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Active flow zones distribution along upper Vistula River established with use of 1D and 2D modelling

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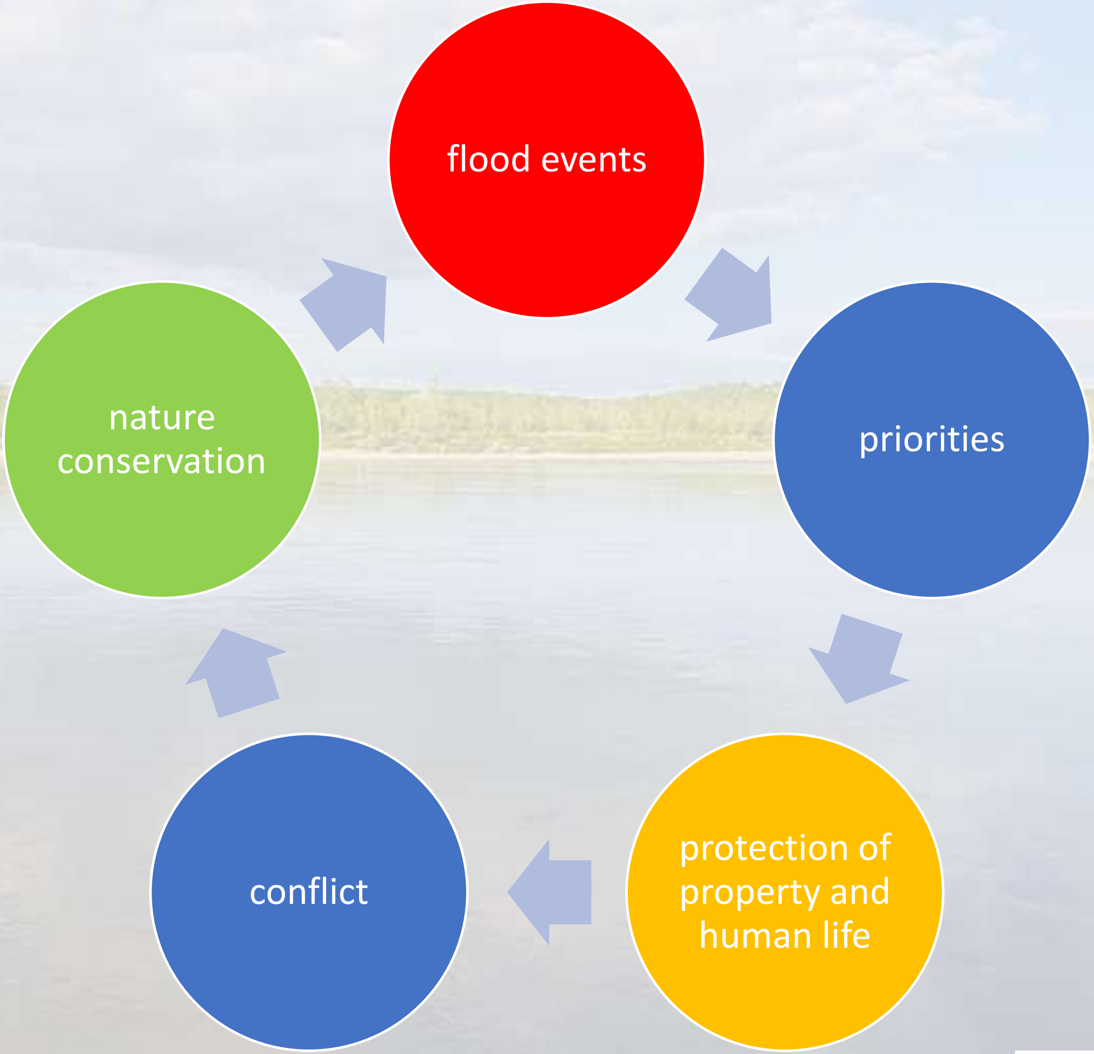

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Potential conflict between flood protection and nature conservation can be resolved using engineering methods without disturbing valuable habitats

The aim is to ensure a minimum required channel capacity and at the same time to limit the impact maintenance measures on naturally valuable areas

The interaction zone allows the determination of the active cross-section

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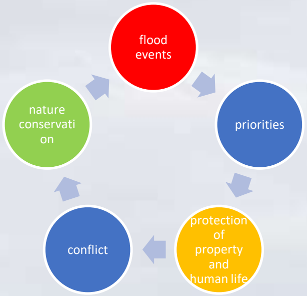

Potential conflict between flood protection and nature conservation can be resolved using engineering methods without disturbing valuable habitats

The aim is to ensure a minimum required channel capacity and at the same time to limit the impact maintenance measures on naturally valuable areas

The interaction zone allows the determination of the active cross-section

The interaction zone b_{II} is determined based on the hydraulic radius of the floodplain R_{hz} [m], the roughness coefficient of the floodplain n_z [$m^{-1/3}\cdot s$] and the so-called slip velocity parameter Pasche C_T [-]

Once the bank flow is exceeded, the depth increases, and the b_{II} interaction zone widens

When land cover changes, a decrease in resistance to water flow causes the b_{II} interaction zone to expand

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The factors that influence the width of the active zone:

- land cover,
- size of the floodplain terraces,
- spacing of the embankments,
- topography on wide floodplain terraces is highly differentiated,
- presence of oxbow lakes,
- ratio of depth in the channel to depth on the floodplain.

The advantage of 2D modelling is that hydraulic parameters and flow directions can be mapped covering the entire area of the model, land cover can be precisely defined.

A temporary limitation to the use of 2D models for modelling is the computing power needed and the time.

An element of flood protection is the Information System for National Defence (ISOK), an essential part of which are flood risk maps for 30.56 thousand km of rivers in Poland (2022). Most in 1D models.

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The results of one-dimensional 1D and two-dimensional 2D modelling analyses of a section of the Vistula River to calculate the size of the active zone of water movement according to the Pasche method:

- to distinguish active zones in floodplains,
- to indicate cases in which the Pasche method works, cases in which it is sufficient, and cases in which another method of determining the active zone should be used.

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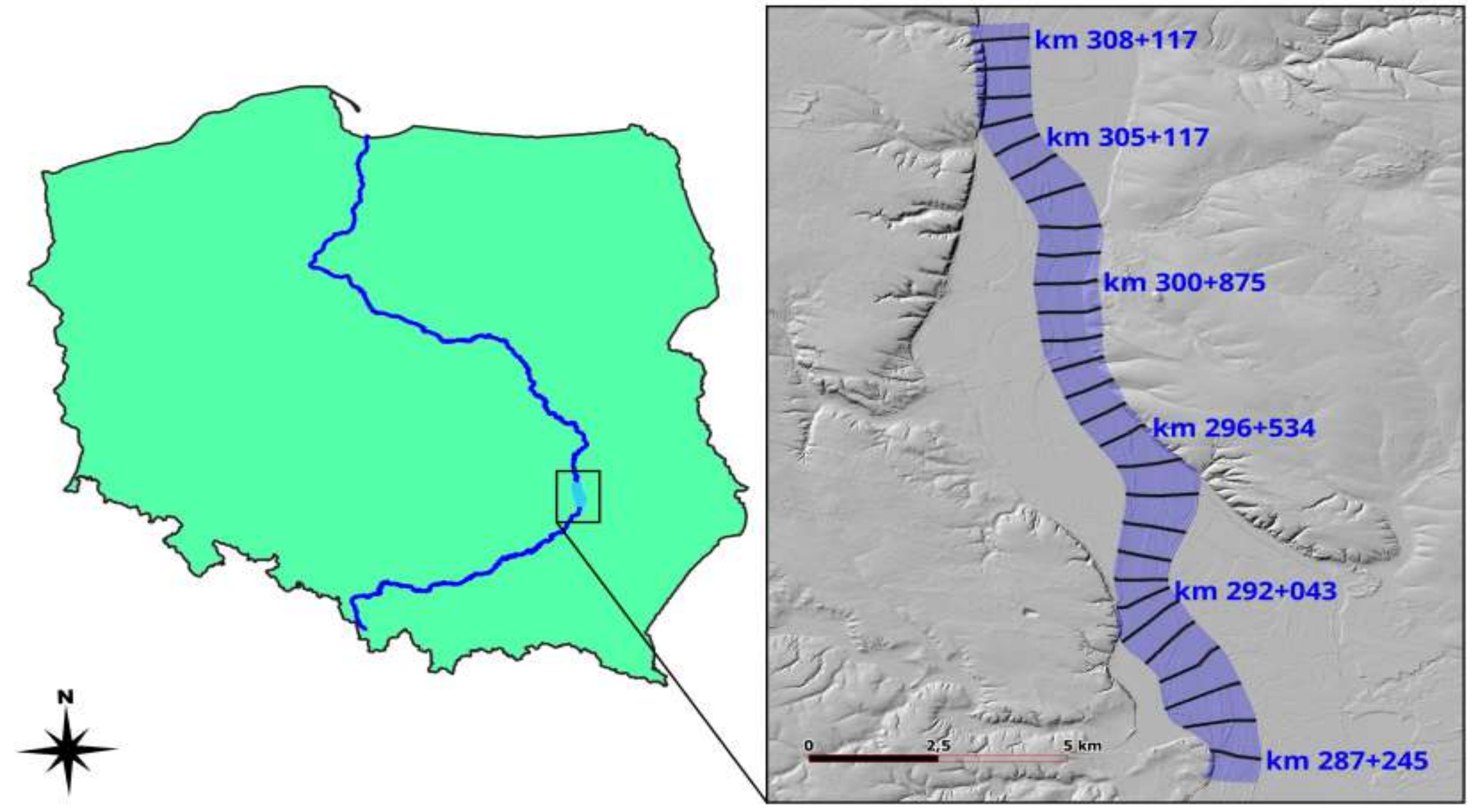

Vistula River covering the Małopolski Przełom Wisły (river kilometer (km); 286+647 ÷ 308+425). The study section begins in Zawichost. The valley is from 2.5 to 5.1 km. The left bank embankment sections are 3.05 km and 10.98 km long, and the right bank embankment sections are 7.17 m and 4.68 km long. The embankment spacing ranges from 0.92 km to 1.52 km. Top 10 in the "Pan-European Strategy for the Protection of Biodiversity and Landscape Diversity„.

NATURA 2000 sites "Przełom Wisły w Małopolsce" (PLH 060045) and "Małopolski Przełom Wisły" (PLB 140006)

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The subject of protection are the habitats - riparian communities, muddy, periodically flooded river banks, and oxbow lakes, and the species - birds: common tern Sterna hirundo (2.5% of the EU population in Poland) and Caspian tern Sternula albifrons (4.4% of the EU population in Poland), toad, and fish.

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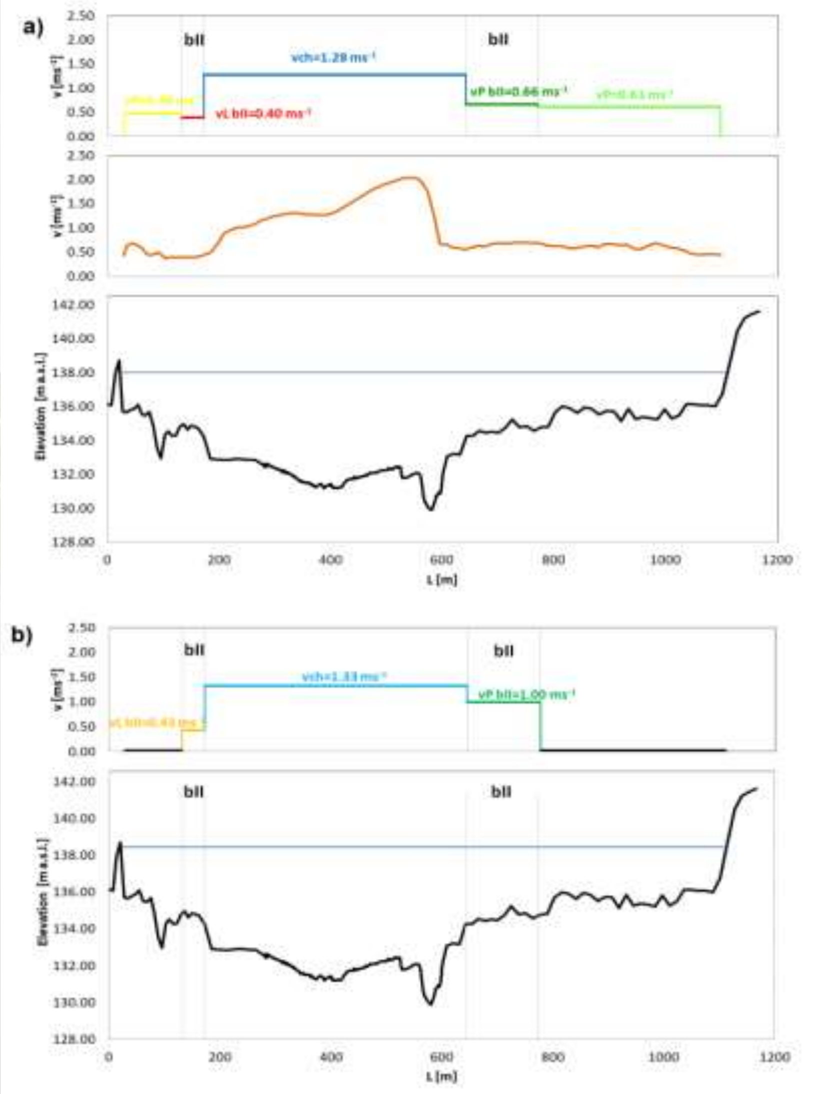

Water surface and velocity in the cross-section km 302+461 for flow Q=4,000 m^3s^{-1}, a) model 2D: distribution of velocities in the cross-section (brown) and averaged velocities according to the Pasche method (yellow and light green – outside the Pasche zone, red and dark green – inside the b_{II} zone according to Pasche, dark blue – main channel), b) model 1D with the implemented zone b_{II} – averaged velocities in zones according to the Pasche method (orange and green – inside the b_{II} zone according to Pasche, dark – main channel).

Steady-state conditions for a flow of Q=4,000 m^3s^{-1},

Discharge	Q [m^3s^{-1}]
$Q_{28\ Jun\ 2017}$	205
SSQ	436
$Q_{10\%}$	4,750
$Q_{1\%}$	7,440
$Q_{0.2\%}$	9,220

Model 1D – the one-dimensional hydraulic model HEC-RAS

Model 2D – the CCHE2D® is a depth-averaged two-dimensional numerical model for simulating unsteady, turbulent, free-surface flow in open channels

The 2D and 1D numerical models was about 21.8 and 20.87 km long and 0.92-1.53 km wide.

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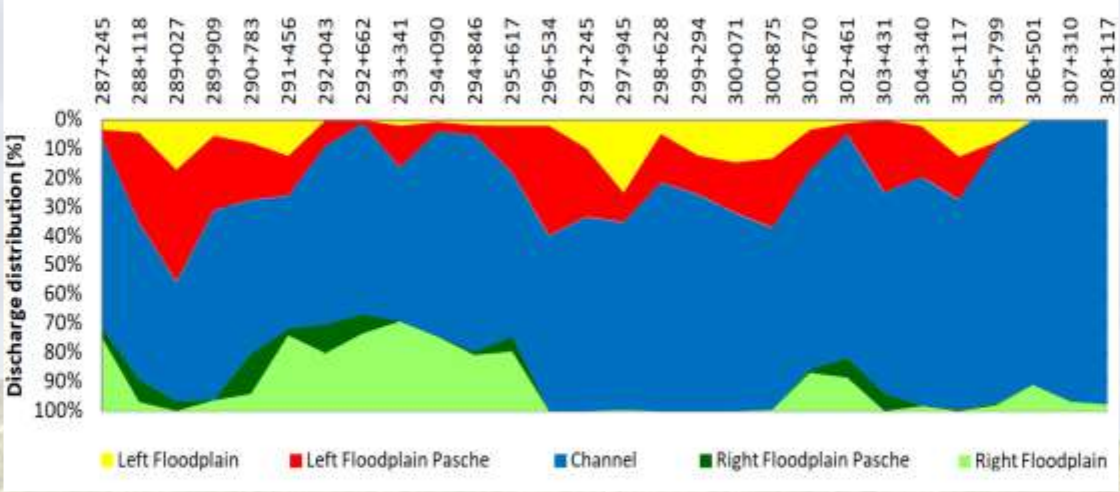
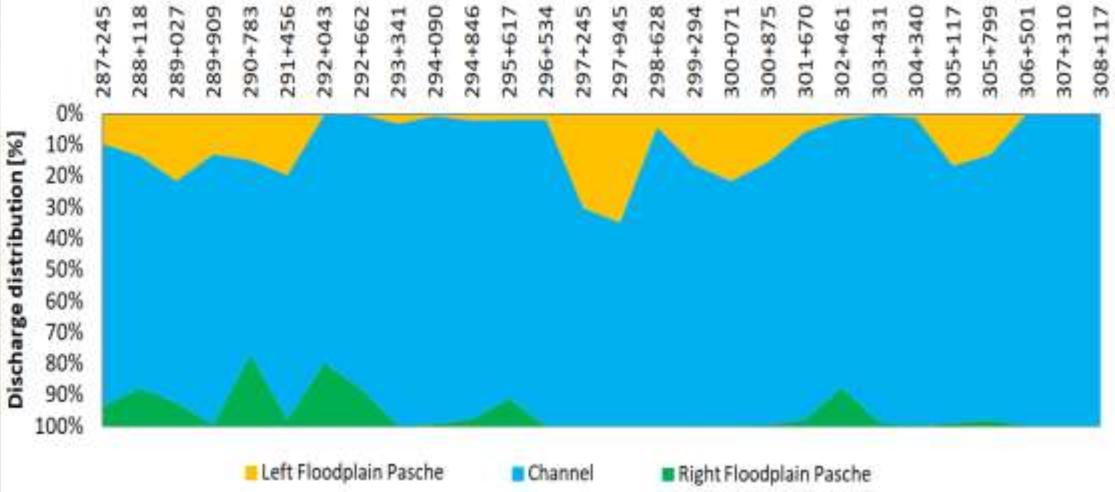


Flow distribution in the 2D model for the flow of $Q=4{,}000\ m^3s^{-1}$: main channel and floodplains inside and outside the Pasche zone.

The differences between 1D and 2D models are due to higher flow in the main channel (increase by 34.3%), in the smaller left b_{II} zone (34.3%) and in the larger right b_{II} zone (67.9%).



Distribution of flows in the 1D model for flow $Q=4{,}000\ m^3s^{-1}$: main channel and the floodplains inside the Pasche zone.

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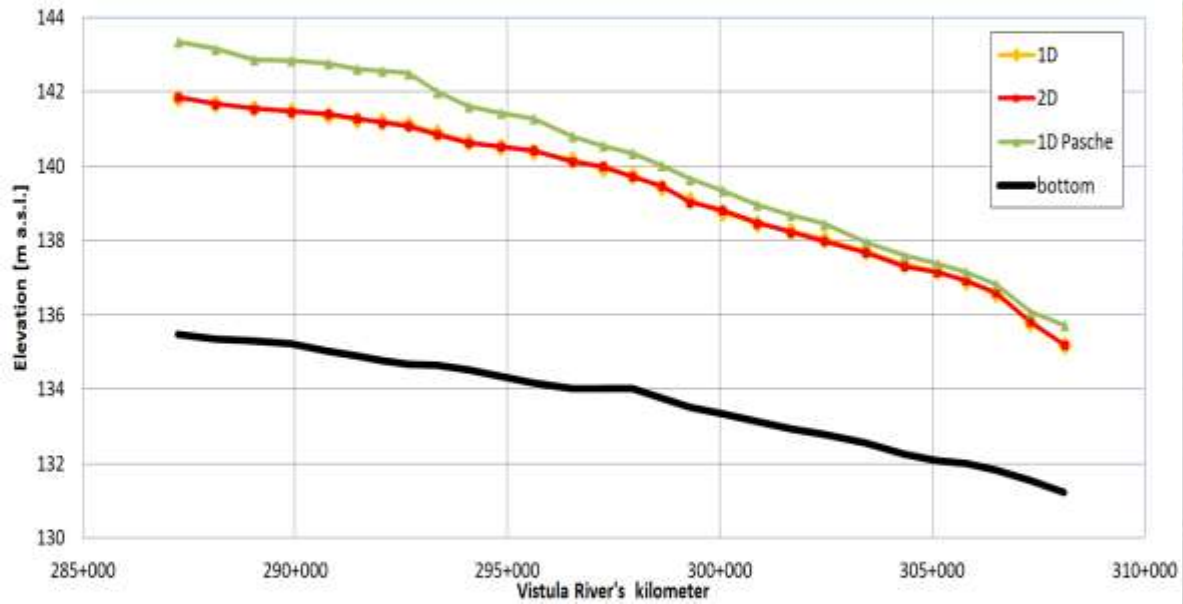
	Discharge distribution [%]				
	Left floodplain		Main channel	Right floodplain	
	outside b_{II}	inside b_{II}		inside b_{II}	outside b_{II}
Model 1D	0	9.3	86.5	4.1	0
Model 2D	5.9	14.2	68.5	2.5	8.9

Discharge distribution on average according to 1D and 2D models on the main channel and floodplains



Elevation of the surface water

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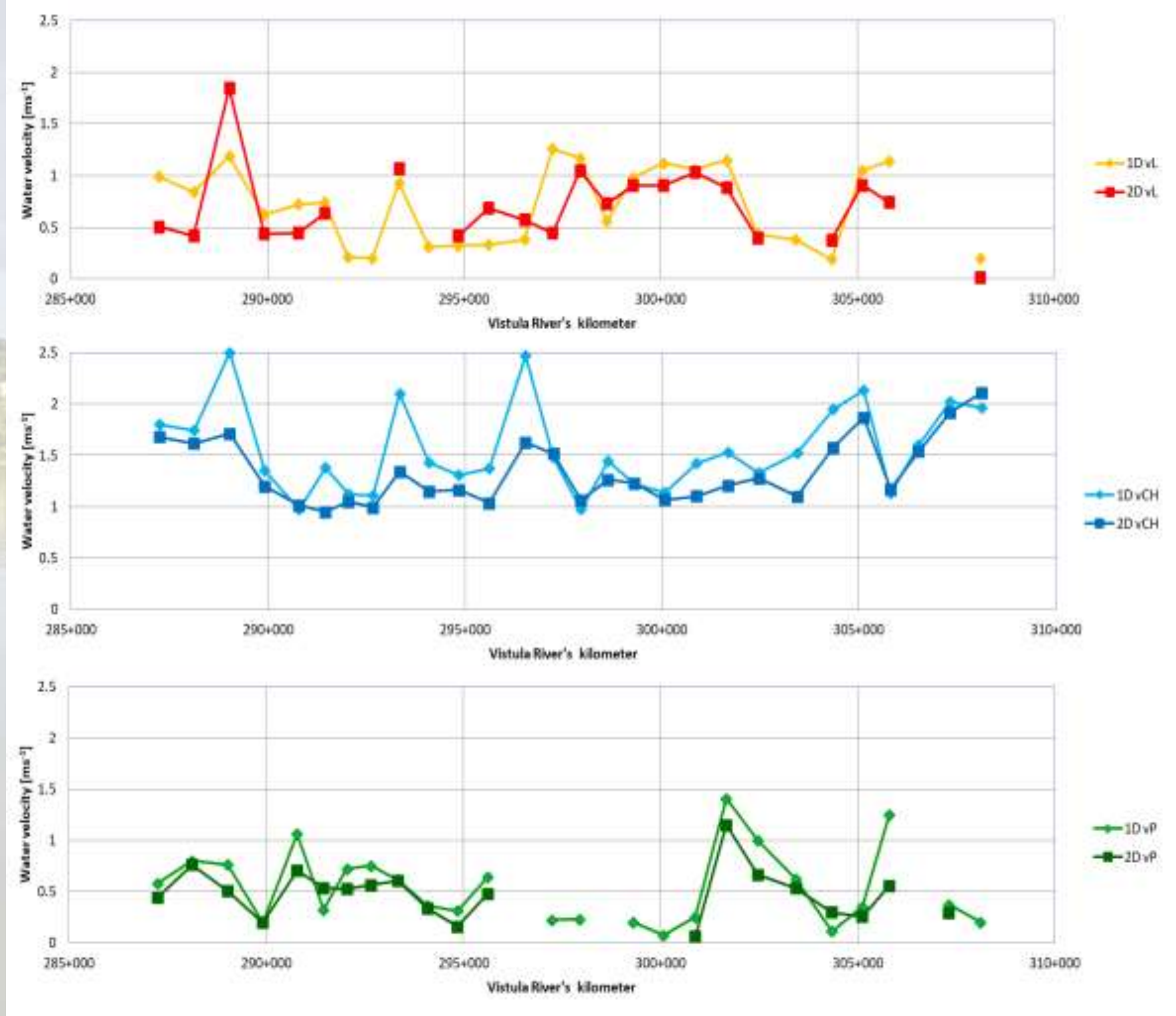

The mean relative velocity changes are 1.20 ms^{-1}, 1.16 ms^{-1} and 1.42 ms^{-1} while the mean velocity changes are 0.26 ms^{-1}, 0.24 ms^{-1}, 0.18 ms^{-1}. The higher the mean velocities in the zones of model 1D: 0.71 ms^{-1}, 1.55 ms^{-1}, 0.54 ms^{-1} and model 2D: 0.70 ms^{-1}, 1.34 ms^{-1}, 0.48 ms^{-1} the smaller the relative differences.

Averaged flow velocity in the 1D model with b_{II} zones and in the 2D model, a) left floodplain; b) main channel; c) right floodplain.

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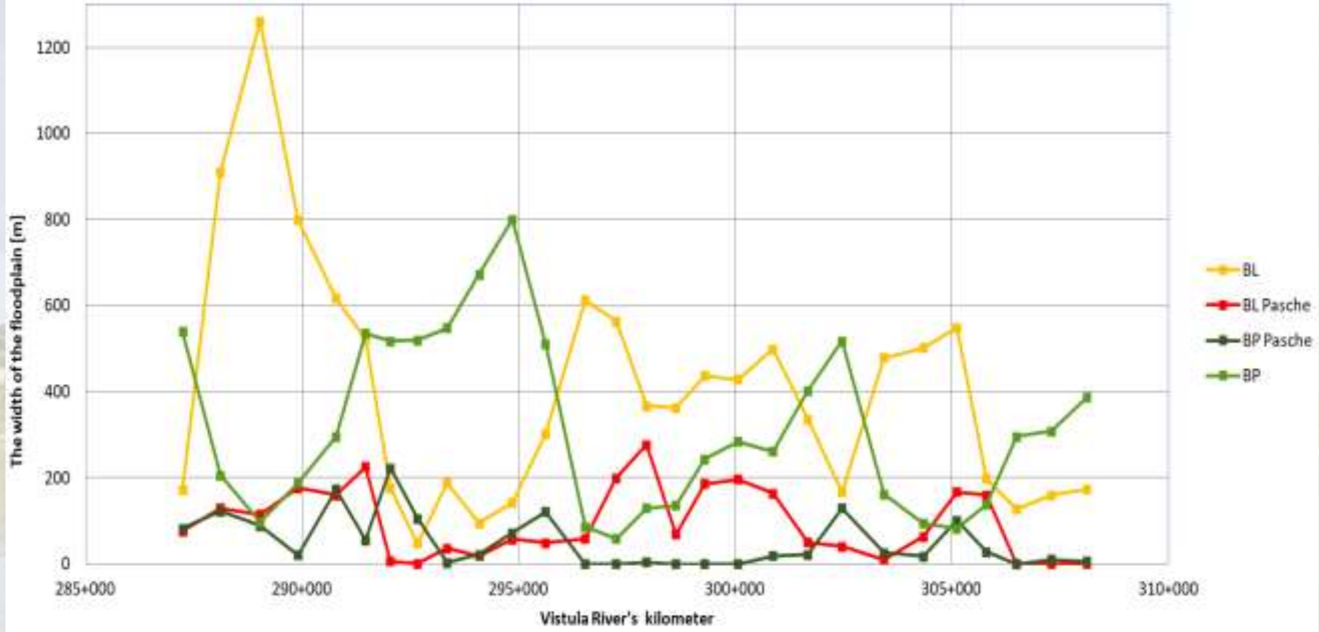

The width of the entire floodplain and the b_{II} zone according to the Pasche method, models 1D and 2D.

The size of the active zone in the individual cross sections calculated using the Pasche method is not consistent with the width of the entire floodplain

The left floodplain has a significant size and velocity discrepancy, while the right floodplain has the greatest size discrepancy and good velocity compatibility.

h_L=3.21 m and h_R=3.62 m. The greater depth of the right floodplain, combined with its smaller size ($b_{II,L}$=112.3 m, $b_{II,R}$=63.0 m), ensures better energy transfer from the main channel and thus a better velocity ratio (in the 1D/2D models)

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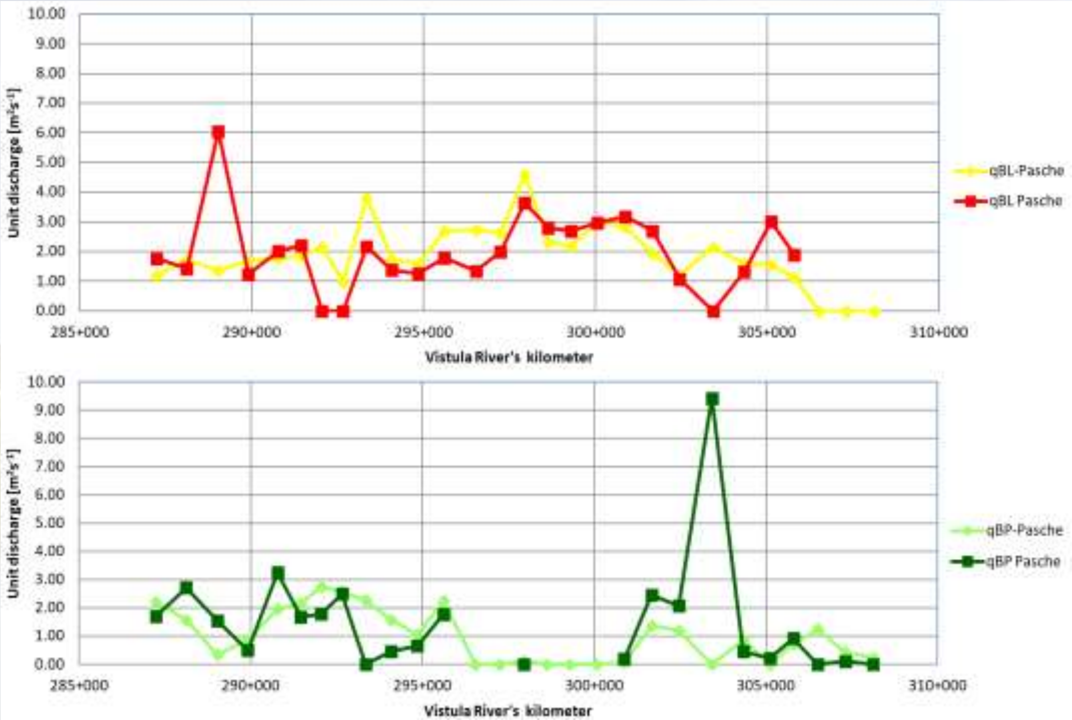

Unit flow in the Pasche zone and outside, model 2D, a) left floodplain; b) right floodplain.

The width of the zone, combined with the unit flow, together represent the flow in the zone,
while the velocity indicates the ability to transfer energy between the different parts of the cross-section.

On the left floodplain, the Pasche method is compatible in 14 cross-sections, while on the right floodpain in 13 cross-sections.

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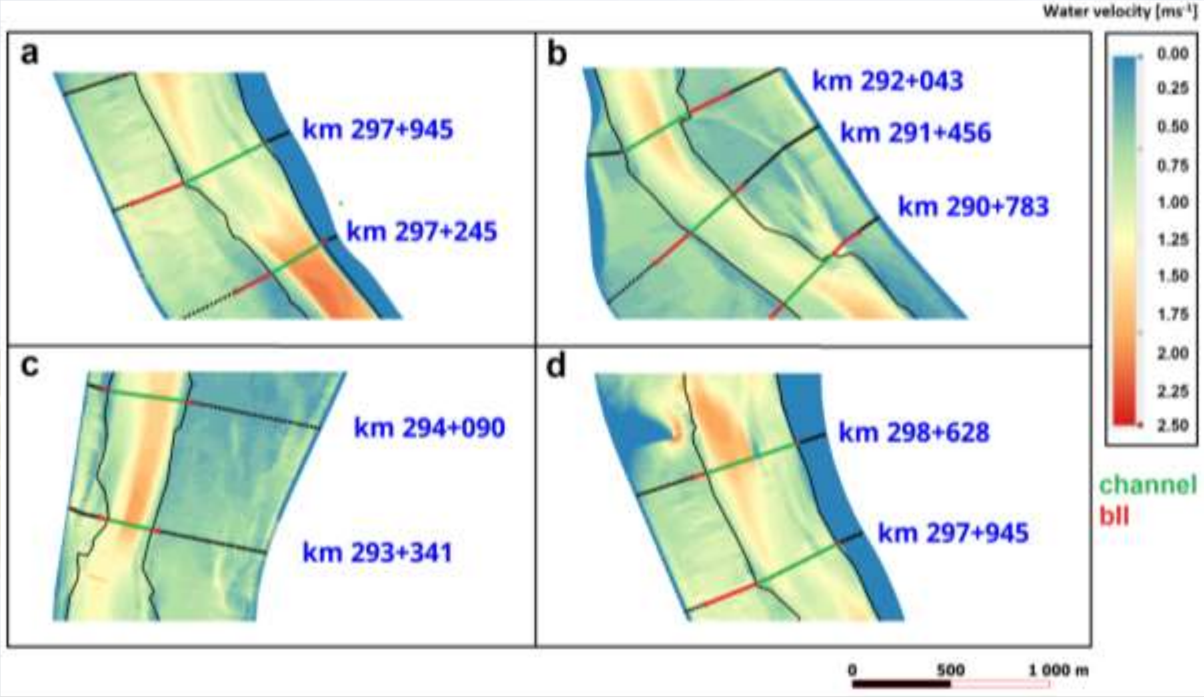

Examples of spatial distributions of velocities:
a - left bank compatible (km 297+245),
b - right bank incompatible (km 291+456),
c - both banks incompatible (km 293+341),
d - both banks compatible (km 298+628).

Spatial distributions of velocities in the cross-sections divided on the zones according to the Pasche method, Vistula river, discharge Q=4,000 m^3s^{-1}, a) compatible left bank, b) right bank incompatible, c) both banks incompatible, d) compatible both banks compatible.

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In order to be able to find not only the size but also the position of the active zones with sufficient accuracy, the procedure for its (1D) use would have to be extended:

- multiple 1D modelling with the assumption of increasing zone b_{II} starting from the channel and up to the end of the available floodplain,
- summary of results as in the presented procedure (Q, v, b_{II}, h, q),
- interpretation of the results to determine the size and location of the active zone.

Accordingly, a significant extension of the 1D modelling process could impose a sequence of modifications to the work of the model itself (perhaps construction of an overlay to the model).

The analysis of the water movement conditions in floodplains (2D model) showed that in 48.2% of cases the area of active water movement is located in direct contact with the main channel. This means that using the assumptions of the Pasche method everywhere does not give correct results. Both the location and size of the active zones depend on local conditions. Factors that favour the presence of an active zone are low terrain, narrow floodplain, connectivity to the main channel.

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