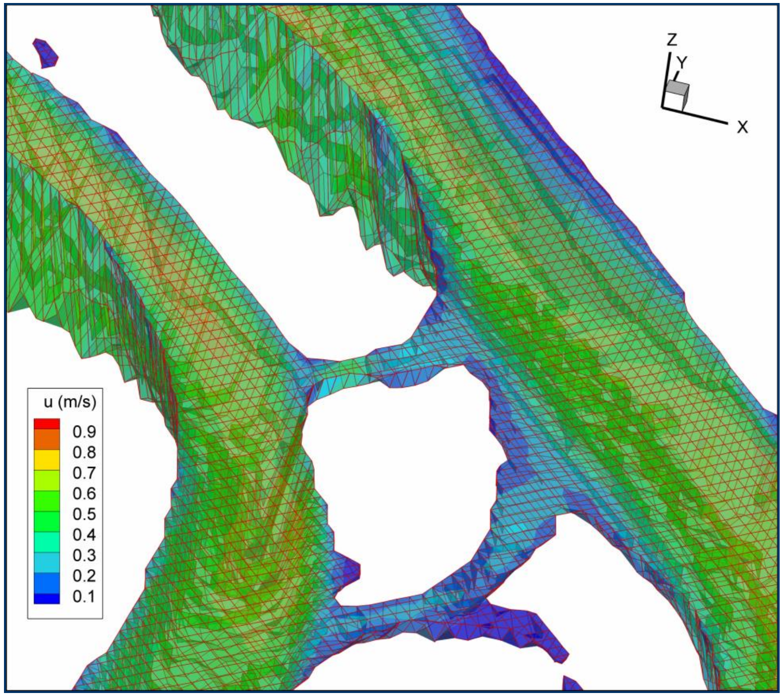
Modelling of flow and sediment transport in rivers and freshwater deltas

Foto: Fjellanger Widerøe AS ©



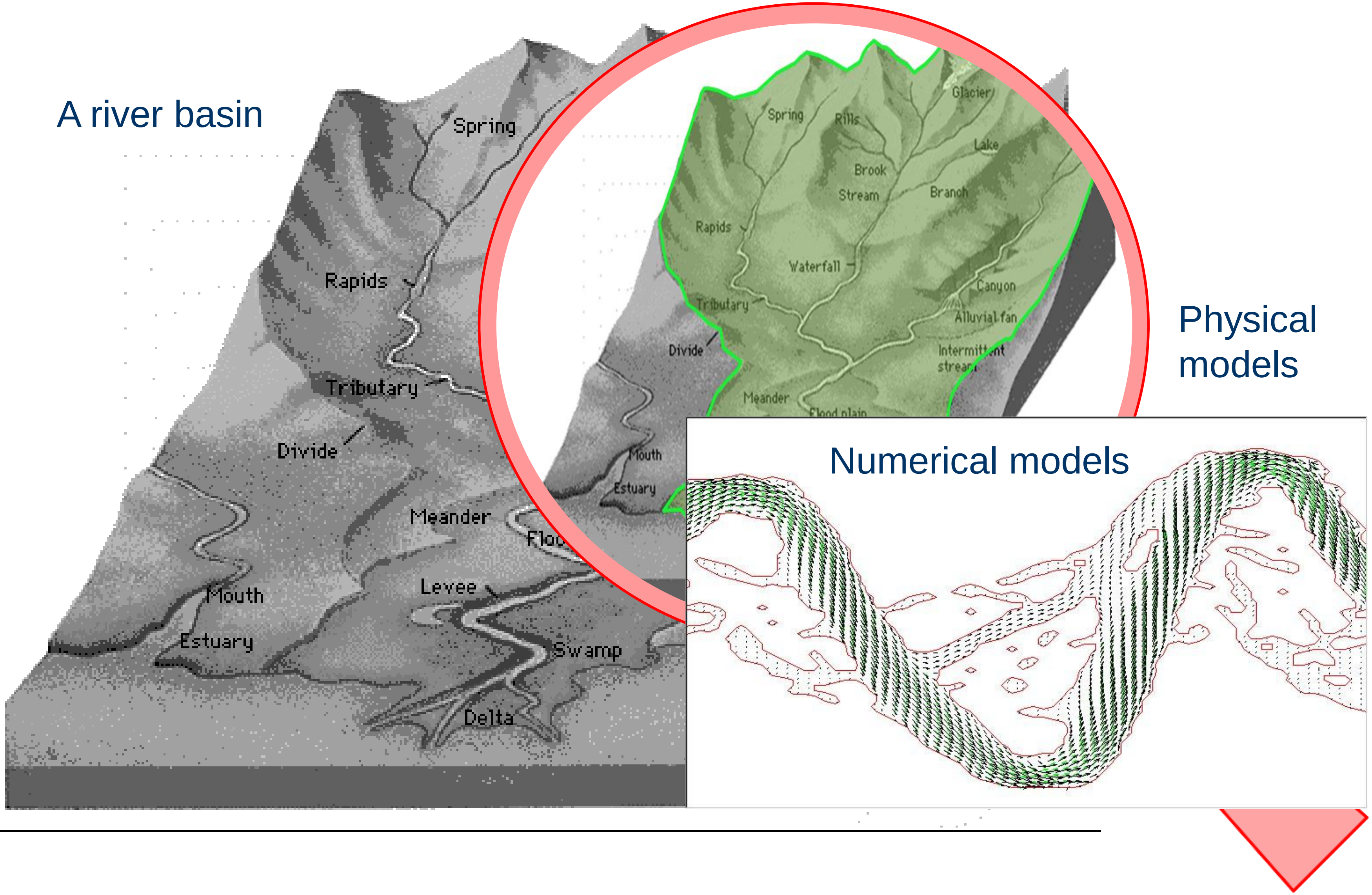
Peggy Zinke

with contributions from Norwegian and international project partners

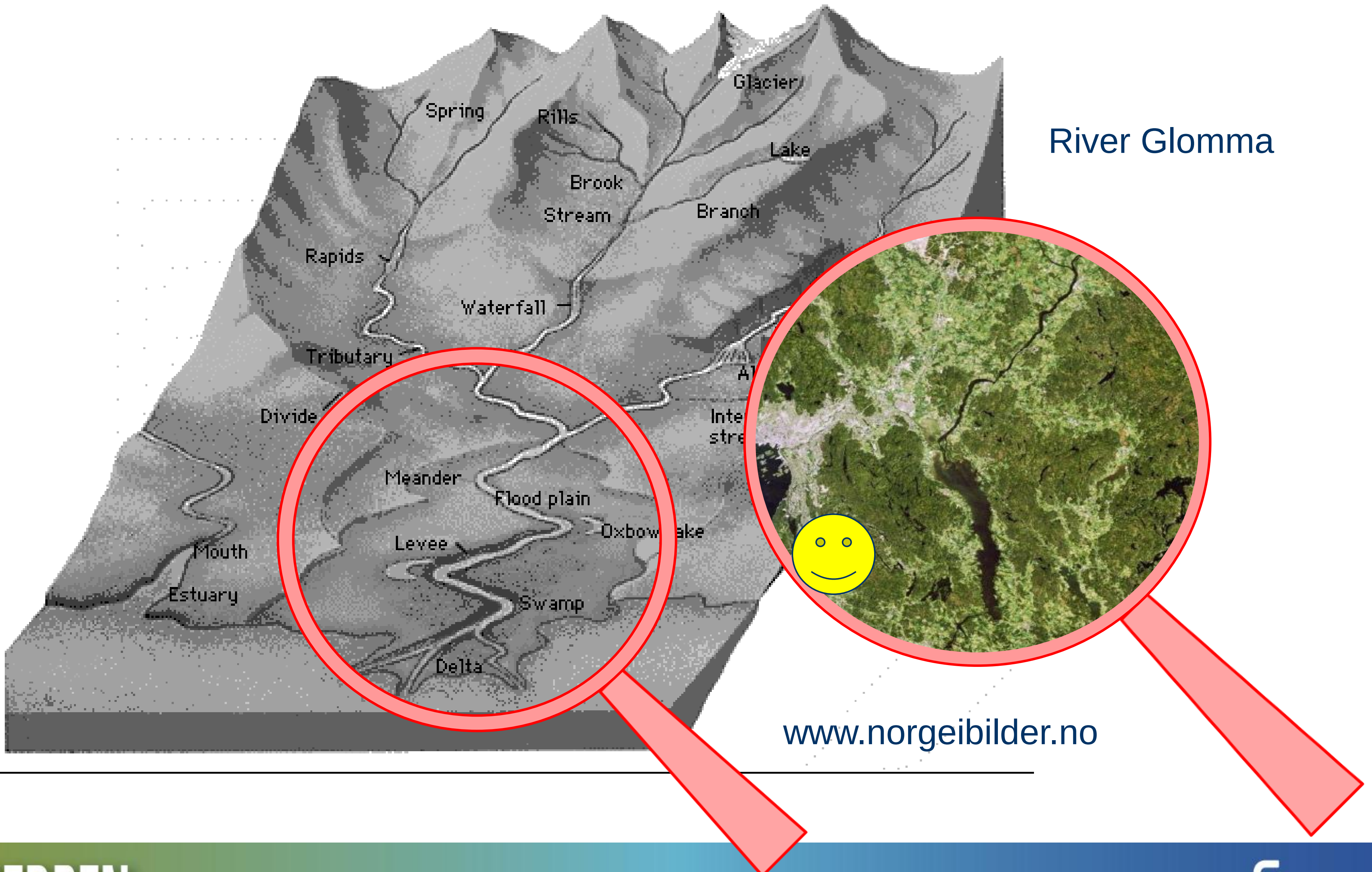
Outline

1. Introduction
2. Basic ideas of flow and sediment modelling in rivers
3. Some examples for flow and sediment models
4. RANS Modelling study for Lake Øyeren's delta
5. Short summary

Introduction



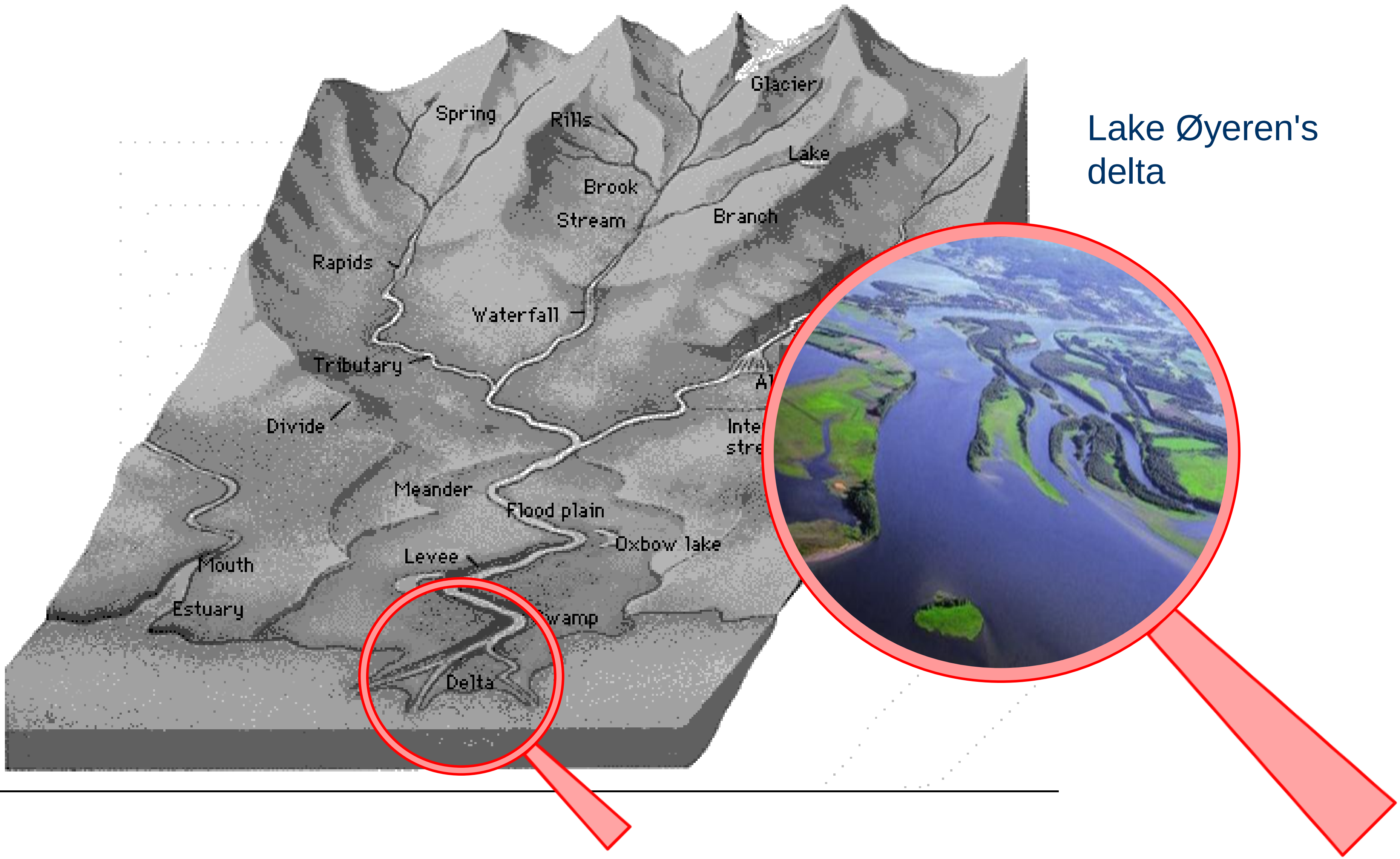
Introduction



River Glomma

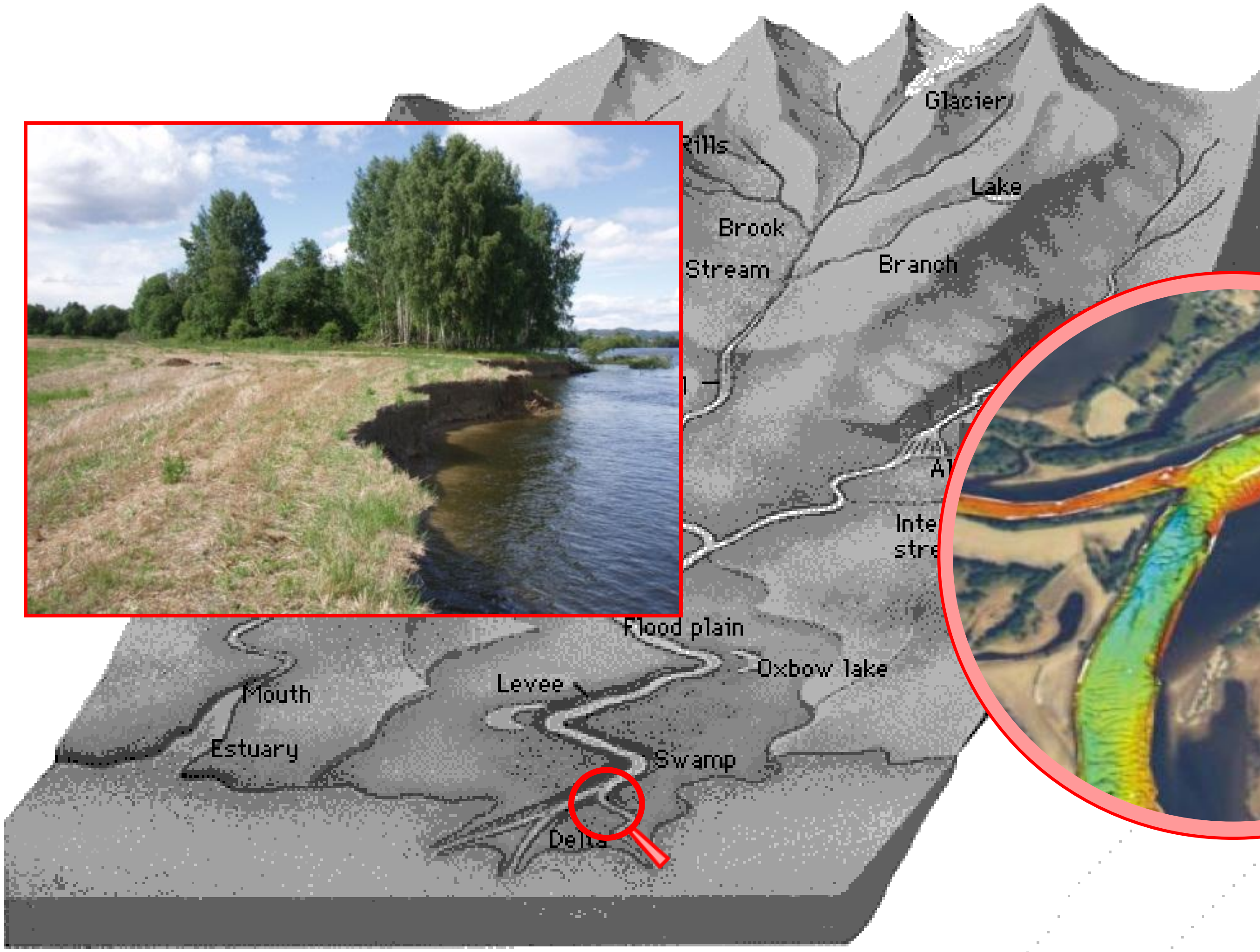
www.norgeibilder.no

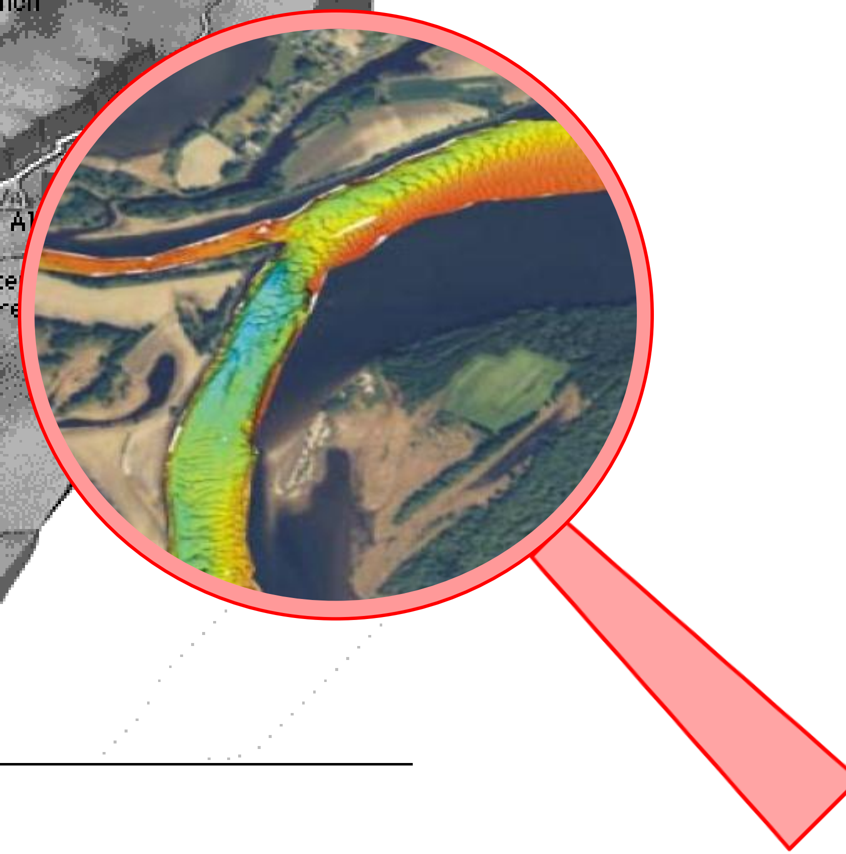
Introduction



Lake Øyeren's delta

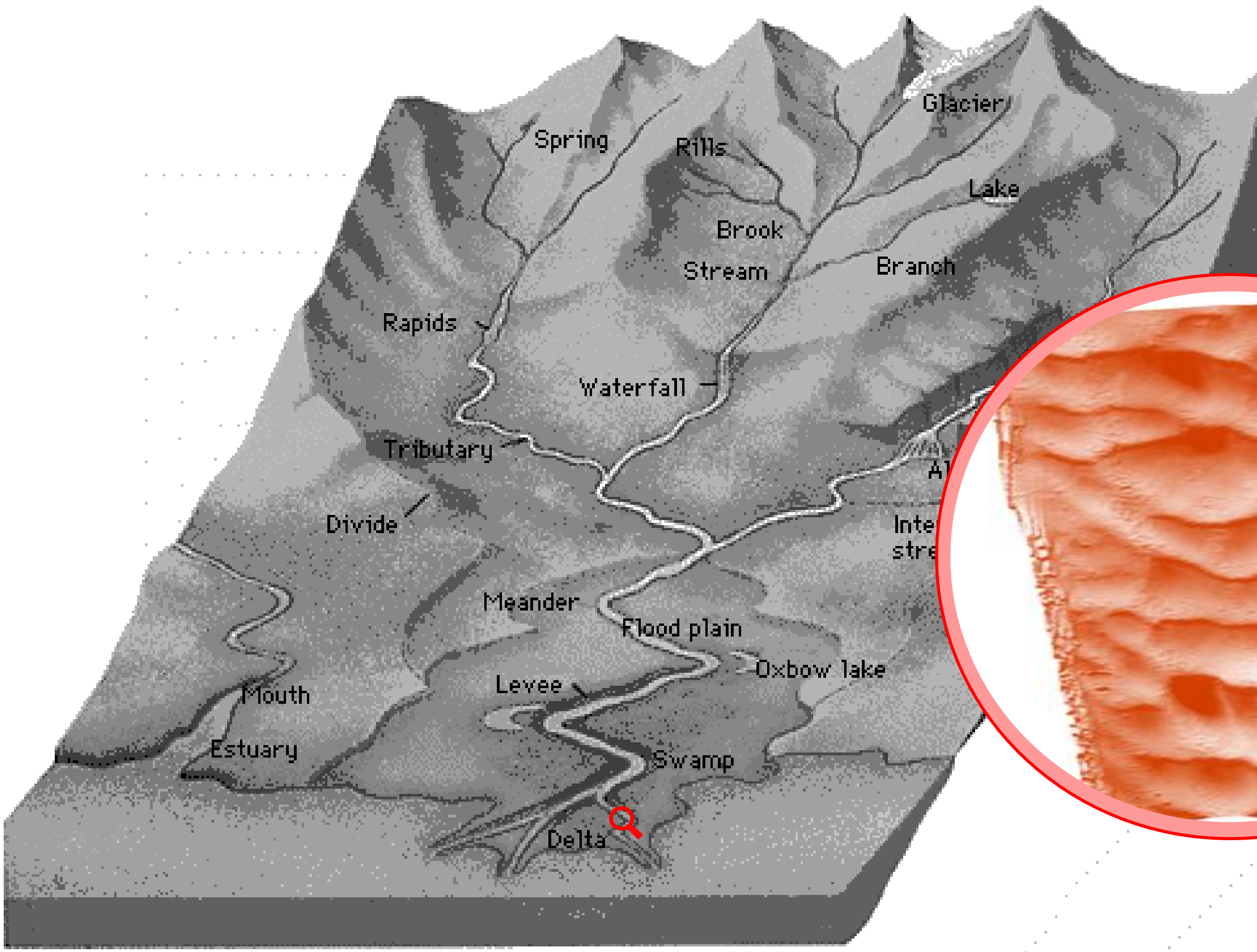
Introduction



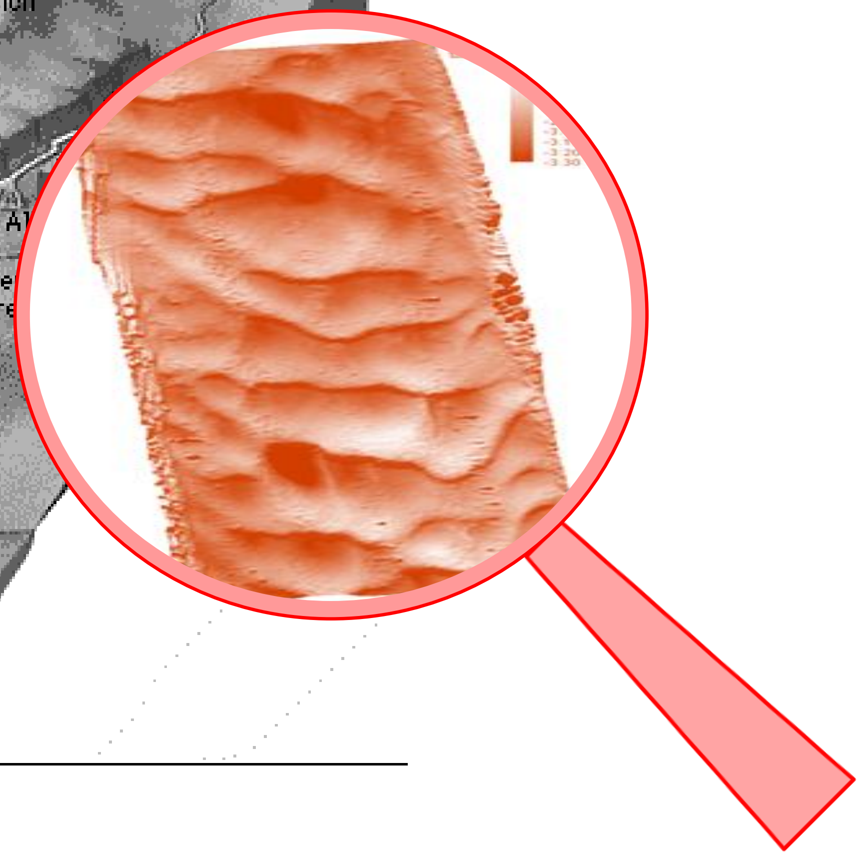


Single channels, bifurcations and confluences

Introduction



Bedforms of a sand-bed channel

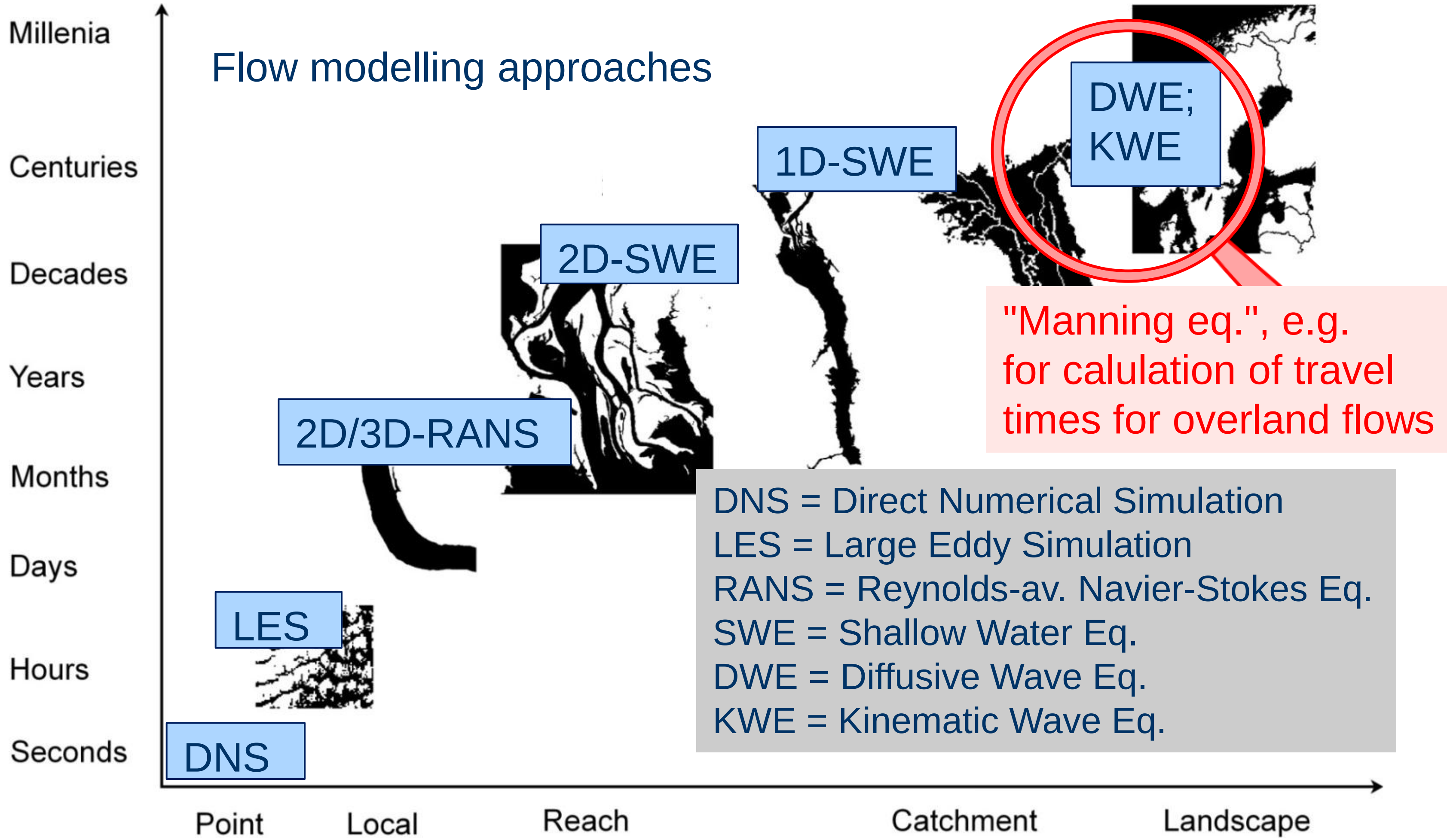


Computational effort & resolution requirements

Degree of averaging & simplification

Modelling of flow and sediment transport in rivers

2. Basic ideas of flow and sediment modelling



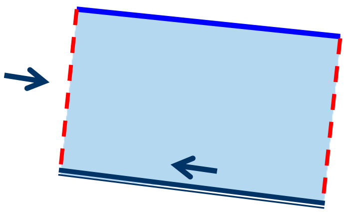
DNS = Direct Numerical Simulation
LES = Large Eddy Simulation
RANS = Reynolds-av. Navier-Stokes Eq.
SWE = Shallow Water Eq.
DWE = Diffusive Wave Eq.
KWE = Kinematic Wave Eq.

Hydraulic resistance =
the pressure (head) loss per flow rate
because of energy dissipation

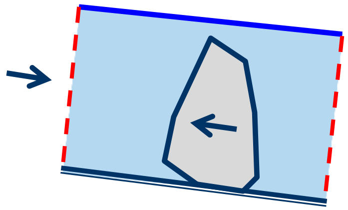
Classical division into two compounds:

Hydraulic resistance

Friction resistance + Form resistance

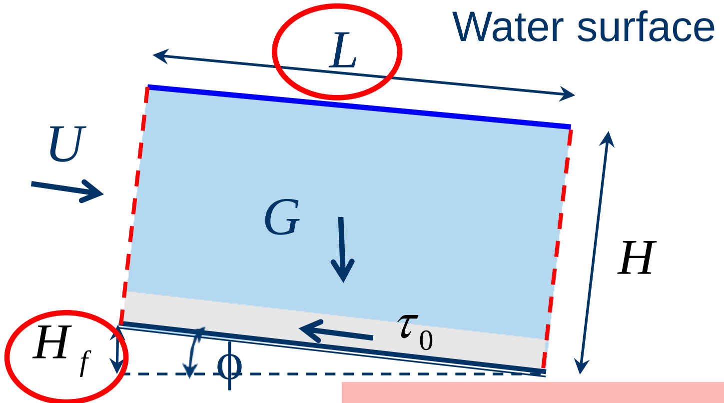


Shear forces
(act tangentially
over the surface)



Pressure forces
(act normally over the
surface of the body)

The most simple model:



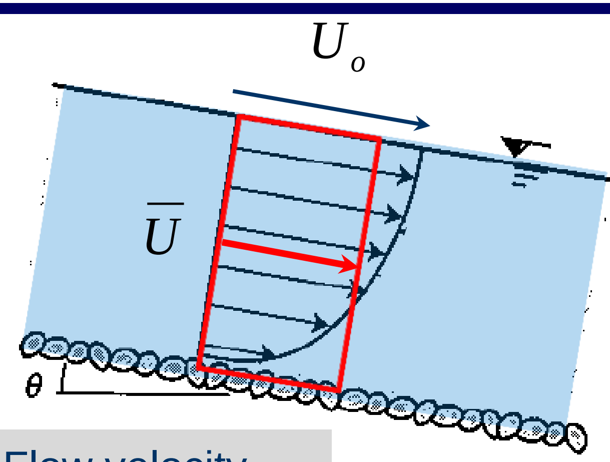
"Bed shear stress"

Gravity force component = Shear force on the river bed

Basic ideas of flow and sediment modelling

$$\tau_0 \propto U^2$$ For rough turbulent flow

Skin friction coefficient C_f = the bed shear stress normalized by a reference velocity, e.g. bulk velocity $\overline{U}$



$$C_f = \frac{\tau_0}{\frac{1}{2}\rho\overline{U}^2}$$

$$\tau_0 = R \cdot \rho \cdot g \cdot S$$ "Bed shear stress"

$$\overline{U} = \sqrt{\frac{R \cdot \rho \cdot g \cdot S}{C_f \frac{1}{2}\rho}} = \sqrt{\frac{2g}{C_f}}\sqrt{R \cdot S} = C\sqrt{R \cdot S}$$

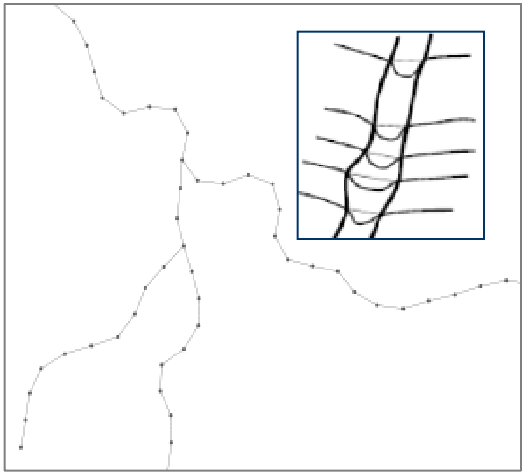
U = Flow velocity
R = Hydraulic radius
S = Slope

Chezy	Manning	Strickler	Darcy-Weisbach
$U = C\sqrt{RS}$	$U = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$	$U = k_{ST} R^{\frac{2}{3}} S^{\frac{1}{2}}$	$U = \sqrt{\frac{1}{\lambda} 8gRS}$
C = Chezy coefficient	n = Manning coefficient	k_{ST} = Strickler coefficient	λ = Darcy-Weisbach friction factor

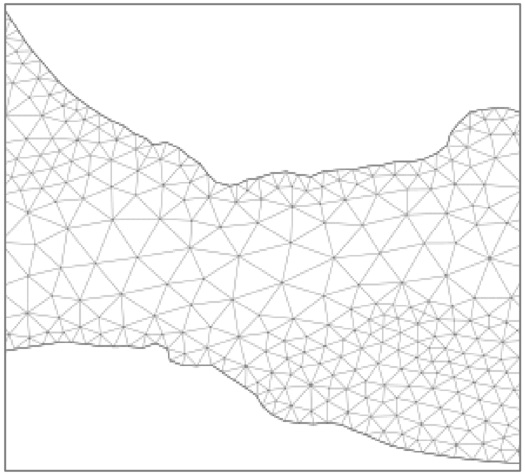
For steady uniform flow!!!

Overall resistance values; Friction factors

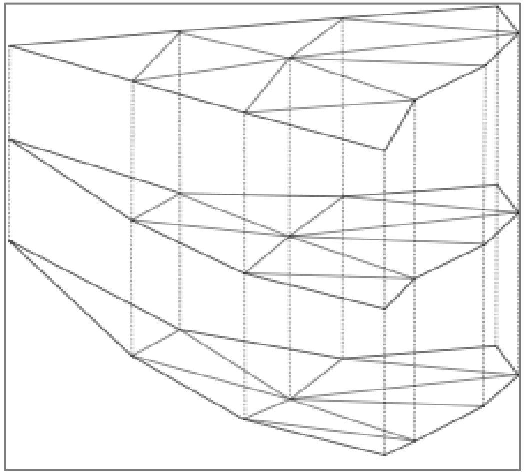
1D, 2D and 3D hydrodynamic models



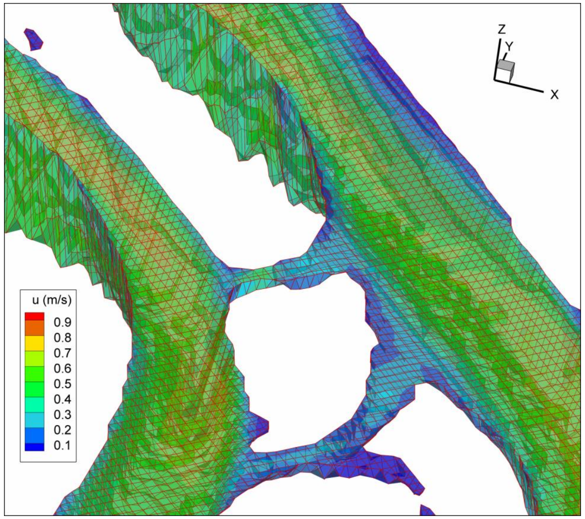
a) 1D mesh



b) 2D mesh



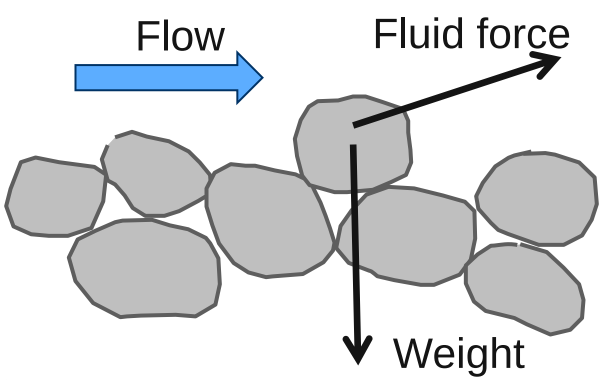
c) 3D mesh

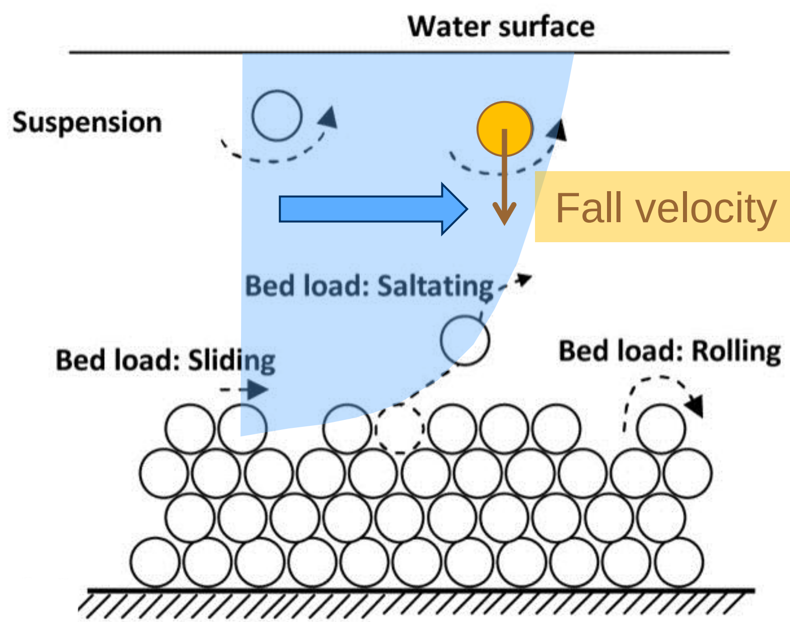


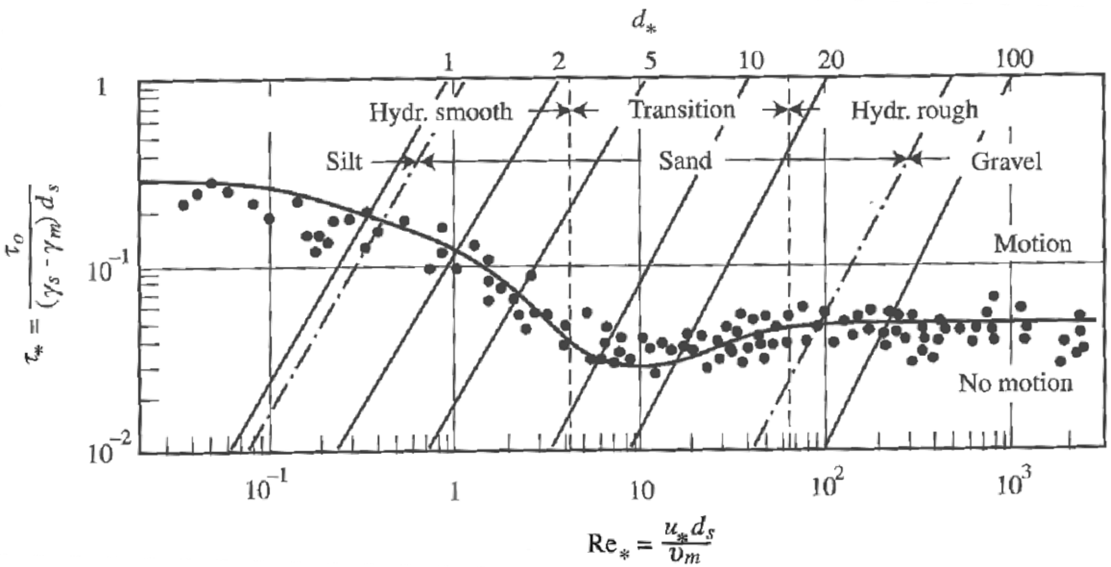
Computation of average flow parameters

a) Over the cross-section (1D)
b) Over the vertical, per model cell (2D)
c) Per model cell (3D)

Sediment modelling







Particle in suspension = when the flow velocity exceeds the fall velocity

Begin of sediment transport (erosion) = when the bed shear stress exceeds a critical Shield's stress

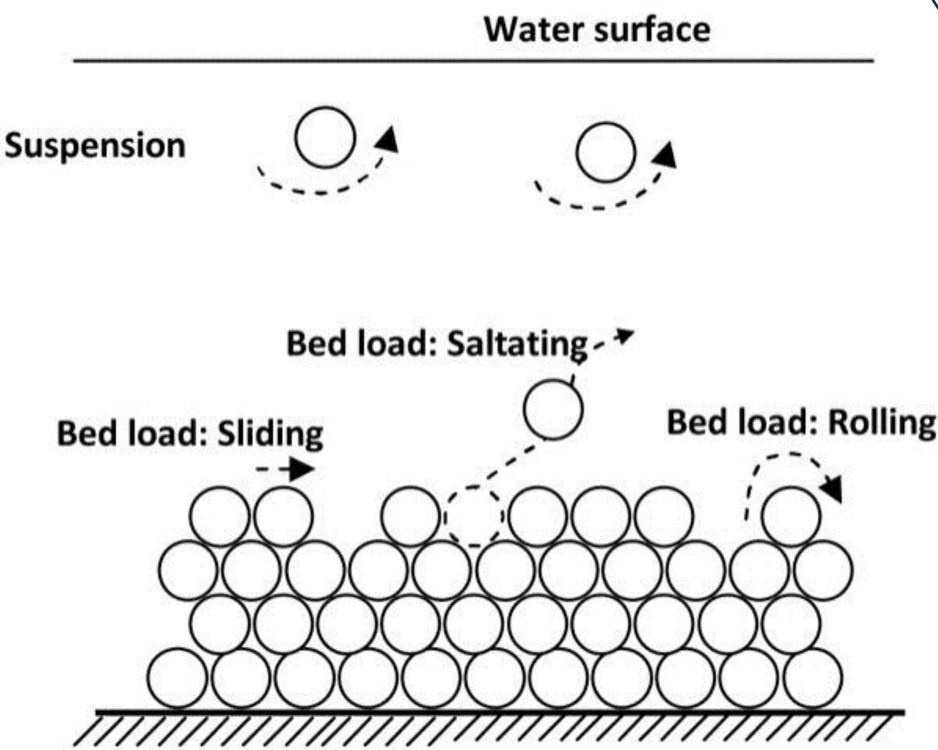
Basic ideas of flow and sediment modelling

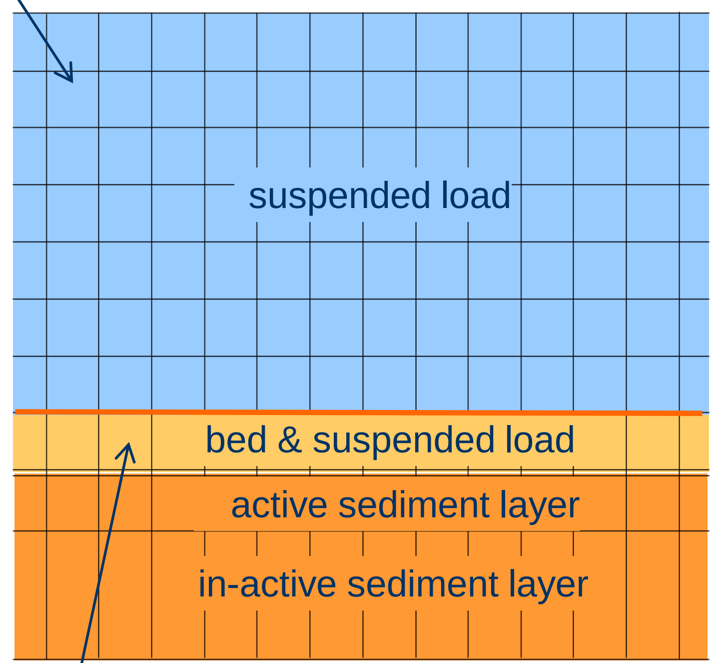
c = Sediment concentration
Γ = Diffusion coefficient

Convection-diffusion equation for suspended sediment:

$$\frac{\partial c}{\partial t} + U_j \frac{\partial c}{\partial x_j} + w \frac{\partial c}{\partial x} = \frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial c}{\partial x_j}\right)$$

Fall velocity



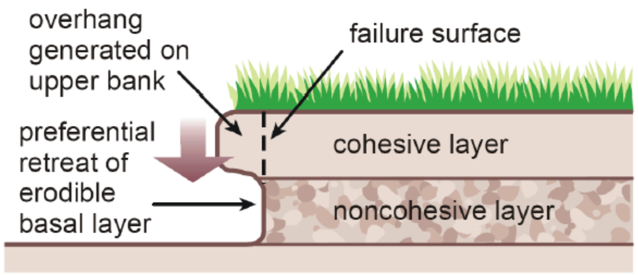


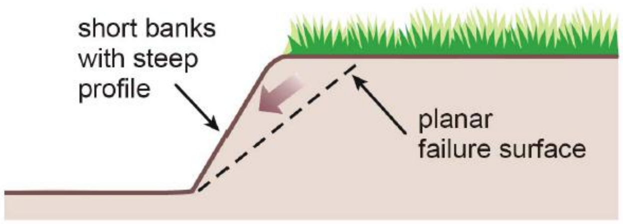
Empirical formula (Van Rijn) for the equilibrium sediment concentration close to the bed

$$c_a = 0.015 \frac{D_{50}}{a} \frac{T^{1.5}}{D_*^{0.3}}$$

Sediment processes:

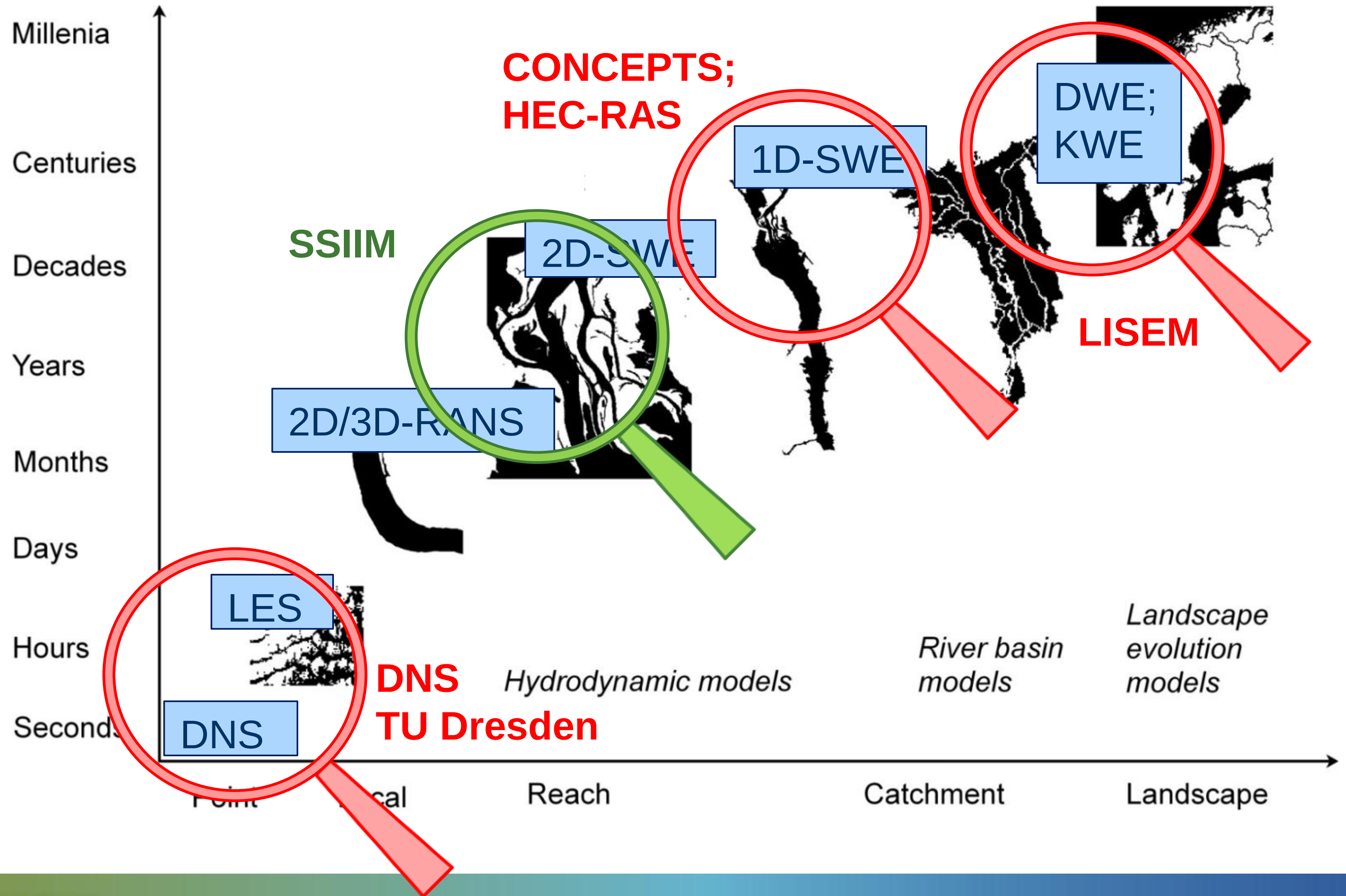
- Much less understood
- Many different approaches, often based on empirical formulas
- Large differences between sand-bed rivers and gravel-bed rivers
- High uncertainties



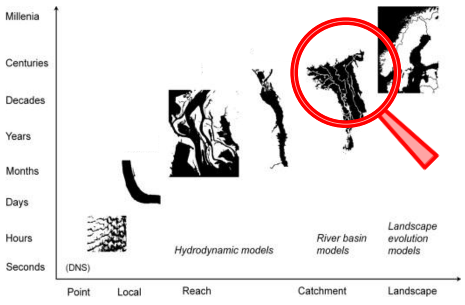


- Sediment transport functions
- Cohesion / coagulation of fine sediments
- Interaction between grain sizes (Hiding-exposure, sorting ….)
- Bank failure
- ……

3. Some examples for flow and sediment models

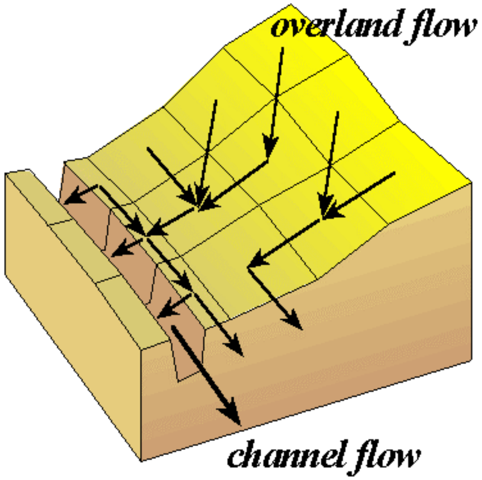


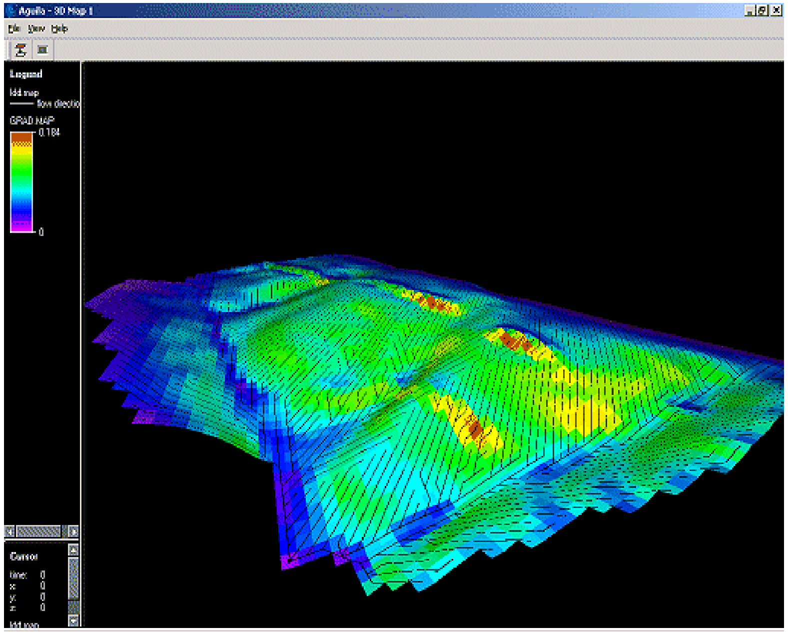
Model examples



LISEM

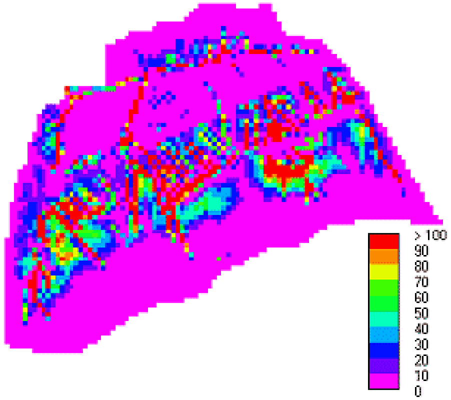
Overland and channel flow routing: Manning's eq. + Kinematic wave



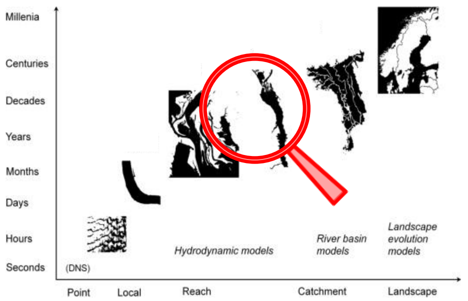


The net sediment in suspension is transported between gridcells with the kinematic wave.

Output: Erosion and deposition maps

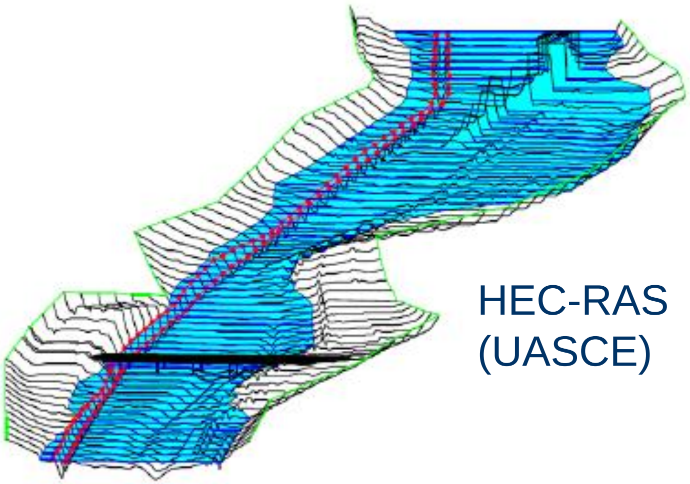


Model examples

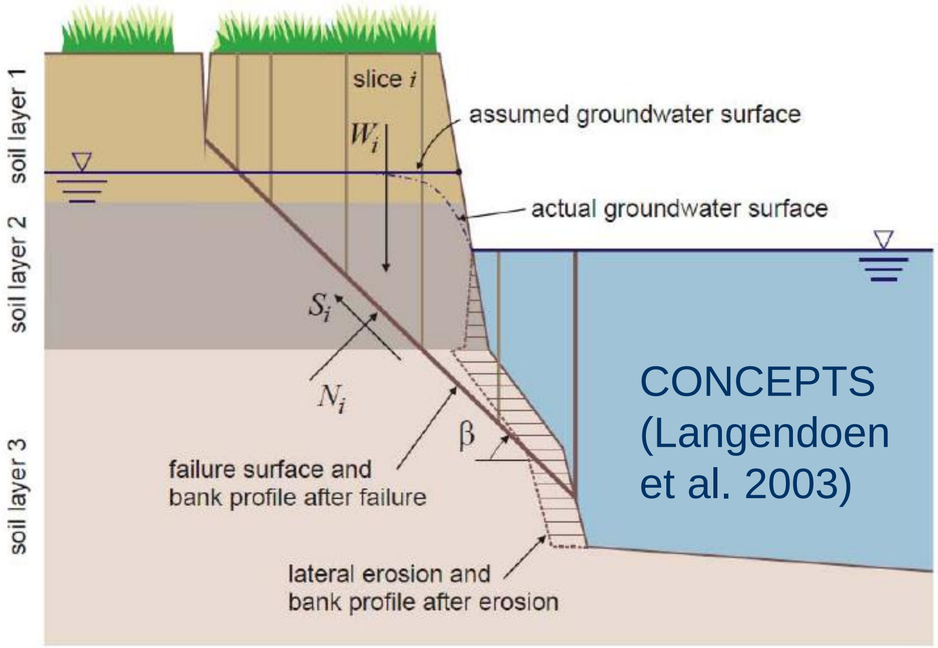


1D Models

Examples for unsteady 1D flow models with sediment transport

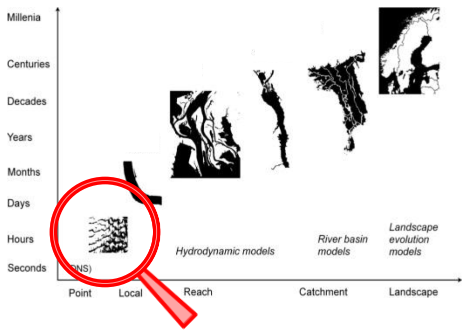


HEC-RAS (UASCE)

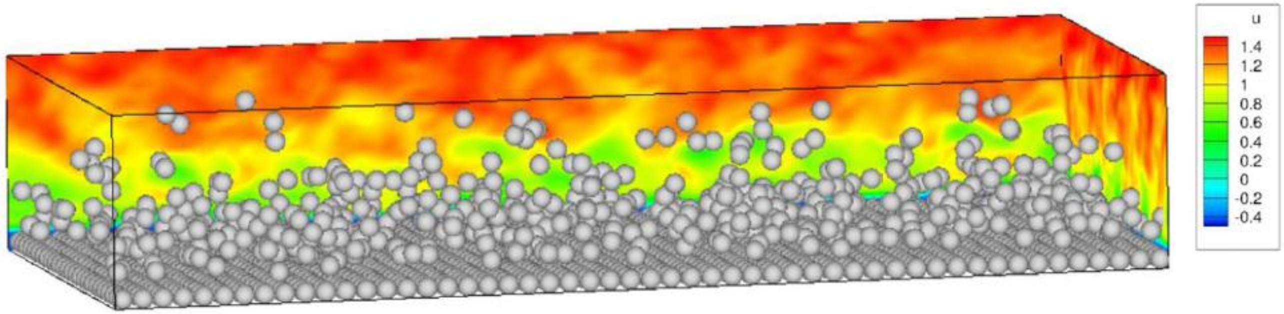


CONCEPTS (Langendoen et al. 2003)

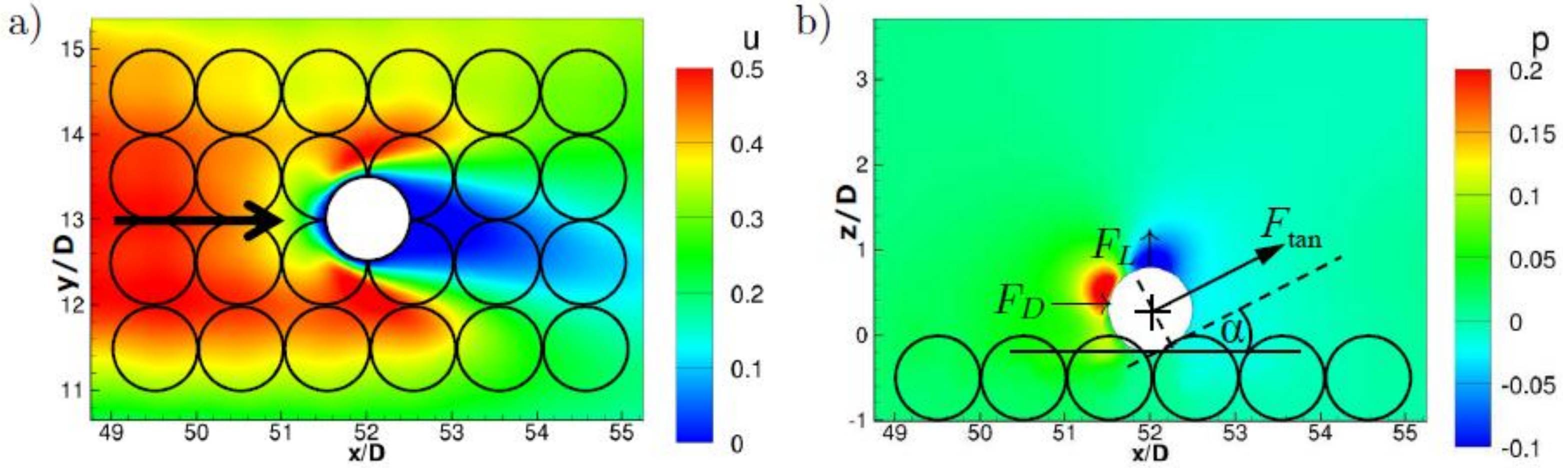
Sediment modelling feature	HEC-RAS 6	CON-CEPTS
Several grain sizes	x	x
Tracking bed changes	x	x
Susp. & bed load	x	x
Cohesive and non-cohesive sed.	x	x
Sorting & Armoring	x	?
Stream bank failure		x



Direct Numerical Simulation (DNS)

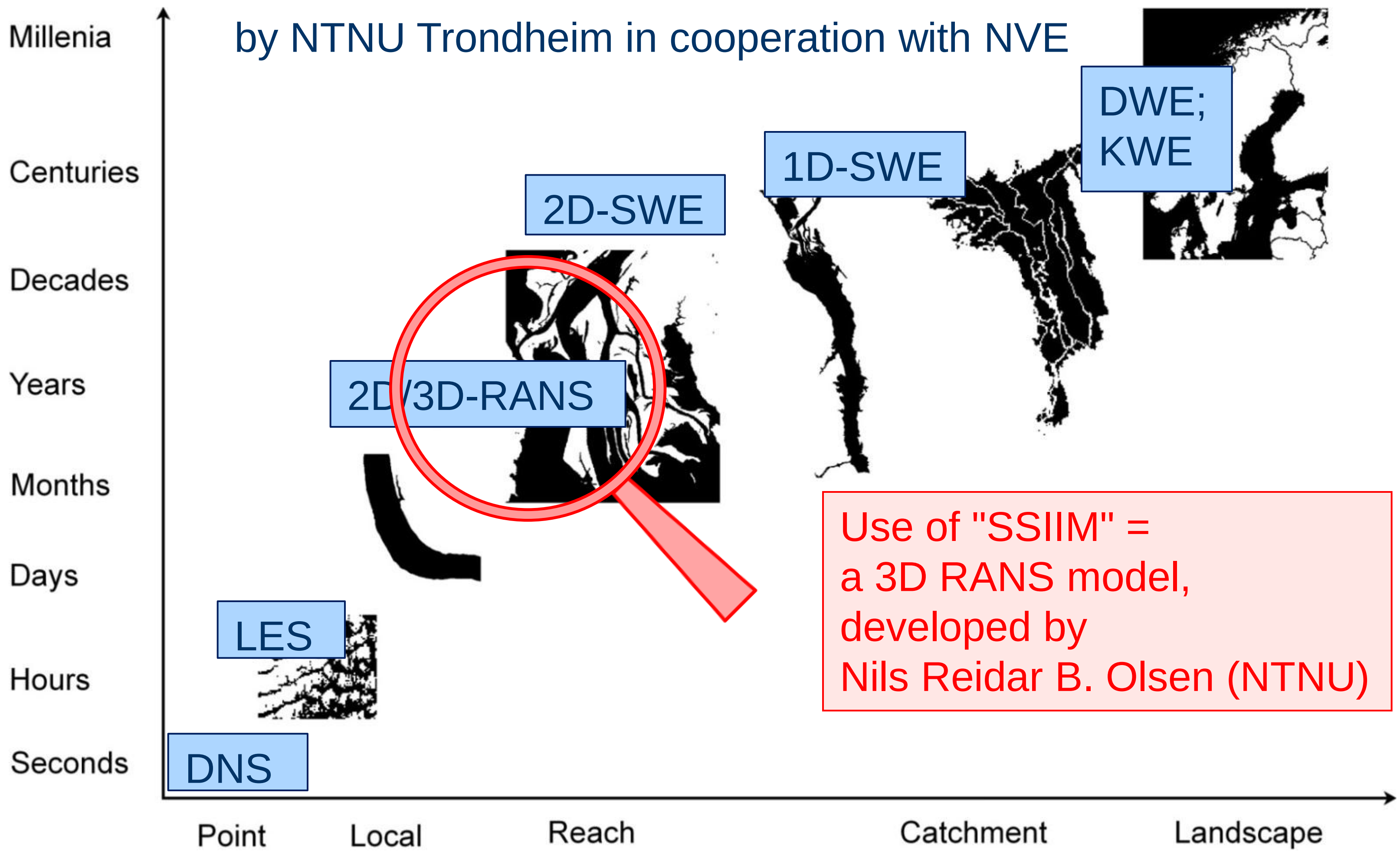


Herwig et al. 2011; Vowinkel et al. 2011



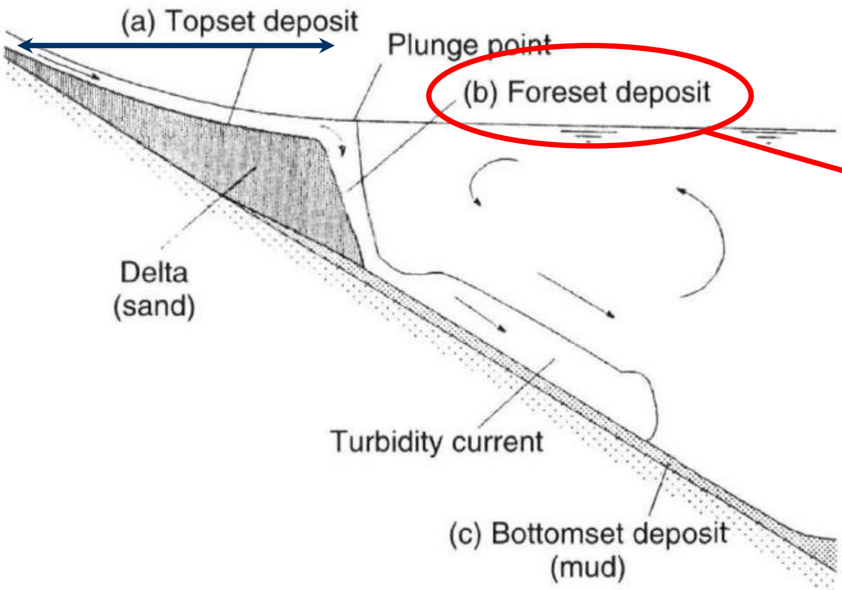
Resolving the flow field around each single particle;
Each grain is directly moved by the calculated flow forces

4. RANS Modelling study for Lake Øyeren's delta

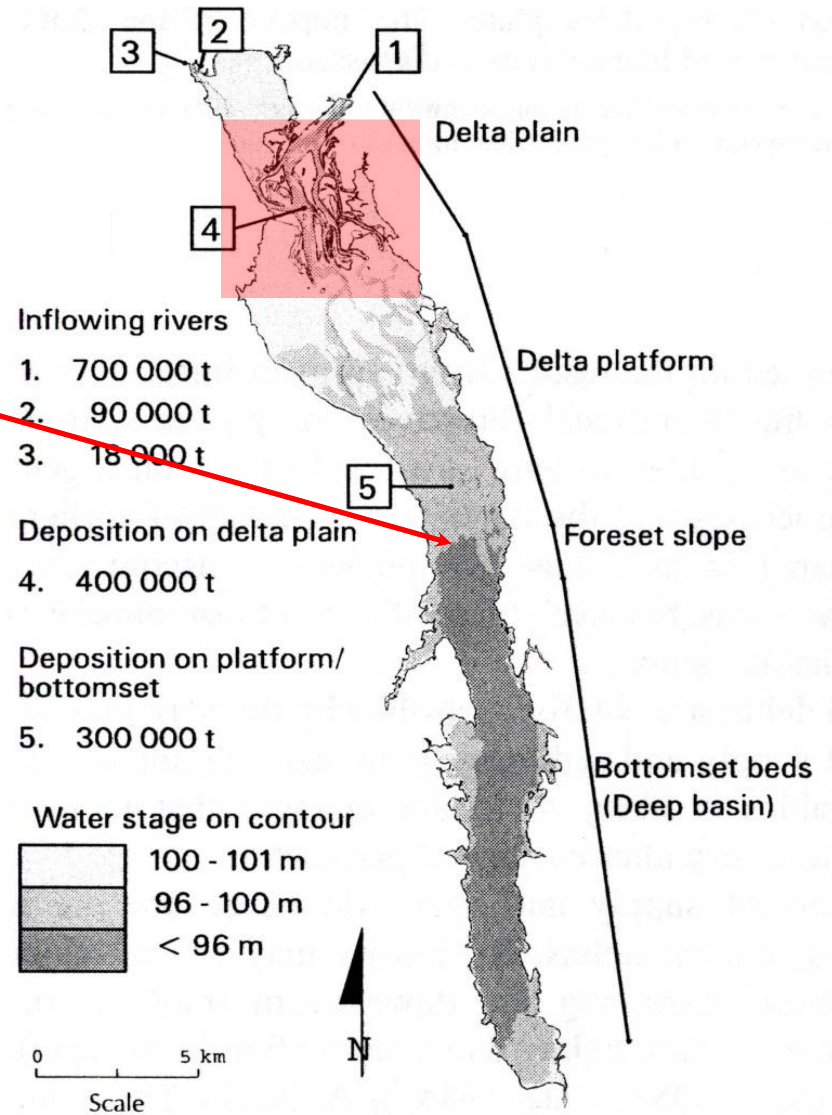


Morphological features of the delta

Delta plain and platform



Structure of a deltaic deposit
in a lake or reservoir (Kostic & Parker 2003)



Bogen & Bønsnes (2002)

In this work, we investigated only processes on the delta plain!

4. RANS Modelling study for Lake Øyeren's delta

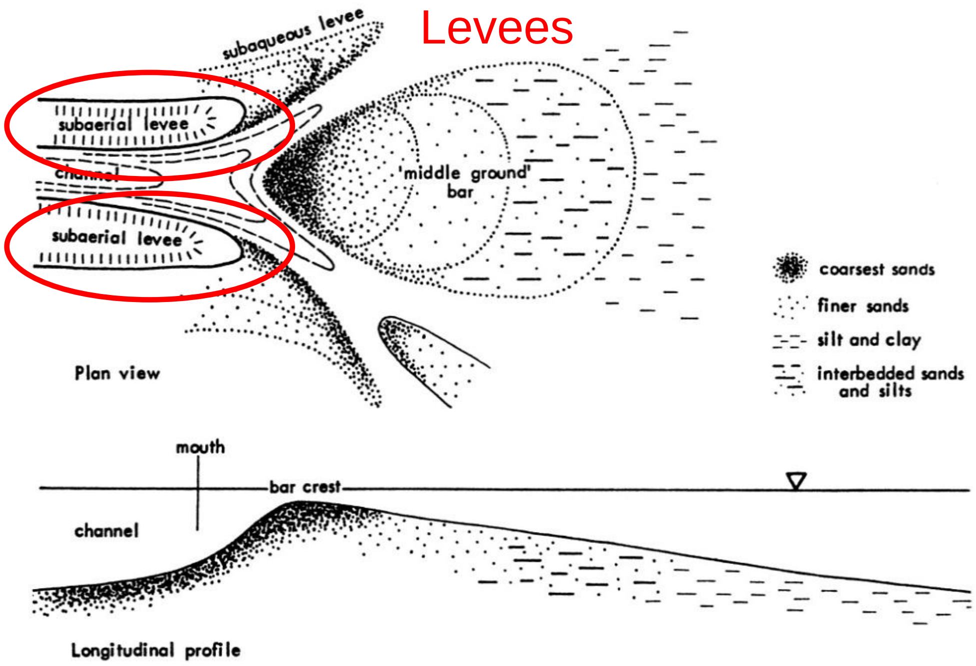
Foto: Fjellanger Wideroe AS ©

Under mean conditions

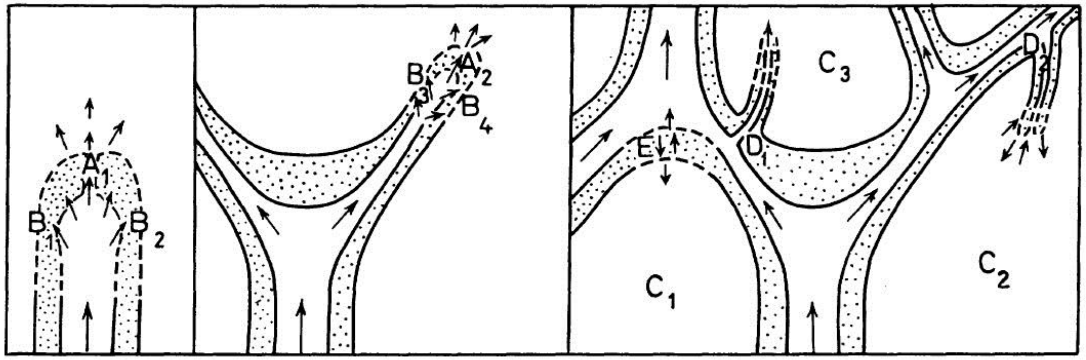
During the 1995 flood

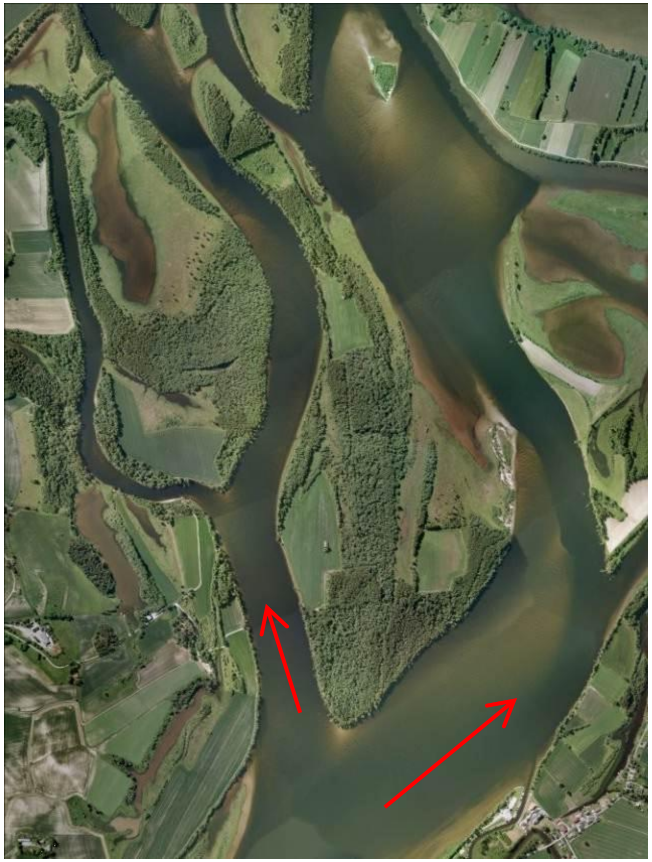
During the winter lowering

4. RANS Modelling study for Lake Øyeren's delta



Morphological processes on the delta plain





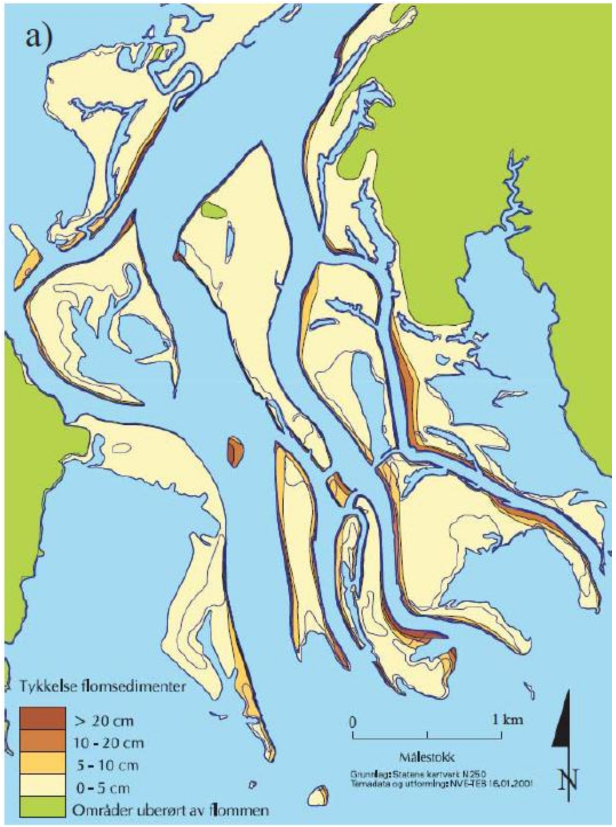
Levee deposition = an important process for delta formation and development

4. RANS Modelling study for Lake Øyeren's delta

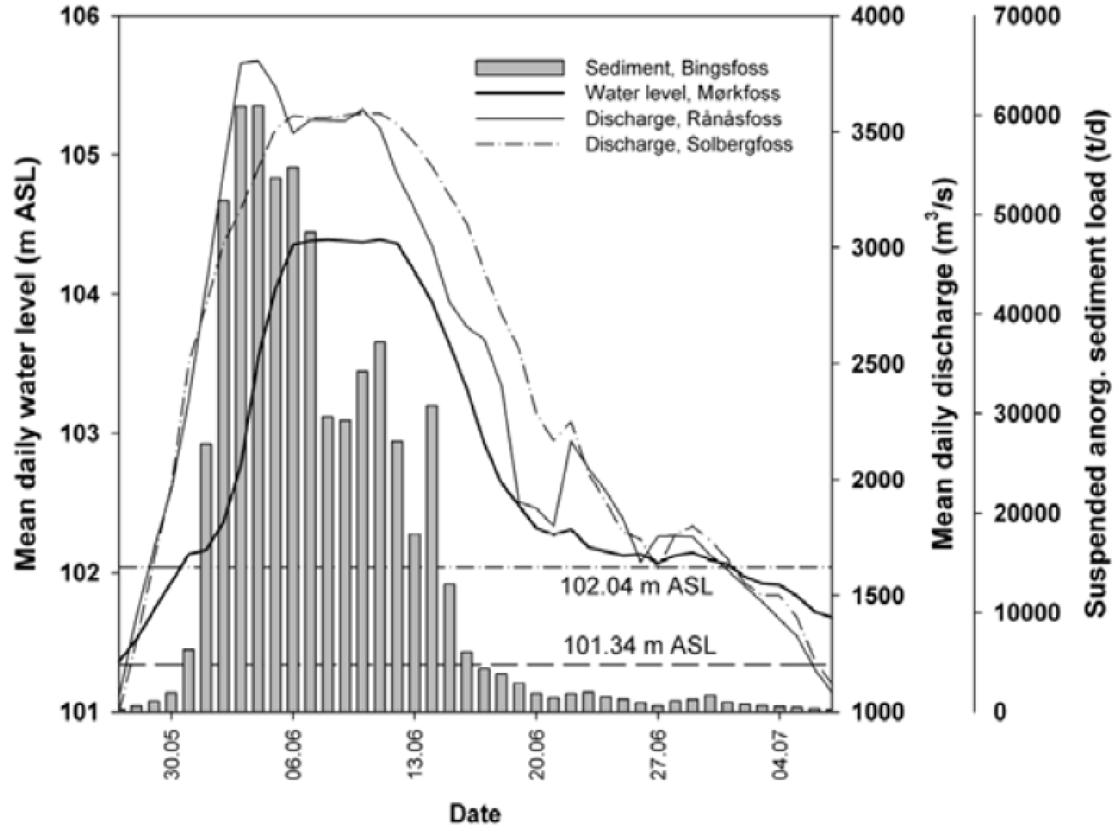
Sediments deposited by the flood 1995

Øyeren's delta, 6. Juni 1995
(Water level 104,35 m a.s.l.)

4. RANS Modelling study for Lake Øyeren's delta



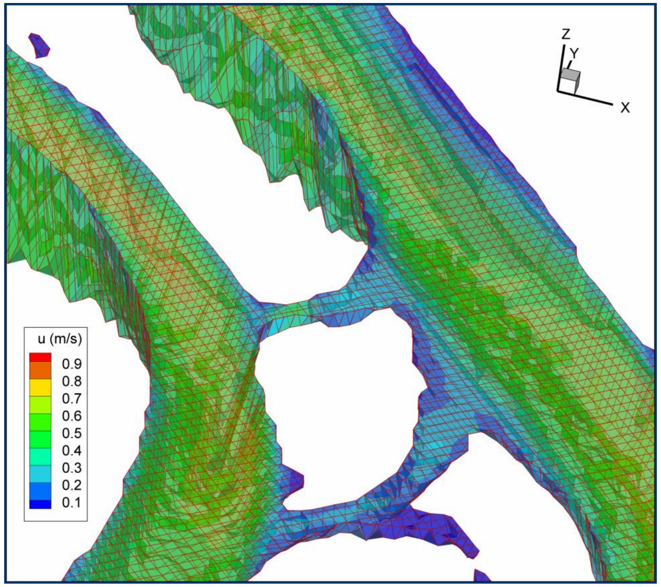
Sedimentation heights 1995 (Bogen et al. 2002)



Water and sediment time curves during the 1995 flood (NVE Database)

How good can we model the levee depositions of 1995?

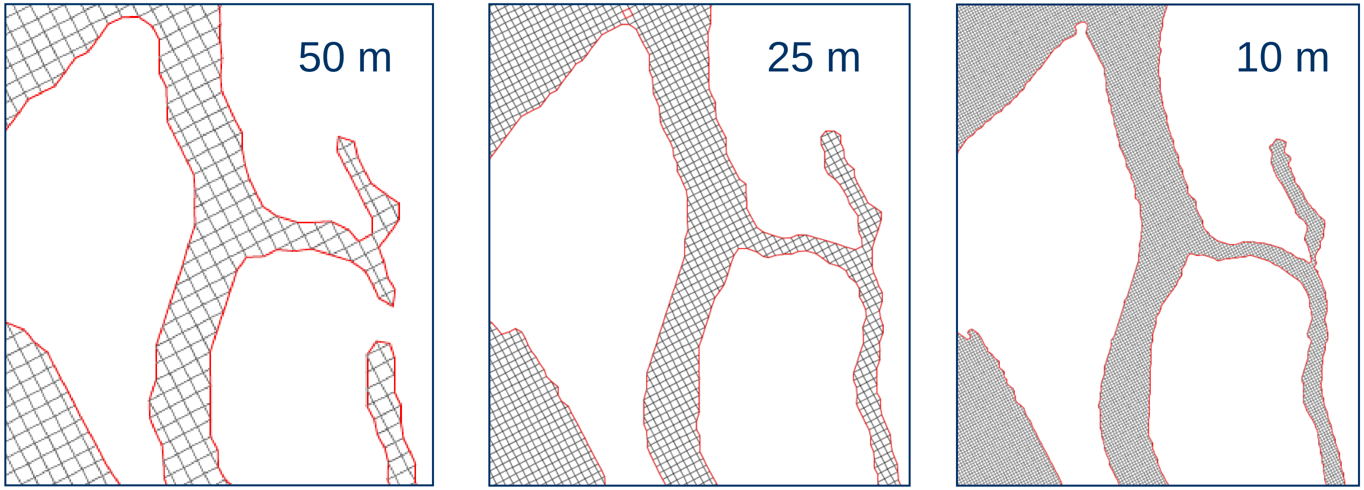
4. RANS Modelling study for Lake Øyeren's delta



The choice of the mesh size –
a balance between the quality of the input data,
the processing power of the computer
and the accuracy of the numerical solution

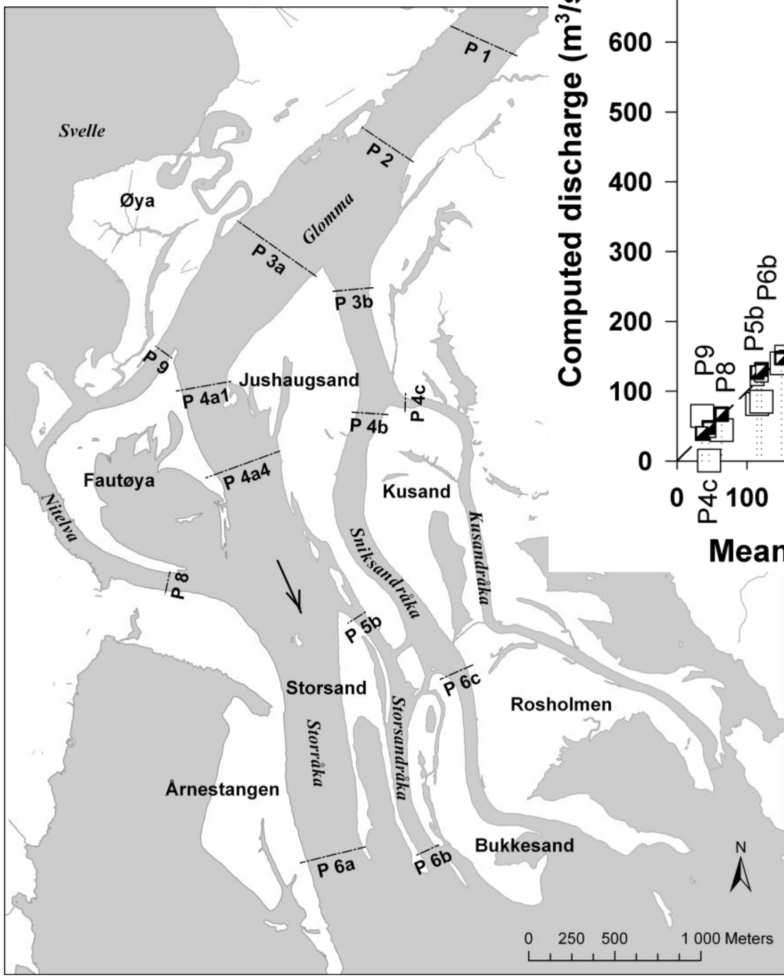
Number of grid cells for the 10 m mesh shown: $1.7*10^6$ (computational time on a 16 processor 1.9 GHz IBM Power PC node: 2 to 17 hours for a stationary computation, 2-3 weeks for a flood simulation, 2009)

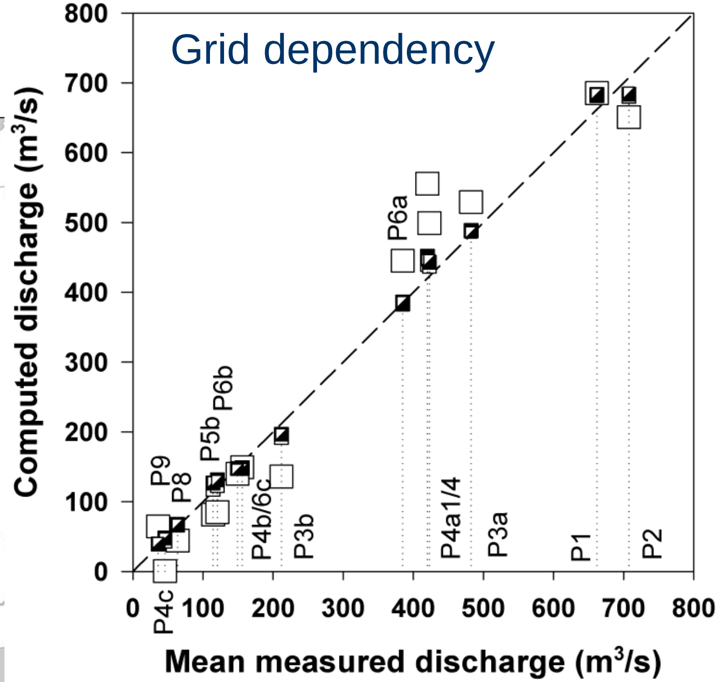
Spatial structure of the grid for lake stage 101.37 m a.s.l.



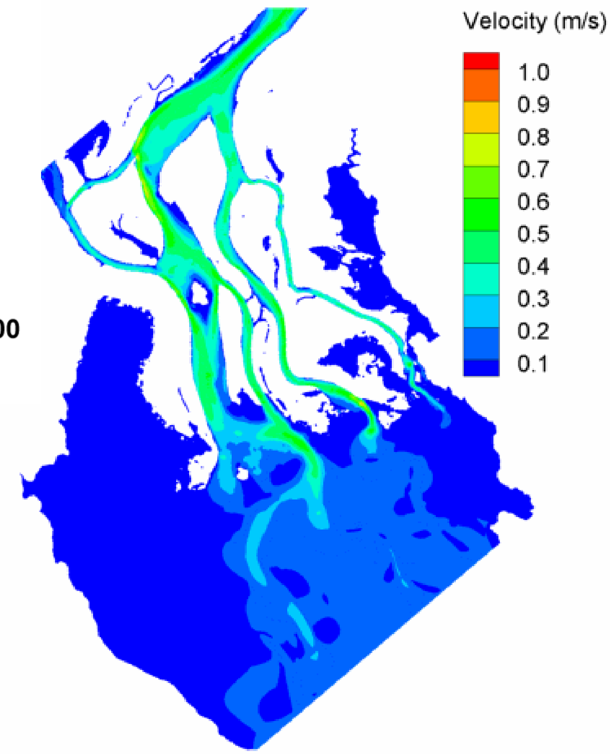
4. RANS Modelling study for Lake Øyeren's delta

NVE's ADCP measurement cross-sections





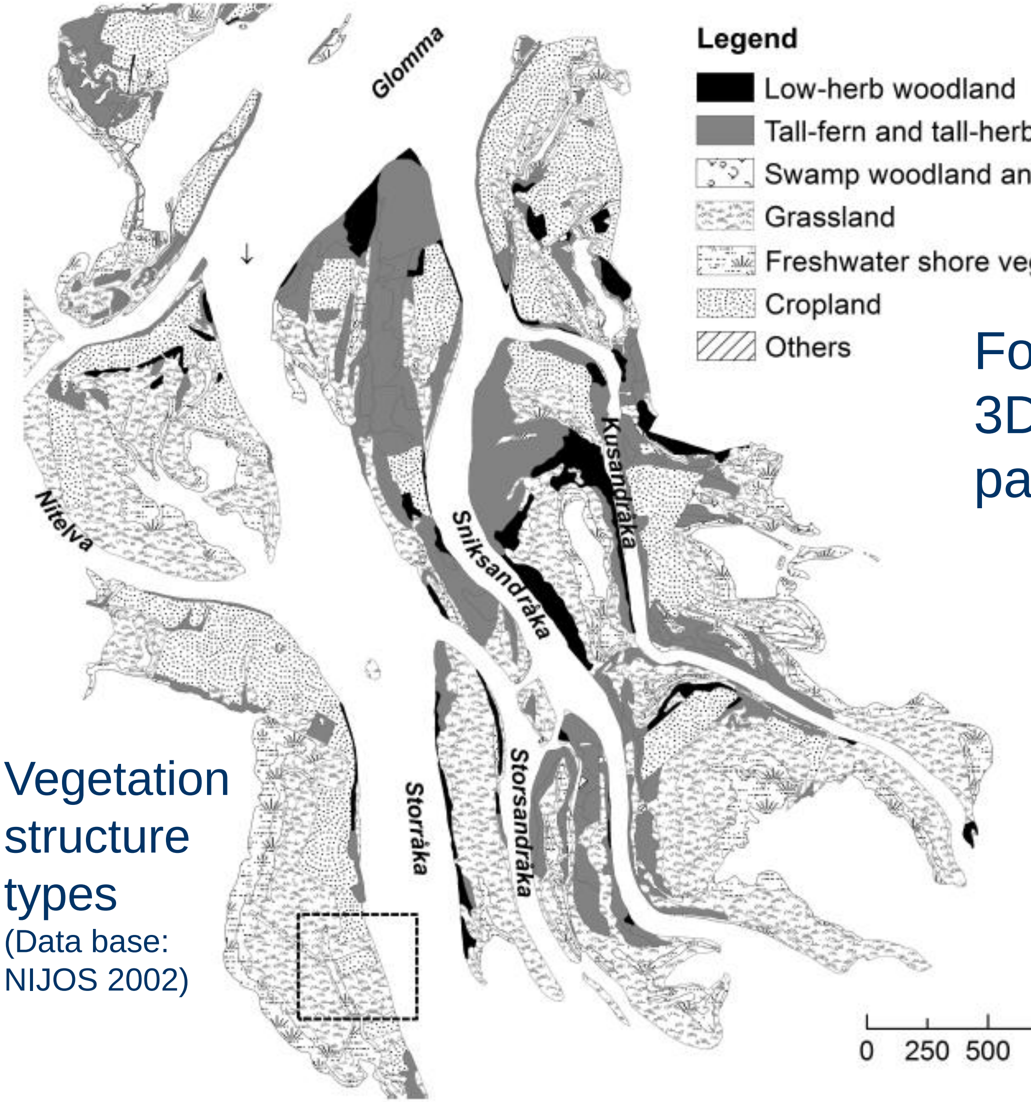
Comparison of model results with measured discharges and water levels for 3 flow situations



a) October 1996
Lake Stage at Mørkfoss 101.37 m ASL

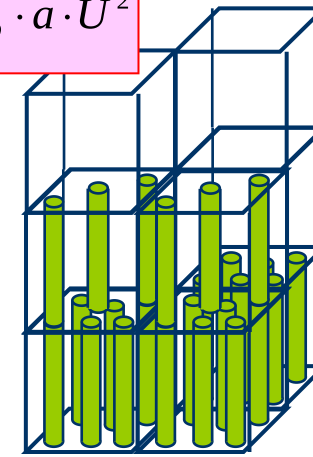
Set-up and calibration of the flow model
(Zinke et al. 2010)

4. RANS Modelling study for Lake Øyeren's delta



Vegetation structure types
(Data base: NIJOS 2002)

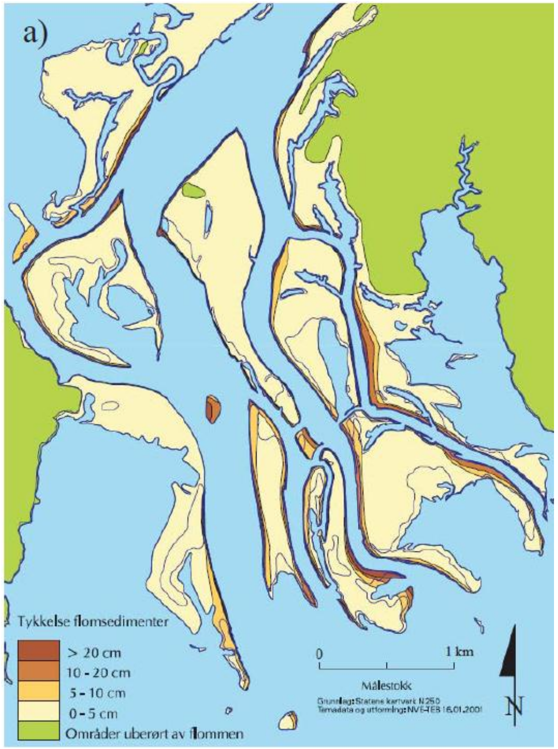
$$F_{cell} = \frac{1}{2}\rho \cdot C_D \cdot a \cdot U^2$$



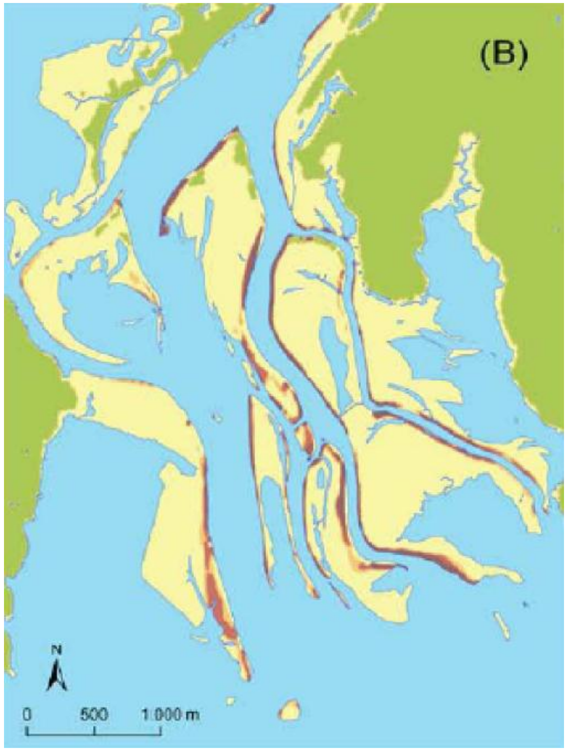
For the flood case:
3D vegetation parameters needed

4. RANS Modelling study for Lake Øyeren's delta

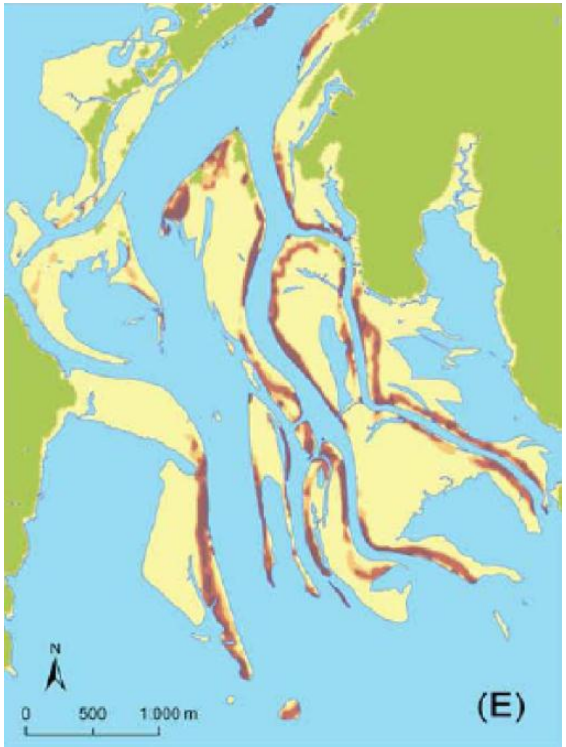
Measurements



Baseline data set



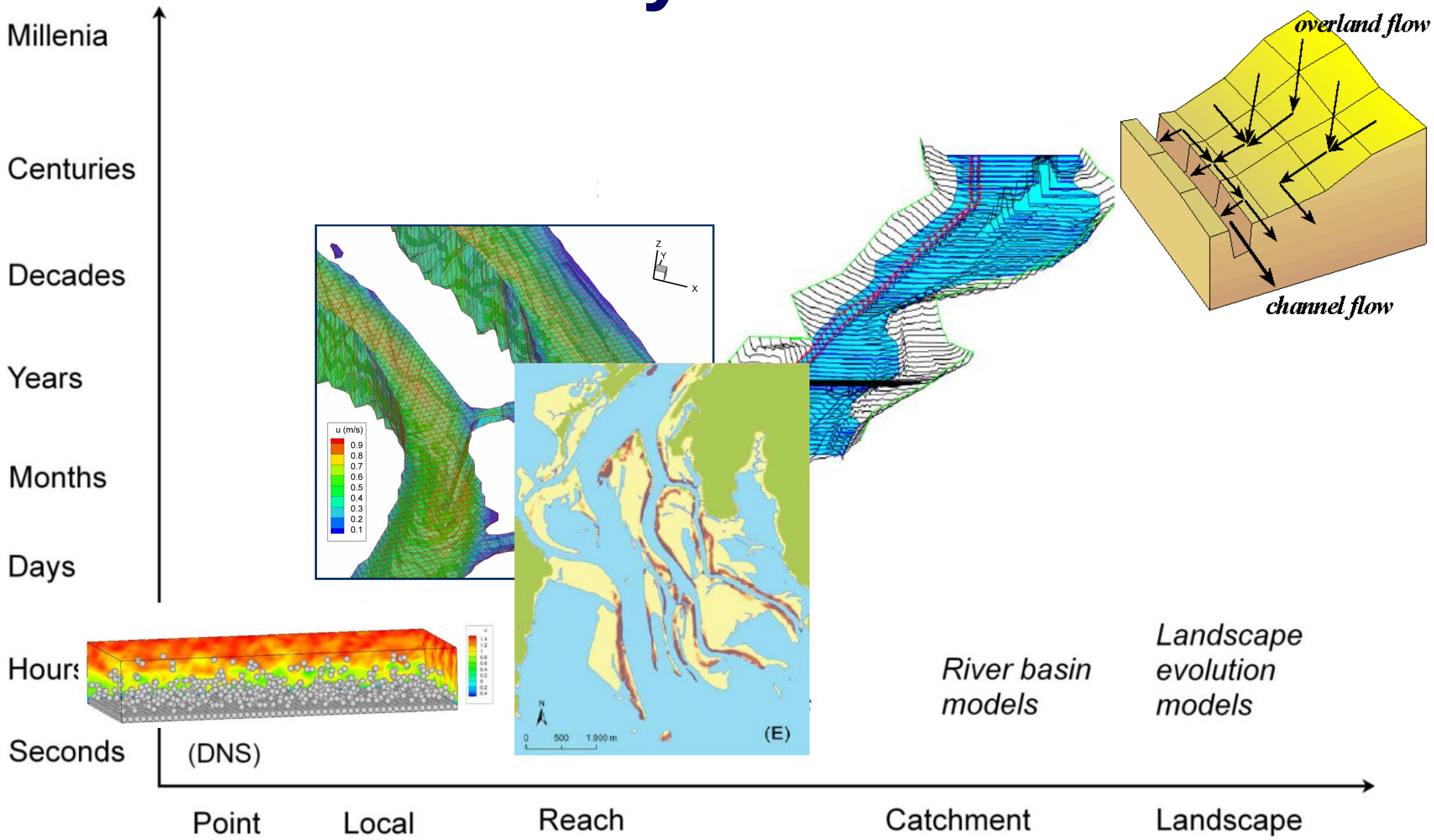
Case ”No vegetation”

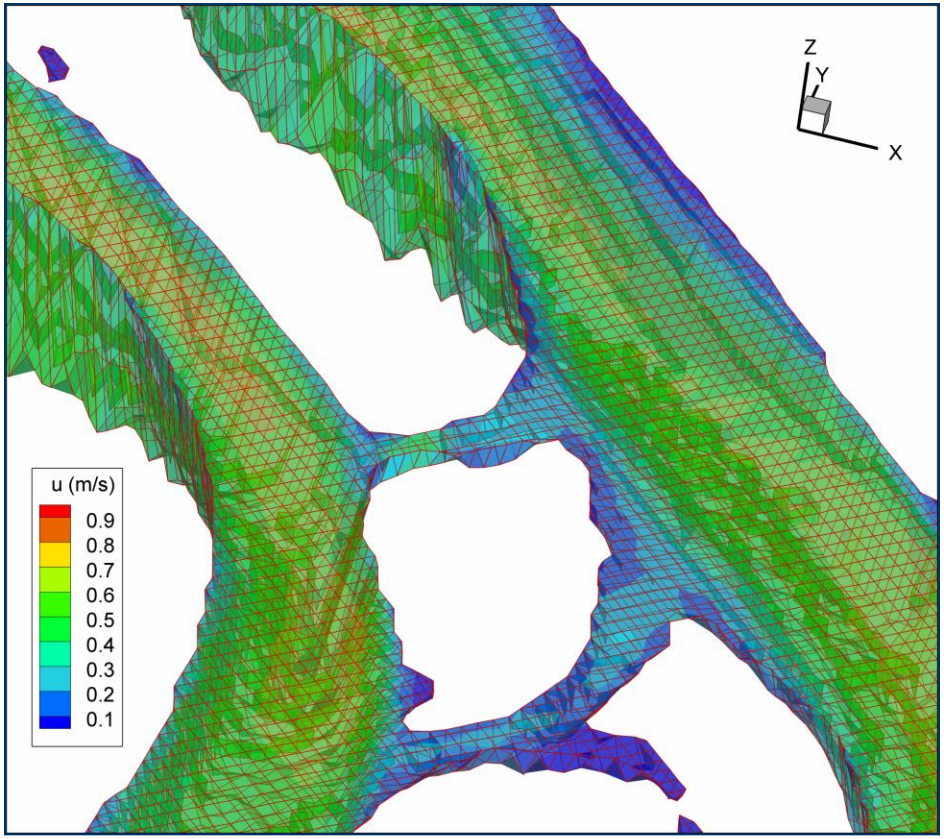


Measured and computed island deposits for the 1995 flood (Zinke et al. 2011)

Uncertainties about vegetation parameters and modelling approaches: one of the key factors for the modelling of levee depositions!

5. Short Summary





Thank you!

Many thanks to the CFD group at NTNU-IVM Trondheim and all research partners!

Contact:
Peggy Zinke
SINTEF Energy Research
Water Resources Research Group
Trondheim
Peggy.zinke@sintef.no