UIT GmbH Dresden • Germany

1.5D River Model for Radionuclide Transport & Accumulation

H. Kalka

More Info:

Interim Technical Task Report 05 – EAP RU 06 – ITT05 (Task 5.1)
May 30, 2007

Modeling Radionuclide Transport

1	Model Concept
2	Mathematical Model
3	Software
4	Input Data
5	Basic Scenario Studies

EUROPEAID 121579/C/SV/RU: "Monitoring and Warning System for the Ob/Irtysh River Basin", Service Contract 99310, funded by the European Union

The Extraordinary Task

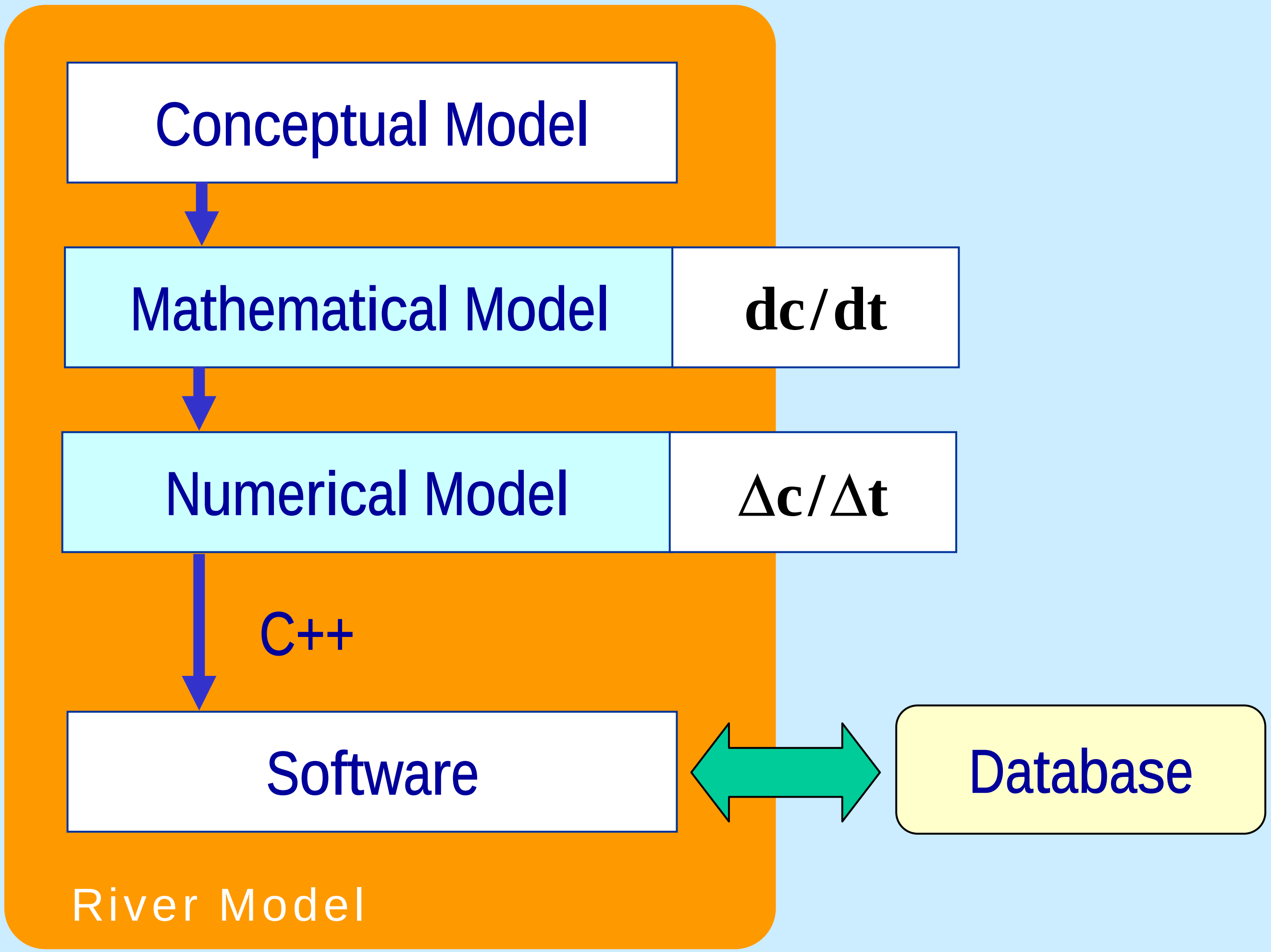
... requires a new approach.

River Basin

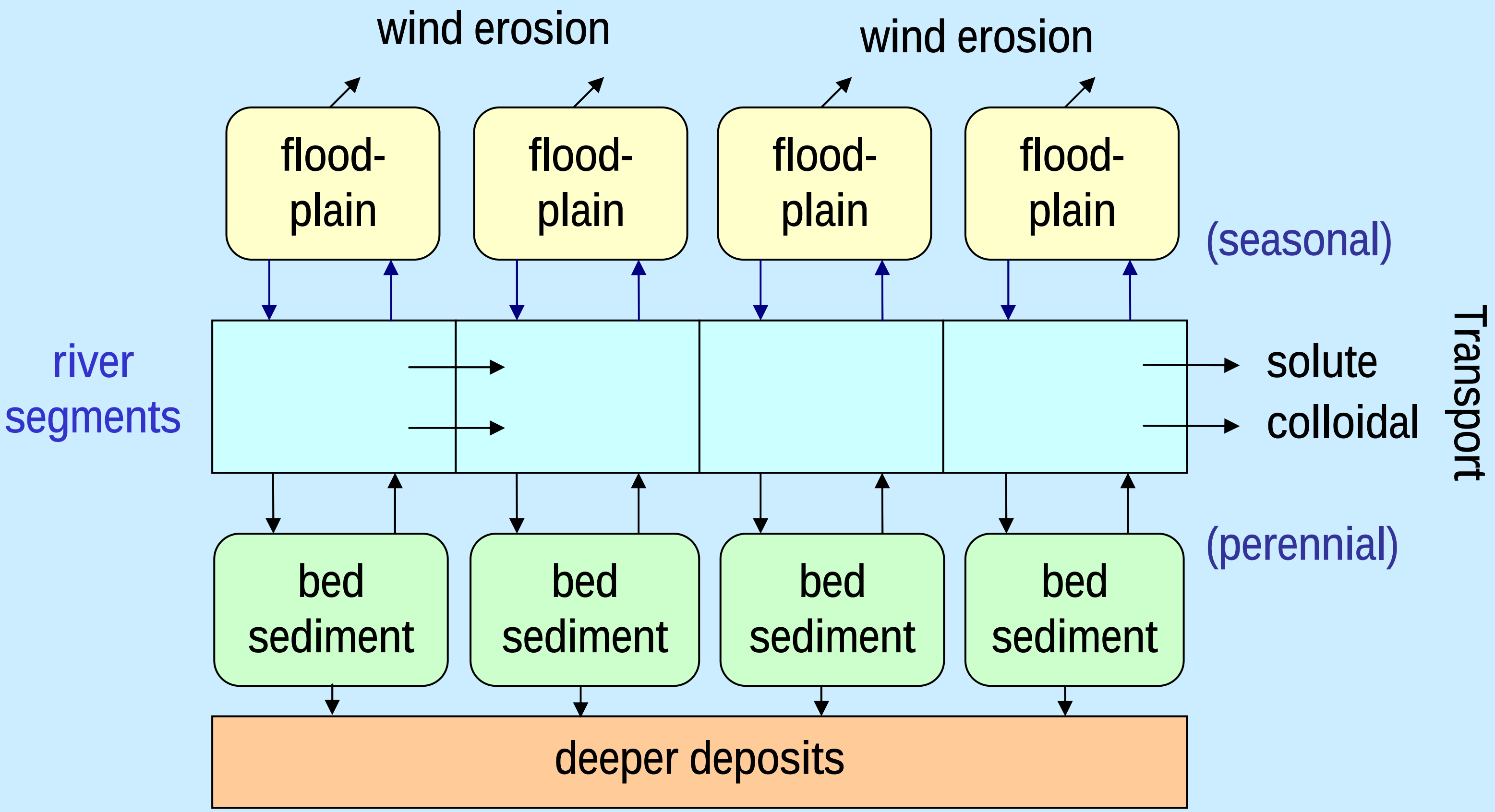
		Ob-Irtysh	Amazon
Drainage Basin Area	km^2	2 950 000	2 200 000
Mean Annual Discharge (MAD)	m^3/s	12 000	100 000
Flood Discharge	m^3/s	29 400	140 000
Reservoir Capacity	% of MAD	15	< 5

→ model space discretization

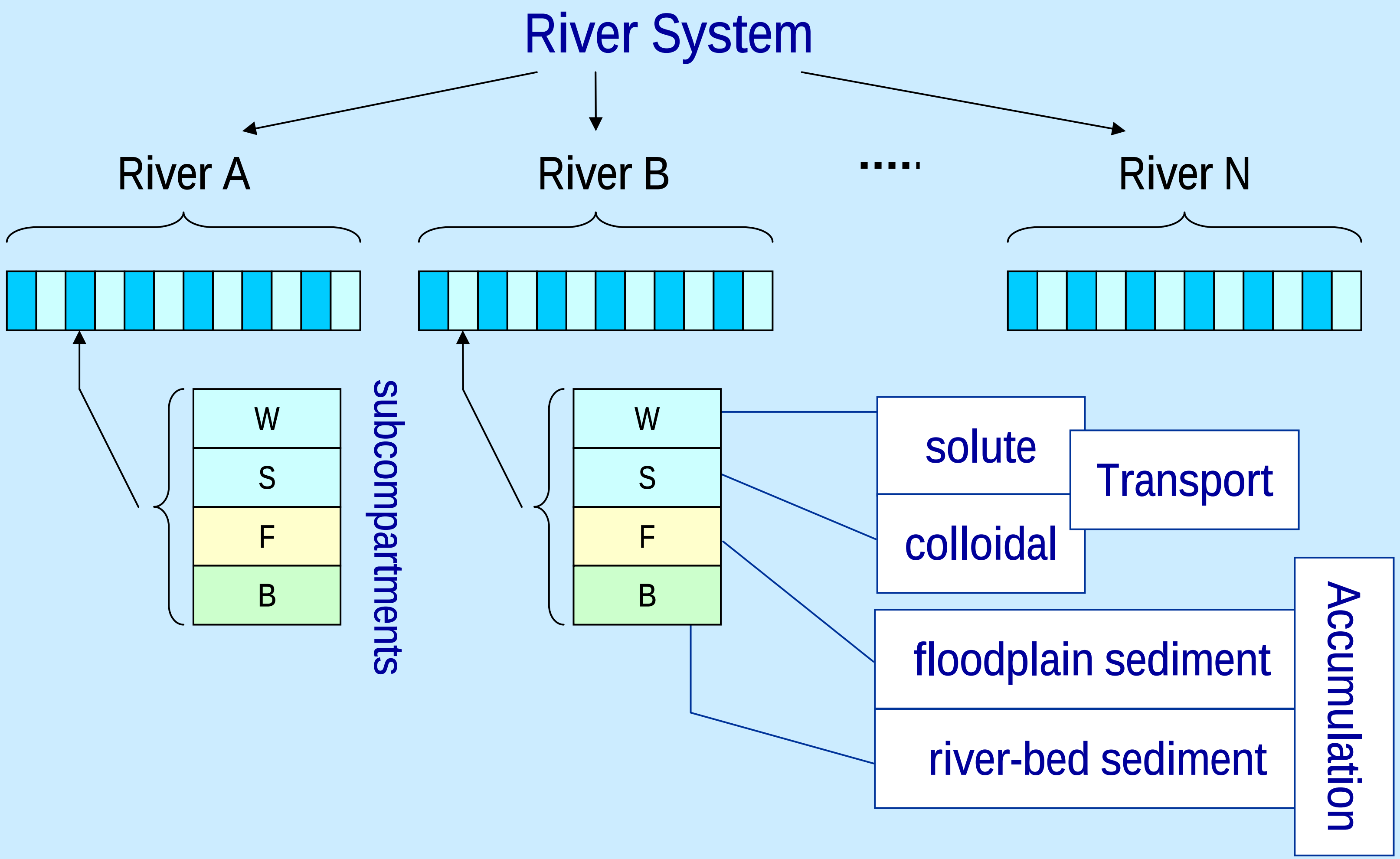
Modus Operandi



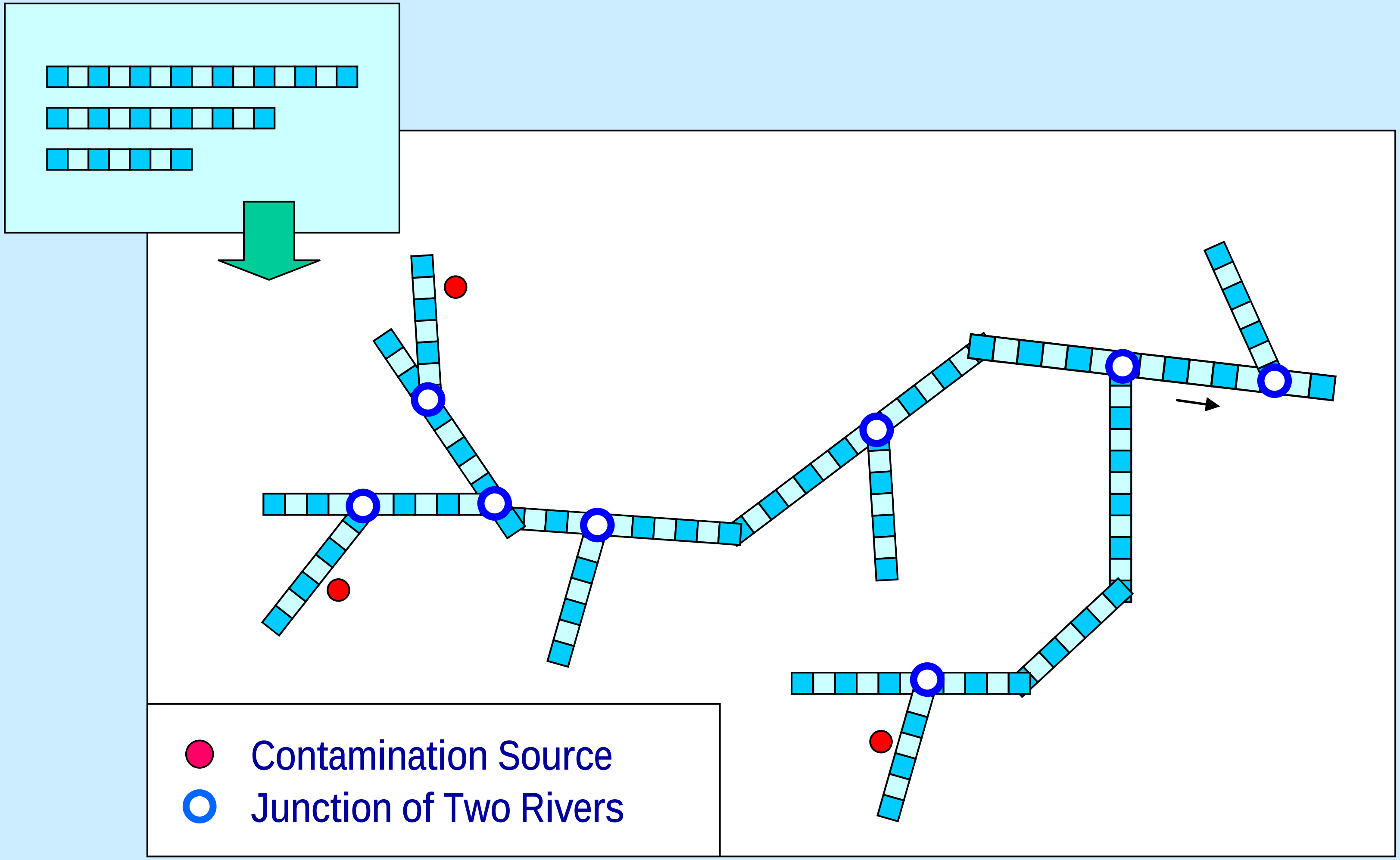
Radionuclide Transfer



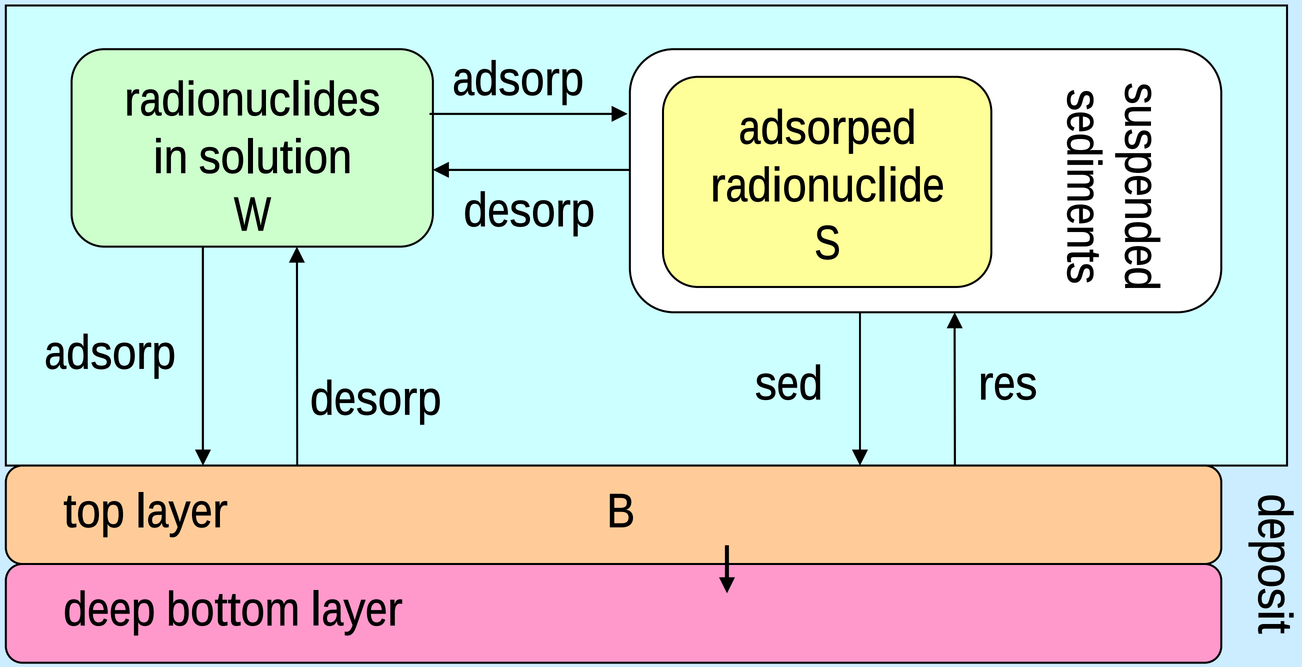
Compartment Structure I



Compartment Structure II



Radionuclide Transport



Mass & Concentrations

dissolved radionuclides	$M = CV_W$	Bq
radionuclides adsorbed on colloids	$M^S = C^S \cdot SV_W$	Bq
radionuclides in bed sediment	$M^B = C^B \cdot m^{sed}$	Bq
radionuclides in floodplains	$M^F = C^F \cdot m^F$	Bq

mass of suspended particles	$m^{sus} = SV_W$	kg
mass of top-layer bed sediment	$m^{sed} = \rho_S V_{sed}(1-\varepsilon)$	kg

→ **6 dynamical variables**

Submodels (SM)

Water Flow SM	→	**v , Q**
Sediment Transport SM	→	**S**
Radionuclide Transport SM	→	C , C^S , C^B
Inundation / Floodplain SM	→	C^F

Water Flow Submodel

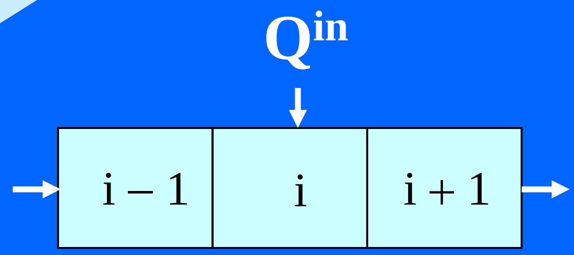
Mass Conservation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q^{in}$$

$$v = \frac{Q}{A}$$

Integration ($\Delta x \rightarrow i$)

$$Q_{i \rightarrow i+1} = Q_{i-1 \rightarrow i} + Q_i^{in}$$



Water Budget

Sediment Transport

dispersion

$$\frac{\partial S}{\partial t} + v\frac{\partial S}{\partial x} - \frac{1}{A}\frac{\partial}{\partial x}\left\{A D_S \frac{\partial S}{\partial x}\right\} = \frac{1}{h}(f_{\uparrow} - f_{\downarrow}) + \frac{q^{in}}{A}(S^{in} - S)$$

$$\frac{\partial m^{sed}}{\partial t} = -\frac{V_W}{h}(f_{\uparrow} - f_{\downarrow})$$

inflow

resuspension

sedimentation

Radionuclide Transport

dispersion

decay

solute

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial x} - \frac{1}{A}\frac{\partial}{\partial x}\left\{AD\frac{\partial C}{\partial x}\right\} = -\lambda C + \frac{q^{in}}{A}(C_{in} - C) - \Gamma_{ads} S$$

$$\frac{\partial C^S}{\partial t} + v\frac{\partial C^S}{\partial x} - \frac{1}{A}\frac{\partial}{\partial x}\left\{AD_S\frac{\partial C^S}{\partial x}\right\} = -\lambda C^S + \frac{q^{in} S^{in}}{AS}(C^S_{in} - C^S) + \Gamma_{ads} + \frac{1}{hS}(C^B - C^S)\, f_{\uparrow}$$

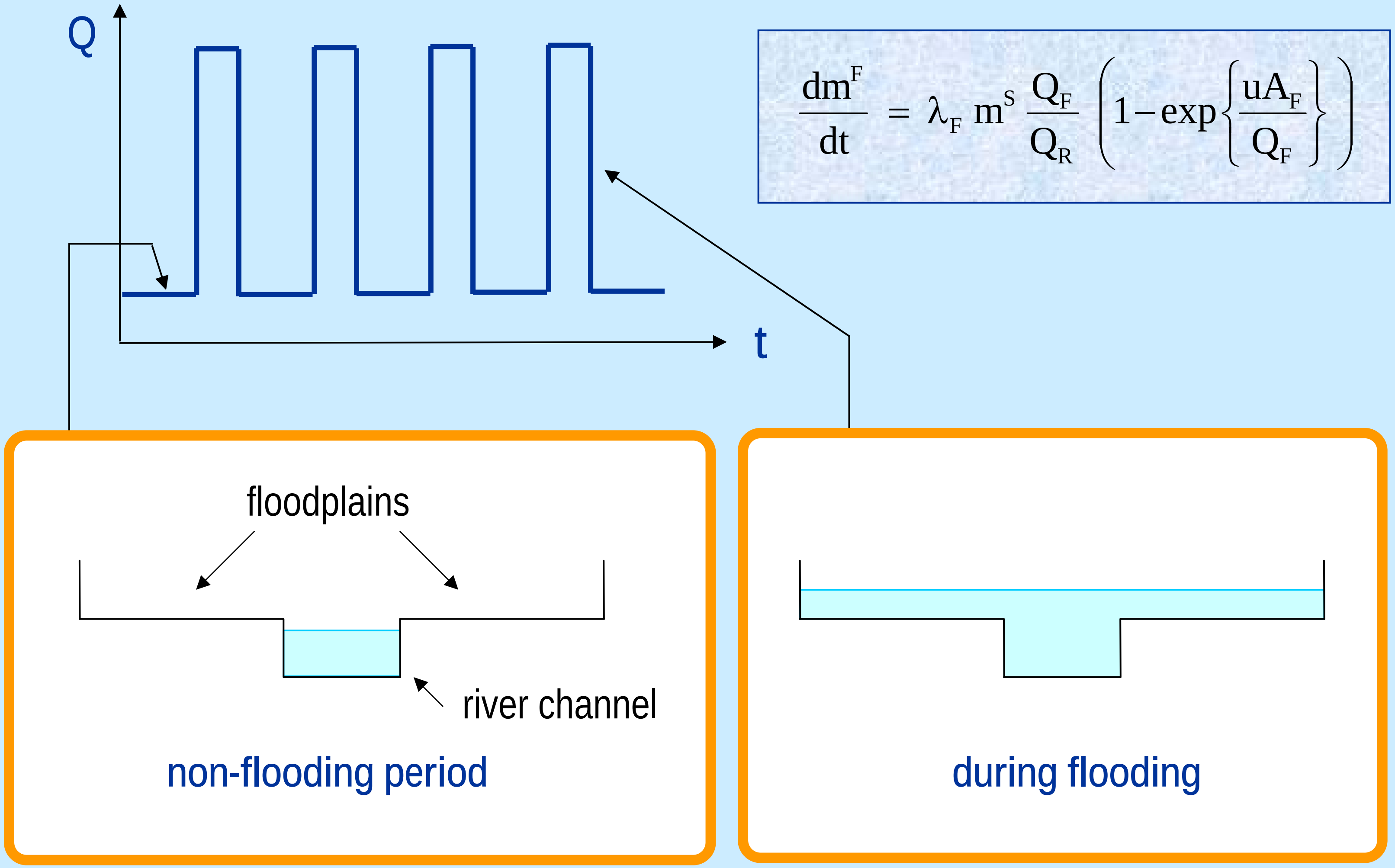
colloidal

advection

sources

Floodplains

$$\frac{dm^F}{dt} = \lambda_F \, m^S \, \frac{Q_F}{Q_R} \left(1 - \exp\left\{ \frac{uA_F}{Q_F} \right\} \right)$$



Software in C++

- Fast running model for scenario analysis
- Modular design (OOP)
- User-friendly graphical interface
- Online- and offline graphics
- interface to databases / warning systems

Generating Input Data

Model-Space Discretization

Geometrical / Global Data

Hydrological Data

Initial Concentrations (t = 0)

Radionuclide Sources

^{90}Sr ^{137}Cs

$j(t)$ in Bq/s

Geometrical Data

Segment length	**L**	m
Average channel width	**B**	m
Average water stage	**h**	m
Thickness of top-layer sediment	**Z**	m

Average sediment porosity	ε	m^3/m^3
Average particle density	ρ_S	kg/m^3

Average floodplain area	$\mathbf{A_F}$	m^2

Hydrological Data

Non-flooding period

Average lateral inflow	q^{in}	m²/s
Average inflow into 1st segment	$Q_{0 \to 1}$	m³/s
Initial colloid concentration	$S(t_0)$	kg/m³

Flooding period

Average flow	Q_F	m³/s
Average colloid concentration	S_F	kg/m³

Initial Concentrations ($t=t_0$)

Radionuclides (^{90}Sr, ^{137}Cs)

dissolved in river water	C	Bq/m^3
adsorbed on colloids	C^S	Bq/kg
in river-bed sediments (top layer)	C^B	Bq/kg
in floodplain sediments	C^F	Bq/kg

Model Validation / Calibration

1 Water Flow / Water Budget

- Non-Flooding
- Flooding Period

2 Radionuclide Transport & Accumulation

Basic Scenarios (Examples)

1. "historical" reconstruction of actual state
   - since t_0 = 1949
2. long-term behavior of current state
   - forecast without incidents
3. short-term after sudden natural events
   - flooding etc.
4. short-term after sudden incidents
   - failures of radionuclide reservoirs

Finally Remark

The success of modeling depends on ...

1. the proper implementation of the main processes within the numerical model
2. the quality of input data

↑ model calibration

complete time series of monitoring data