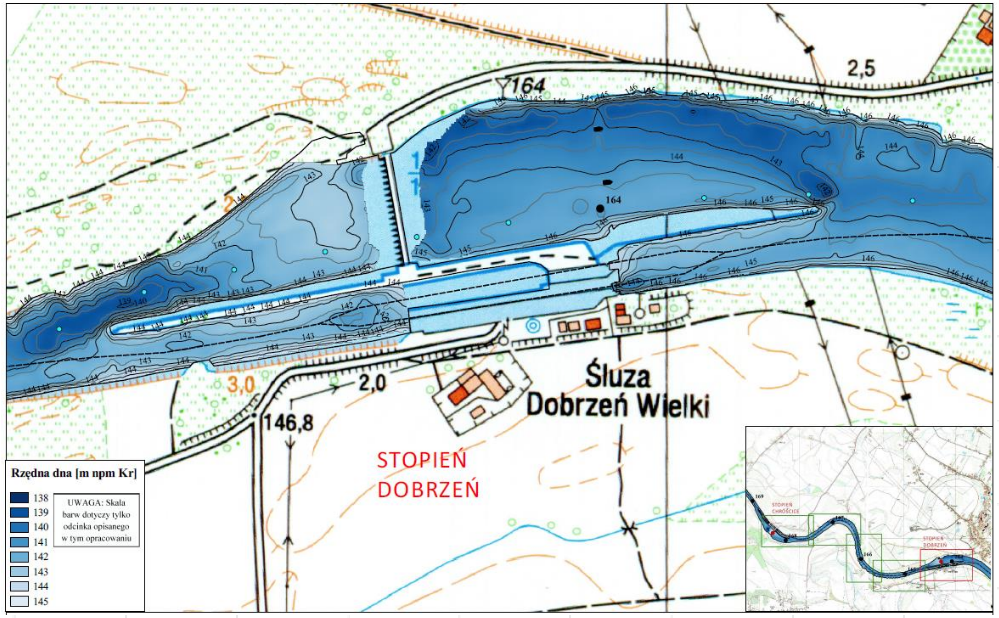



DEM source: GUGIK (PL)

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)





Rzędna dna [m npm Kr]
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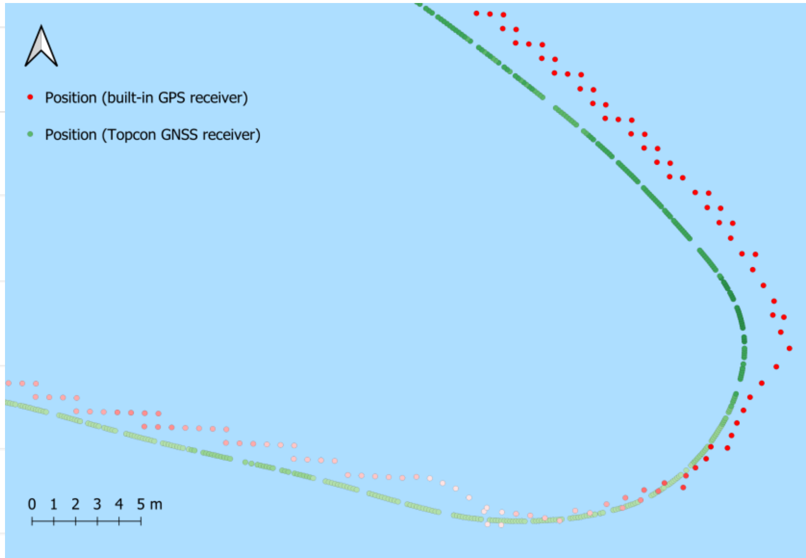
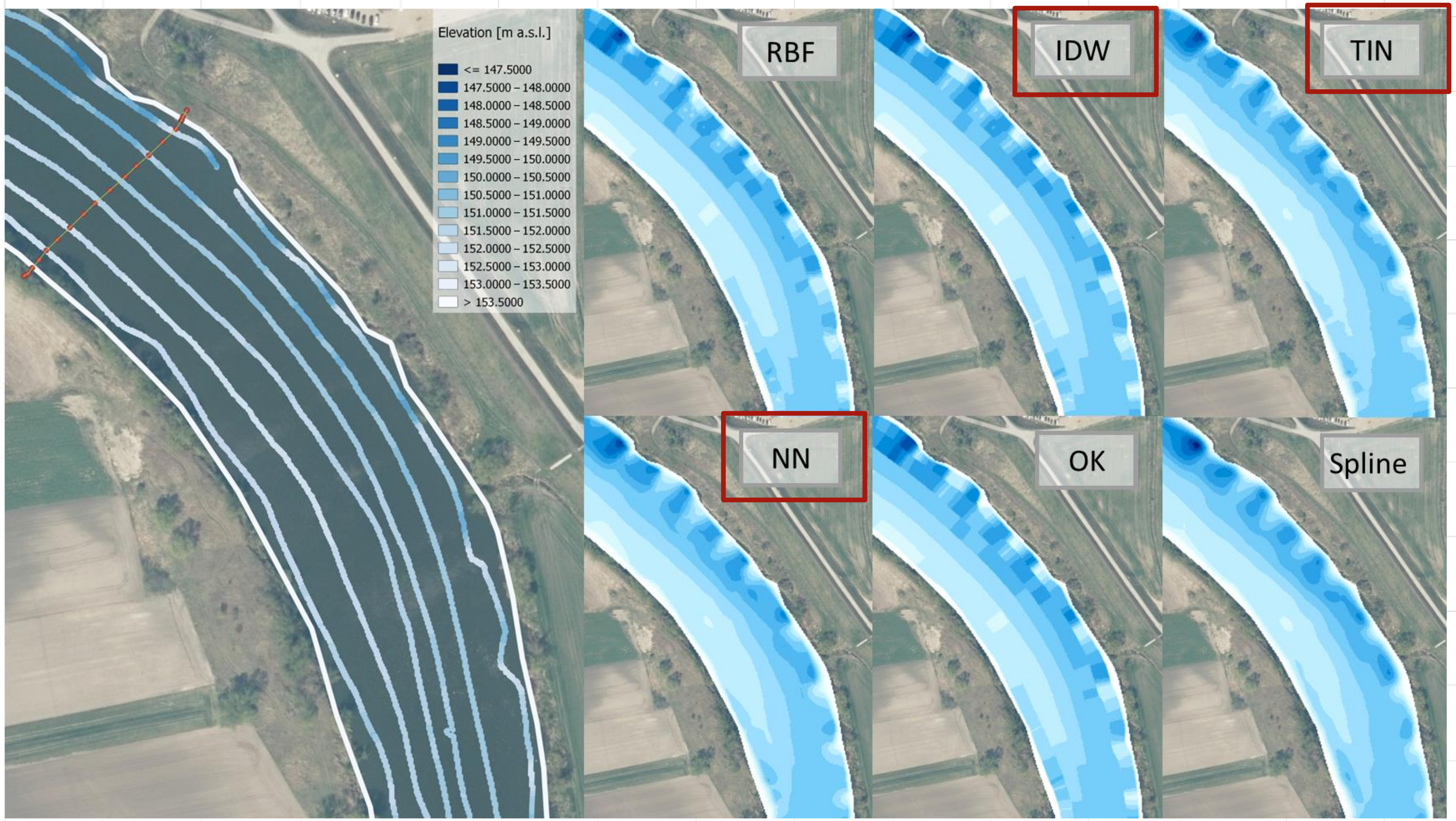
167
2,0
2,5
2,5
STOPIEŃ CHRÓŚCICE
STOPIEŃ DOBRZEŃ

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

The process of mapping bathymetry (River Bed Mapping—RBM) of shallow rivers can be defined as the application of remote sensing techniques for collection river bed elevations and later on to use this information and interpolation techniques to build a DEM (Digital Elevation Model) or the DBM of the surveyed area (Uciechowska-Grakowicz &  Herrera-Granados, 2021).




Example of RBMs generated for a small non-straight part of the Odra Cascade (reach from the barrage “Kąty” to the barrage “Groszowice”) using six different interpolation methods (Uciechowska-Grakowicz &  Herrera-Granados, 2021).

## Boundary conditions

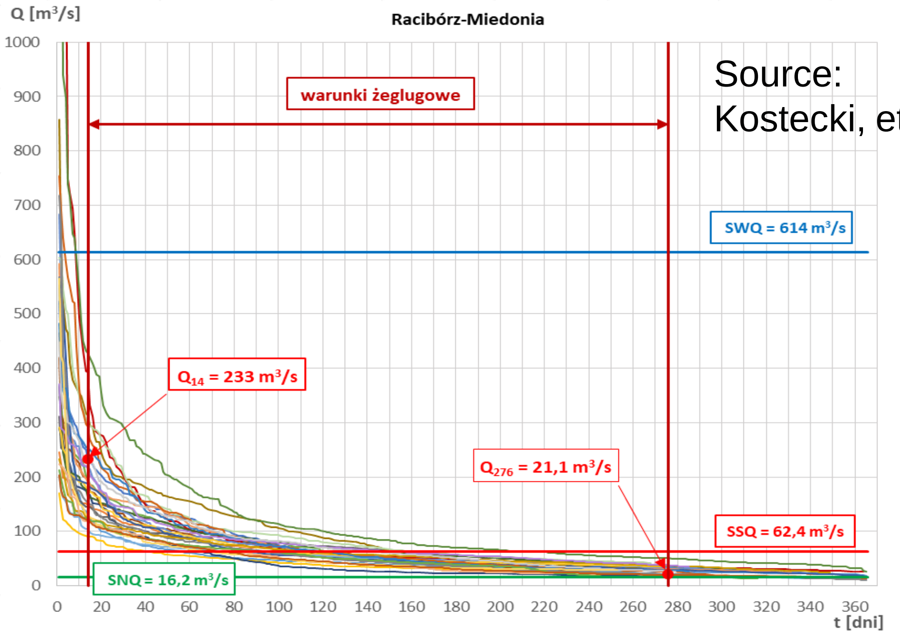
Once the geometry is defined and the numerical model has been chosen. The next step is to establish appropriate boundary and initial conditions (Herrera-Granados, 2022).

The event that was analyzed was flow under exploitation conditions (for inland navigation). Therefore, the flow can be considered almost uni-directional and two boundary conditions can be established.

An appropriate initial condition will accelerate the computational time.

**Upstream:** The average flow with the probability of occurrence of 276 days per year ($Q_{276}$ or $Q_{nmin}$ upstream), which meets the minimal conditions for inland navigation (Herrera-Granados, 2022).

**Downstream:** The operational reservoir level of the barrage Chróścice was used as downstream boundary condition.




Source:
Kostecki, et-al., 2019

Scenario 1: $Q_{Nmin}$ = 35.3 m$^3$/s (Boundary condition (BC) upstream)

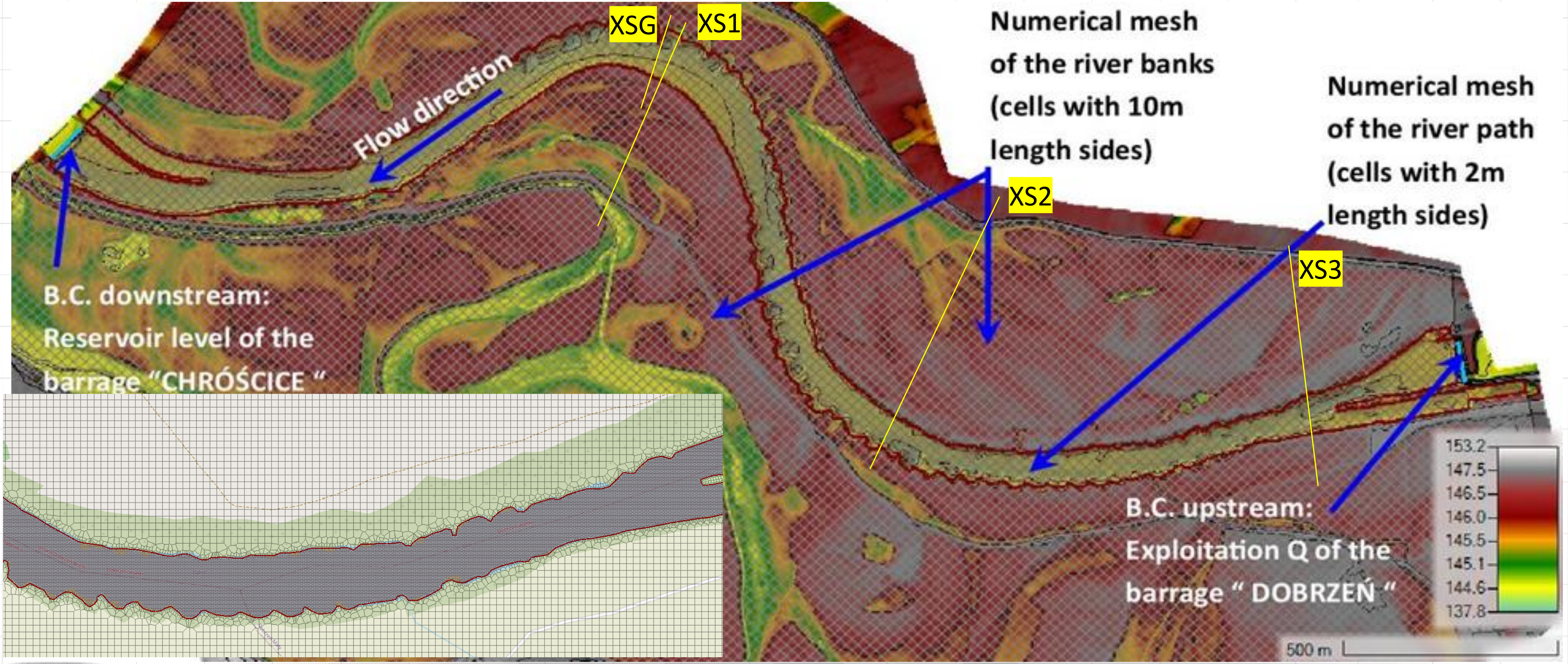
Scenario 2: $Q_{Nmax}$ = 304.0 m$^3$/s (BC for validation purposes)

Boundary condition downstream: WSE = 144.43 m a.s.l.

Initial condition: WSE = 144.43 m a.s.l at the beginning of the computations in the grid.

# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

## Geometry: Setting up the computational domain and boundary conditions



# Comparison of 2D numerical hydraulic modelling results using different Digital Bathymetric Models (DBMs)

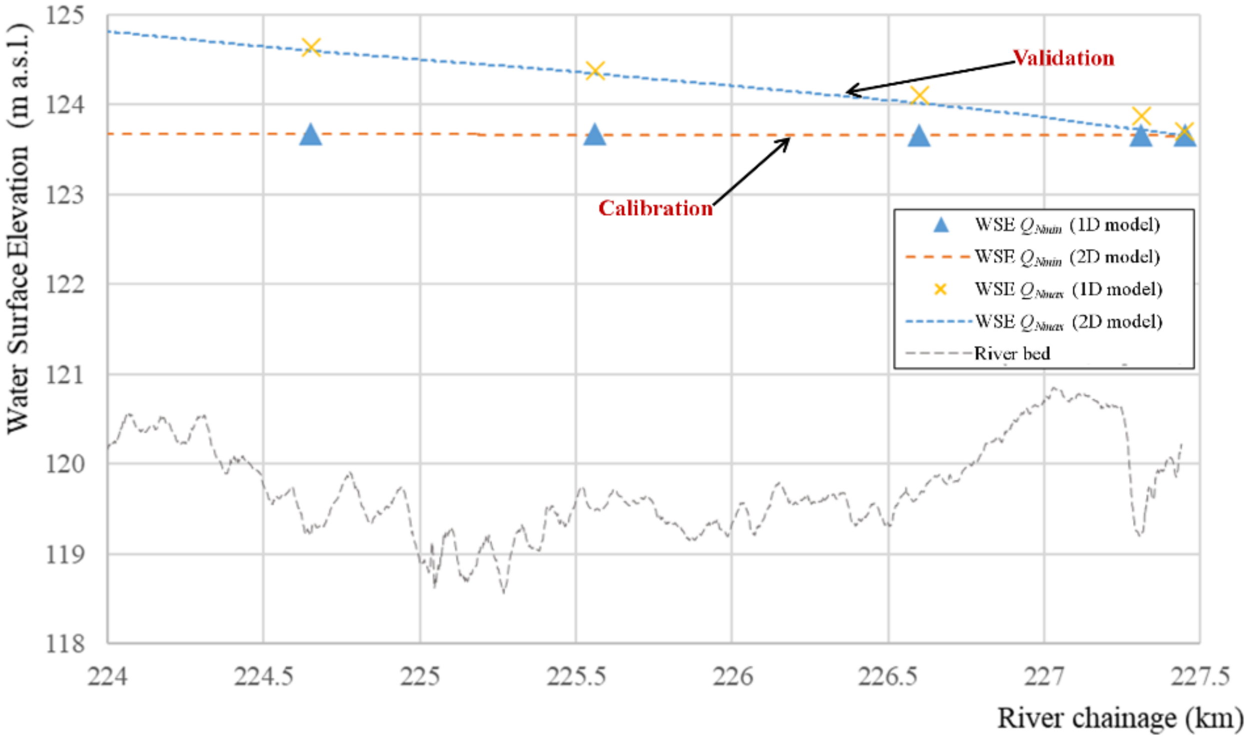
## Calibration and validation

Is it possible to blindly believe in the outcomes of a numerical model? The best practice of assuring confidentially of our models is the process of validation and calibration (Brath et al., 2006).

Additionally, the maximal flow rate ($Q_{nmin}$ or $Q_{14}$) suitable for inland navigation was also analyzed. By analogy, $Q_{14}$ is the average flow with the probability of occurrence of 14 days per year or less. Above this flow rate, inland navigation shall not be allowed along the waterway.

The first model was carried out using the TIN method for calibration and validation purposes (Herrera-Granados, 2022). The calibration of the model was based on the comparison of the Water Surface Elevation (WSE) values with the previously registered. Once an acceptable error was achieved, the validation of the model was carried out on the same comparison but running the model under $Q_{14}$ flow conditions (Kostecki, et-al. part 1C, 2019).

The output of the model is in this case compared with the observed data of a 1D numerical model that was calibrated and validated (Fig. beside). Therefore, as the 1D model is already verified, the 2D model was calibrated comparing the output of the 2D model. The WSE is compared with $Q_{nmin}$. The difference between the first run of the 2D model and the values of the 1D model varies from 10 up to 50 cm in five compared locations.



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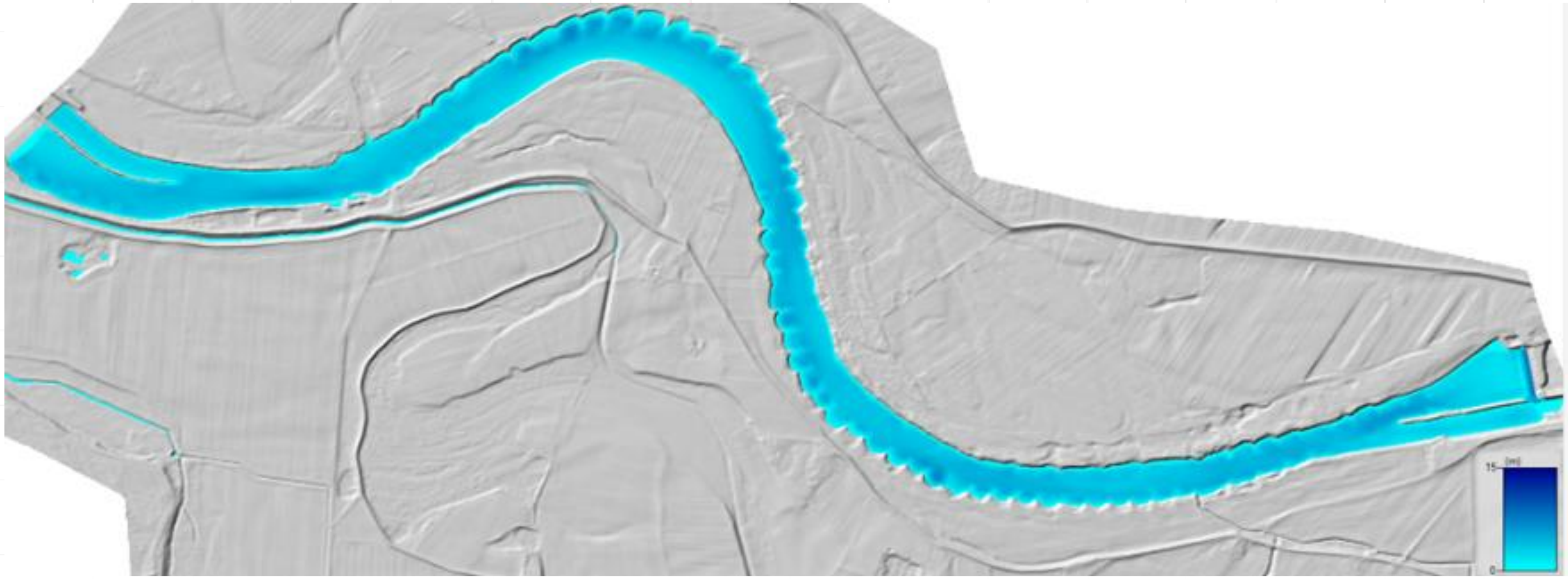
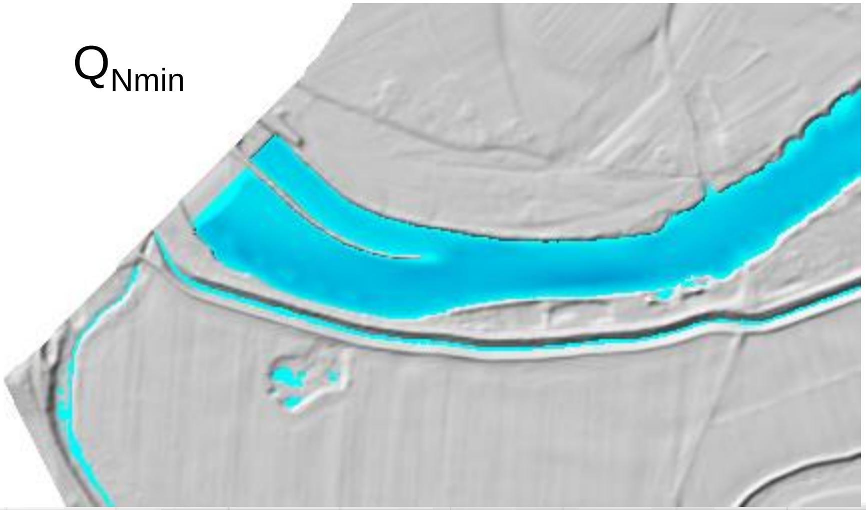
# Results and discussion

Enjoying the model output

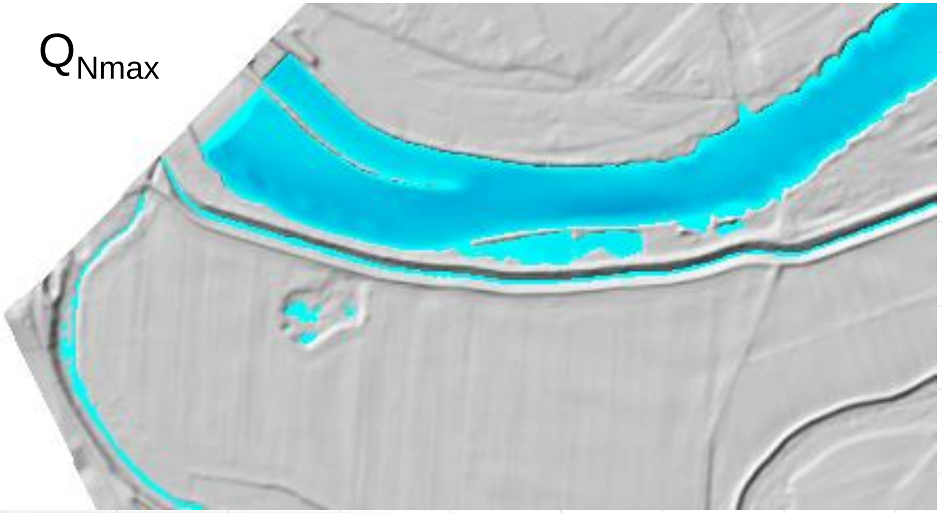
☺



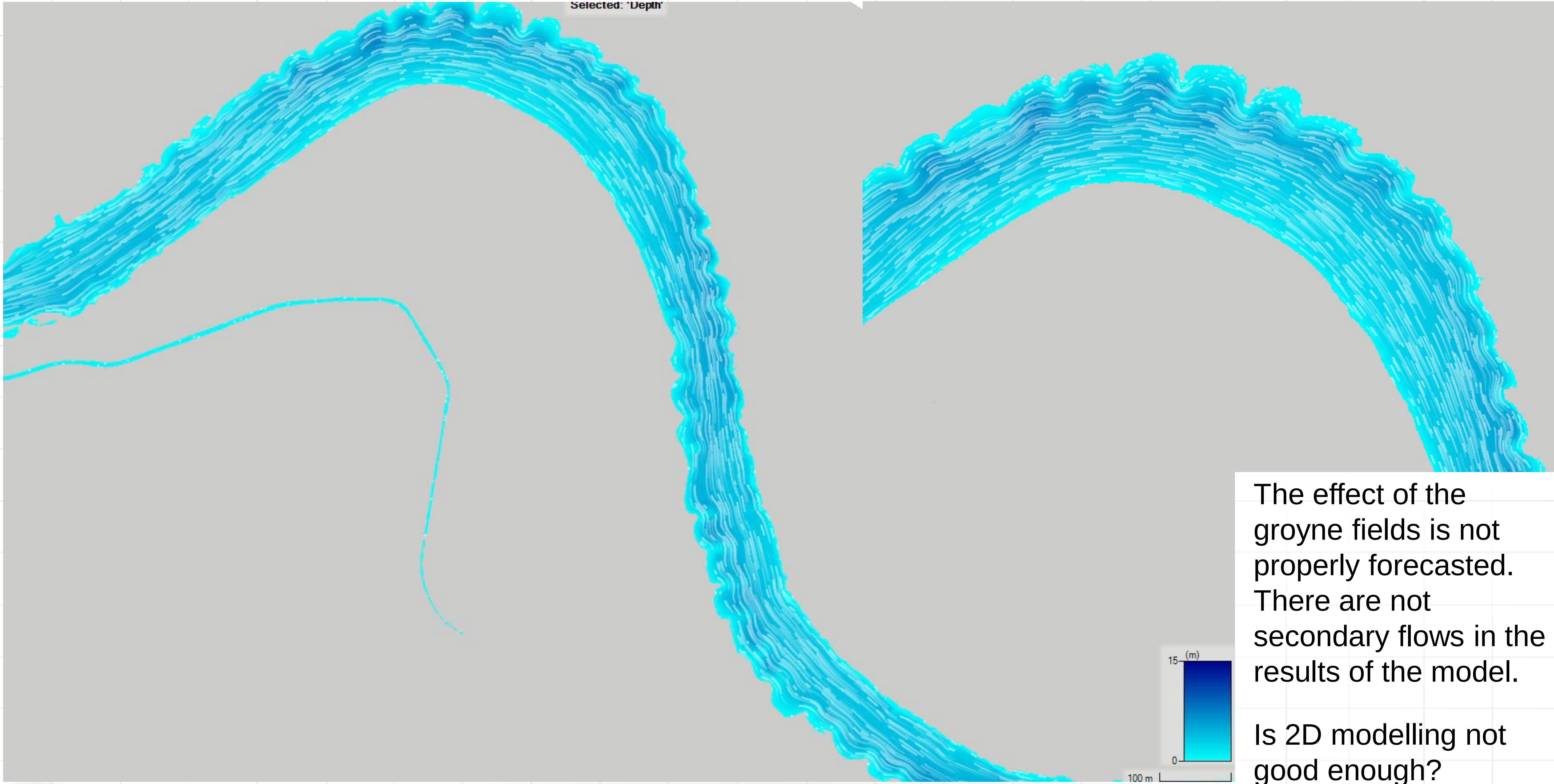
$Q_{Nmin}$



$Q_{Nmax}$



Computed water depth along the study case river reach (TIN bathymetry) under $Q_{Nmin}$ flow conditions.




The effect of the groyne fields is not properly forecasted. There are not secondary flows in the results of the model.

Is 2D modelling not good enough?

# Results and discussion

1. Data retrieval and geometry construction of the computing domain
2. Choosing the mathematical model to analyse the natural phenomenon
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In HEC-RAS, the computer program applies the following assumptions: Incompressible flow, uniform density and that the vertical length is much smaller than the horizontal lengths (shallow water). Therefore, the vertical velocity is small, and the pressure is hydrostatic, leading to the differential form of the SWE (Shallow Water Equation). The momentum equation then becomes the two-dimensional form of the Diffusion Wave Approximation. Combining this equation with mass conservation yields a one equation model, known as the Diffusive Wave Approximation of the Shallow Water (DSWa) equations (USACE, 2021):

$$\frac{n^2}{R_{\mathrm{h}}^{4/3}}|\boldsymbol{V}|\boldsymbol{V} = -\nabla z_s$$

where $n$ is the Manning coefficient [$L^{-1/3}T$], $R_h$ [L]is the hydraulic radius, $V$ [$LT^{-1}$] is in this case the velocity vector, $z_s$ is the WSE [L] and $\nabla z_s$ is the WSE gradient [-].





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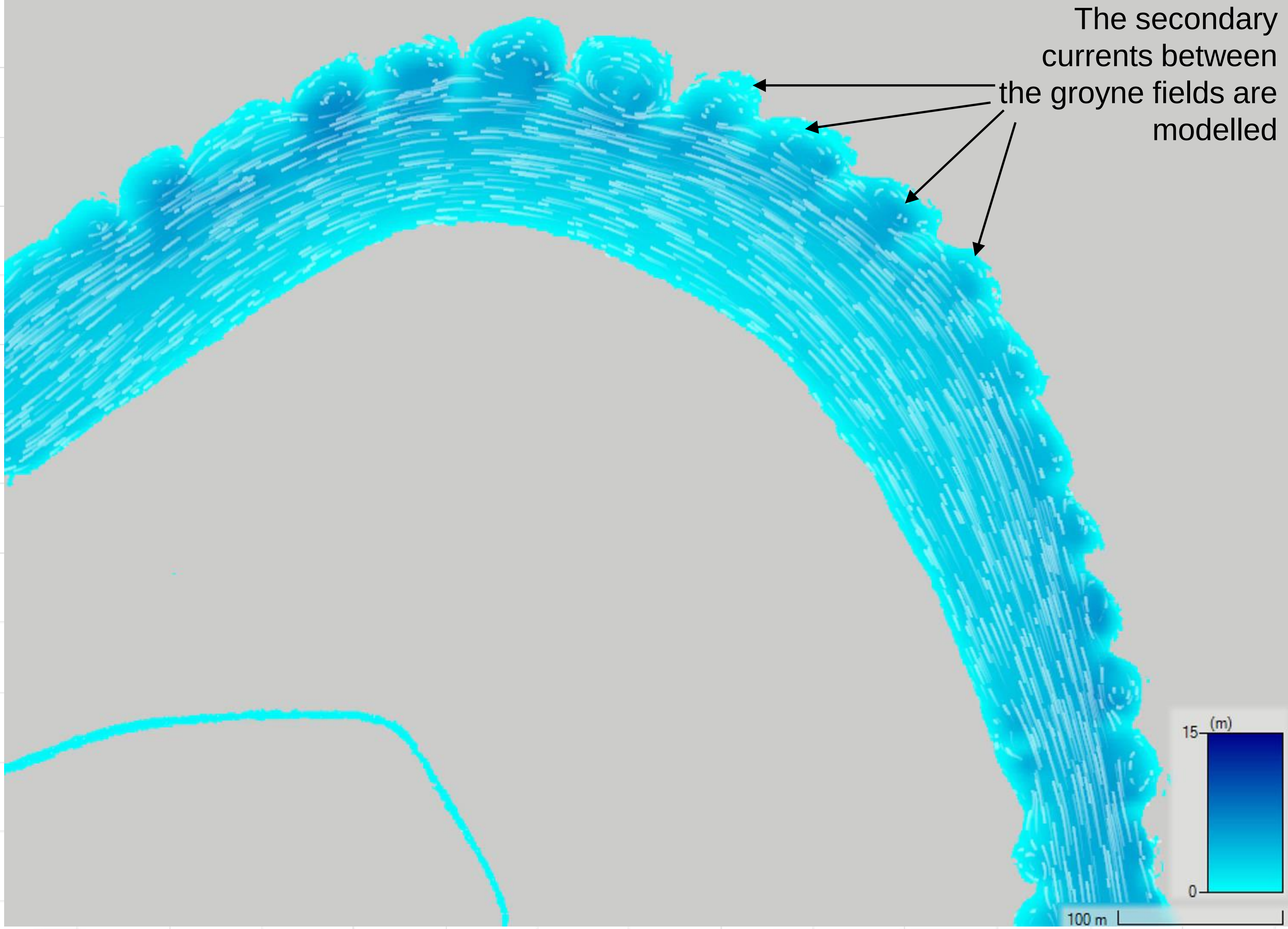
# Results and discussion

In HEC-RAS, the full momentum equation in 2D can be also be modelled. However, there is a computational cost in the time to be invested to model the additional terms of the SWE equation.




**IDW**

| Computation Task | Time(hh:mm:ss) |
|---|---|
| Completing Geometry | 43 |
| Preprocessing Geometry | <1 |
| Completing Event Conditions | <1 |
| Unsteady Flow Computations | 1:58:31 |
| Computing Maps | <1 |
| Complete Process | 1:59:16 |

| Computation Speed | Simulation/Runtime |
|---|---|
| Unsteady Flow Computations | 24.8x |
| Complete Process | 24.7x |

**NN**

| Computation Task | Time(hh:mm:ss) |
|---|---|
| Completing Geometry | 53 |
| Preprocessing Geometry | <1 |
| Completing Event Conditions | <1 |
| Unsteady Flow Computations | 1:34:52 |
| Computing Maps | <1 |
| Complete Process | 1:35:47 |

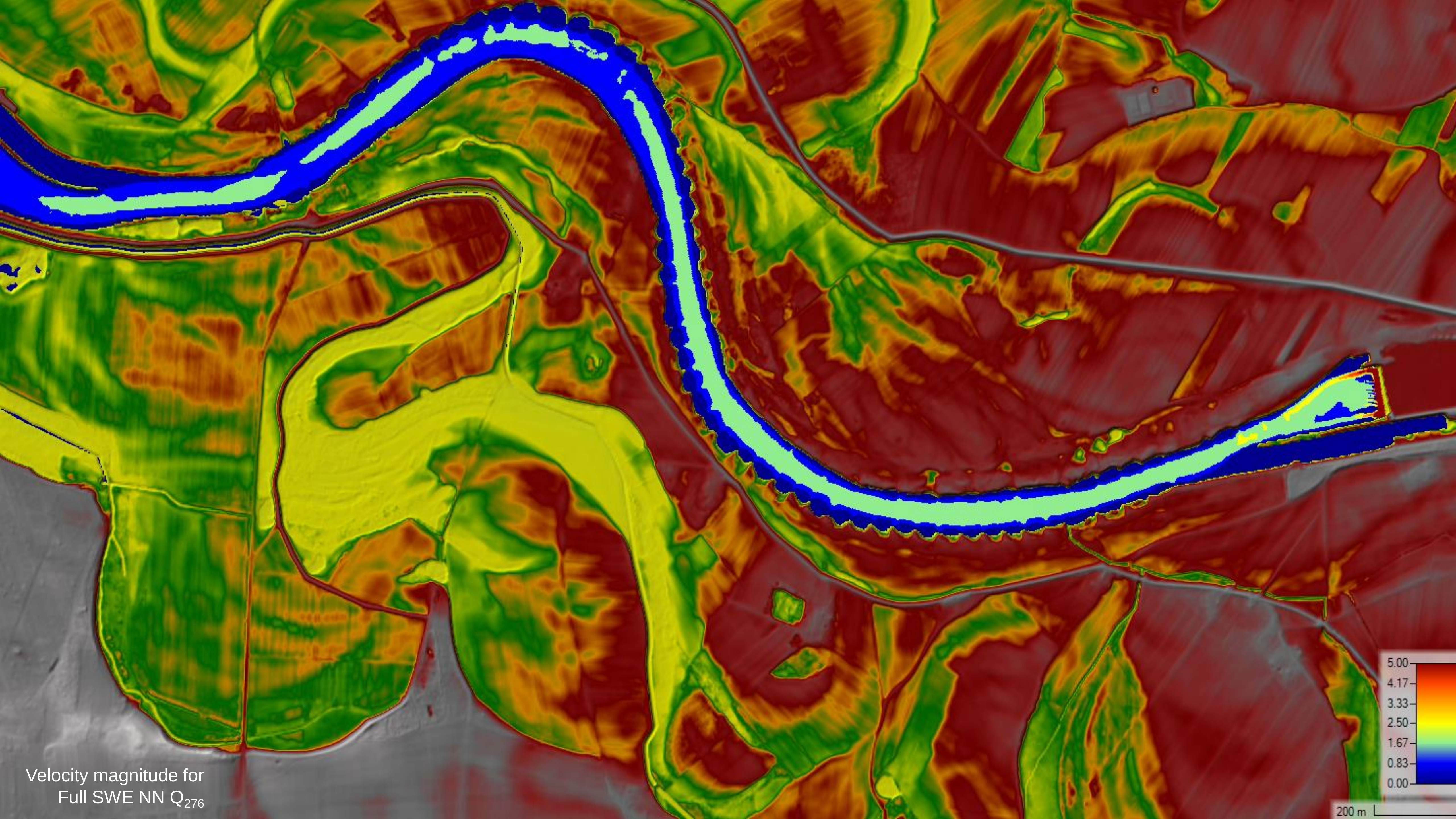
| Computation Speed | Simulation/Runtime |
|---|---|
| Unsteady Flow Computations | 31.0x |
| Complete Process | 30.7x |

**TIN**

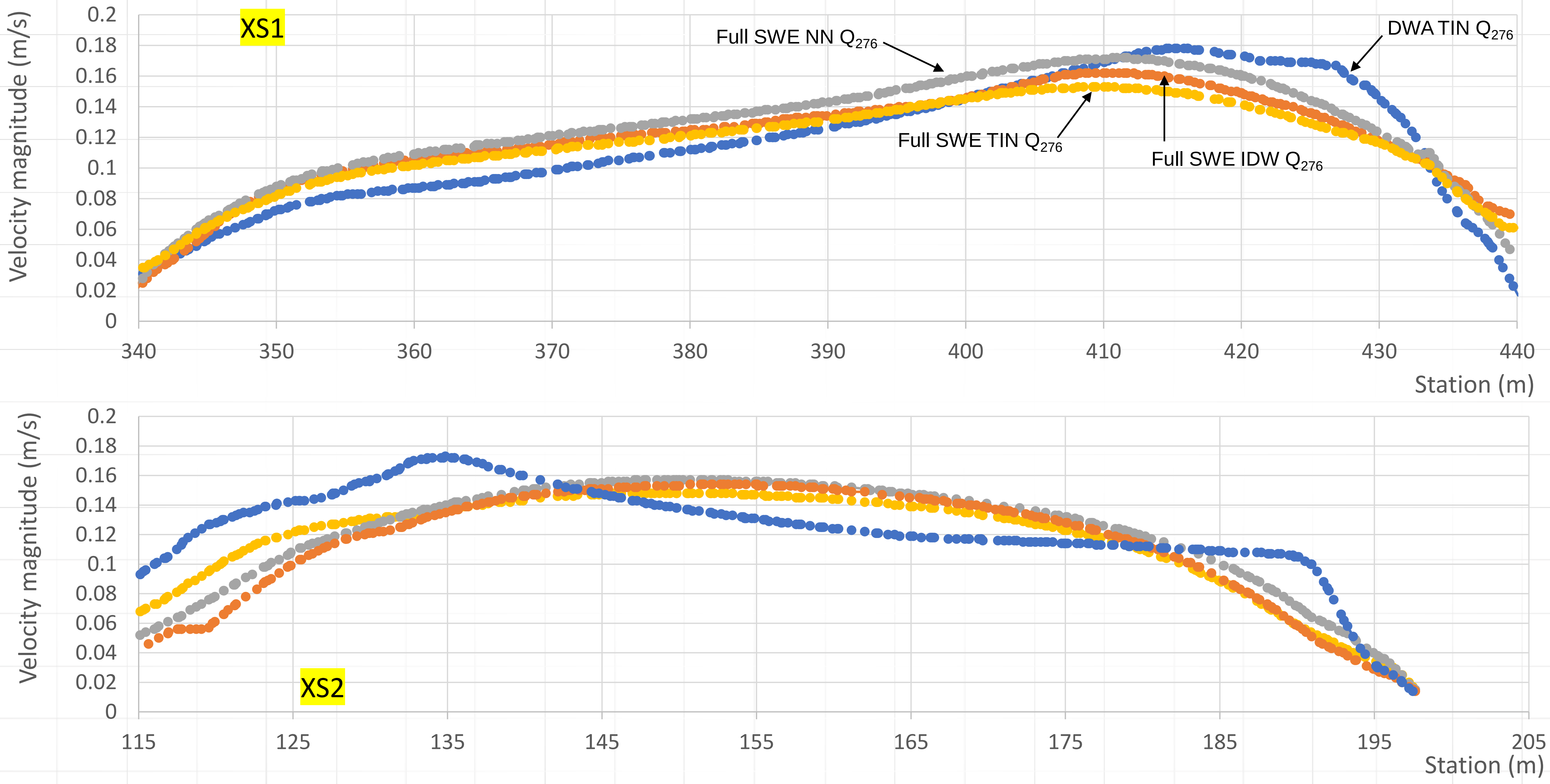
| Computation Task | Time(hh:mm:ss) |
|---|---|
| Completing Geometry | 46 |
| Preprocessing Geometry | <1 |
| Completing Event Conditions | <1 |
| Unsteady Flow Computations | 3:01:30 |
| Computing Maps | <1 |
| Complete Process | 3:02:17 |

| Computation Speed | Simulation/Runtime |
|---|---|
| Unsteady Flow Computations | 16.2x |
| Complete Process | 16.1x |

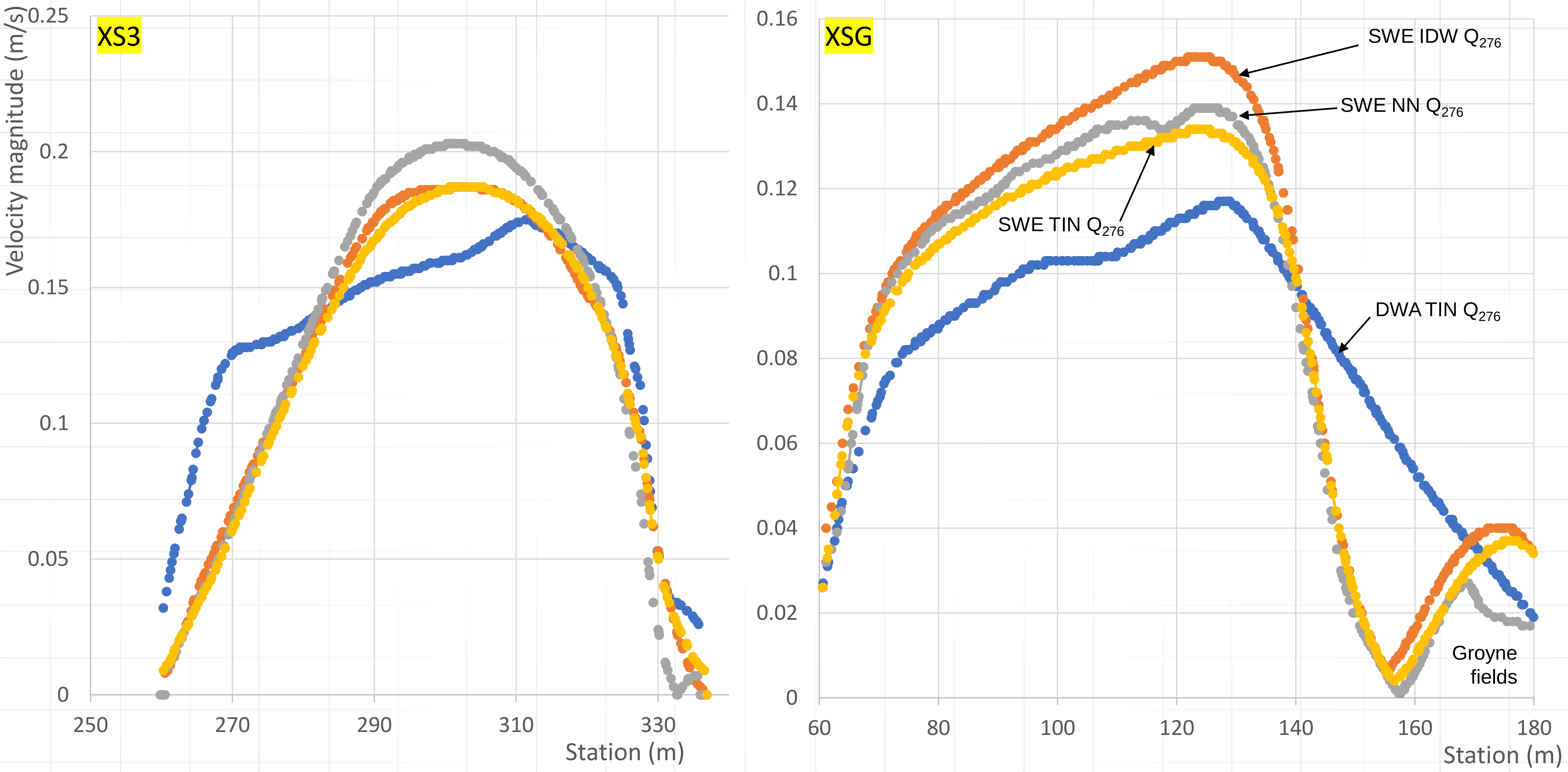
**Model size:** around 4 km river reach; ca. 175 000 computational cells with size of around 10x10 meters and 1x1 meters.
Computational time: ca. 20 minutes (DWA). PC details: Win11. processor 11th Gen Intel(R) Core(TM) i7-11800H @ 2.30GHz, 32 GB RAM




Velocity magnitude for
Full SWE NN $Q_{276}$




Herrera-Granados, O. *et-al* (2023).




Herrera-Granados, O. *et-al* (2023).

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# Summary and Conclusions

- In this presentation, a 2D numerical model was set-up and run using different DBMs to compare the influence of the different interpolation techniques on the modelling results.
- Thanks to the project *Research and Development Conception on the modernization of the canalized reach of the Odra River to a navigable waterway of class Va*, a large bathymetric survey was carried out along 200 km of the channelized part of the Odra River. Several interpolation methods were applied to build different DBMs to be used for numerical modeling purposes.
- The end-users of available numerical models shall be aware of the mathematical and numerical methods that are applied by the computer programs to avoid misjudgments of the model's outputs.
- The TIN model seems to be the one that gives the best results in the whole part of the waterway. Moreover, the TIN model provides the lowest error values in comparison with the onsite survey values.
- The differences between the WSE using the TIN & other DBMs are not significant (less than 20 cm difference in the WSE). However, the TIN model is giving a less error (output) for modeling purposes.
- The values of the velocity profiles seem to be similar in the center part of the river. However, there larger discrepancies close to the banks and above all within the groyne fields.
- The modeler (regardless his age and experience) shall consult other colleagues to give a proper statement and interpretation of the numerical outputs as well as for calibrating/validating the model.

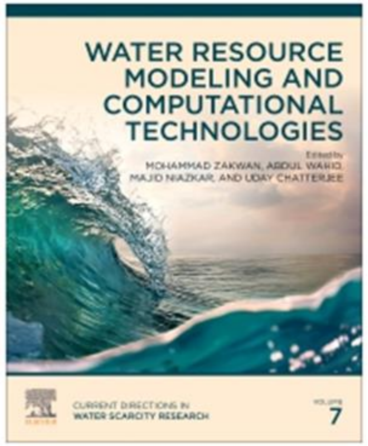
# References

*remote sensing*

## Riverbed Mapping with the Usage of Deterministic and Geo-Statistical Interpolation Methods: The Odra River Case Study

by Anna Uciechowska-Grakowicz *,† and Oscar Herrera-Granados †

Faculty of Civil Engineering, Wrocław University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland




## Water Resource Modeling and Computational Technologies

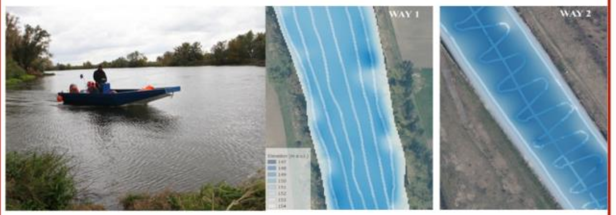
1st Edition - October 1, 2022

☆☆☆☆☆ Write a review

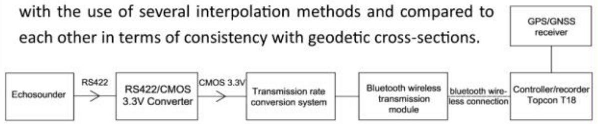
Editors: Mohammad Zakwan, Abdul Wahid, Majid Niazkar, Uday Chatterjee

Paperback ISBN: 9780323919104

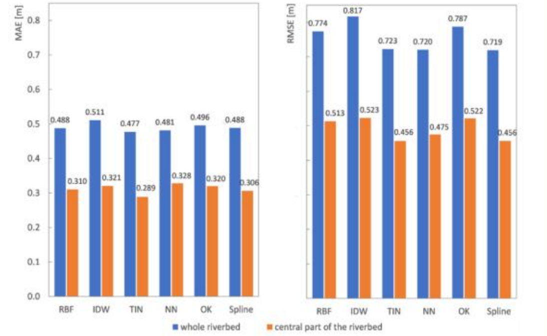
**Data source:** echosounder Lowrance HDS7 with GPS receiver and an InSite survey

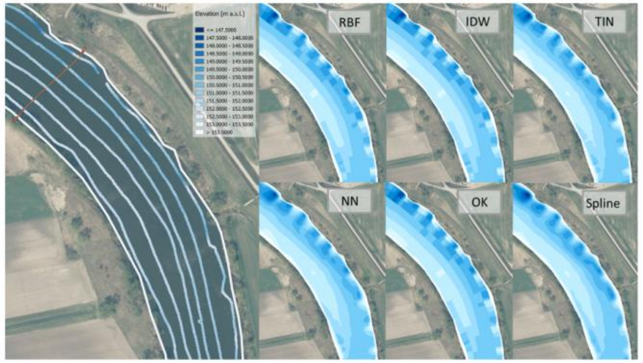



DBM raster files were created from paths parallel to riverbanks with the use of several interpolation methods and compared to each other in terms of consistency with geodetic cross-sections.

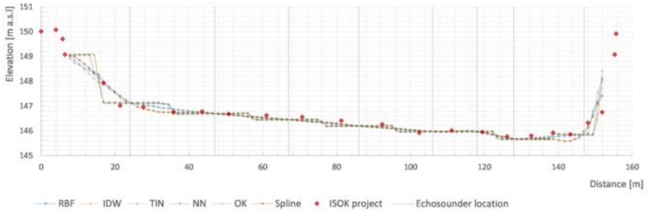



Two statistical errors between the interpolation values and the survey were estimated: the Mean Absolute Error - MAE & the Root Mean Square Error—RMSE.




- The echo sounder data should be complimented with a RTK-GNSS data collector to obtain the exact geographical coordinates;
- The submerged groynes can be spotted for navigation way along the river, while using zig-zags can provide false results due to incomplete or false data;
- IDW presents the largest differences between raster and geodetic cross-sections;
- NN and TIN presents the lowest error values.

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# *Thank you very much for your attention*


***Oscar Herrera-Granados***

Contact details: e-mail: ockap_lt@hotmail.com
Skype: ockap_lt LinkedIn: oscarhg
Wrocław University of Science and Technology