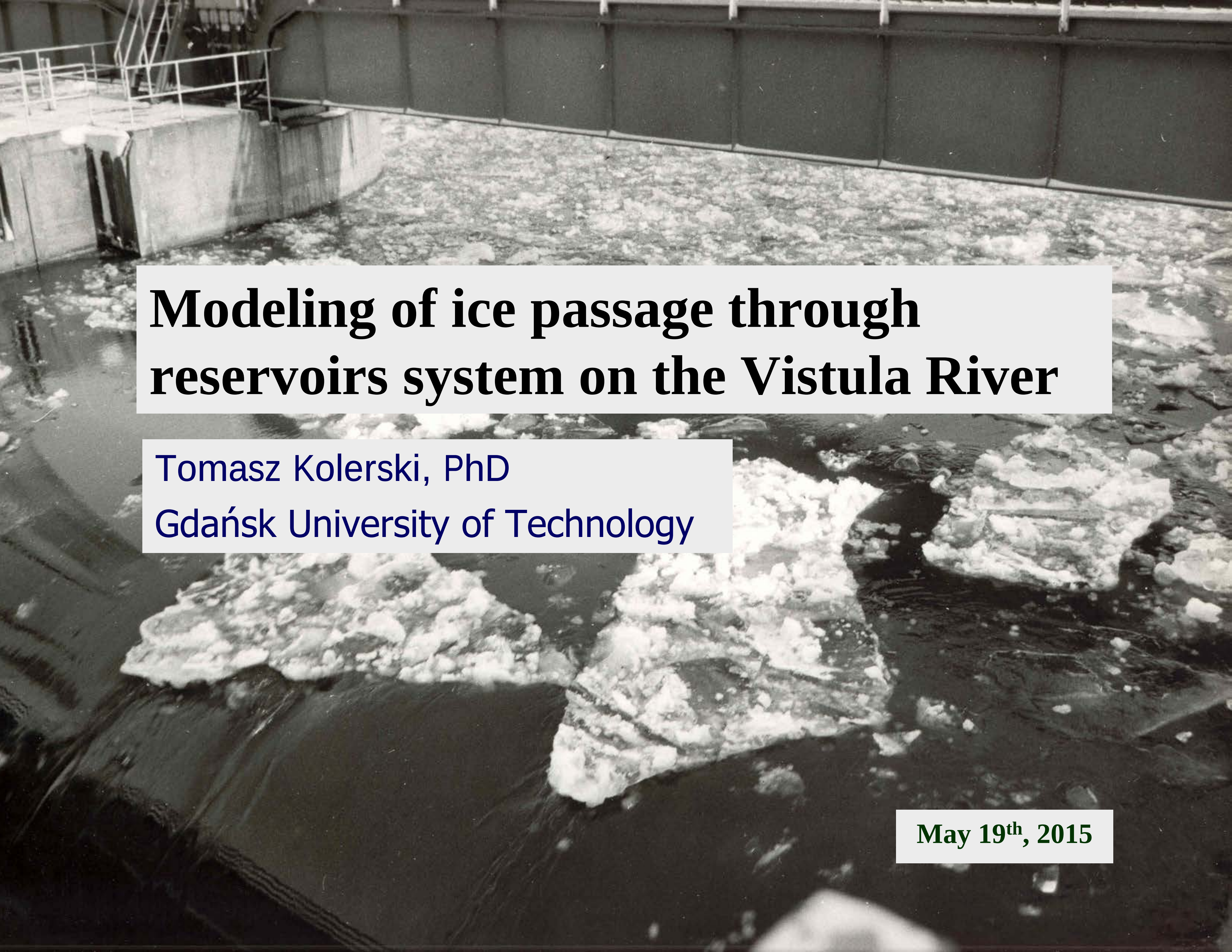

Modeling of ice passage through reservoirs system on the Vistula River

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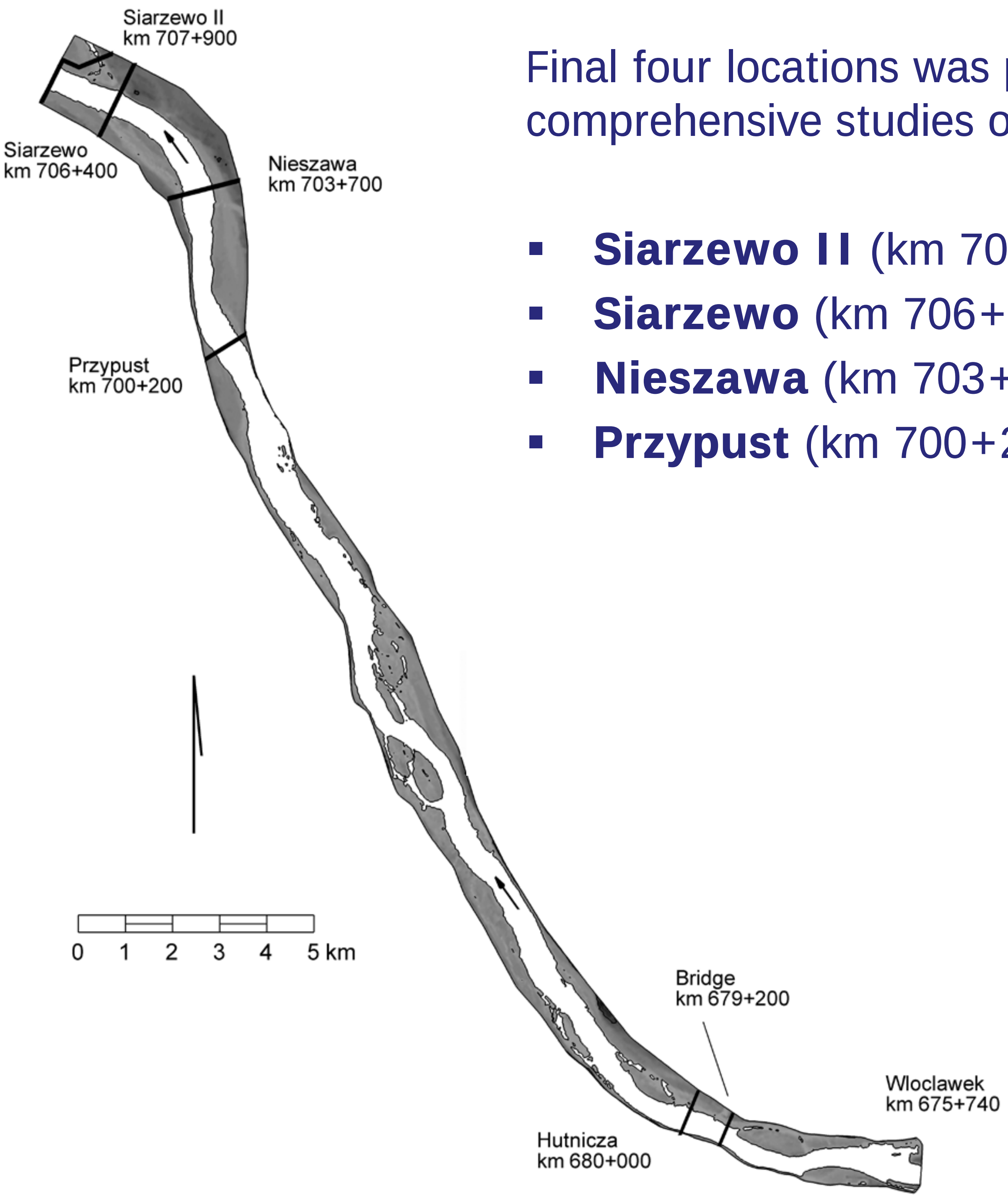
Gdańsk University of Technology

May 19th, 2015

Ice phenomena in the Lower Vistula River

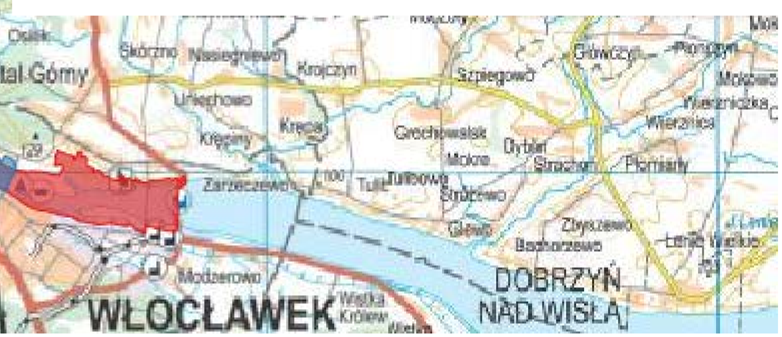
Potentially possible locational variants of the new dam



Final four locations was proposed after the comprehensive studies of exclusive analysis

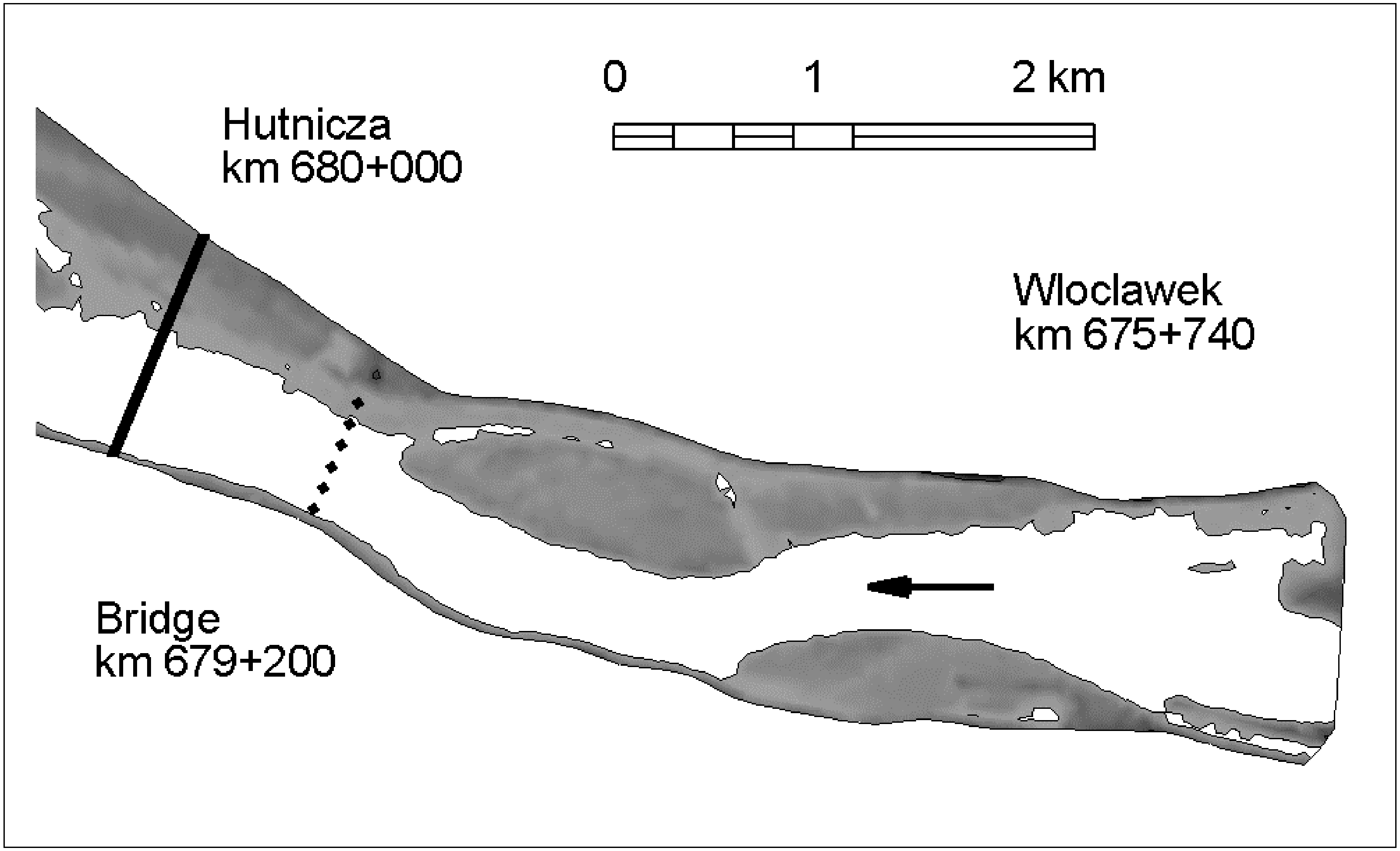
- **Siarzewo II** (km 707+900)
- **Siarzewo** (km 706+400)
- **Nieszawa** (km 703+700)
- **Przypust** (km 700+200)

Areas included as Natura 2000 sites



- Arbitrarily introduced environment and species protection program
- Restrictive provisions within the Natura 2000 areas
- Investments are possible if complying with conditions described in Article 34 of the Environmental Protection Law

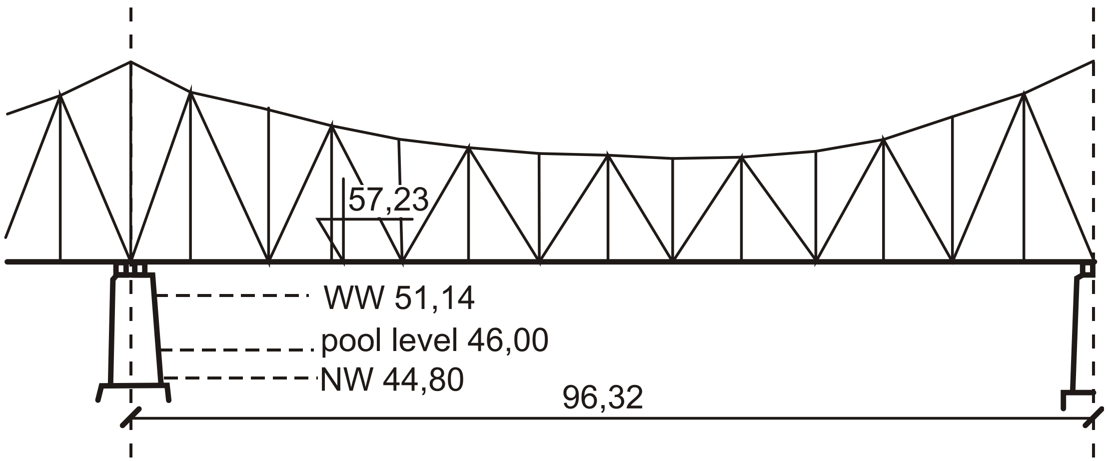
Włocławek – Hutnicza dam km 680+000



The project is not economically reasonable

Considered because it not affects the Natura 2000 sites

Rydz Śmigły Bridge



Truss bridge on the local road

- 6 caisson piers in a main channel
- 10 m vertical clearance (for normal and low flow conditions)

Courtesy of M. Grześ

Numerical Model Formulation

DynaRICE is a two-dimensional numerical model for dynamic transport and jamming of surface ice.

- Hydrodynamics - Explicit characteristic upwind Petrov - Galerkin FEM method, with dry-wet bed conditions, for transitional flows.

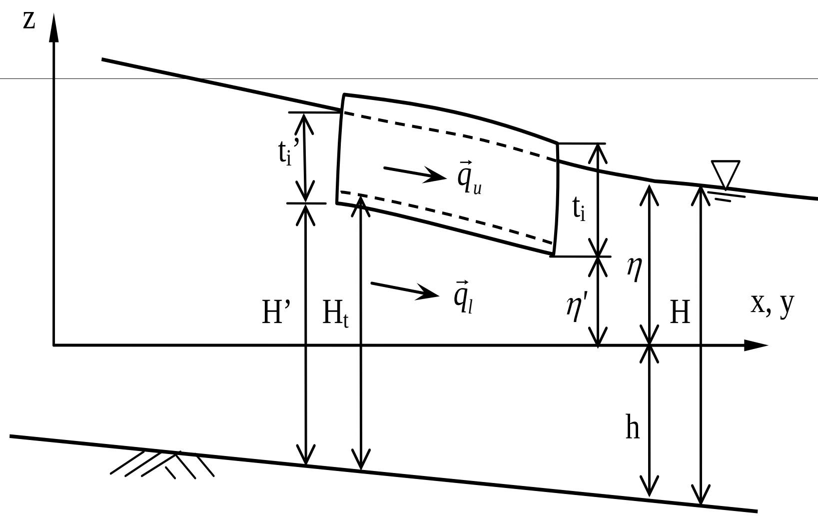
- Ice Dynamics - SPH (Lagrangian discrete parcel method).

The model simulates the coupled dynamics of ice motion and water flow, including the flow through and under the ice rubble.

The ice dynamic equations consider all the external and internal forces.

The model has been extended to include thermal ice

Hydrodynamic Equations



Continuity equation:

$$\frac{\partial H}{\partial t} + \frac{\partial (q_{tx})}{\partial x} + \frac{\partial (q_{ty})}{\partial y} = \frac{\partial}{\partial t}(N t_i')$$

Momentum equations:

$$\frac{\partial q_{tx}}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_{tx}^2}{H_t}\right) + \frac{\partial}{\partial y}\left(\frac{q_{tx} q_{ty}}{H_t}\right) = f q_y + \frac{1}{\rho}(\tau_{sx} - \tau_{bx}) + \frac{1}{\rho}\left(\frac{\partial T_{xx}}{\partial x} + \frac{\partial T_{yx}}{\partial y}\right) - g H_t \frac{\partial \eta}{\partial x}$$

$$\frac{\partial q_{ty}}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_{tx} q_{ty}}{H_t}\right) + \frac{\partial}{\partial y}\left(\frac{q_{ty}^2}{H_t}\right) = - f q_x + \frac{1}{\rho}(\tau_{sy} - \tau_{by}) + \frac{1}{\rho}\left(\frac{\partial T_{xy}}{\partial x} + \frac{\partial T_{yy}}{\partial y}\right) - g H_t \frac{\partial \eta}{\partial y}$$

Ice Dynamics Equations

Momentum equation of the surface ice in Lagrangian form:

$$M\frac{D\vec{V}_i}{Dt} = \vec{R} + \vec{F}_a + \vec{F}_w + \vec{G} + \vec{C}$$

$\vec{R}$ – internal ice resistance

$\vec{F}_a$ – wind drag

$\vec{F}_w$ – water drag

$\vec{G}$ – gravity force

$\vec{C}$ – Coriolis force

Ice mass conservation equation:

$$\frac{DM}{Dt} + M\nabla \cdot \vec{V} = 0$$

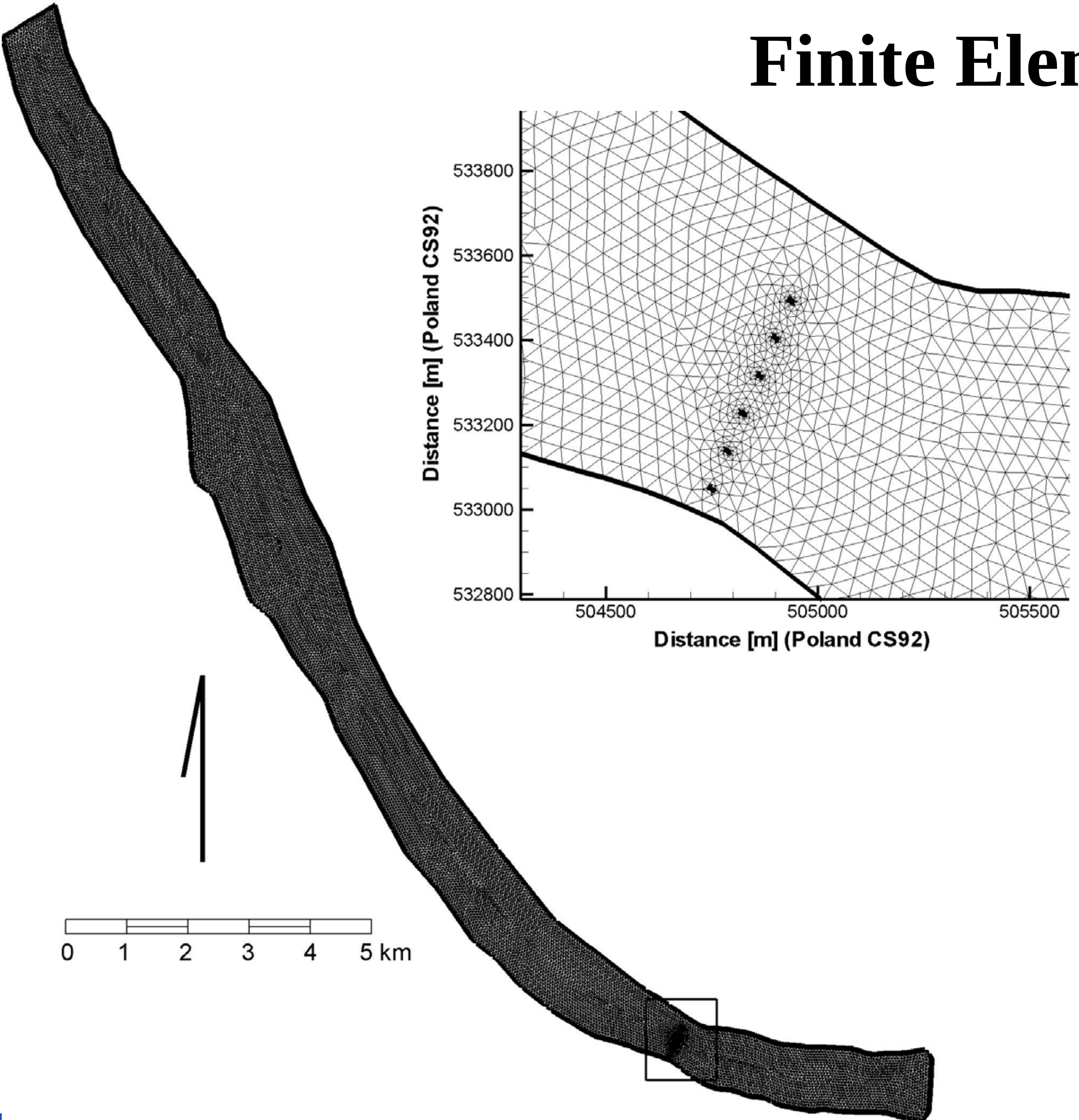
Area conservation equation:

$$\frac{DN}{Dt} + N\nabla \cdot \vec{V}_i = 0$$

Dynamic boundary condition at land boundaries and bed friction:

$$\vec{F}_B = -\mathrm{sgn}(v_t)\mu_B F_n \vec{t}$$

Finite Element mesh



Boundary conditions

- **Upstream** (Włocławek Dam)
  Discharge Q(t)
  - 300 m^3/s – 3 spans open; 105 m^3/s each
    (one span 20 m width; 3 x 20 = 60 m)
  - 600 m^3/s – 6 spans open
    (6 x 20 = 120 m)
- **Downstream** (new dam)
  water surface elevation at pool level H=46 m npm (HKron86)
  - 300 m^3/s – 3 spans open
    (one span 25 m; 3 x 25 = 75 m)
  - 600 m^3/s – 6 spans open (6 x 25 = 150 m)

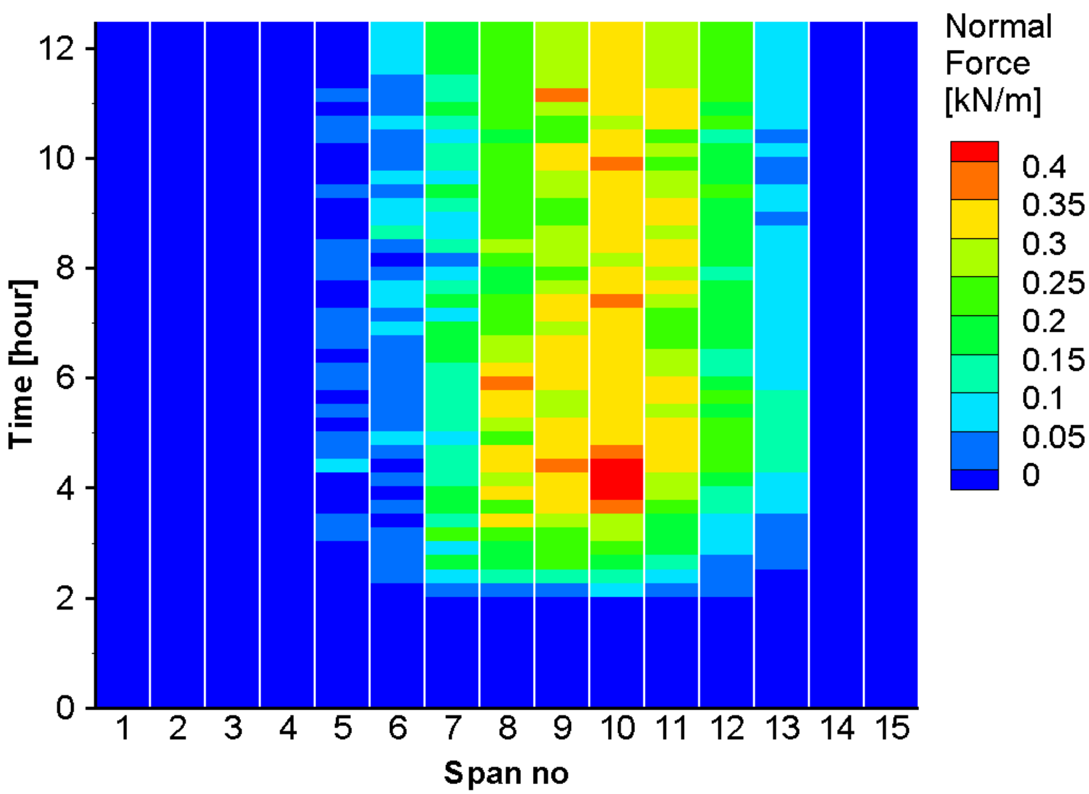
Courtesy of M. Grześ

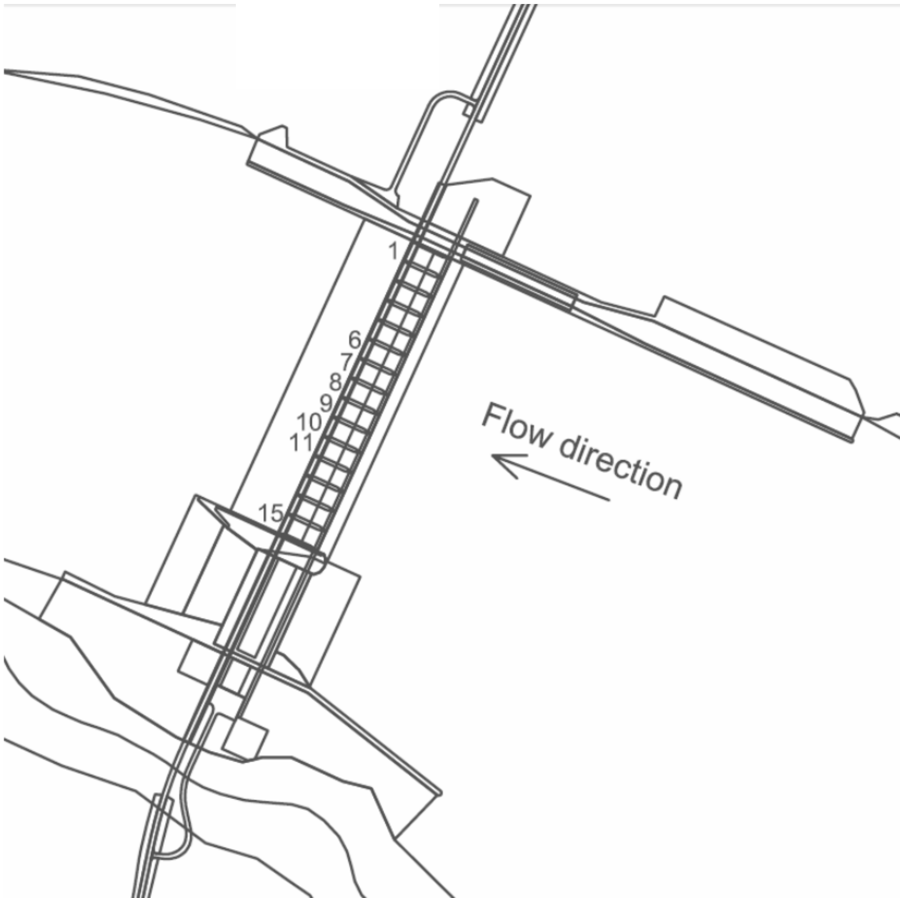
Ice load calculations

- ice run without sluicing was simulated for average water discharge (900 m^3/s)
- Spans with the highes normal force recorded were selected for ice sluicing

i.e. Nieszawa Dam:

- For discherge 300 m^3/s – spans no 9, 10 i 11
- For discherge 600 m^3/s – spans no 7, 8, 9, 10, 11 i 12





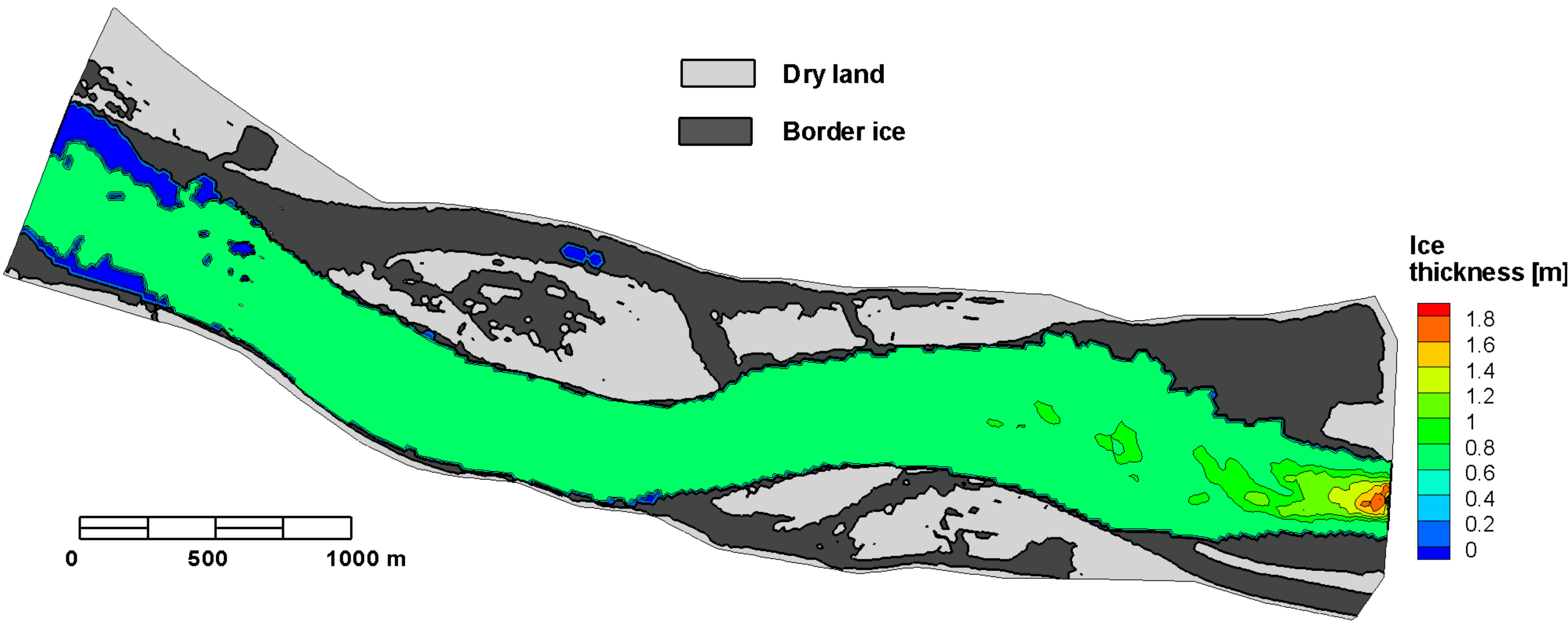
Border ice zones in the Hutnicza reservoir for average discharge Q=900 m³/s

Sensitivity study

	Q	Wind Velocity	Remarks
	[m^3/s]	[m/s]	
Case 1	600	0	
Case 2	600	2	
Case 3	600	5	
Case 4	300	0	Low Discharge
Case 5	300	5	
Case 6	300	2	

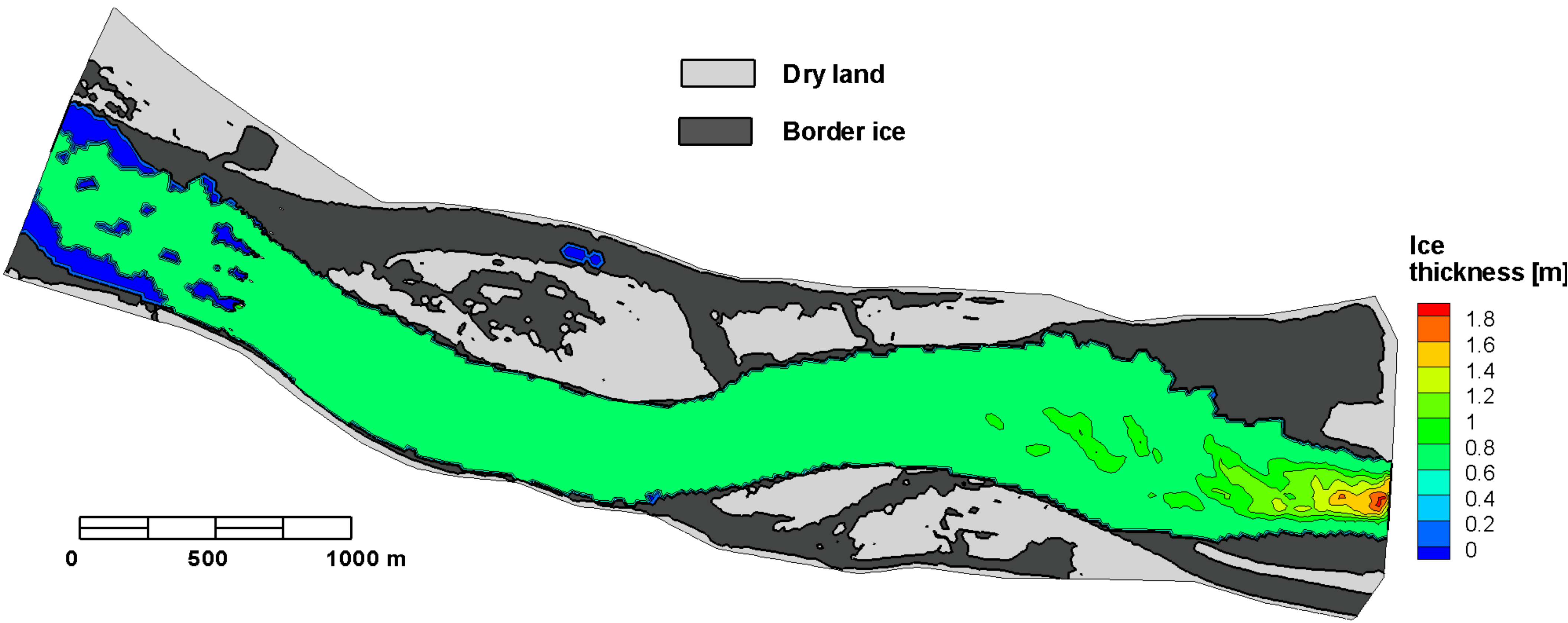
Włocławek – Hutnicza Dam

- $Q = 600\ m^3/s$
- No wind



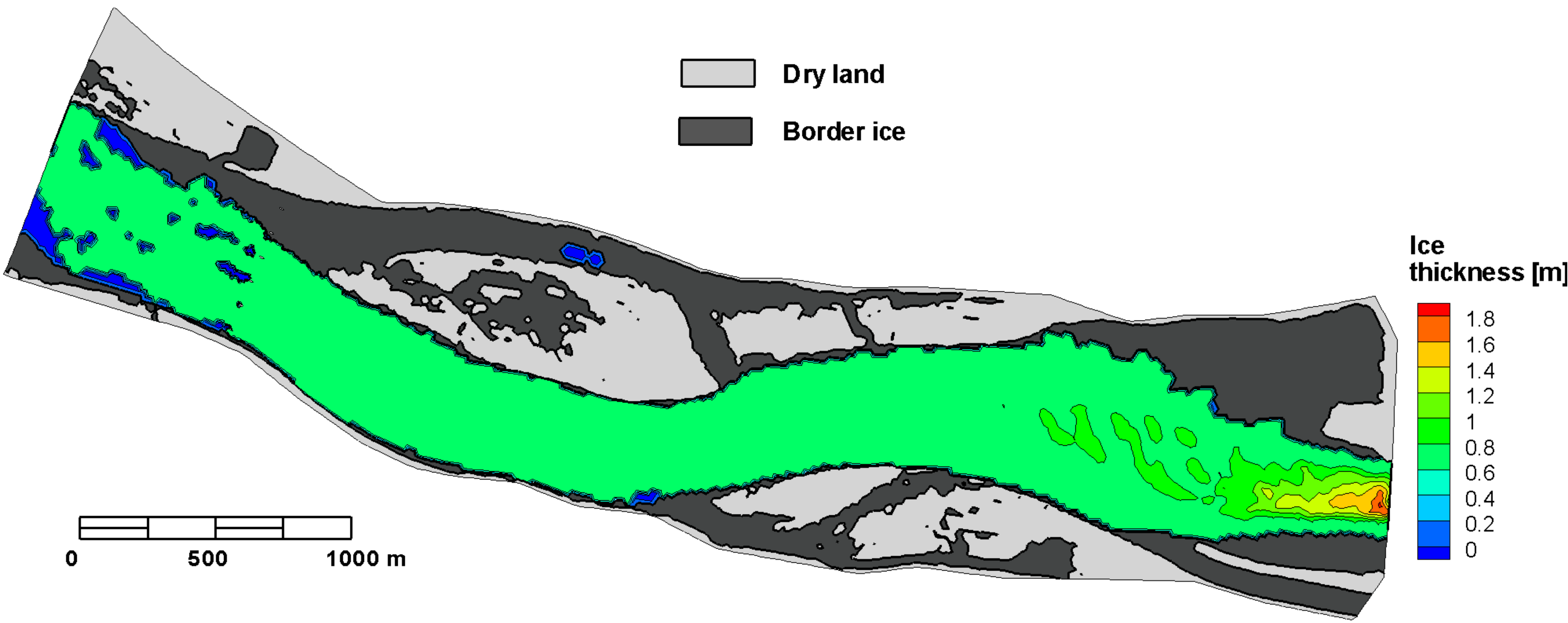
Włocławek – Hutnicza Dam

- Q = 600 m^3/s
- Wind 2 m/s



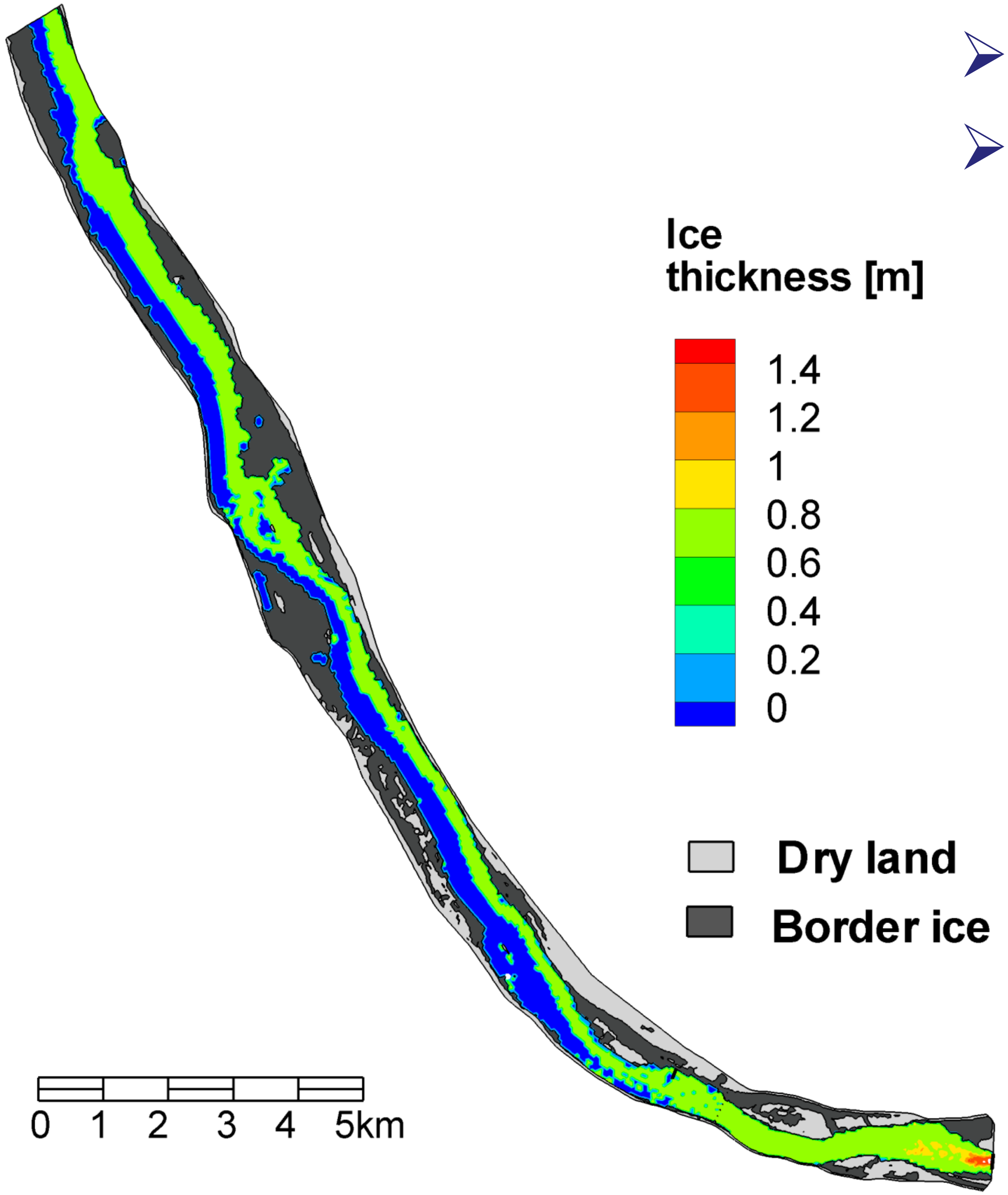
Włocławek – Hutnicza Dam

- Q = 600 m^3/s
- Wind 5 m/s



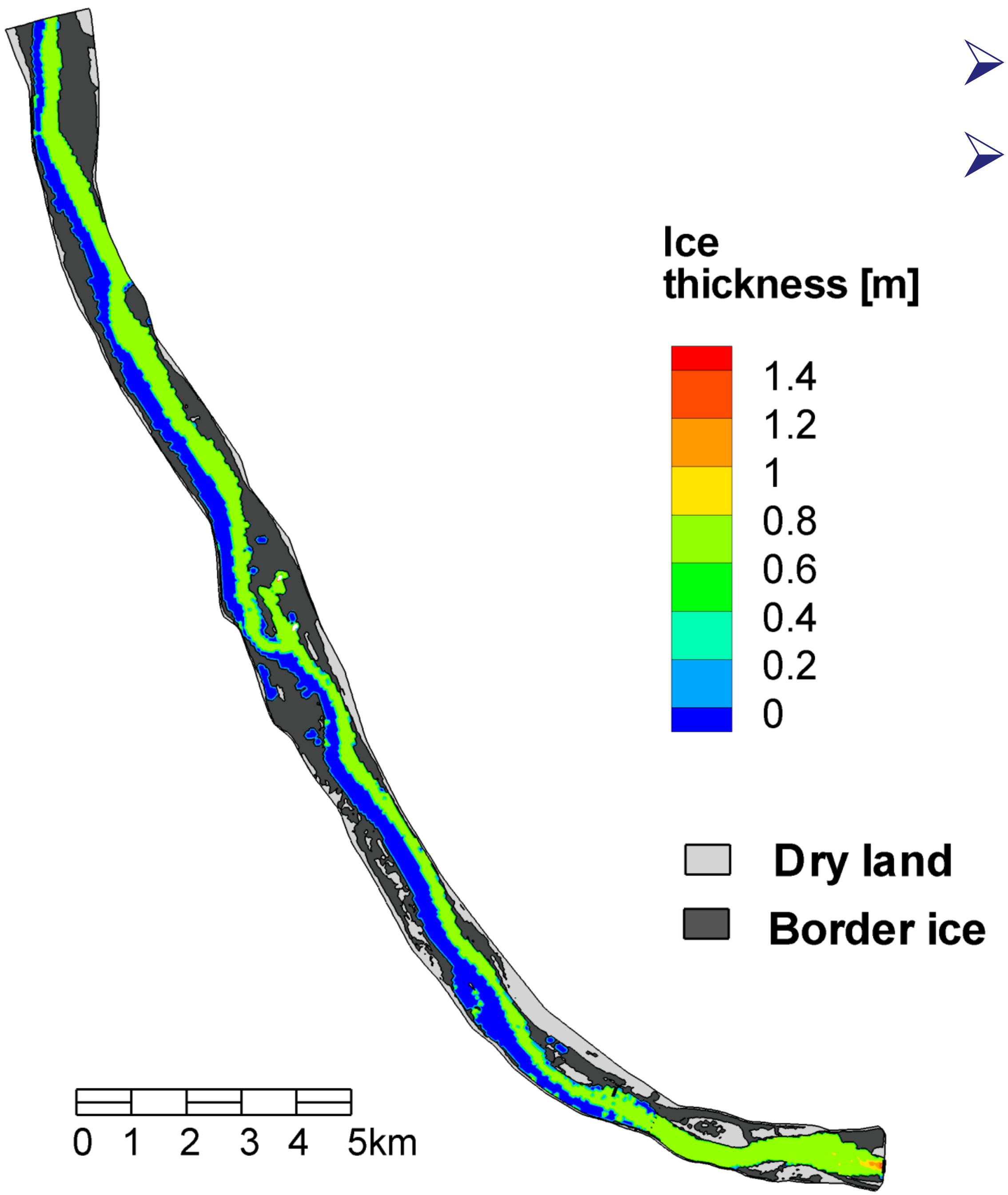
Przypust Dam (km 700+200)

- Q = 600 m^3/s
- Wind 5 m/s



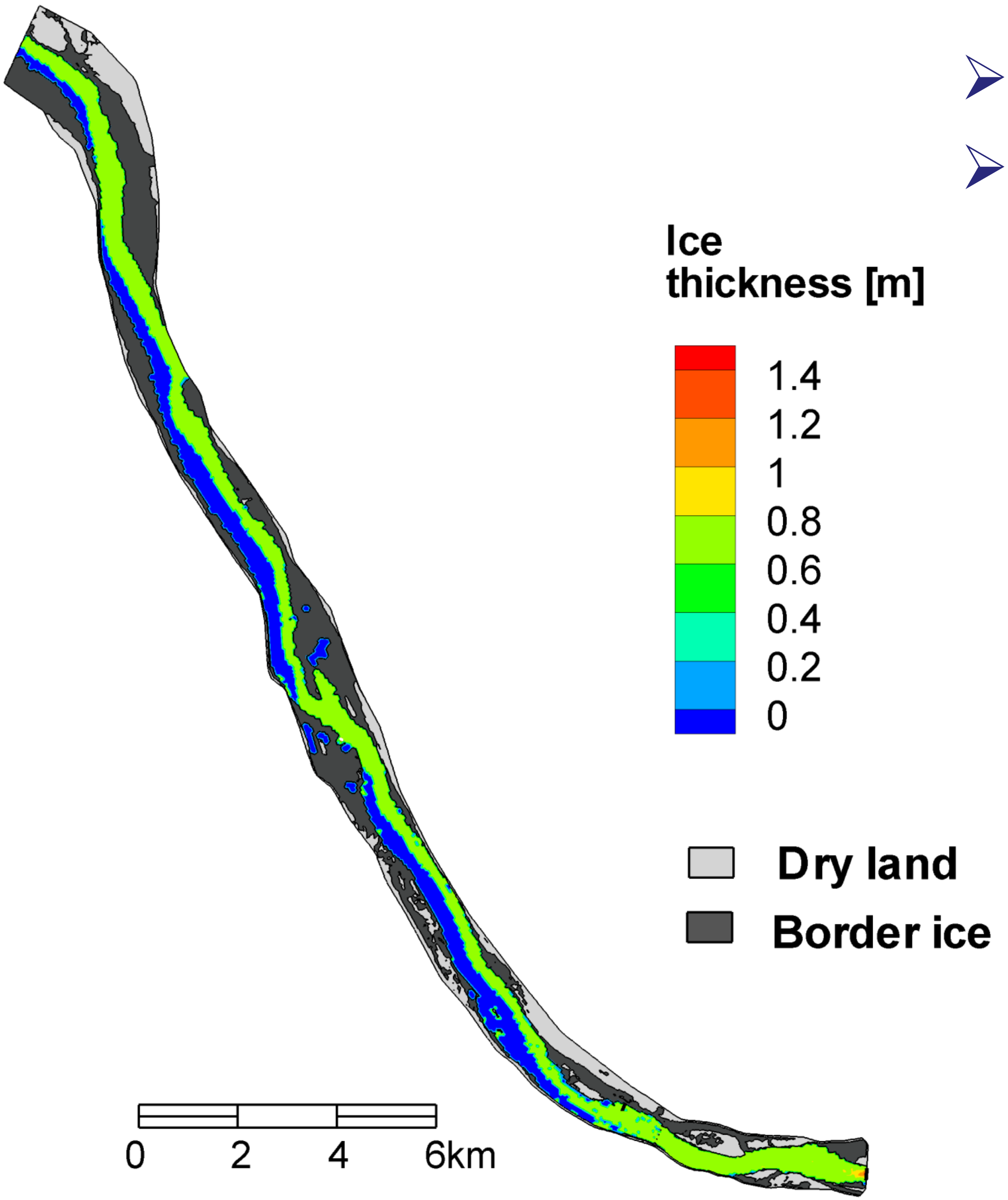
Nieszawa Dam (km 703+700)

- Q = 600 m^3/s
- Wind 5 m/s



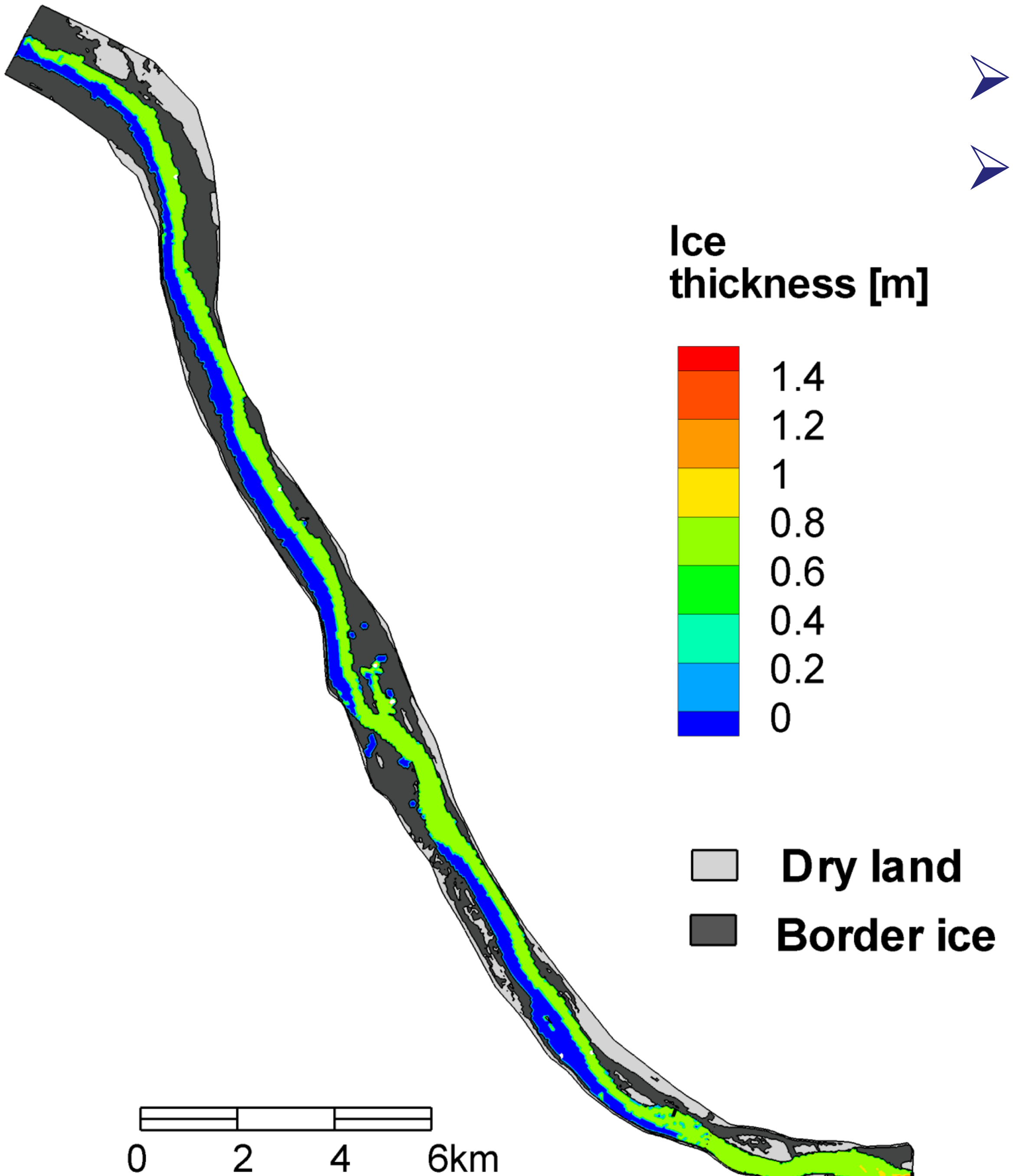
Siarzewo Dam (km 706+400)

- Q = 600 m^3/s
- Wind 5 m/s



Siarzewo II Dam (km 707+900)

- Q = 600 m^3/s
- Wind 5 m/s



Conclusions

- ice passage through the new reservoir is generally possible for any dam location and do not cause significant jam risk for no wind condition
- the major problem for the Hutnicza reservoir is the small size, therefore the ice retention possibility is limited
- In all simulated cases results shown some ice accumulation as an effect of bridge piers interaction
- ice sluicing during the unfavorable western wind conditions could proceed only for dam locations at Przypust and **Siarzewo**

Areas where dredging is required