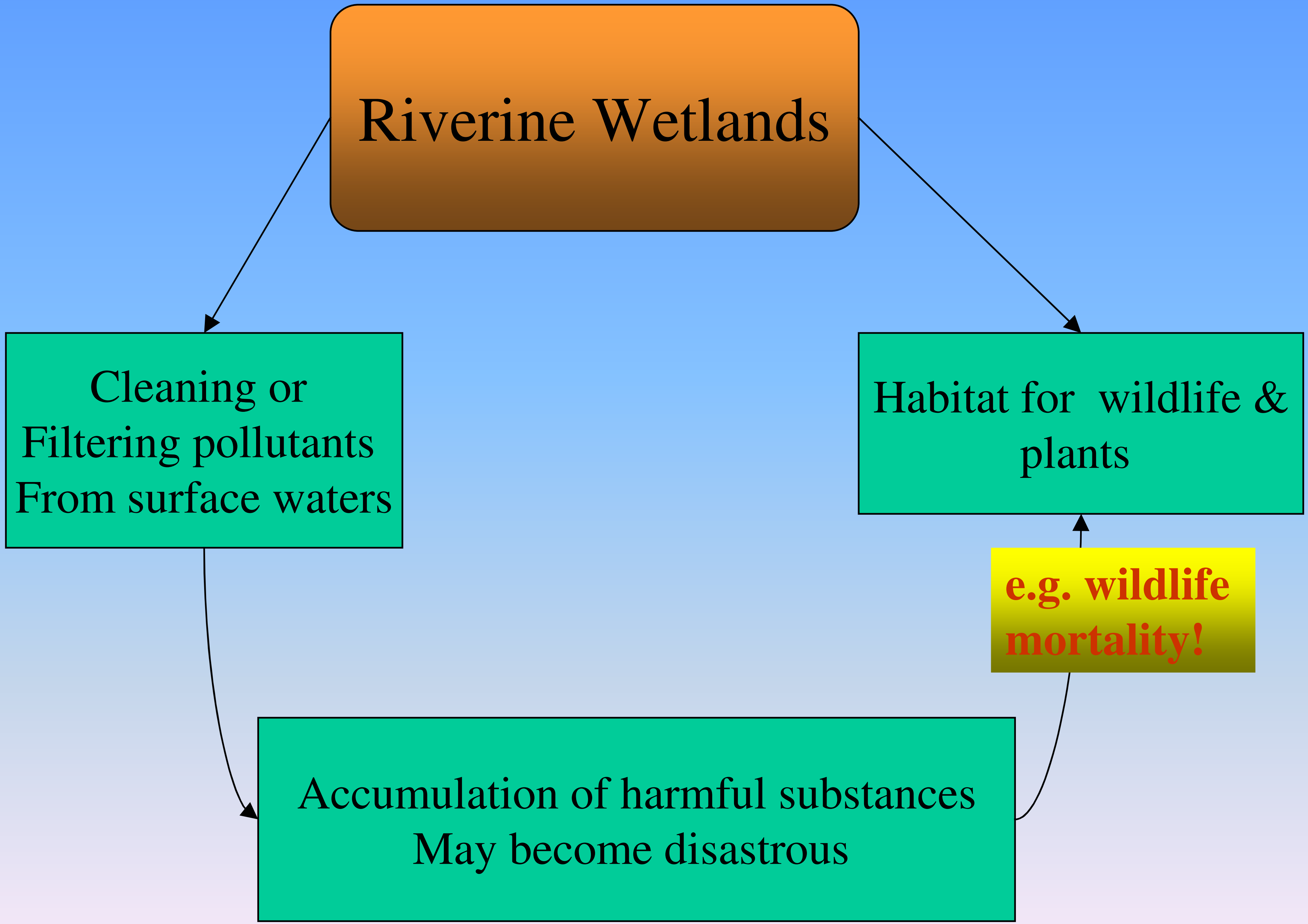
Transport of pollution in the rivers flowing through wetland areas

Paweł M. Rowiński
Jarosław J. Napiórkowski
Tomasz Dysarz

Institute of Geophysics
Polish Academy of Sciences
Warsaw, Poland

Riverine wetlands

- Riverine wetlands form as linear strips, generally paralleling river & stream channels.
- They are found at lower elevations in a floodplain and tend to be more frequently inundated and for a longer duration than areas at slightly higher elevation.



Riverine Wetlands
Cleaning or Filtering pollutants From surface waters
Habitat for wildlife & plants
e.g. wildlife mortality!
Accumulation of harmful substances May become disastrous

AIMS

- understanding of the mechanisms governing pollution transport in the river wandering through a wetland area.

- creation of respective mathematical models of the pollution transport in the stream as a starting point

AIMS -CONTINUATION

- Evaluation of the threats by an accidental release of the pollutants at the downstream locations in a complex multi-channel river system.
- Particular aim: determination of concentration pattern of accidental inputs of toxic materials within the Narew National Park.

Example - anastomosing river

- In case of the Upper Narew we deal with the multi-channel system on a flood plain but in contrast to the typical braided rivers, they are represented by relatively small slopes.
- Anastomosing multichannel streams develop when vegetation has stabilized the stream banks and the channel.

Methods

- Tracer study in which a known mass of a conservative solute (Rhodamine WT) is released into the stream.
- Study consists in the examination of the concentration versus time of the artificially released dye at downstream stations and fitting appropriate models.
- DEVELOPMENT OF MATHEMATICAL MODEL

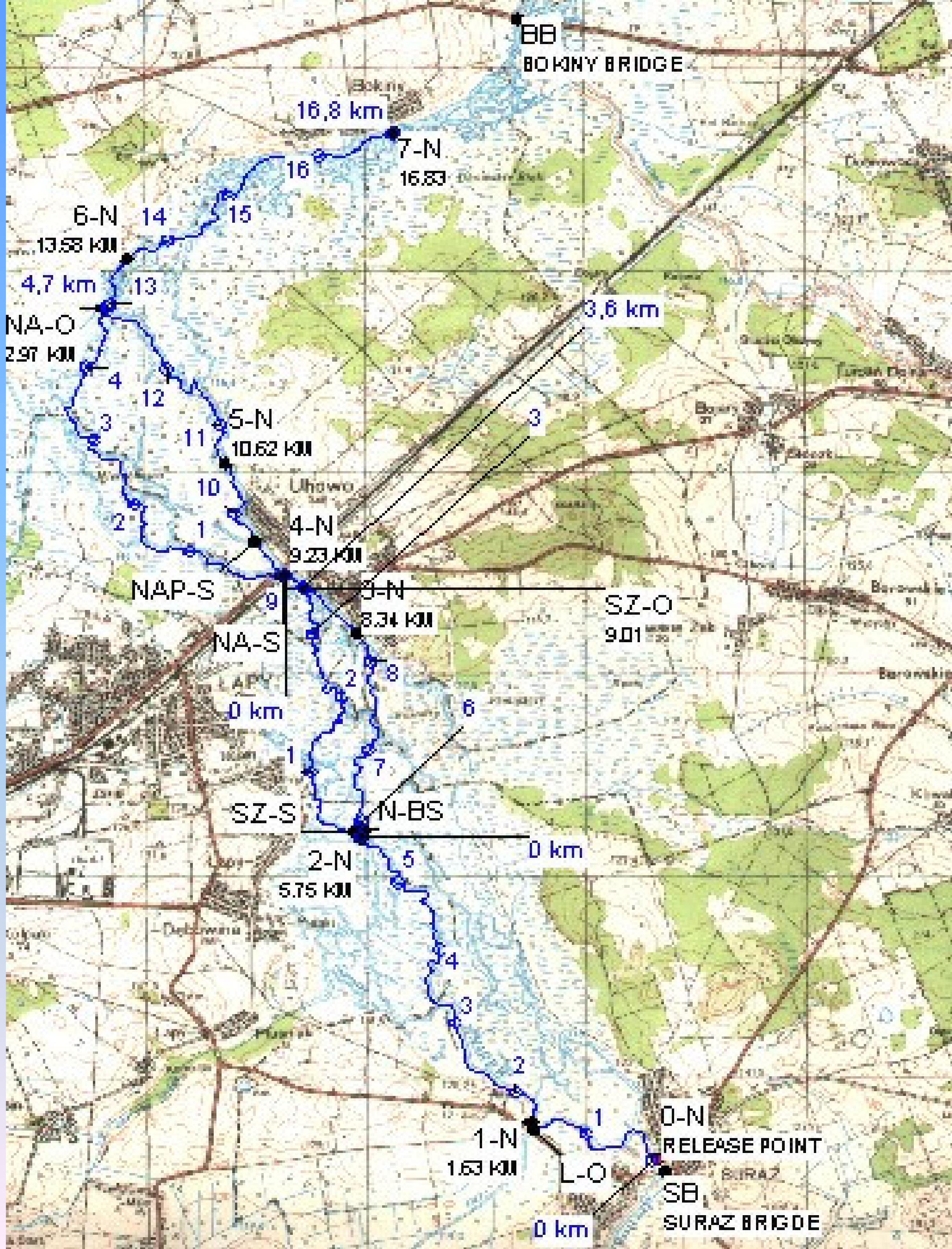
Hydrological Survey

- A precondition for a proper understanding of the physical processes that occur in a river (and among them the processes governing the transport of pollutants) is a detailed recognition of hydrological and morphometric state within the river channel and possibly on the floodplains.

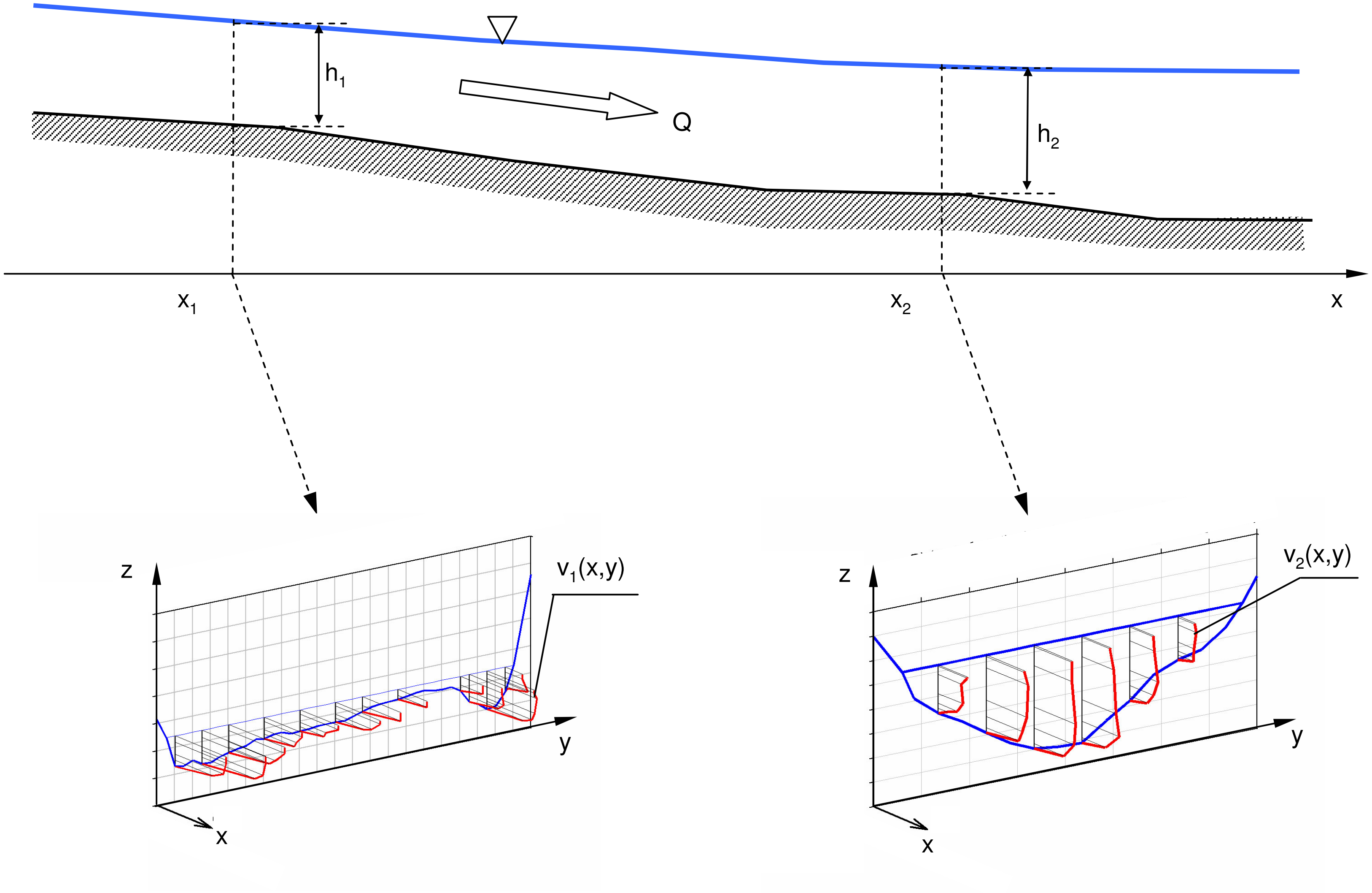
Hydrological Survey (NNP)

- Description of channel network
- Streamwise velocity field
- Discharges at selected cross-sections
- Water surface slopes (along whole river reach and local) and bed slope
- Hydraulic and topographic characteristics

GPS SURVEY RESULTS



Hydraulics computations



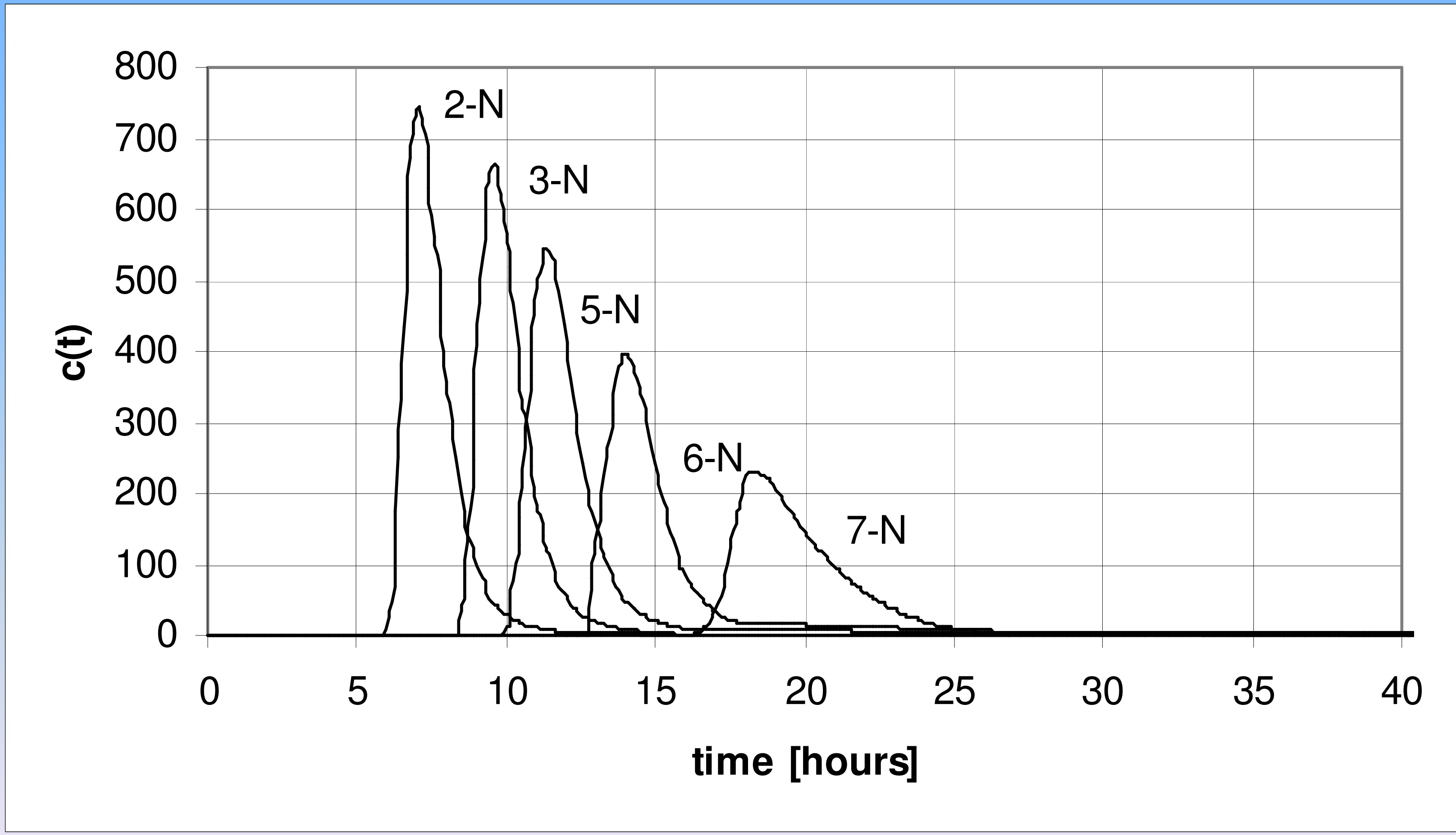
Dye tracer test

- The method of instantaneous injection of the tracer was applied
- The dye release consisted of 20 liters of 20% solution of Rhodamine WT at the cross-section just downstream of the bridge at Suraż.
- Concentrations were measured at six transects (3.62 km, 8.34 km, 9.01 km, 9.23 km, 13.58 km, and 16.83 km). First cross-section was established at a distance at which 1D conditions were supposed to be achieved.

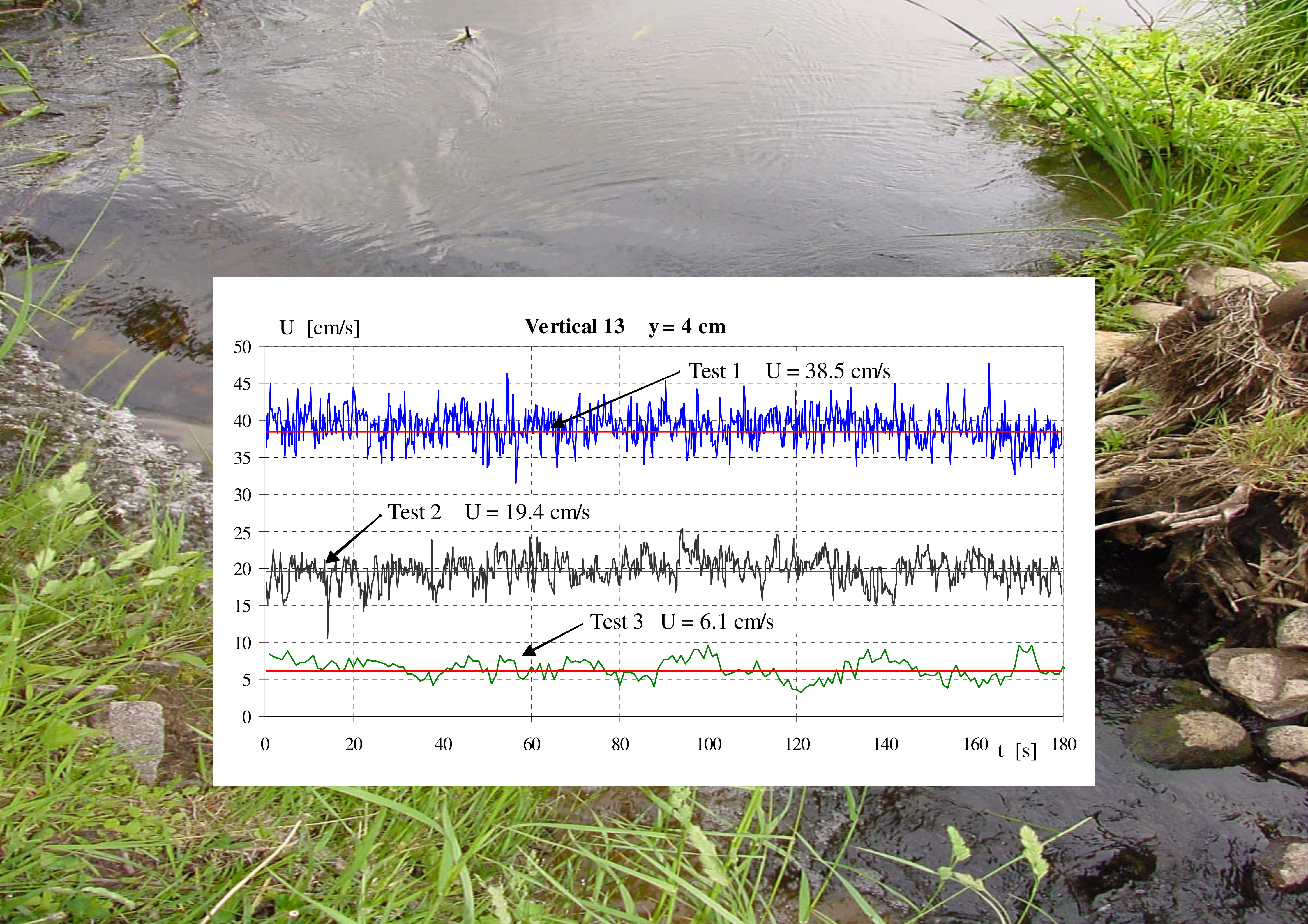

Spreading of Rhodamine WT at the early stage
where lateral mixing occurs


The stage where the tracer is mixed across

Variation of concentration with time at the cross-sections downstream of the injection



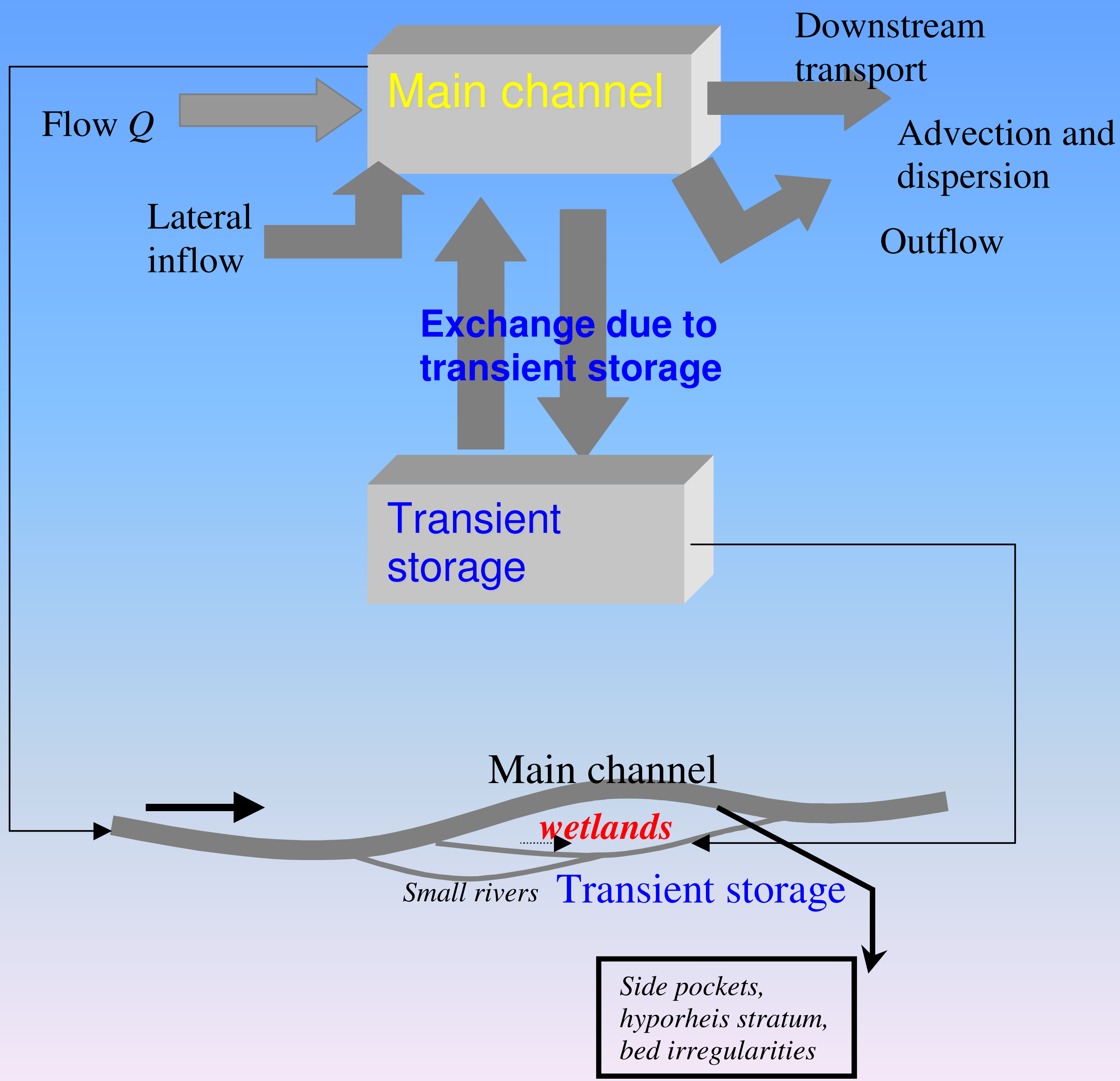
Why the mathematical treatment of pollution transport offers so many difficulties?



U [cm/s]
Vertical 13 y = 4 cm
Test 1 U = 38.5 cm/s
Test 2 U = 19.4 cm/s
Test 3 U = 6.1 cm/s
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
t [s]
180


Secondly:
Extremely complex geometry
especially in wetland areas

Modeling concept



Main channel
Downstream transport
Flow Q
Advection and dispersion
Lateral inflow
Outflow
Exchange due to transient storage
Transient storage
Main channel
wetlands
Small rivers
Transient storage
Side pockets, hyporheis stratum, bed irregularities


Storage zone

Models of pollution transport

Main channel

- **Steady and uniform flow conditions**

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} - D\frac{\partial^2 C}{\partial x^2} = \frac{\varepsilon}{T}\left(C_D - C\right)$$

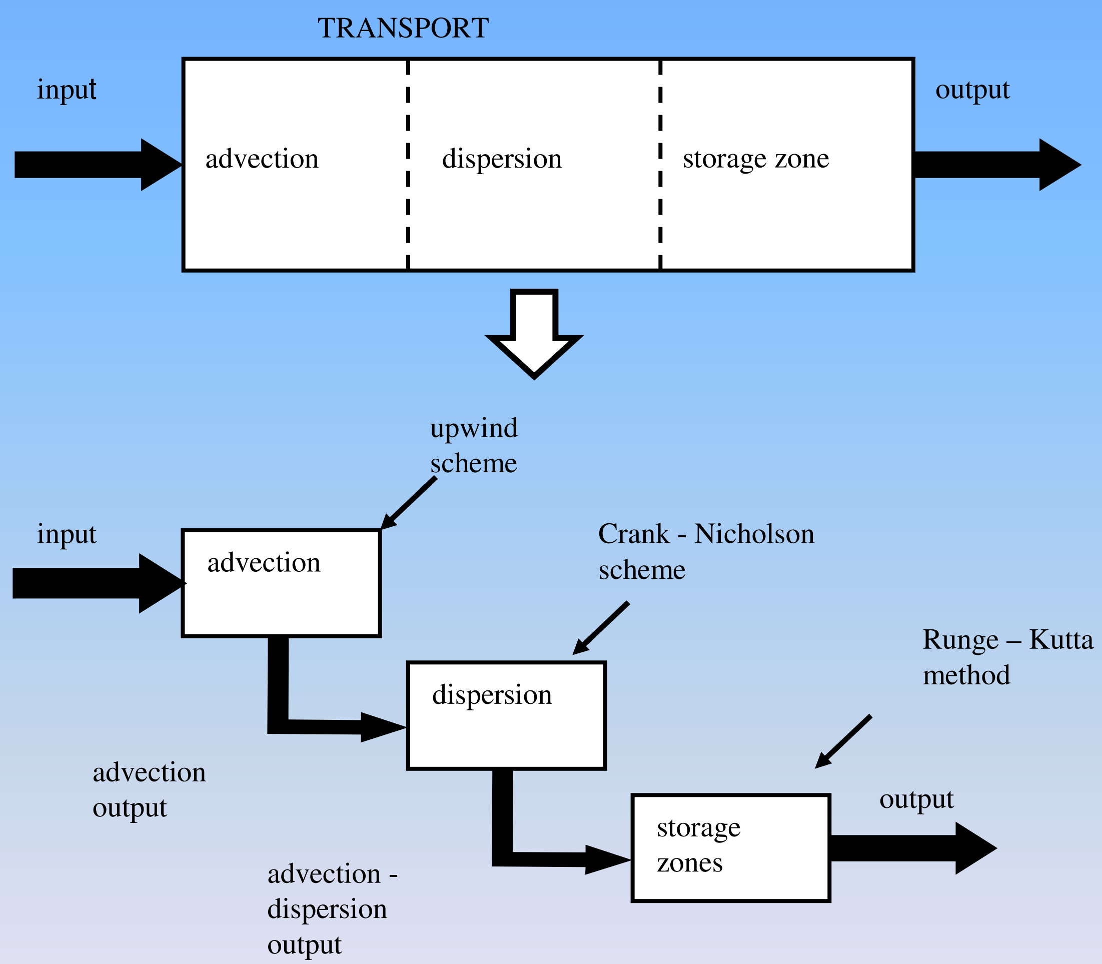
- **Steady but non-uniform flow conditions**

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} - \frac{1}{A}\frac{\partial}{\partial x}\left(DA\frac{\partial C}{\partial x}\right) = \frac{\varepsilon}{T}\left(C_D - C\right)$$

Transient storage zones

$$\frac{\partial C_D}{\partial t} = \frac{1}{T}\left(C - C_D\right)$$

Schematic representation of the solution method – splitting technique



Identification of model parameters

Optimization Procedure 1 – based on frequency response function

$$H(x, i\omega) = \exp\left[\frac{U}{2D}x - \frac{x}{2D}\sqrt{U^2 + \frac{4D\varepsilon T\omega^2}{T^2\omega^2+1} + i\frac{4D(T^2\omega^3+\omega+\varepsilon\omega)}{T^2\omega^2+1}} \right]$$

Optimization procedure on the reach by reach basis with specially designed objective function comparing the reverse of Fourier transformation of function *H* and the measured concentrations.

Another formulation of optimization problem

Criterion for parameters derivation

$$\min_{u,D,\varepsilon,T}\left\{F\left[u,D,\varepsilon,T\right]=\sum_{k=2}^{K}\int_{0}^{T_H}\left[C_m\left(x_k,t\right)-C\left(x_k,t\right)\right]^2 dt\right\}$$

Constraints for the problem

$$X_{\min}\leq X\left(x\right)\leq X_{\max}$$

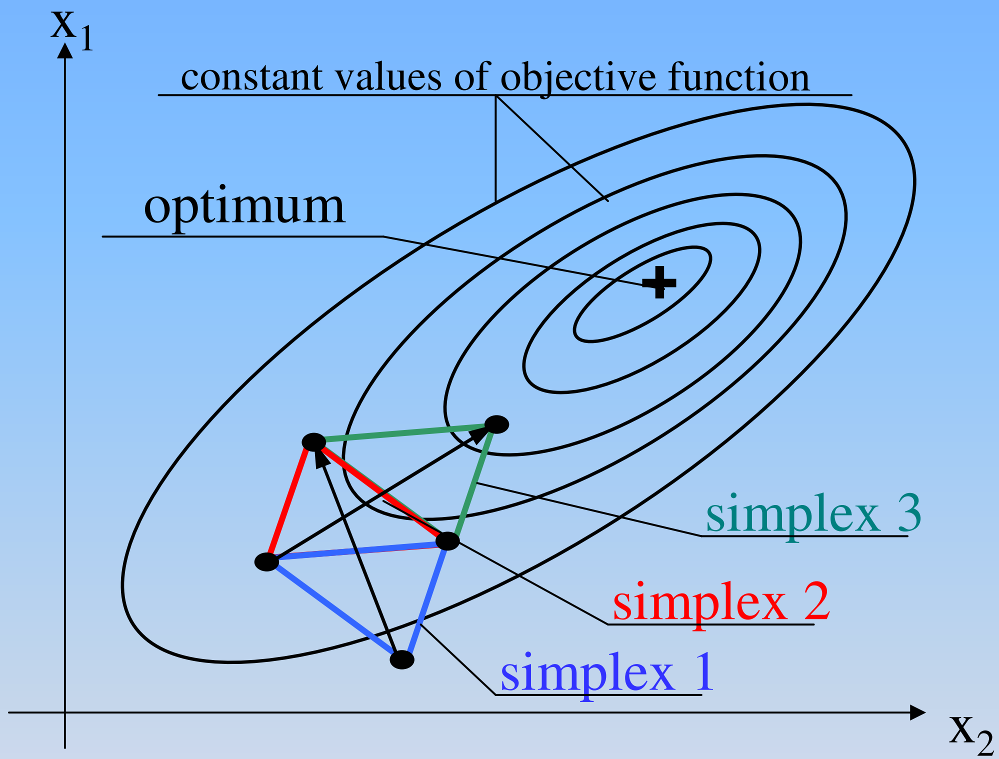
Water continuity equation

$$Q=uA$$

Control Random Search

- Start of computations – set of points
- Determination of the best $\mathbf{x}^L$ and the worst $\mathbf{x}^H$ from the given set
- Formation of a simplex containing $\mathbf{x}^L$
- Reflection of the last point from simplex $\mathbf{x}^{n+1}$ - result: new point $\mathbf{x}^W$
- Replacement of $\mathbf{x}^H$ **by** $\mathbf{x}^W$
- Stop criterion

$$F_{sr} - F\left(\mathbf{x}^L\right) < \varepsilon$$

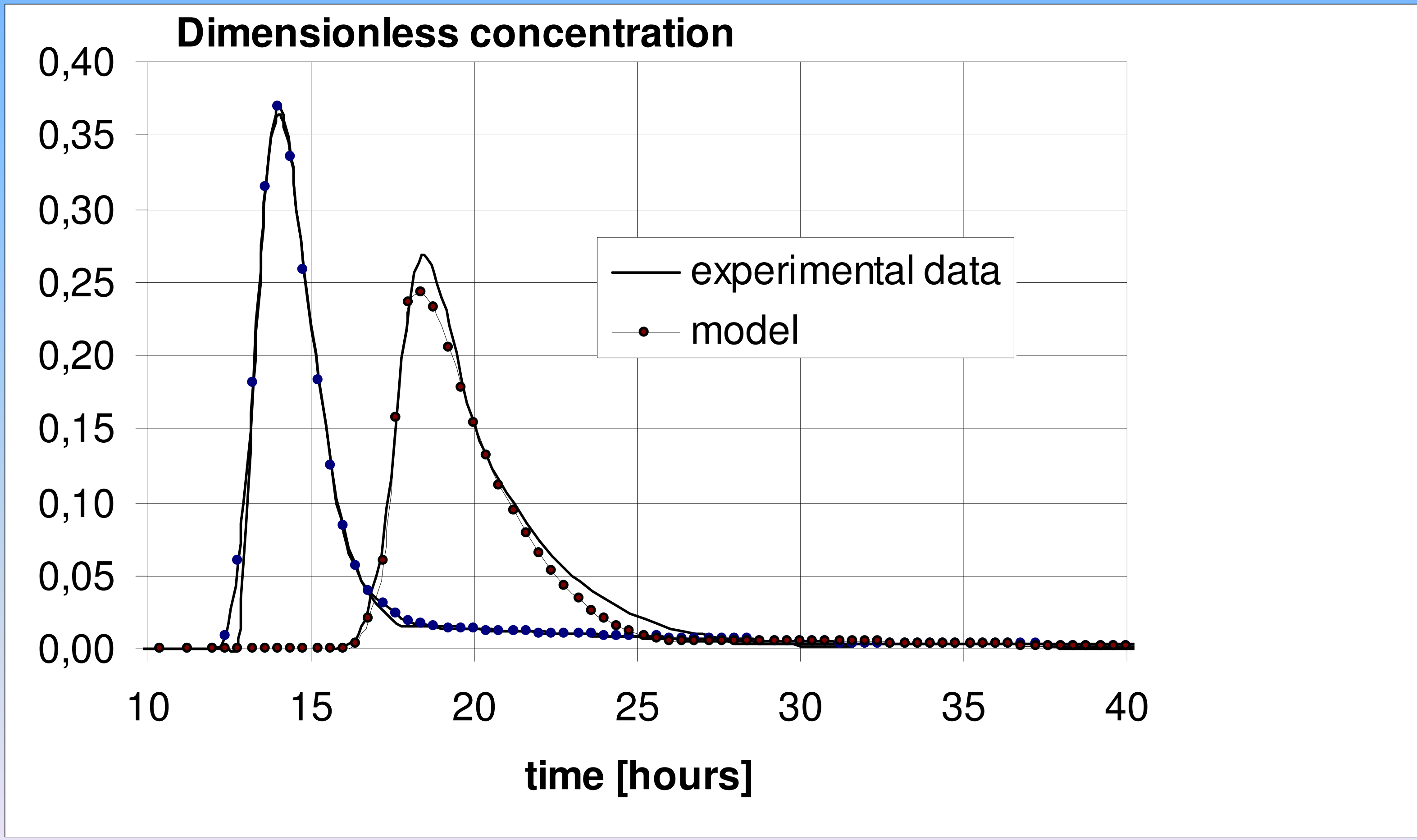


The searching rule for the domain of the objective function by means of simplex method

Dead-zone model parameters – Upper Narew

Parameters	Sections					
	[0-N,2-N]	[2-N,3-N]	[3-N,5-N]	[5-N,6-N]	[6-N,7-N]	[0-N,7-N]
E_L [km²/h]	**0.0027**	**0.0220**	**0.0051**	**0.0338**	**0.0034**	**0.0120**
ε	**0.0920**	**0.0120**	**0.7920**	**0.3690**	**0.2260**	**0.1020**
T[h]	**0.4530**	**0.6550**	**11.2570**	**7.0706**	**0.9030**	**1.440**
U^a[km/h]	**0.5200**	**1.8400**	**0.4880**	**1.6200**	**0.7800**	**0.9190**

Examples of measured and dead-zone model results



Continuation of studies

- Computations under flood conditions, also when the entire floodplain is inundated.
- The above requires a very good recognition of the topography of the entire valley
- Flow computations based on CCHE models – currently conducted

Concluding remarks

- It is shown that because of the asymmetric nature of all the observed breakthrough curves, the temporary storage of the admixture plays a crucial role in the analyses of the pattern of its spread in the multi-thread river system. This reflects the interactions with the adjacent wetland areas (high values of ε in the model)

Concluding remarks -cont

- A tracer test definitely facilitates the analyses and quantification of the hydrodynamic and also chemical processes in surface waters, particularly in such complex environment as the Upper Narew. Because of its complete safeness for the environment such method is recommended as a tool for the recognition of the system behavior.


THANK YOU FOR YOUR
ATTENTION