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UNESCO Chair on Integrated River Research and Management Vienna, Austria

THE WORLD BANK IBRD · IDA

Introduction to Numerical and Physical Modelling

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The power of water in a sustainable, interconnected world

United Nations Educational, Scientific and Cultural Organization

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Outline

1. Introduction
2. Problems and boundary conditions
3. Physical Modelling
4. Numerical Modelling
5. Examples
6. Summary and outlook

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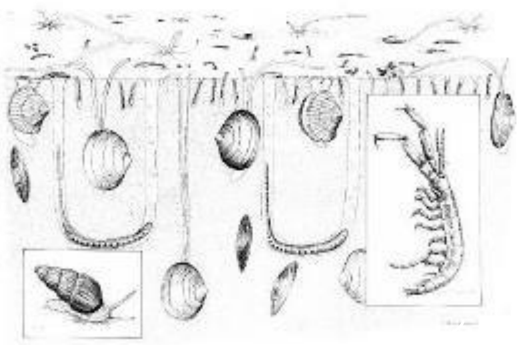
Sediment needs management

Due to:

Too much sediment	Too little sediment	Sediment as resource
Obstruction of channels Storages Rivers fill and flood Reefs get smothered Turbidity	Beaches erode Riverbanks erode Wetlands are lost River profile degradation	Construction material Sand for beaches Wetland nourishment Soil enrichment Habitat and food for life



Sediment = “no waste” =
essential & integral element of river-sea systems

Source scheme: Martin (2002)

Surplus

Deficit

Purpose and types of physical models

Purpose

Determination of hydraulic impacts on hydraulic structures before they are built (hydro-engineering facilities are very expensive and require a lot of planning in most cases) under controlled conditions (the experiment can be repeated as often as necessary):

- Occurence of flow is very complex / not entirely covered by theoretical considerations
- Verification or proof of theoretical approach to the calculation

Evaluation of complex 3D flow processes by:

- **Physical models:**
  - Reproduction of nature at a reasonable scale
- **Numerical models**
- **Hybrid models**
- **Analogy models**

Purpose and types of models

Theoretical and practical limitations of application

- **Physical models:**
  - Model size
  - Discharge
  - Pump capacity
  - Minimum scale of model
  - Model dimensions
  - Methods and data logging
  - Availability of initial and boundary conditions

- **Numerical models:**
  - Memory capacity, processing speed
  - Model approach: e.g.: turbulence models
  - Spatial and temporal resolution (downward limitation)
  - Availability of initial and boundary conditions

Hybrid models:

Linking of physical and numerical models:

- Parts of the problem are solved numerically, other parts are solved physically
- Verification of new numerical solution approaches using data from nature and model tests

Model laws

Basic scale ratios:

- $\phi_r = \phi_n / \phi_m$, scale value = parameter in nature / parameter in the model
  - Length: $L_r = L_n / L_m$
  - Time durations: $T_r = T_n / T_m$
  - Forces: $K_r = K_n / K_m$
- Similarities:
  - Geometric similarity: lengths L - similarity of form
  - Kinematic similarity: time durations T - similarity of motion
  - Dynamic similarity: forces F - similarity of forces
- Miniaturisation of geometry requires an adaption of time periods and forces and their derived variables → depending on chosen law of similarity
- Flow conditions in nature are usually turbulent, therefore flow conditions in scale models should also be turbulent

Model laws

Dynamic laws of similarity:

- **Inertia force / gravity force = v^2 / g L = Fr^2 (Froude number)**
- **Inertia force / friction force = v.L / ν = Re (Reynolds number)**
- Inertia force / pressure force = r.v^2 / p = Eu (Euler number) … p: input parameter
- Inertia force / surface force = r.v^2.L / S = We (Weber number)
- Inertia force / elastic forces (Sarrau-Mach number)…incompressible: neglected
- Complete dynamic similarity (all relations of force are similar) is not achievable; depending on the problem only 2 dominant forces are taken into consideration at the same time
- In physical scale models mainly processes dominated by gravity and friction force are represented (Froude or Reynolds similitude)

Model laws

Law of similarity after Froude (inertia force / gravity force):

- Application, conversion factors
  - Application for models with free water surface (dominated by gravity)
  - Conversion of time, velocity and discharge true to scale:

$$L_r = \frac{L_n}{L_m}$$

$$A_r = L_r^{\,2}$$

$$v_r = L_r^{\,1/2} (\text{bei } g_r = 1)$$

$$T_r = \frac{L_r}{v_r} = L_r^{\,1/2}$$

$$Q_r = v_r \,.\, A_r = L_r^{\,5/2}$$

With L = Length, A = Area, v= Flow velocitiy, T=Time, Q = Discharge

  - Flow conditions in the model and nature are the same (also point of change from subcritical to supercritical flow conditions)

Model laws

Law of similarity after Froude (inertia force / gravity force):

- Limitations (Strobl):
  - Is the neglect of friction forces acceptable? (possible compensation by model distortion)
  - Over-representation of surface tension in the model
  - Less air input in the model
  - Cavitation processes are not transferable
  - Elastic behaviour of materials in the model

Physical scale models

Model laws

Law of similarity after Reynolds (inertia force / friction force):

- Application of small Reynolds number and laminar flow: pressure losses in very smooth pipes, friction resistance of vessels, resistance of immersed moving bodies, …
- Conversion:

$$L_r = L_n / L_m$$

$$A_r = L_r^{\,2}$$

$$v_r = L_r^{-1} (\text{bei } \rho_r = \mu_r = 1)$$

$$T_r = \frac{L_r}{v_r} = L_r^{\,2}$$

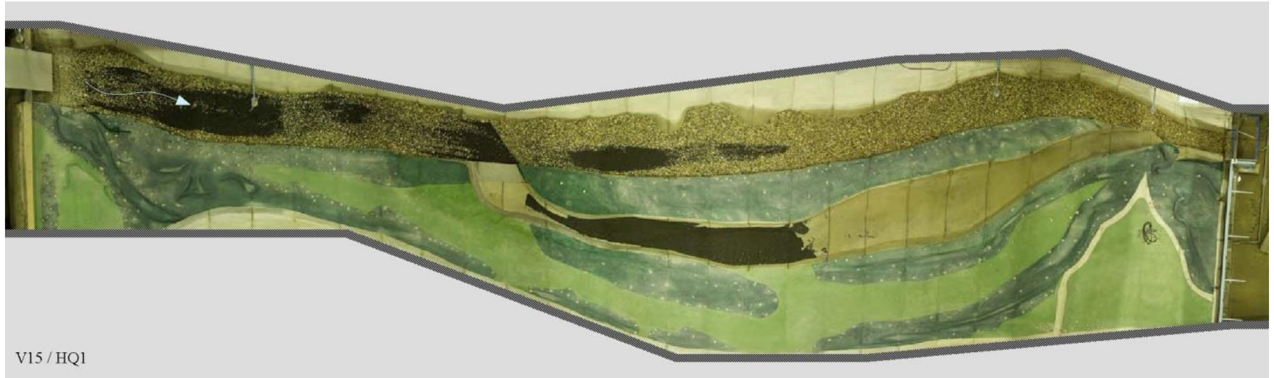
$$Q_r = v_r \cdot A_r = L_r$$

With L = Length, A = Area, v= Flow velocitiy, T=Time, Q = Discharge

Physical scale models

example: model test of the construction of a distributary of the river Steyr as a bed load deposition area

- **conversion:** scale 1:23, discharge NQ / HQ1 / HQ30 / HQ100, fixed river bed
- **aims:** construction of a distributar with permanent discharge in the floodplains of Himmlitz (Steyr), reduced bed load transport rates in case of flood events by selective bed load deposition, study of alternatives, impacts of low flow conditions
- **results:**
  - Minimisation of construction size of intake area (from ecological and economic view)
  - Reduction of length of side weir
  - Efficiency (bed load input into distributary) depending on discharge (HQ_1 to HQ_{100}) between 75% and 85%.

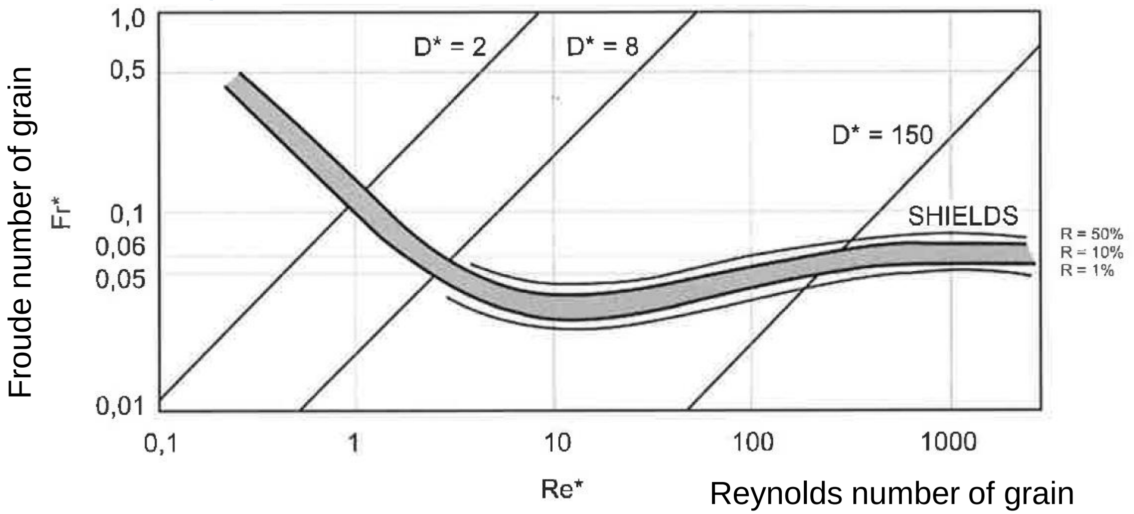


Physical scale models

Model laws

Models with flexible river bed

- Short models (friction processes → slope of water surface neglectable)
    - Discharge process: $\Pi = f$ (Fr, d / h, $\Delta = (r_s - r_{Fl})/r_{FL}$, Fr* = $u^{*2} / (\Delta\, g\, d)$, Re* = (u d) / ν)
    - Similarities to consider:
        - Similarity after Froude, similarity of initiation of sediment motion, similarity of sediment transport



- If the Re* of grain > 70 at hydraulic smooth discharge the Re* - number can be left out in scale calculations

Initiation of motion (Shields Diagram) from Zanke, U.: initiation of motion as a probability problem. Water and soil, volume 1, S. 40-43

Physical scale models

Model laws

Models with flexible river bed

- Short models (friction processes → slope of water surface neglectable)
- Long models (friction processes → slope of water surface not neglectable)
  - Similarities to consider:
    - similarity after Froude,
    - similarity of initiation of sediment motion,
    - similarity of sediment transport,
    - similarity of water level

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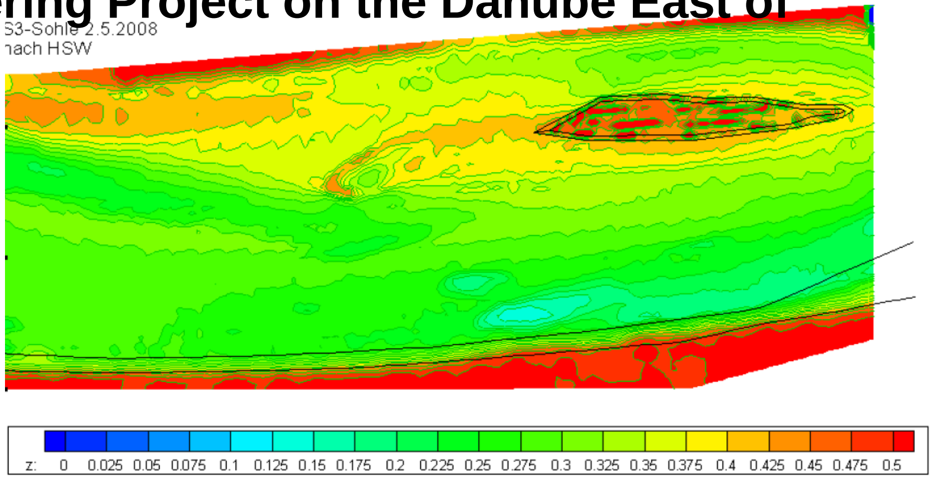
Physical scale models

Surface model, Integrated River Engineering Project on the Danube East of Vienna

- realisation: TU Vienna, Institute for Hydraulic Engineering and Hydrometrical examination
- aim: application of granulometric river bed stabilisation

source: final report, hydraulic engineering model test, surface model, Integrated River Engineering Project on the Danube East of Vienna (2008)



<u>result:</u>
Layer of coarse gravel material with a grain size curve of d = 40-70mm withstands pressures up to 40 -45N/m²

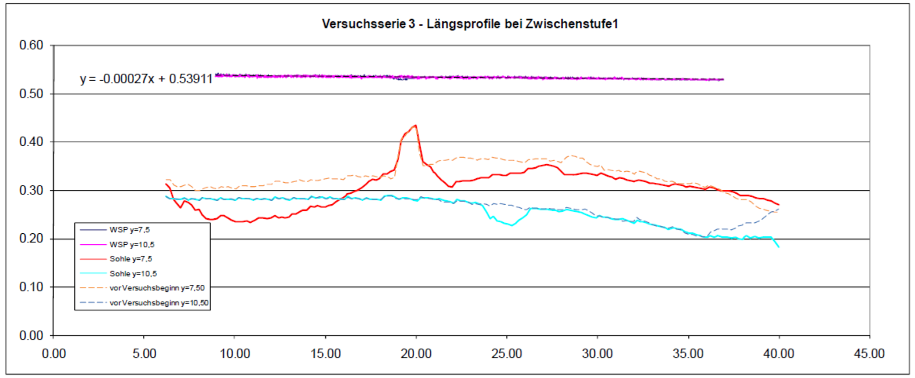
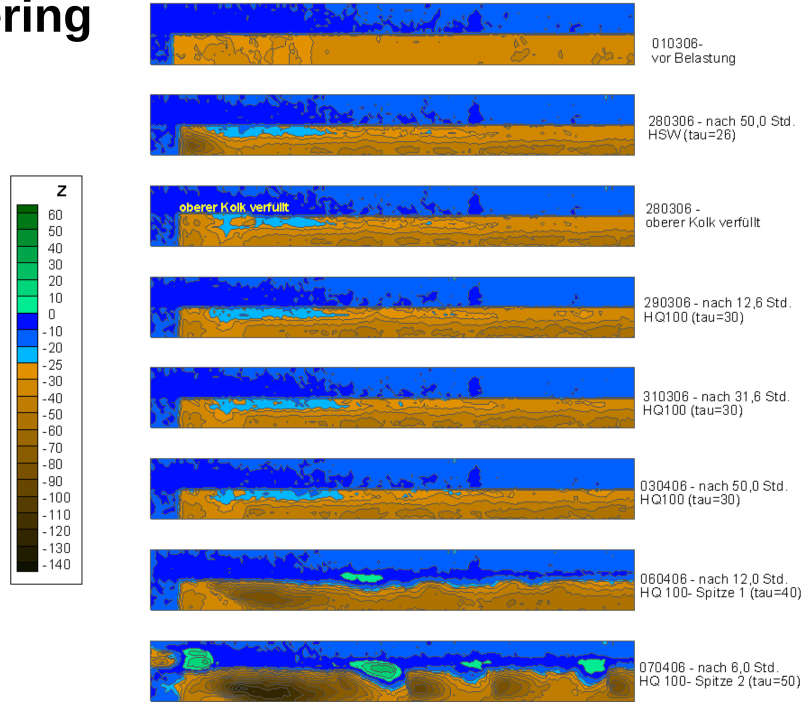


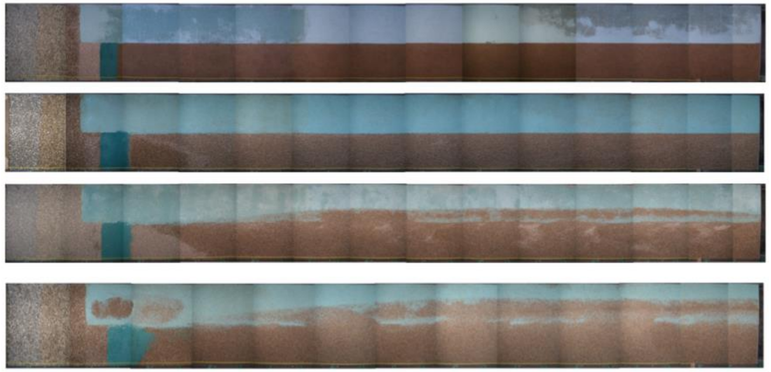
Abbildung 160 – Versuchsserie 3, Längsprofile bei Zwischenstufe1

Physical scale models

Channel model, Integrated River Engineering Project on the Danube East of Vienna

- realisation: TU Vienna, Institute for Hydraulic Engineering and Hydrometrical examination
- aim: applicability of granulometric river bed stabilisation



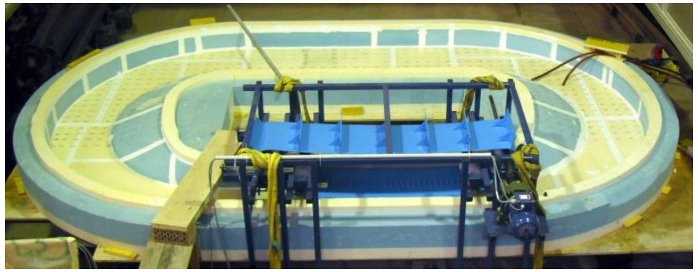


source: final report, hydraulic engineering model test, surface model, Integrated River Engineering Project on the Danube East of Vienna (2008)

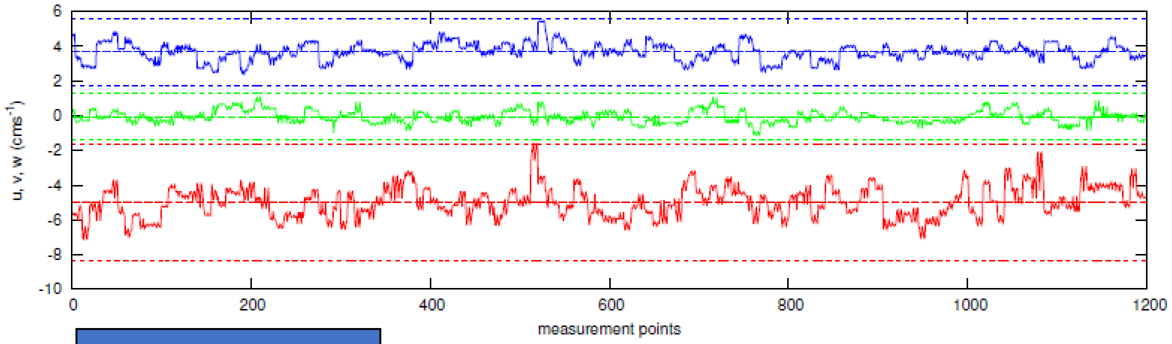
Physical hydraulic modelling

Analysis and Interpretation

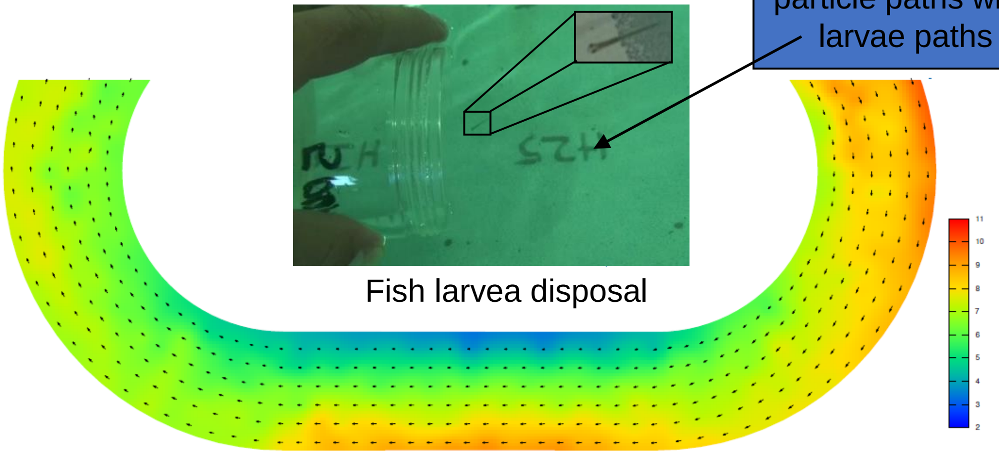
- example: Modelling of distribution mechanisms of fish larvae
  - Time series from ADV measuring (duration: 30 seconds)
  - Flow field from ADV measuring



Flume: Hydraulic Engineering Lab BOKU

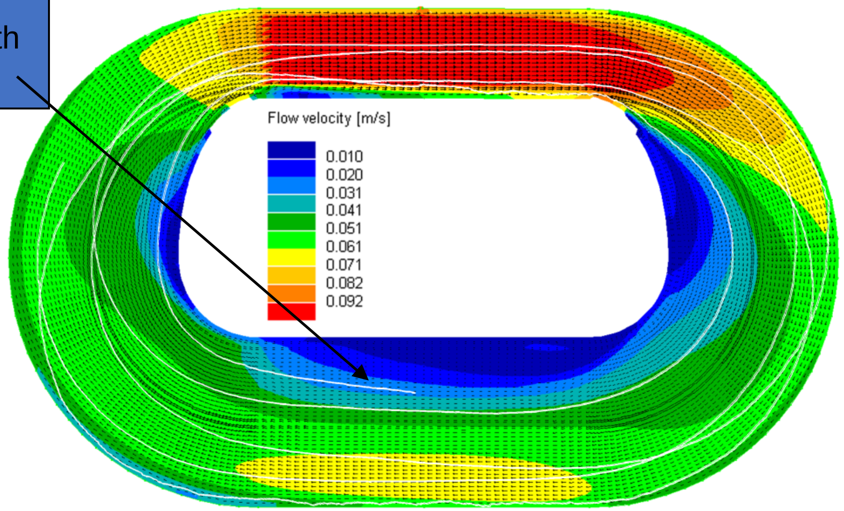


Comparison of particle paths with larvae paths



Fish larvea disposal

Flow field from 3D numerical model, in layer 2 of 4



Flow field from 3D numerical model, depth-averaged

Physical hydraulic modelling

Analysis and Interpretation

- example: weir reconstruction, hydropower plant Hallein and flood protection Hallein at the Salzach river at a scale of 1:50

  - Weir and bed load construction

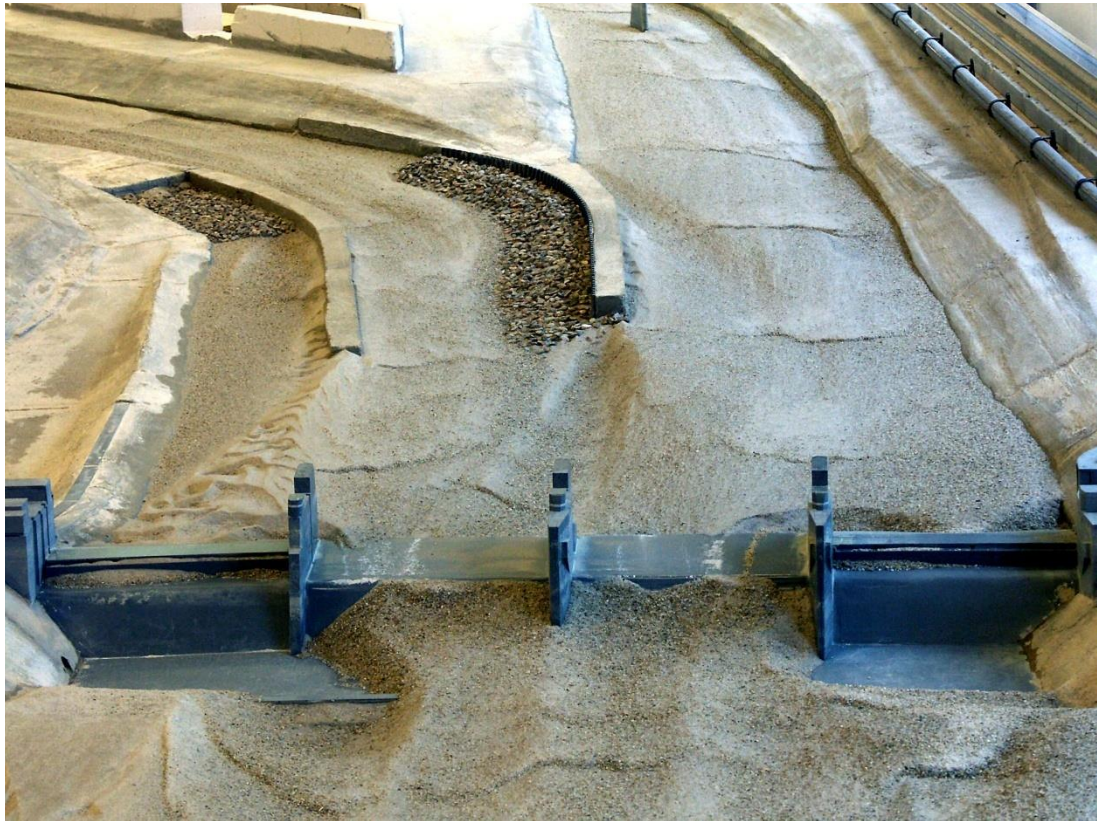
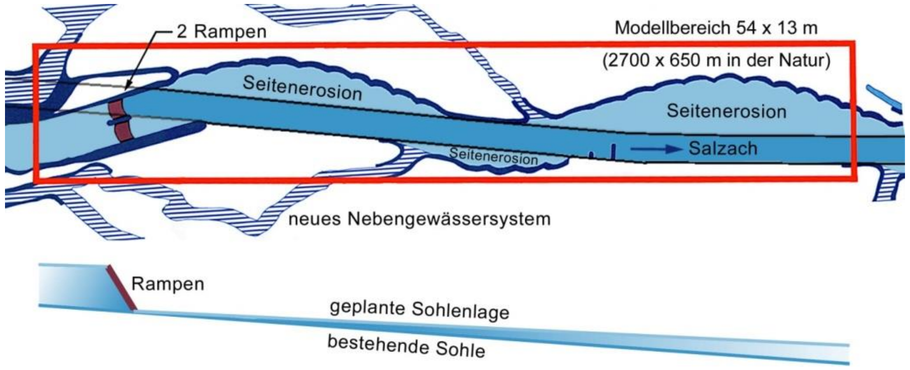


photo: Experimental hall Severingasse, federal agency of water management Vienna, Institute for Hydraulic Engineering and Hydrometrical examination, upstream view

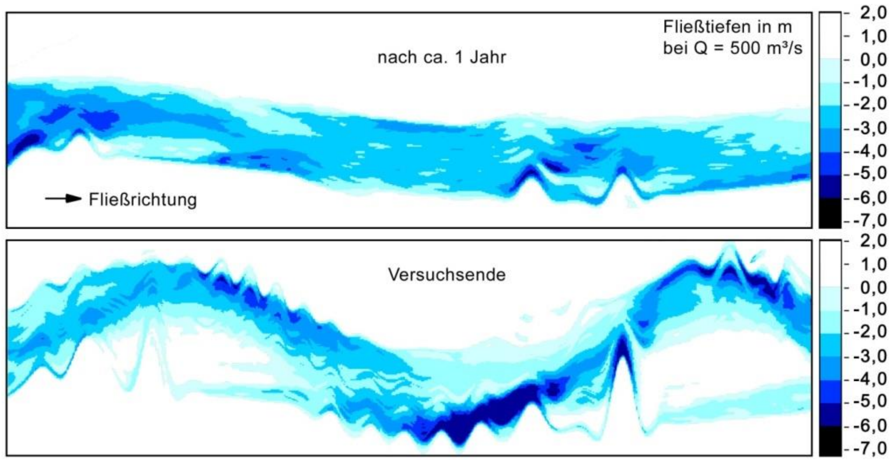
Physical hydraulic modelling

Analysis and Interpretation

- example: Hybrid model for the water management master plan of the Salzach river
  - Project area: 53,3 km river reach at the lower Salzach river
  - aim: prevention of lowering of river bed and threat of sudden erosion of river bed down to fine clay
  - Solution approaches: Initial measures: ramps, groynes, training structures

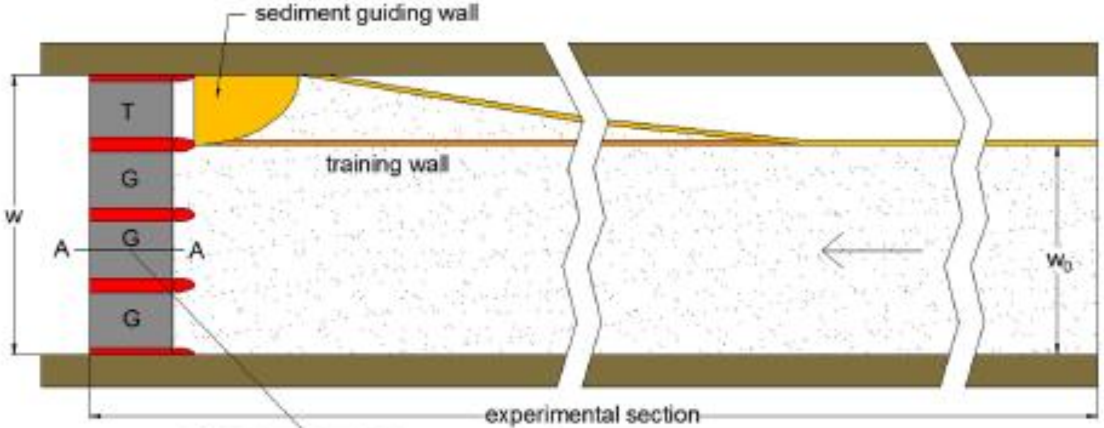


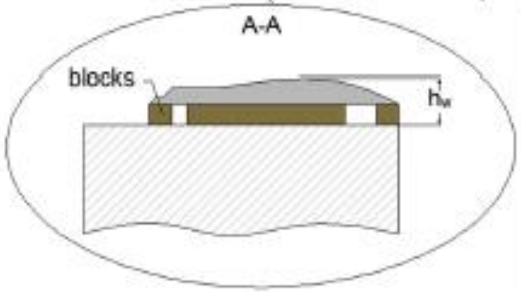
Detail physical model

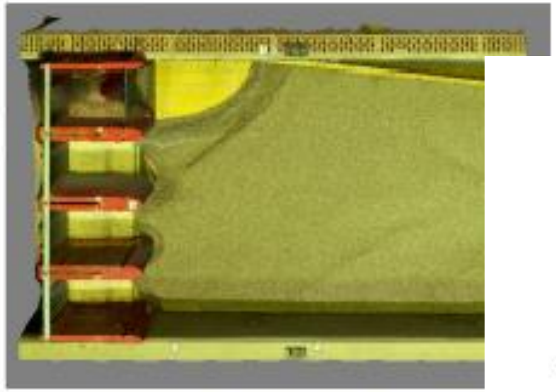


Results from depth-variances analysis, from the water management master plan of the Salzach river

Sediment continuity

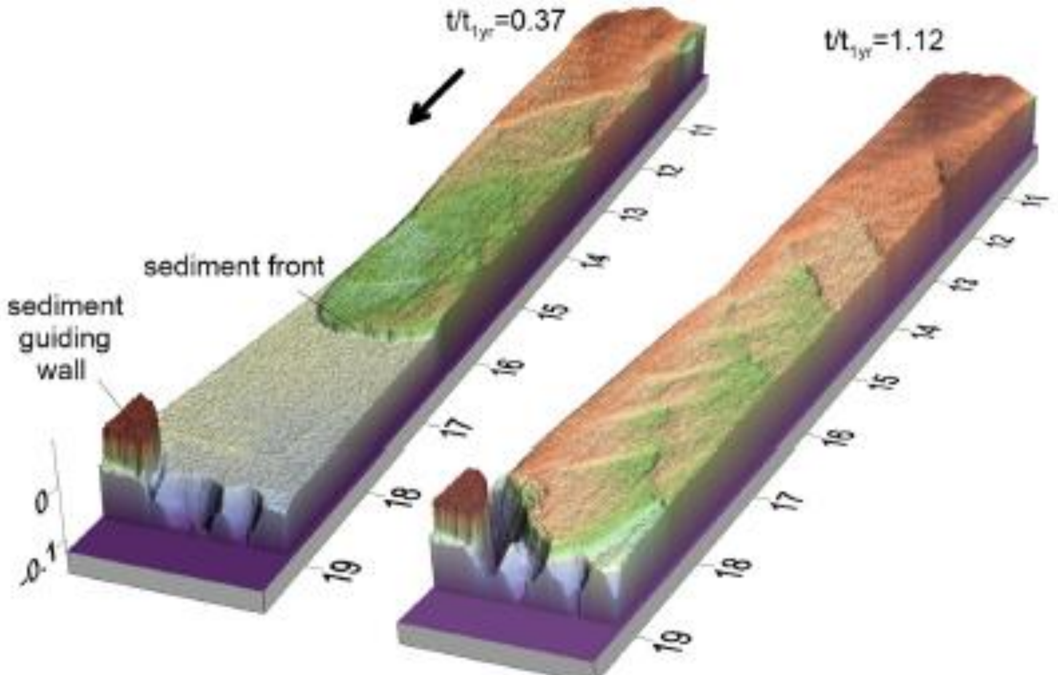






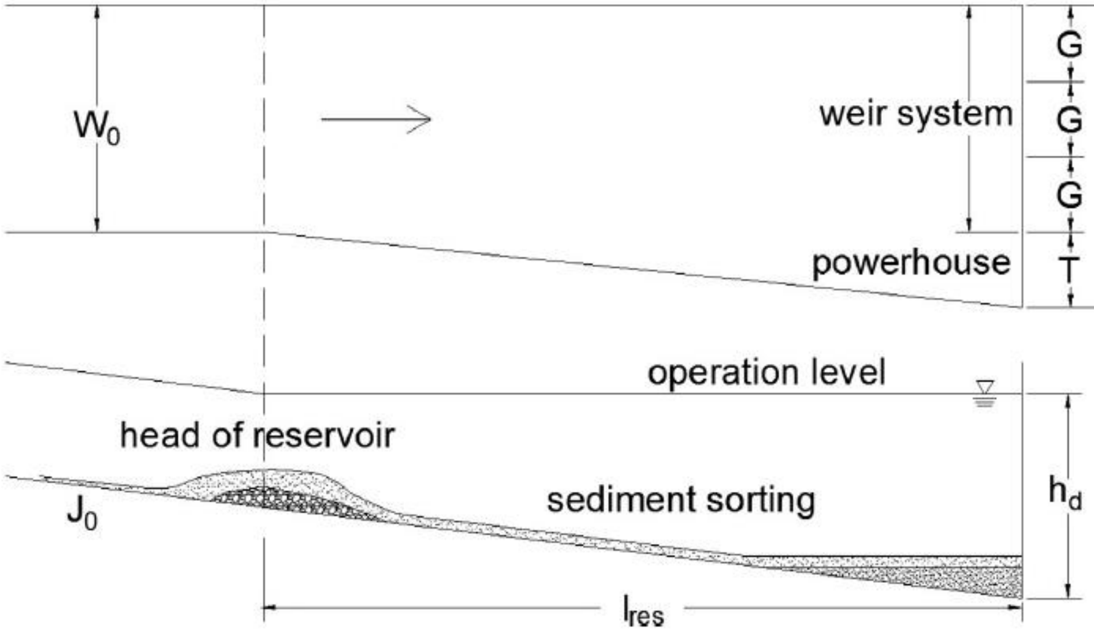
$$l_{res} \approx \frac{2(h_d - h_0)}{J_0}$$

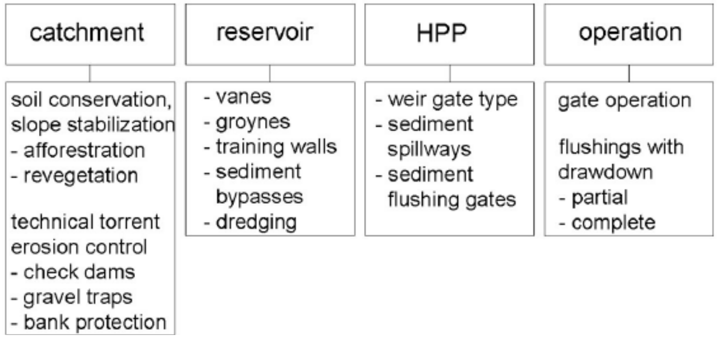
$$J \approx J_0 \left[1 - \frac{h_w}{2(h_d - h_0)}\right]$$

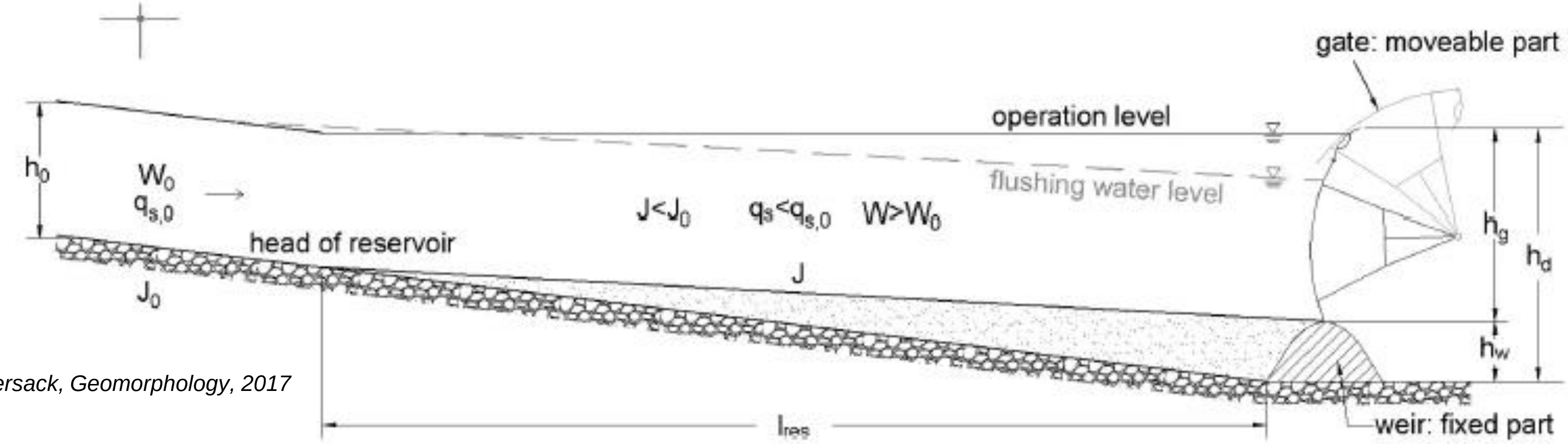


Sindelar, Schobesberger, Habersack, Geomorphology, 2017

Sediment continuity

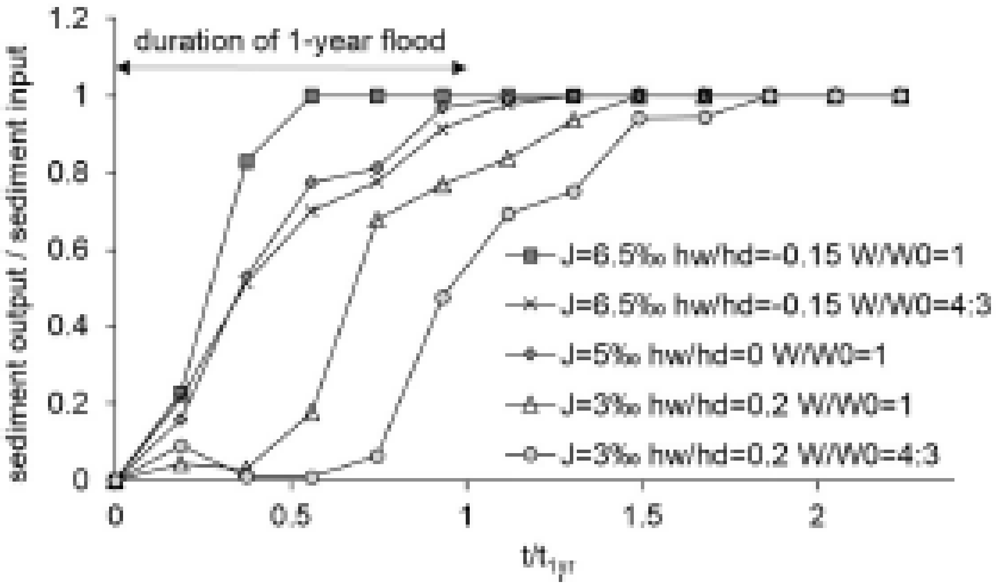


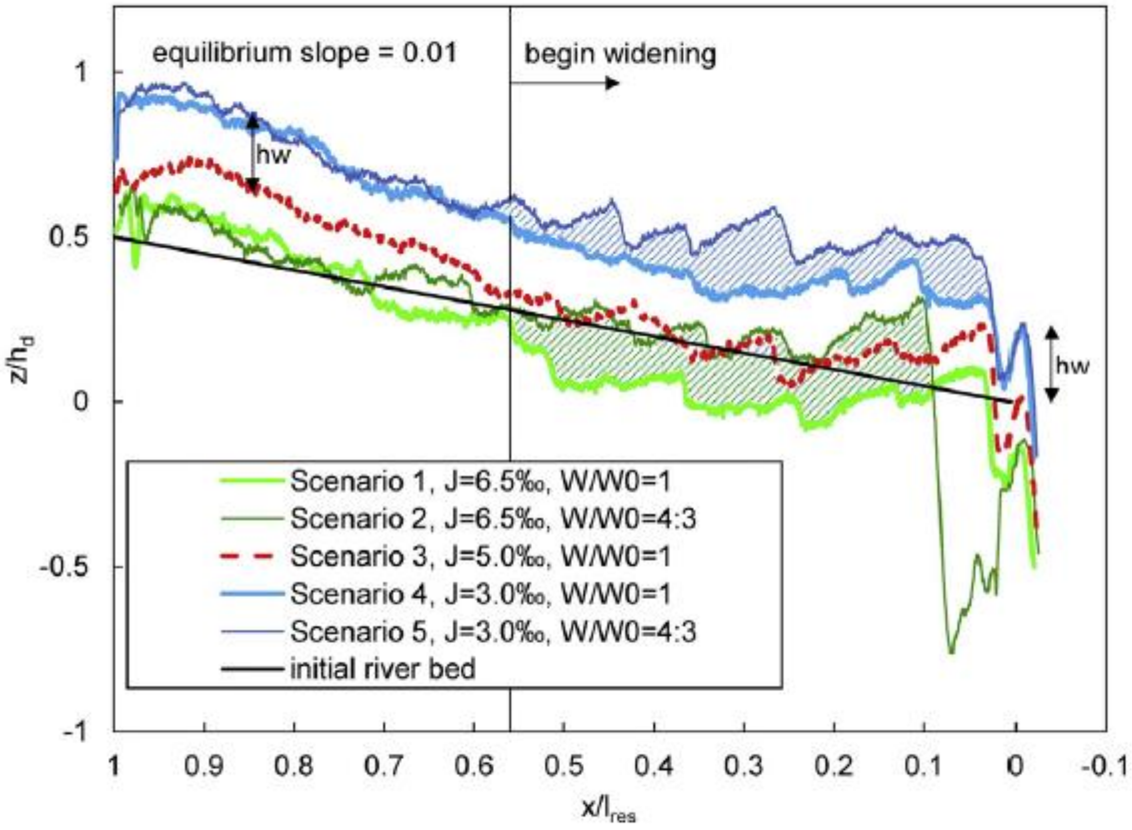




Sindelar, Schobesberger, Habersack, Geomorphology, 2017

Sediment continuity





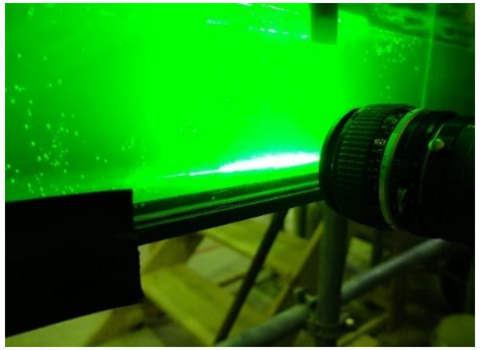
Sindelar, Schobesberger, Habersack, Geomorphology, 2017

Lack of process understanding

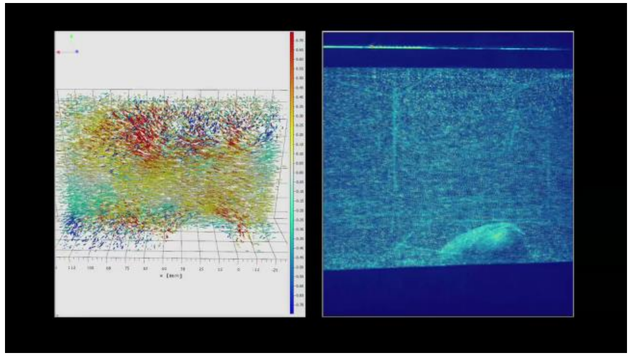
Interaction sediment transport and turbulence / cohesive material and mathematical descriptions:
PIV – measurements in combination with LES (Large Eddy Simulations)

(PIV) BOKU: 1000 hz (detection of coherent structures) – analysis Reynolds-Stress terms

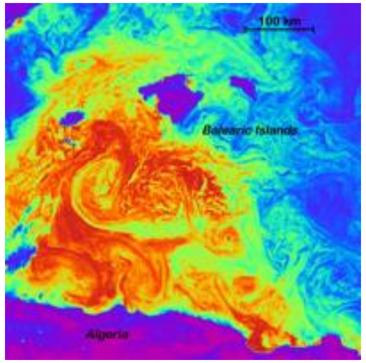
Measurements of shear stress and flow velocity

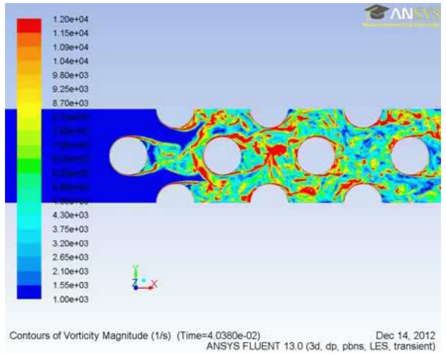


PIV and PTV measurements of sediment dynamics
(IWHW – BOKU Wien)



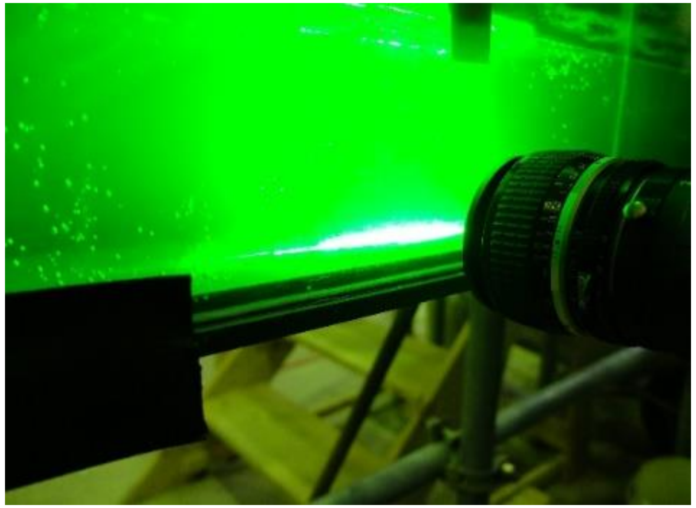
Large Eddy Simulations (LES):

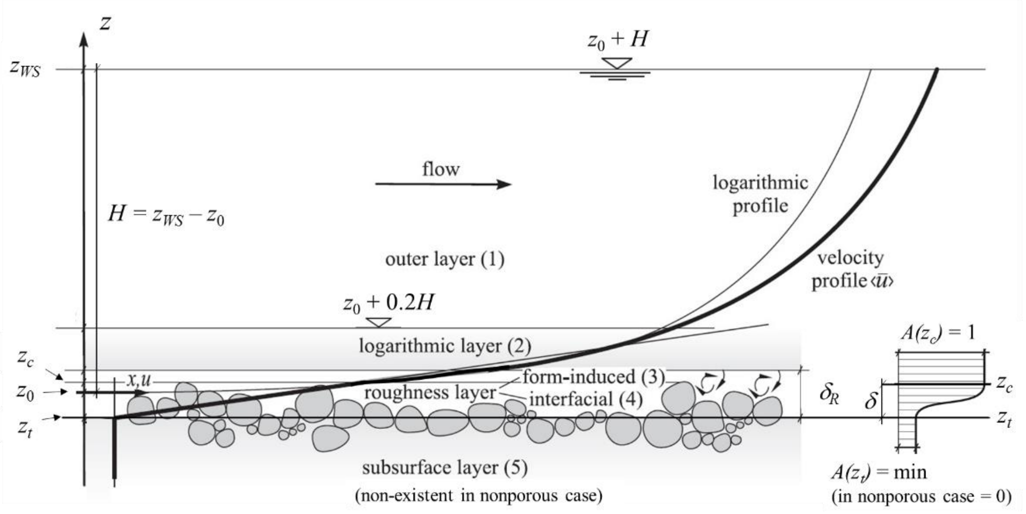




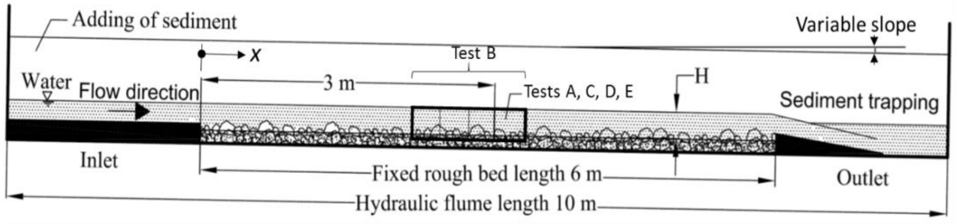
Improved process understanding as basis for numerical modelling

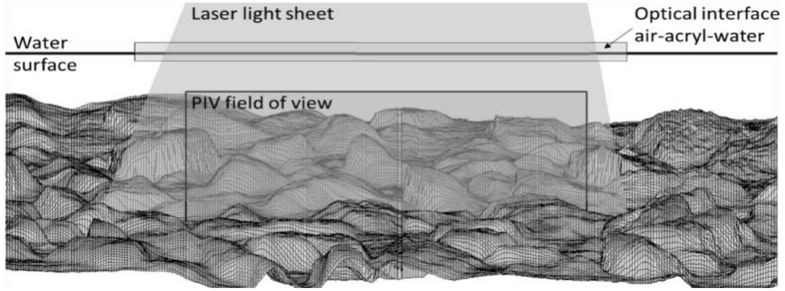
PIV-Measurements IWA





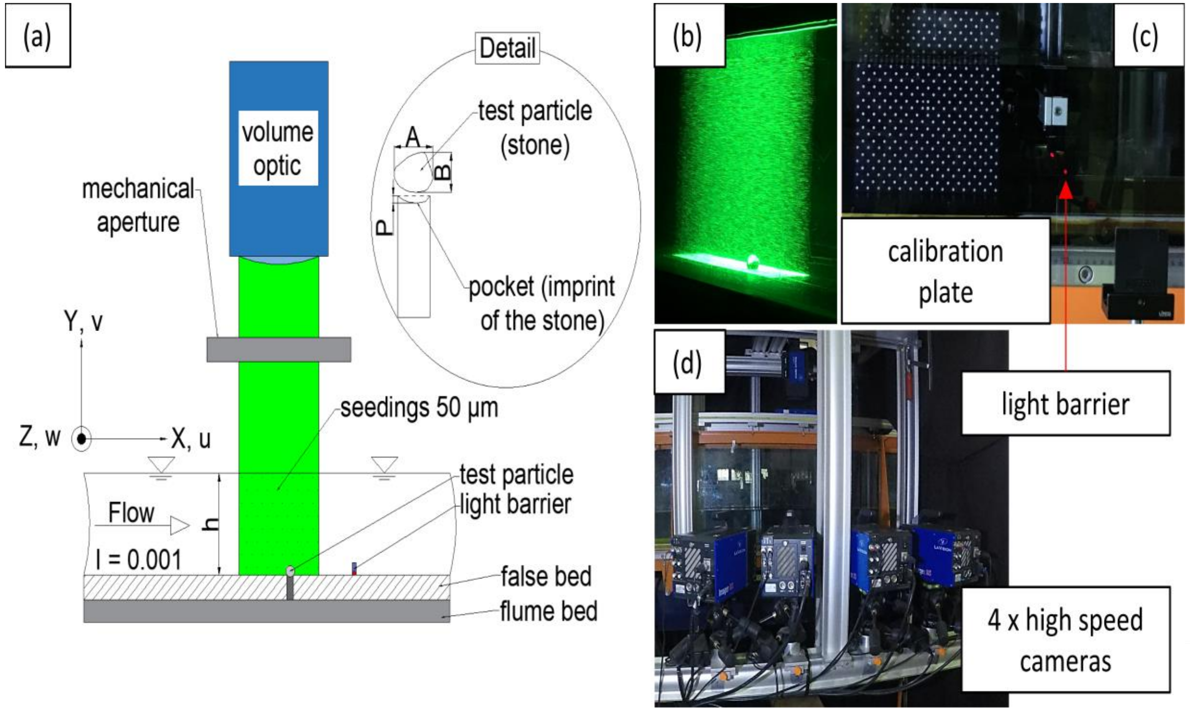
Lichtneger et al., 2018 subm.

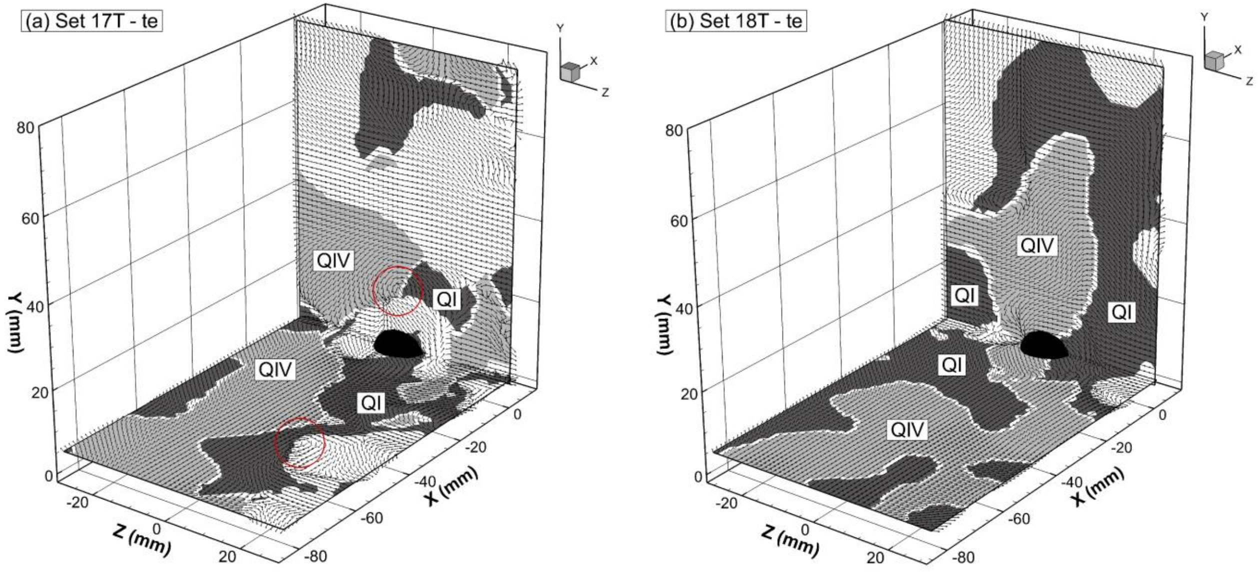




Improved process understanding as basis for numerical modelling

Tomo-PIV-Measurements IWA/BOKU





Schobesberger et al., J. Hydraulic Engineering, 2019

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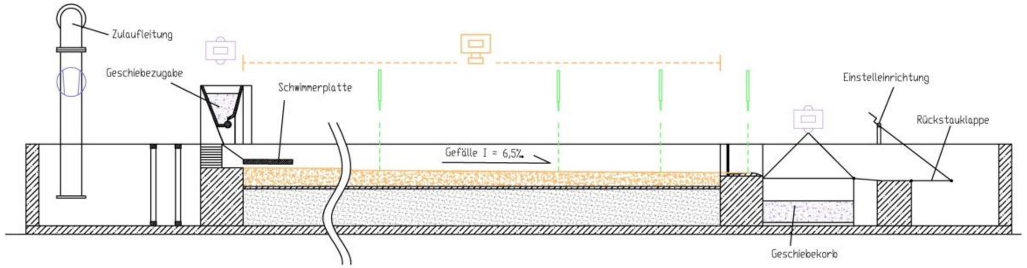
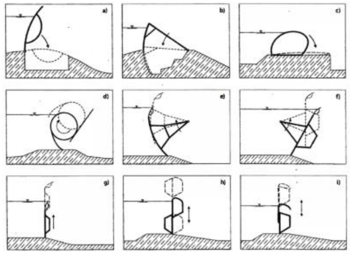
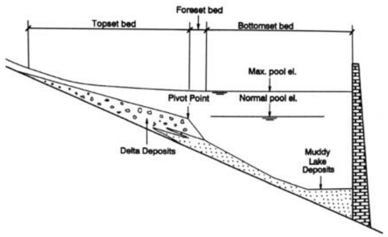
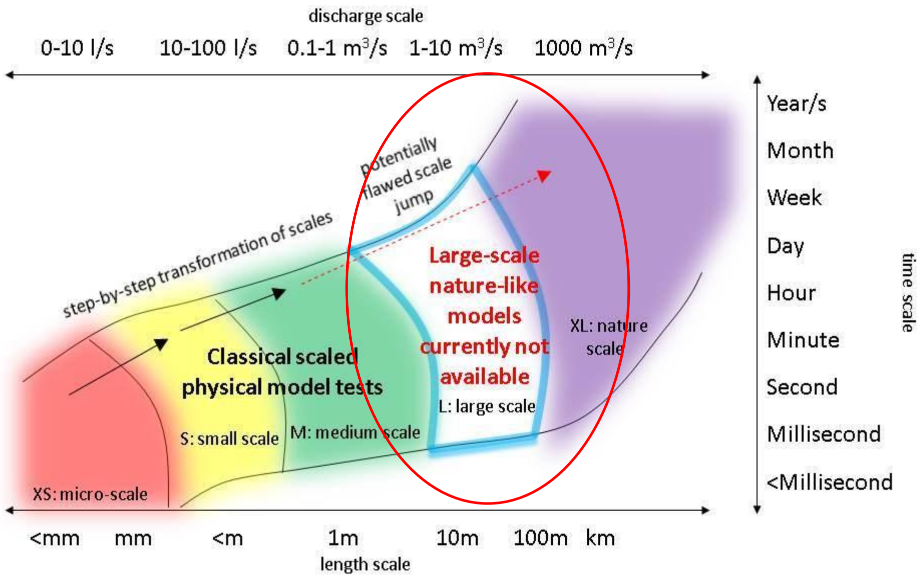
Physical Modelling in Hydraulic Engineering Laboratories







➡ in **small scale physical models** it is not possible, to reproduce **variables** (**viscosity**, **hydraulic-jump**, **roughness**, …) **correctly**. Thus, the **Transferability** of results to nature contains **unavoidable errors**. – especially for **experiments** including **sediment dynamics**.



➡ the ***higher*** the selected ***model scale***, the ***lower*** the ***risk*** of ***unavoidable errors*** in nature.

nut Habersack

Research Channel – New BOKU Hydraulic Eng. Lab.

- Scale issues → 10.000 l/s free flowing

Helmut Habersack

Numerical Modelling

Governing equations of sediment transport modelling

(simplified 1-D view)

Energy balance equation water	$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial z}{\partial x} + gAI_R = 0$
Continuity equation water	$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$
Flow formula	$u_m = k_s R_h^{\frac{2}{3}} I_R^{\frac{1}{2}}$
Continuity equation sediment	$(1-n_p)\frac{\partial A_s}{\partial t} + \frac{\partial Q_s}{\partial x} - q_s = 0$
Sediment transport equation (example)	$q_s = c_{\mathrm{MPM}}\sqrt{\frac{\rho_s-\rho}{\rho} g d_m^3 \left[\frac{u'^2_*}{\frac{\rho_s-\rho}{\rho} g d_m} - \theta_{c,\mathrm{MPM}}\right]^3}$

Methods of sediment transport modelling

Uncoupled method	Water movement ➔ sediment movement ➔ change of the river bed
Coupled method	All variables (flow, sediment, morphodynamics) are determined simultaneously
„Known-Discharge“ method	During a time step the discharge is considered to be constant (therefore only sediment continuity and steady-state water surface elevation calculations)

Incipient motion

Bed shear stress 1-D: $\tau = \rho g I_R h$ (via critical bed shear stress)

Critical bed shear stress after Shields: $\tau_c = \theta_c(\rho_s - \rho)gd$

Stability condition:

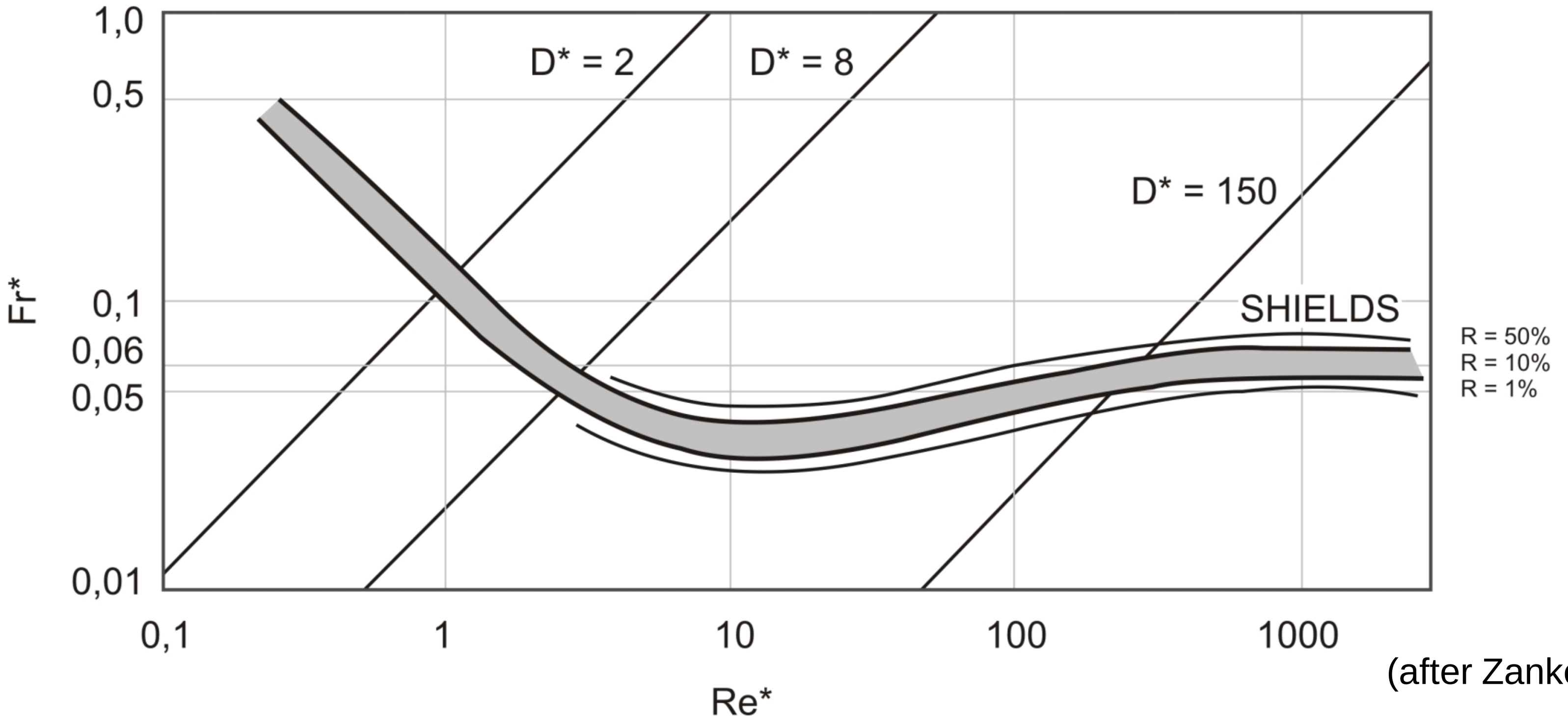
$$\frac{\tau}{g(\rho_s - \rho)d} = \frac{\tau_c}{g(\rho_s - \rho)d}$$

$$\theta = \theta_c$$

θ … Shields parameter resp. grain Froude number (Fr*)

Incipient motion

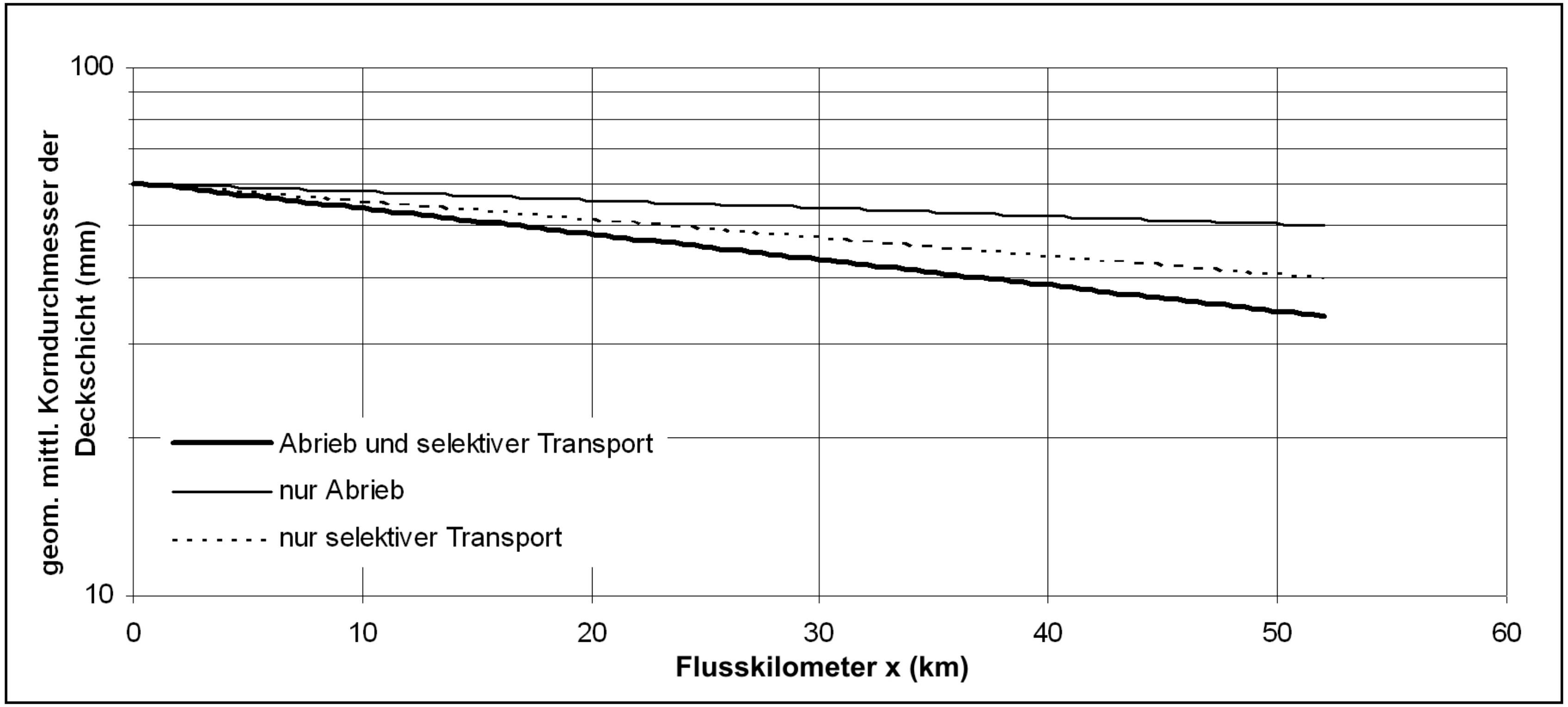
(via critical bed shear stress)



(after Zanke, 1990)

$$\mathrm{Re}^* = \frac{d u_*}{\nu} \qquad u_* = \sqrt{\frac{\tau}{\rho}} \qquad \mathrm{D}^* = \left[\left(\frac{\rho_s}{\rho} - 1\right)\frac{g}{\nu^2}\right]^{1/3} d$$

Abrasion



(Habersack)

$$dw = -a_w w \, ds \quad \rightarrow \quad w = w_0 e^{-a_w s}$$

a_w … Material constant (empirical)

w … Particle weight

s … Transport distance

Bedload transport formulas

Deterministic formulae

➔ empirical relationships, based on critical flow velocity, critical discharge or (often) critical bed shear stress

➔ e.g. Meyer-Peter & Müller (1948), Ackers & White (1973)

Formulae based on statistic considerations

➔ Consideration of the turbulent fluctuations by statistical formulations

➔ e.g. Einstein (1950), Sun & Donahue (2000)

Selection and adaption of bedload transport formulas

General considerations:

- Formulae often derived from empirical data obtained in *laboratory flumes* under *certain (controlled) conditions*
- Often rather *limited data base* for formulae derivation

Conclusions:

➔ *No generally valid bedload* transport equations for all slopes, sediments or flow conditions!

➔ *Range of applicability* of the formulae to be considered during application (see “Arbeitsbehelf Feststofftransport”)!

➔ Perform *selection and calibration* of formulae based on *field measurement data*!

Aims for BOKU iSed model development

Development of an integrated sediment transport and morphodynamics model

- Usage of the flow field as provided by coupling with external hydrodynamic models (2D and 3D)
- Calculation of nonuniform sediment transport with unlimited number of grain size fractions
- Consideration of an unlimited number of bed layers
- Calculation of morphodynamics and sorting processes
- Separate implementation of suspended sediment and bedload transport (processes can be calculated independently of each other)

iSed – suspended sediment transport I

- Transport governed by an advection-diffusion equation (evaluated for every grain fraction) :

$$\frac{\partial c}{\partial t}+\frac{\partial(u_1 c)}{\partial x_1}+\frac{\partial(u_2 c)}{\partial x_2}=\frac{\partial}{\partial x_1}\left(K_t\frac{\partial c}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(K_t\frac{\partial c}{\partial x_2}\right)+\left(s_{dep}-s_{ero}\right)$$

- Solution by applying a generalized Finite Volume Method on control volumes of arbitrary shape (different mesh types in different hydrodynamic models)
- Exchange with the river bed modelled by sedimentation and erosion fluxes (source and sink terms)

iSed – suspended sediment transport II

- Deposition flux according to Van Rijn (1984):

$$s_{dep} = w_{ci} \frac{c_i}{F_i} \qquad F_i = \frac{\left(\frac{z_{0i}}{h}\right)^{Z_i^{*'}} - \left(\frac{z_{0i}}{h}\right)^{\beta_n}}{\left(1 - \frac{z_{0i}}{h}\right)^{Z_i^{*'}} \left(\beta_n - Z_i^{*'}\right)}$$

- Erosion flux according to Garcia and Parker (1991):

$$s_{ero} = w_{ci} p_i E_{sk,i} \qquad E_{sk,i} = \frac{A\left(\lambda Z_{mi}\right)^5}{1 + \frac{A}{0,3}\left(\lambda Z_{mi}\right)^5}$$

iSed – bedload transport

- Four equations for nonuniform bedload transport: Meyer-Peter/Müller (1948), van Rijn (1984), Egiazaroff (1965), Hunziker (1995)
- Meyer-Peter/Müller equation – nonuniform formulation (ATV-DVWK, 2003):

$$q_{si} = p_i c_{MP} \sqrt{\frac{\rho_s - \rho}{\rho} g d_i^3} \left[\left(\frac{d_i}{d_{ref}} \right)^{\alpha} \frac{u^{*2}}{\frac{\rho_s - \rho}{\rho} g d_i} - \theta_c \right]$$

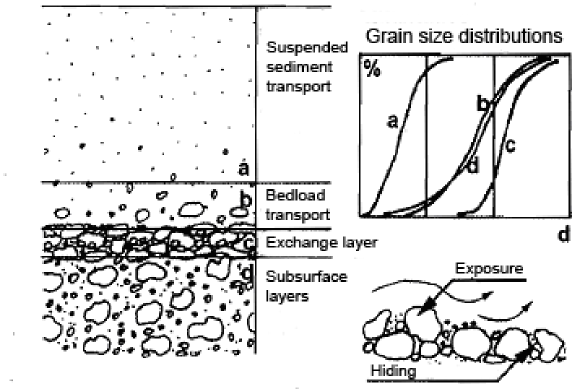
p_i … Anteil der Kornfraktion i
d_{ref} … Referenzkorndurchmesser (=d_m)
α … Expositionskorrekturkoeffizient

iSed – bed evolution and sorting

- Exner equation for calculation of bed evolution considering bedload and suspended sediment transport:

$$\left(1-n_p\right)\frac{\partial z_i}{\partial t}+\frac{\partial q_{si,x}}{\partial x}+\frac{\partial q_{si,y}}{\partial y}=s_{dep,i}-s_{ero,i}$$

- Sorting processes – exchange layer concept:

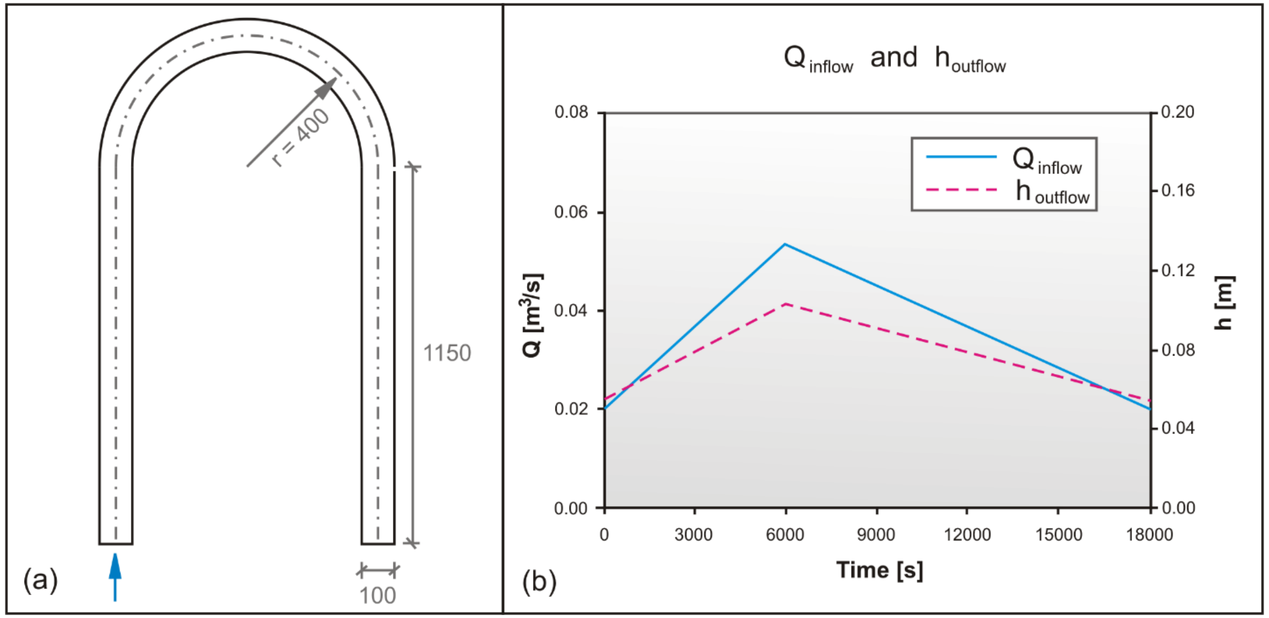


(modifiziert nach ATV-DVWK, 2003)

Thickness of the exchange layer: calibration parameter

Model validation – 180° bend

- Laboratory experiment by Yen and Lee (1995)



- Rectangular flume, bed slope I=0.0002
- Duration of the experiment: 300 min
- Underlying hydrodynamics: RSim-3D (polyhedral cells, 8 layers)

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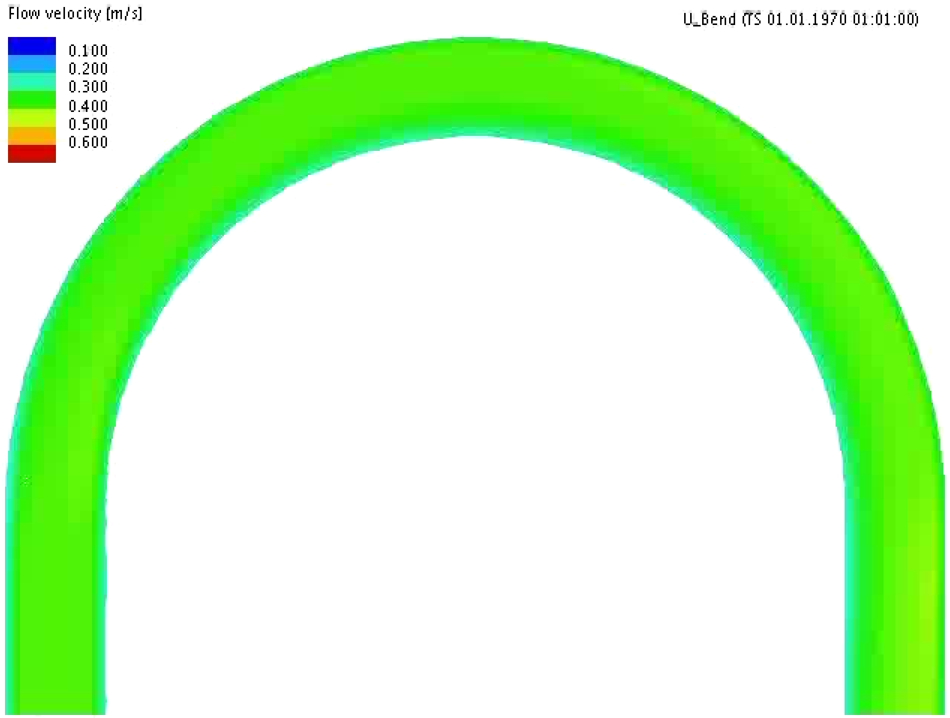

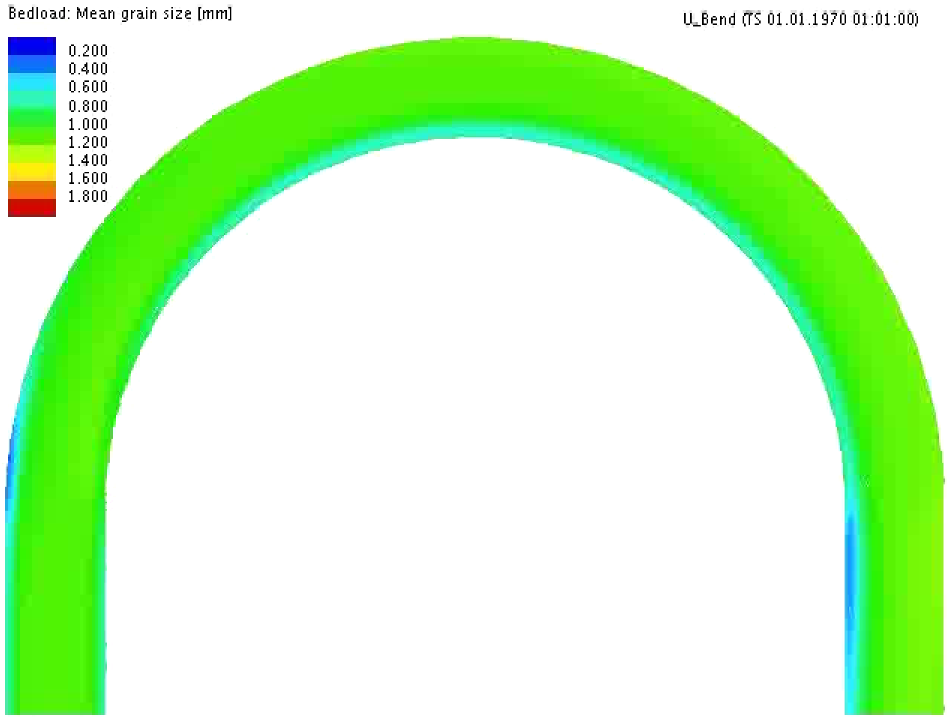

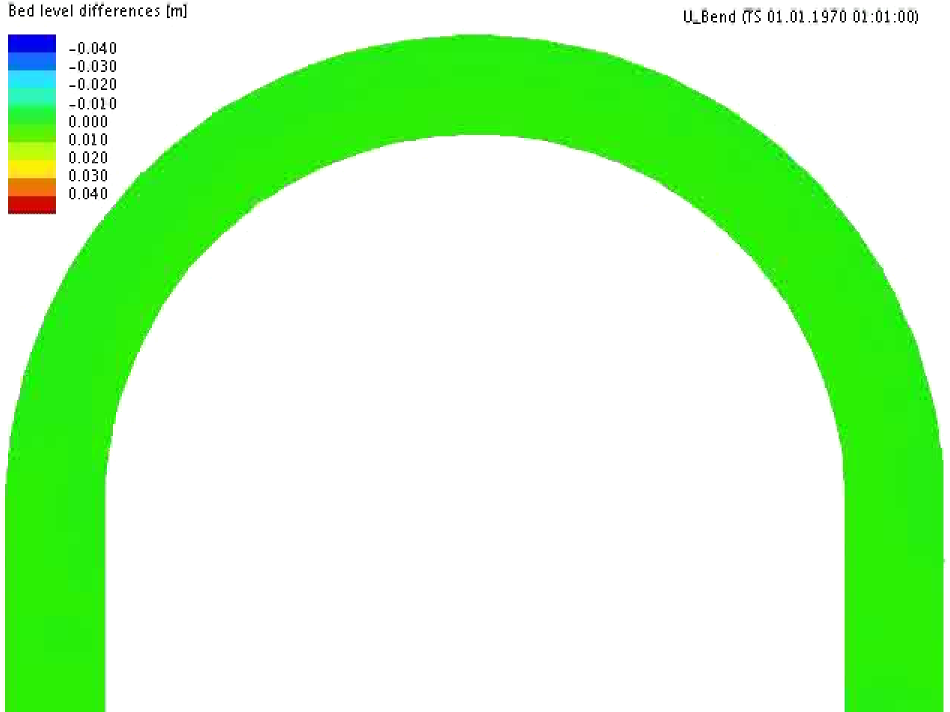

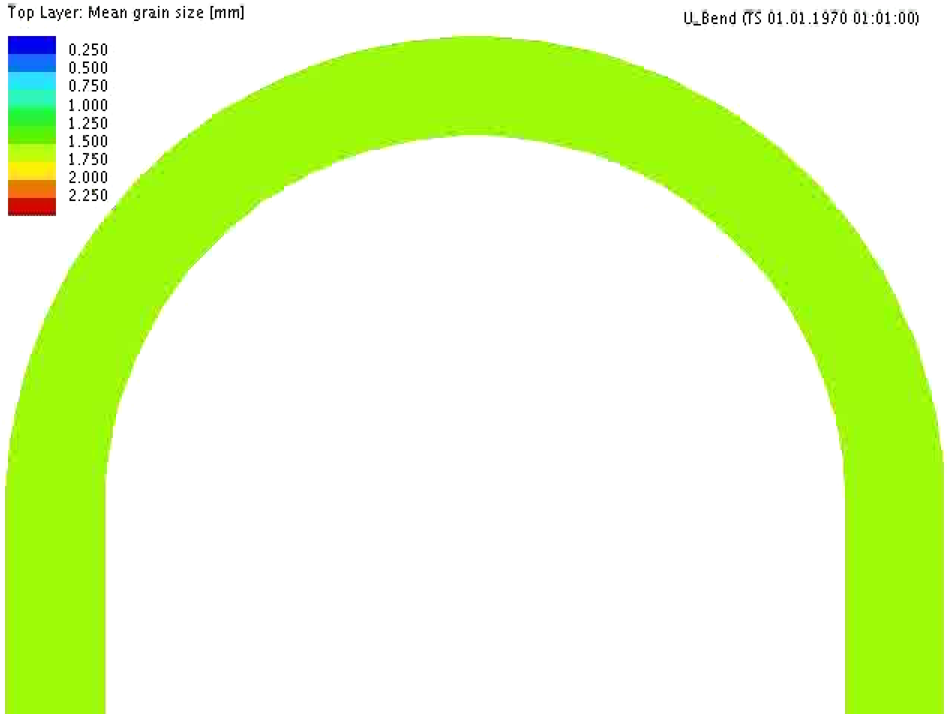

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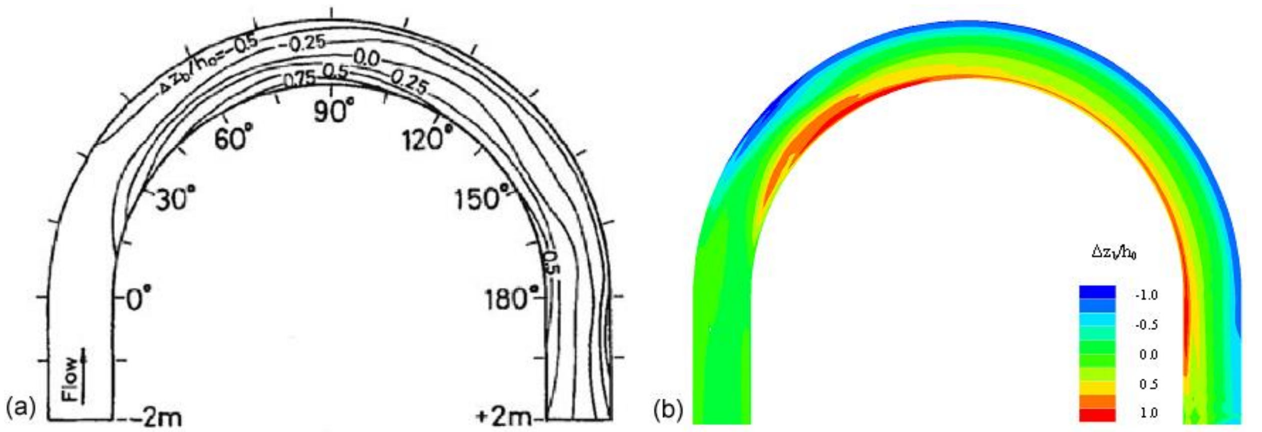
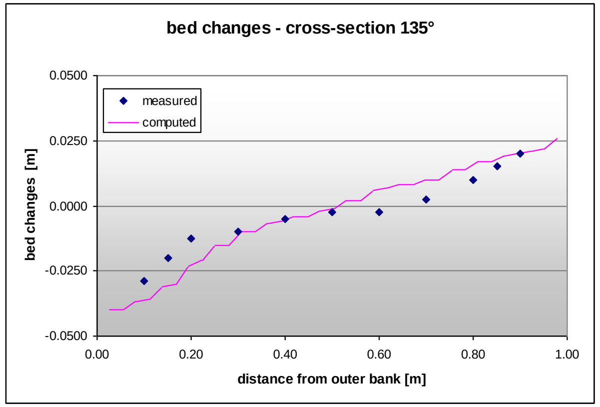
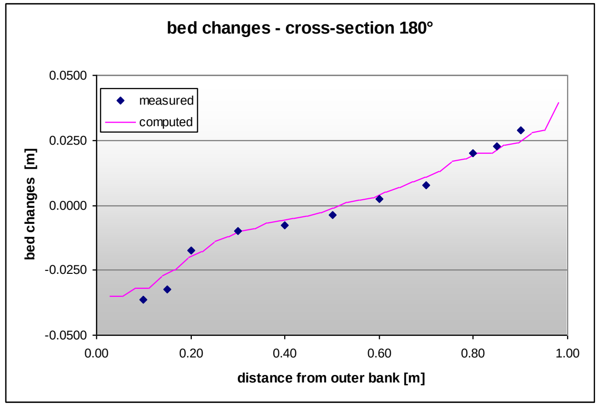
Model validation – 180° bend

Comparison of measured and modelled bed elevations:

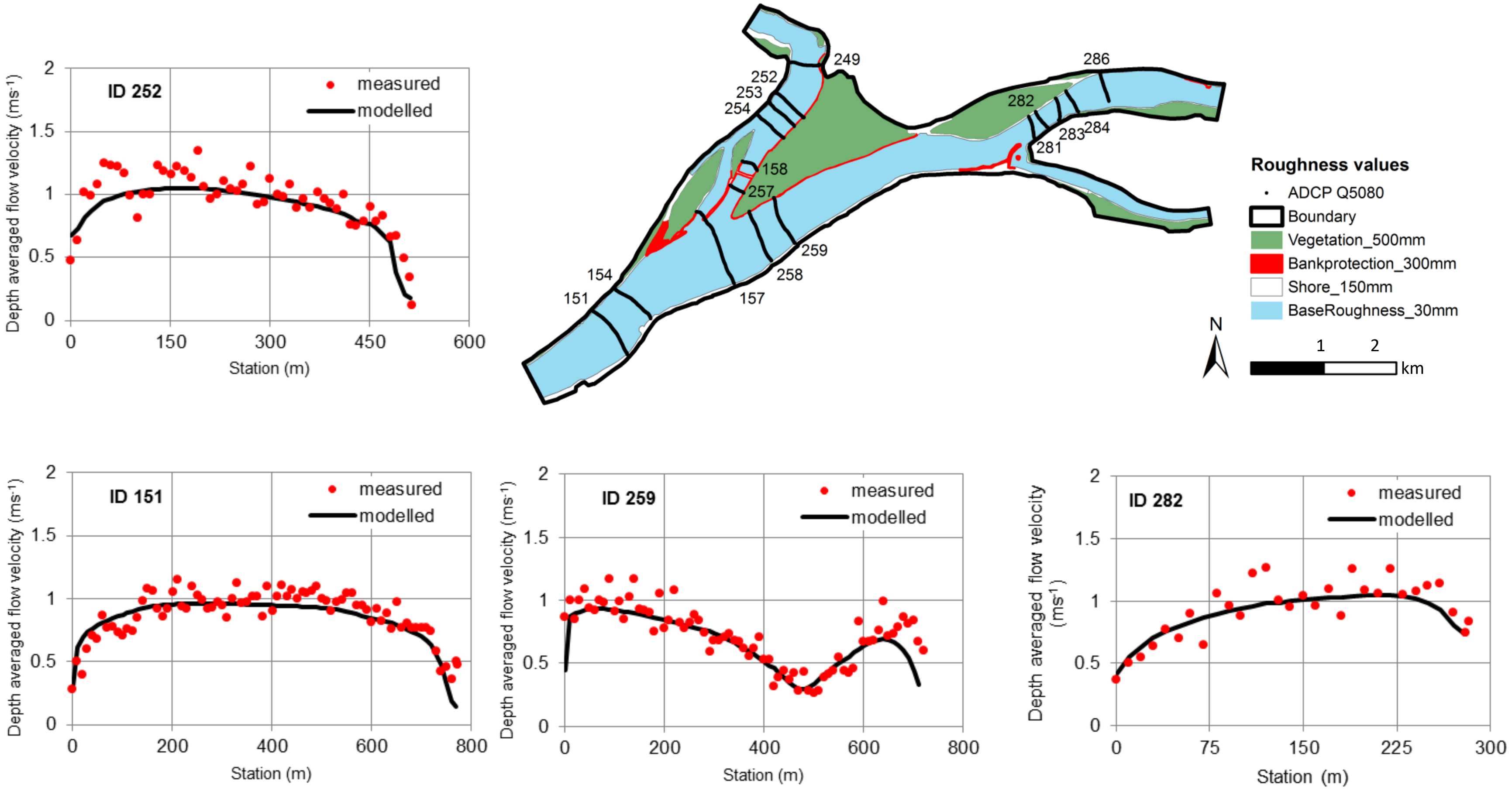






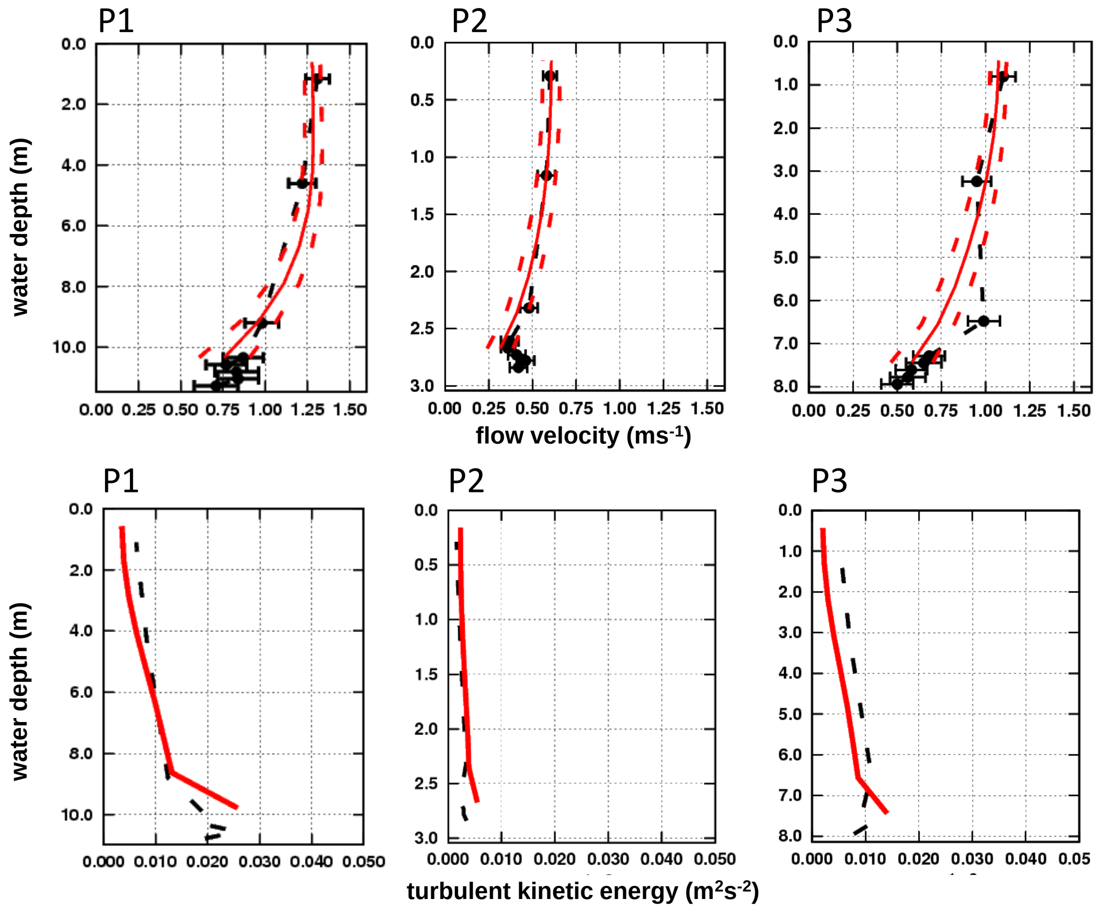
Calibration – 3D hydrodynamic model

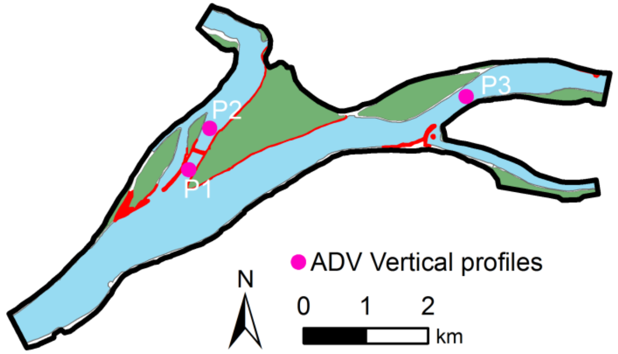
- Calibration by adjusting the roughness values (5080 m^3s^{-1})



Validation – 3D hydrodynamic model

- Validation of the roughness values at three independent discharges
  (2525 m^3s^{-1}, **4600 m^3s^{-1}**, 8360 m^3s^{-1})





measured
modelled

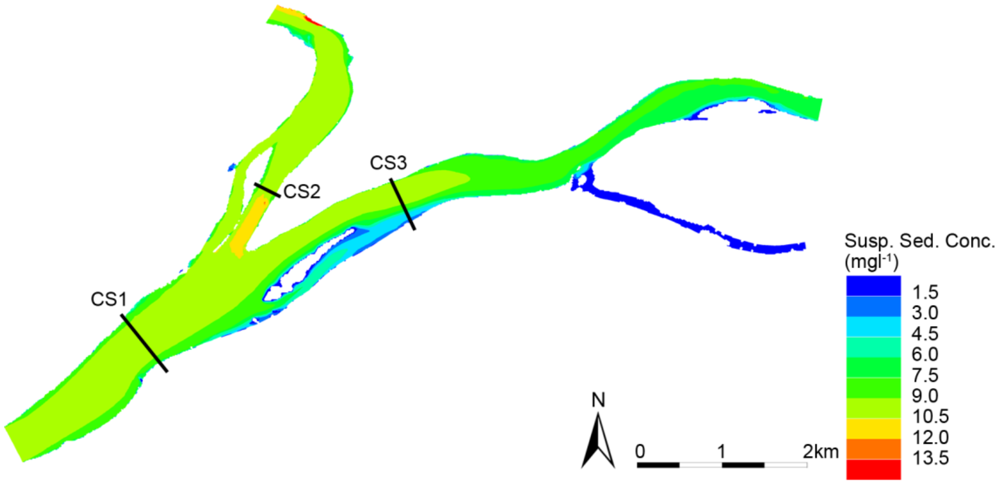
Application of the calibrated and validated model for all variants at two discharges:

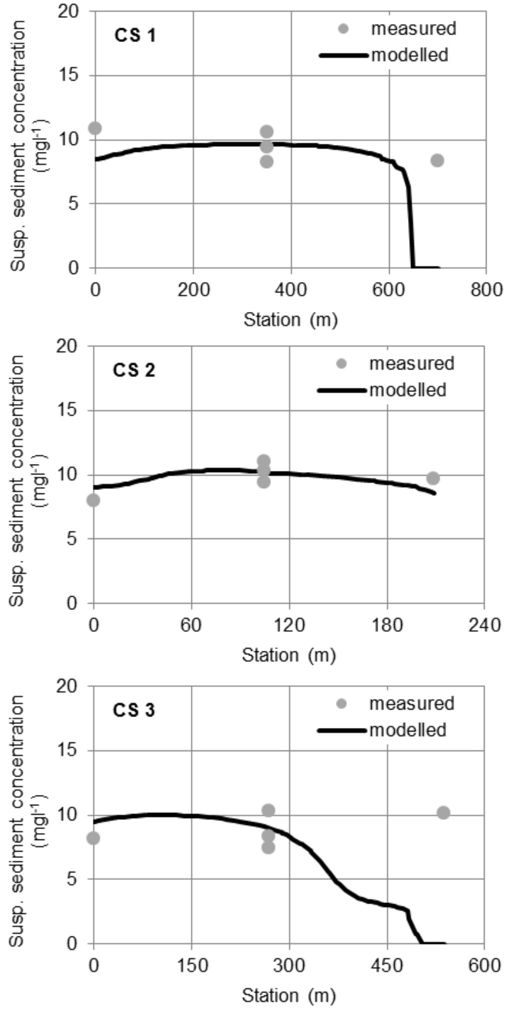
-) Individual extreme event
lower than RNQ: 1940 m^3s^{-1}

-) Corresponding discharge
to MQ: 5530 m^3s^{-1}

Calibration and validation: sediment transport model

- Calibration by adjusting erosion and deposition parameters
  (3800 m^3s^{-1} with a Suspended Sediment Concentration of 10 mgl^{-1})





- Validation of the erosion and deposition parameters
  at two independent discharges
  (5530 m^3s^{-1} with S.S.C. of 30 mgl^{-1}, 3840 m^3s^{-1} with S.S.C. of 12 mgl^{-1})

→ Application of the calibrated & validated model for all variants at a discharge of 5530 m^3s^{-1} (3 months steady-state simulation)

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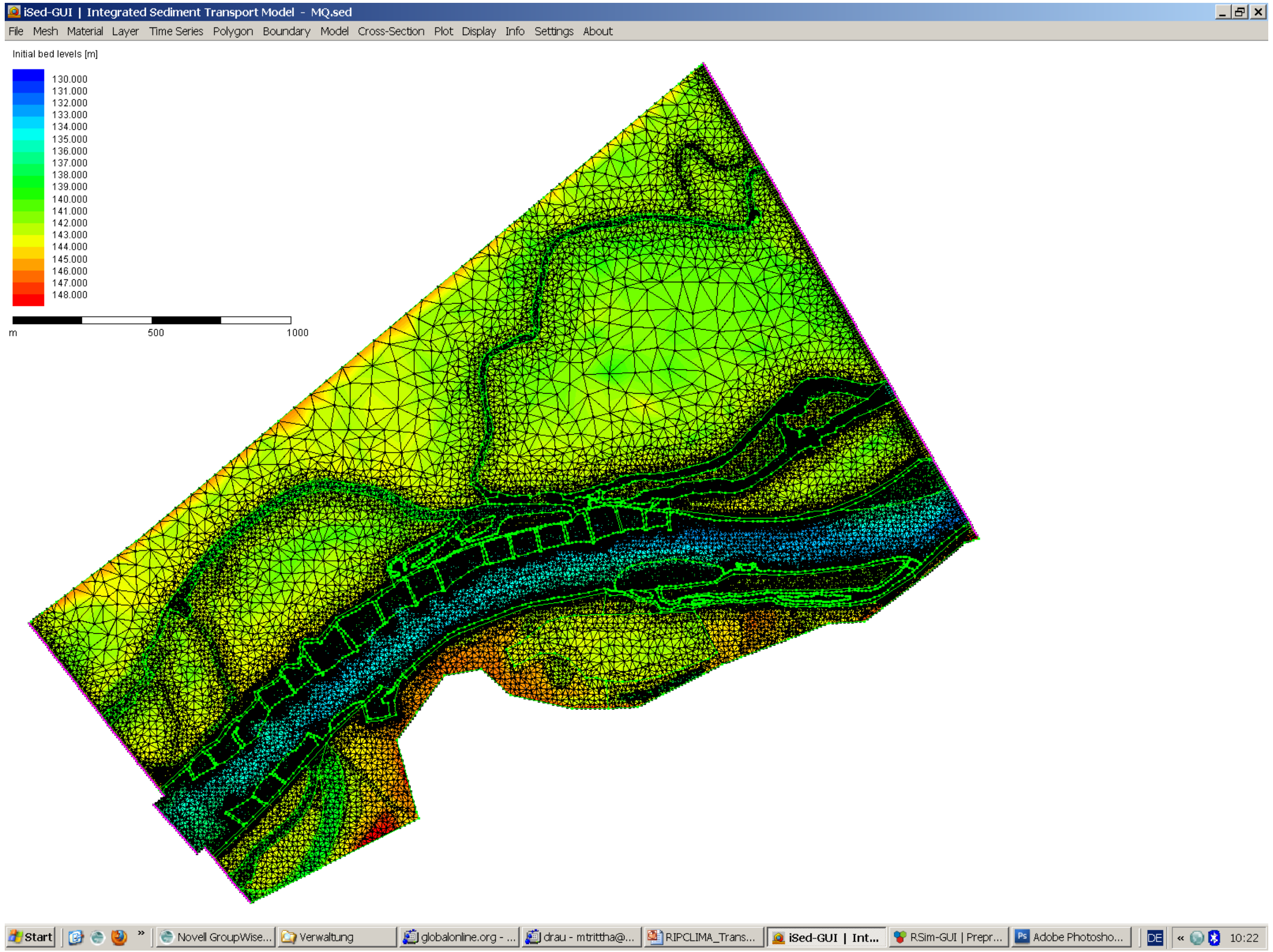
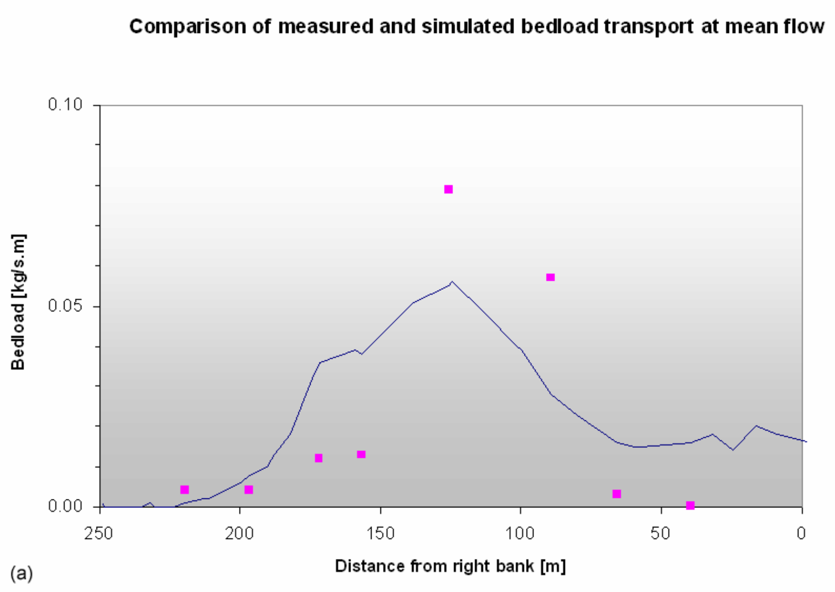
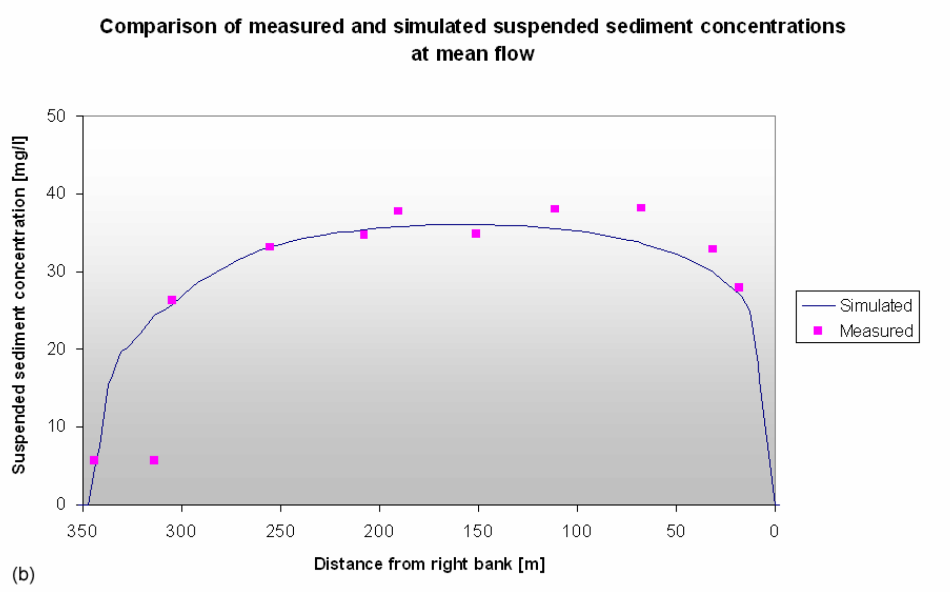
iSed – pilot reach Danube



Validation of simulation results based on measurement data

Bridge cross-section Hainburg

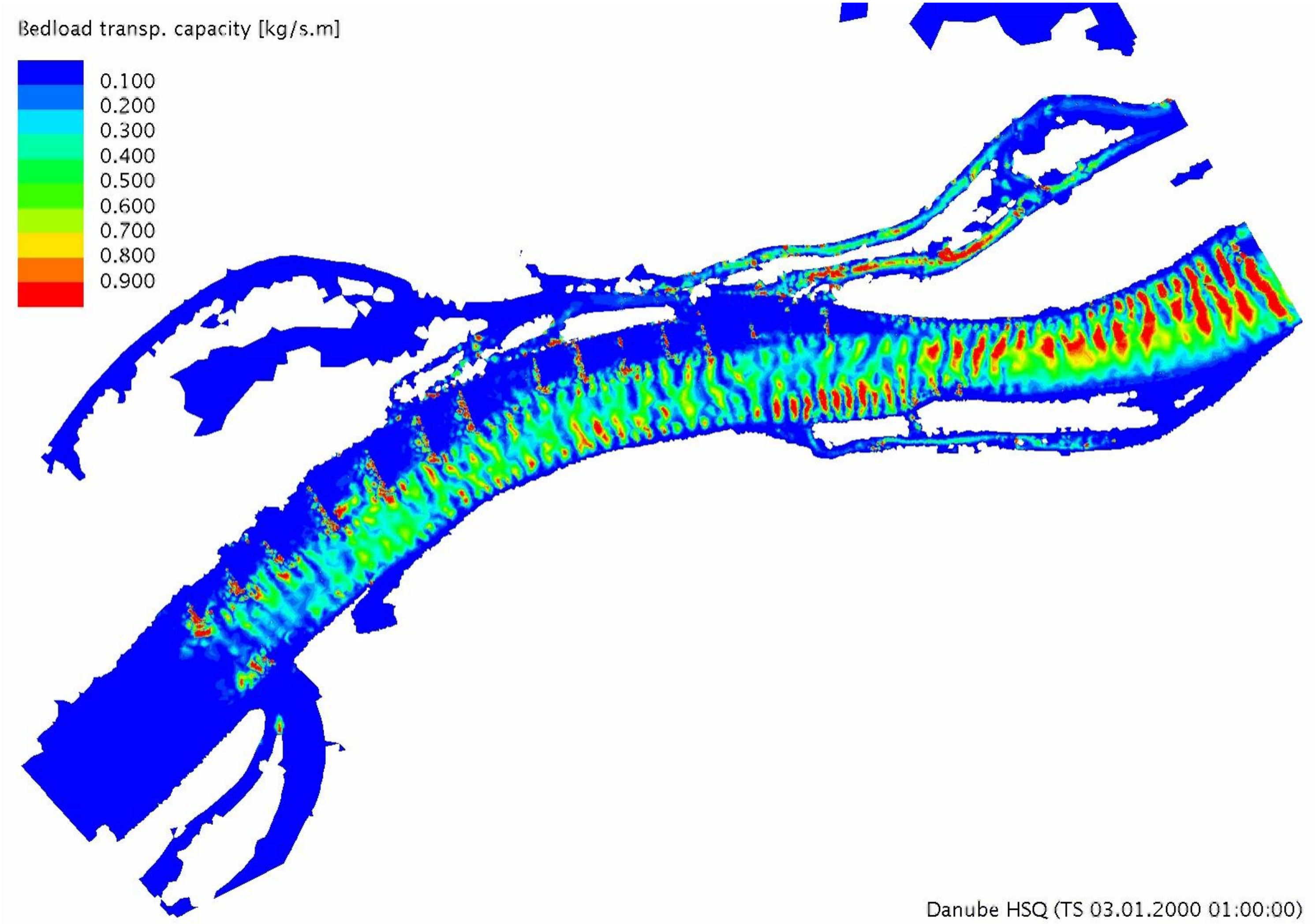




Bedload: high variability; model results represent mean values

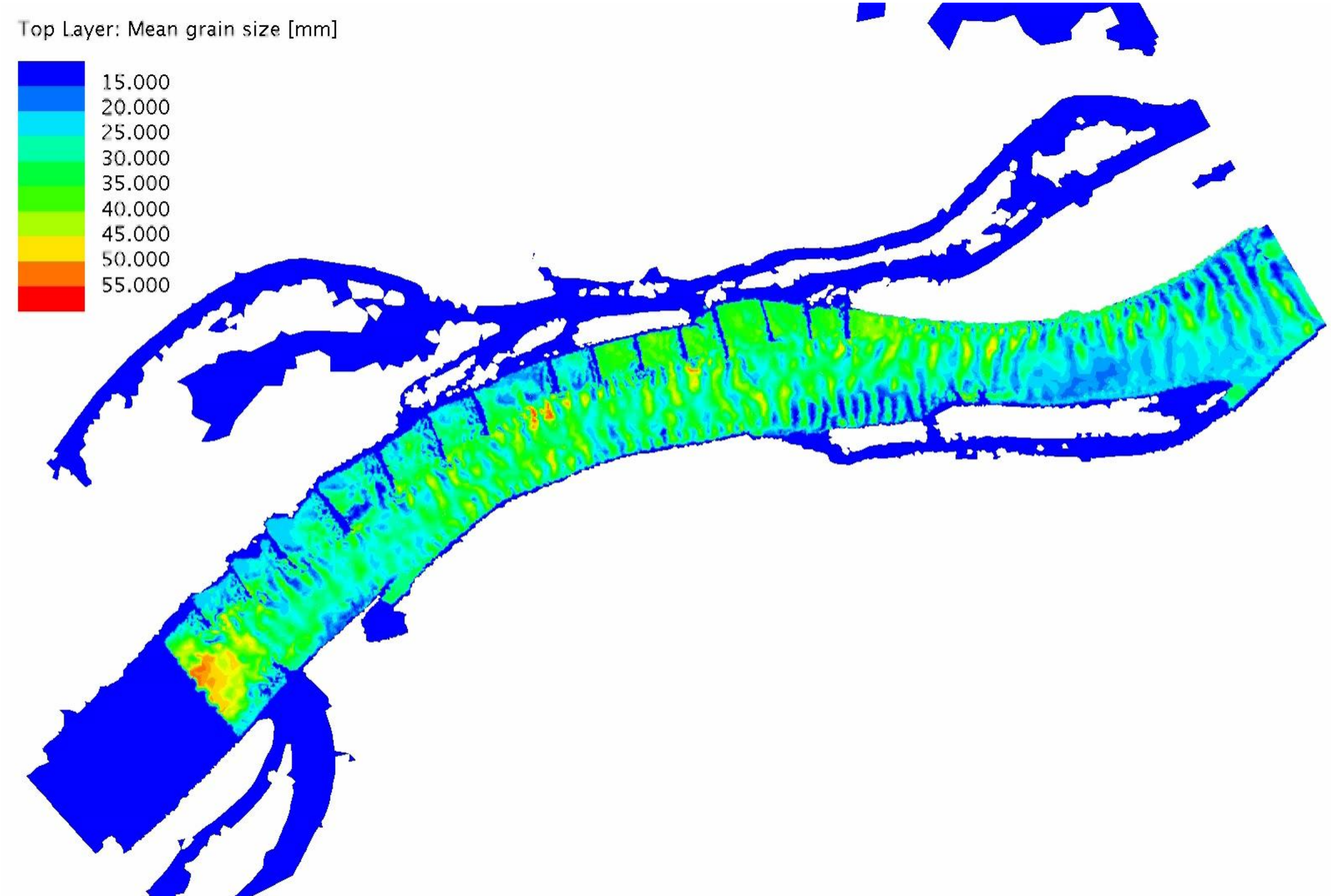
Suspended load: good agreement

Sediment transport in bed forms



Temporal variability of bedload transport rates

Sediment transport in bed forms



Temporal variability of the mean grain diameter

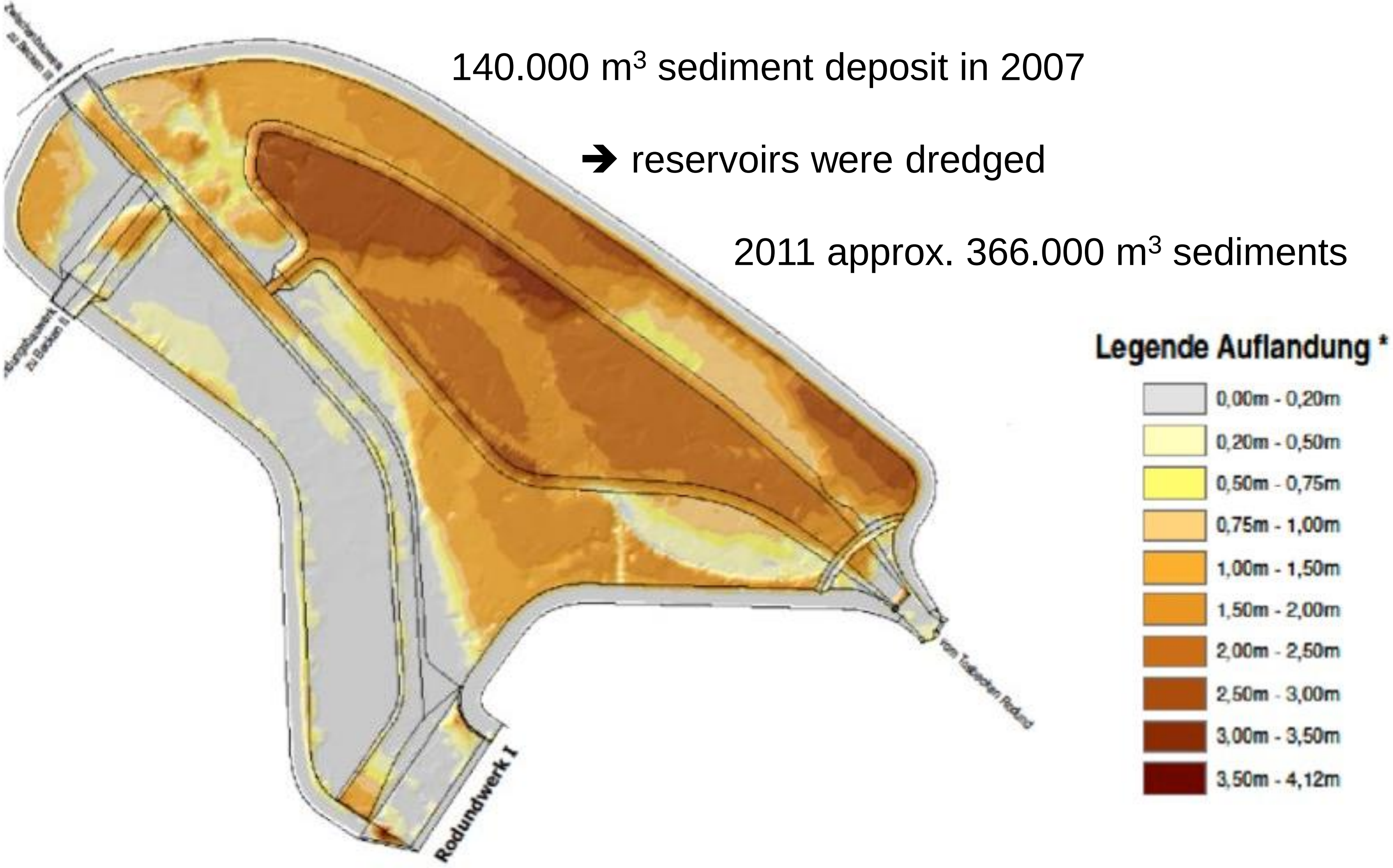
Reservoir example #1: Rodund

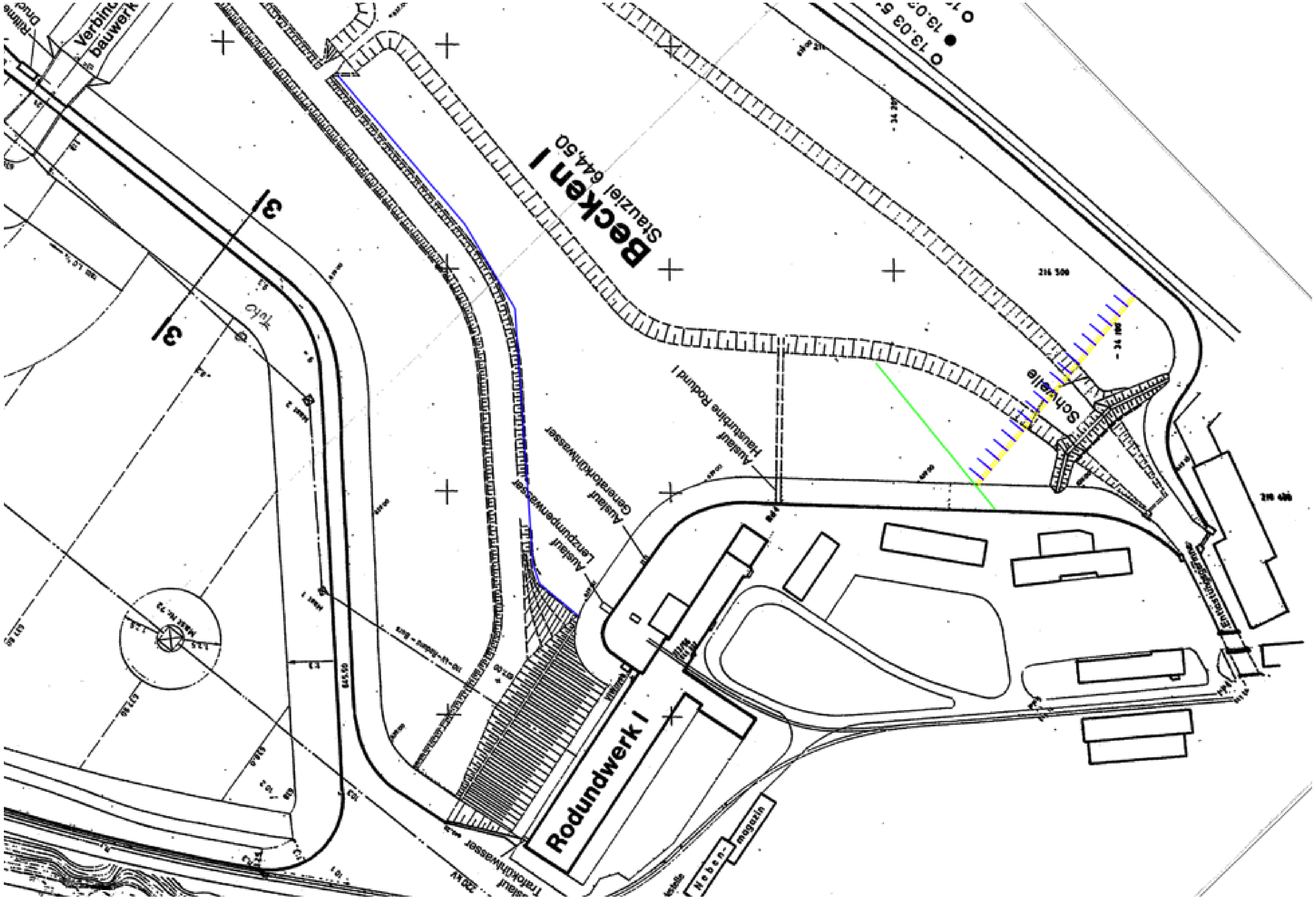
Sedimentation in reservoir 1

140.000 m^3 sediment deposit in 2007

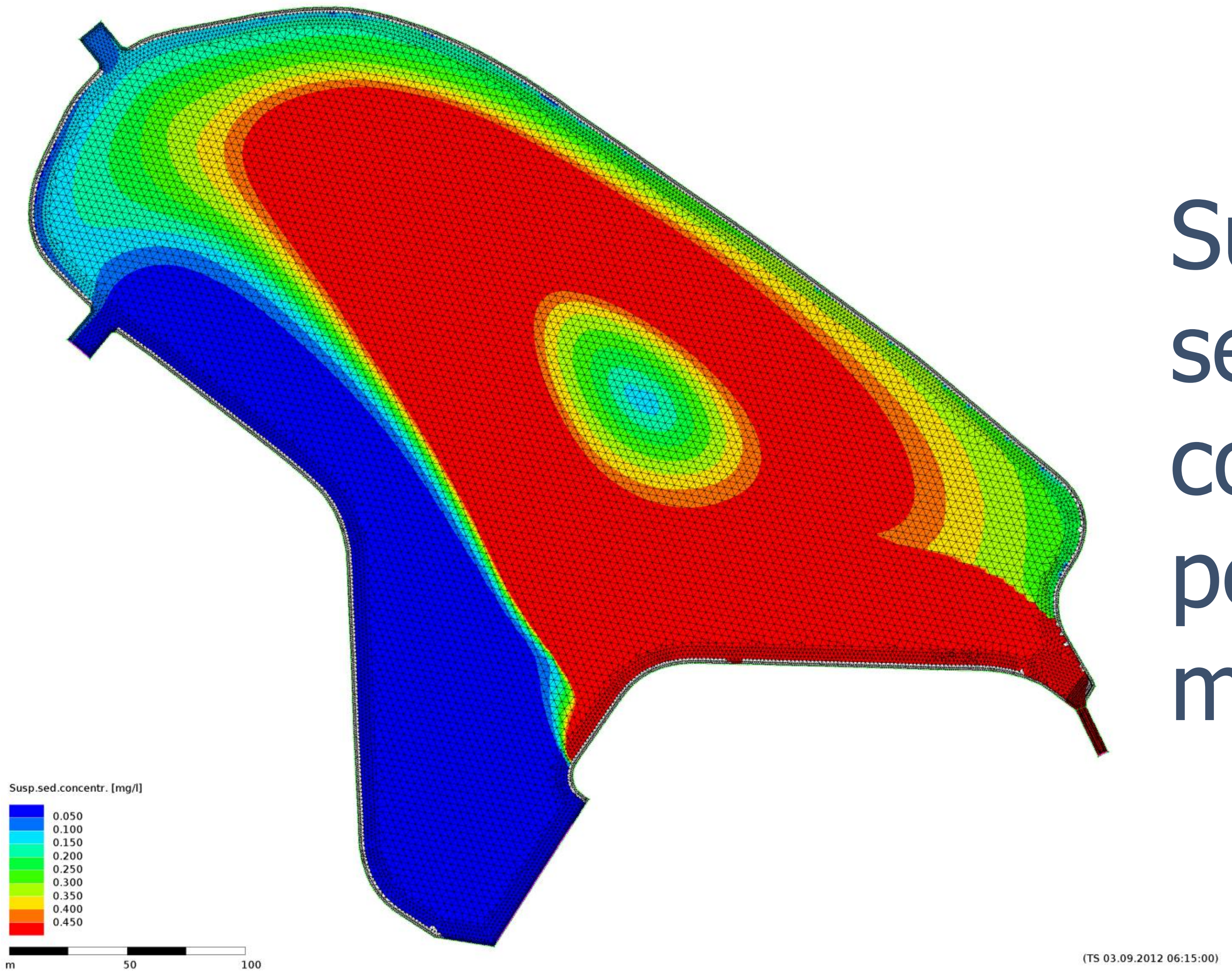
➔ reservoirs were dredged

2011 approx. 366.000 m^3 sediments





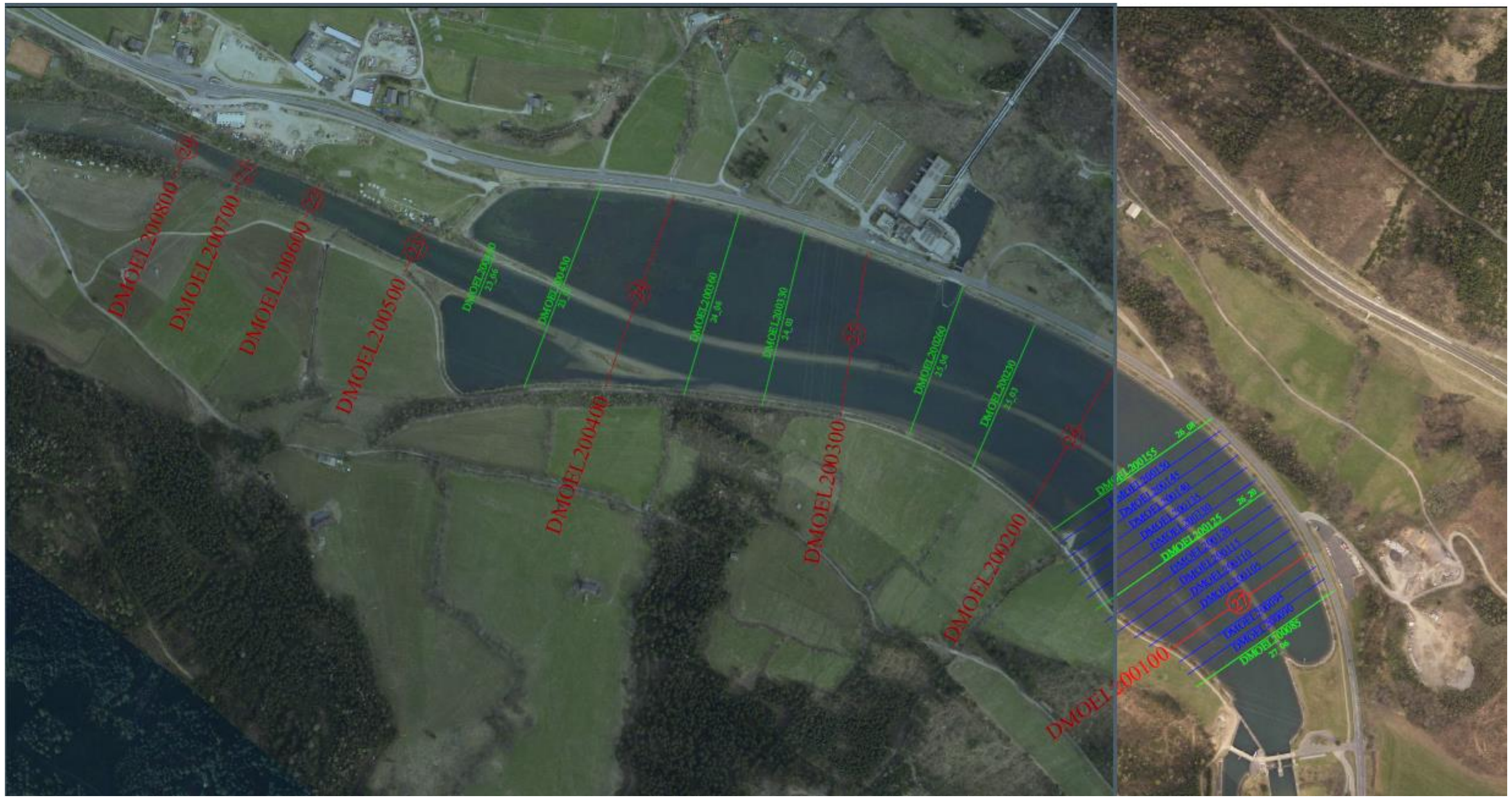
Synthesis: Proposal of measures to achieve concentrated sedimentation patches for reduced dredging effort



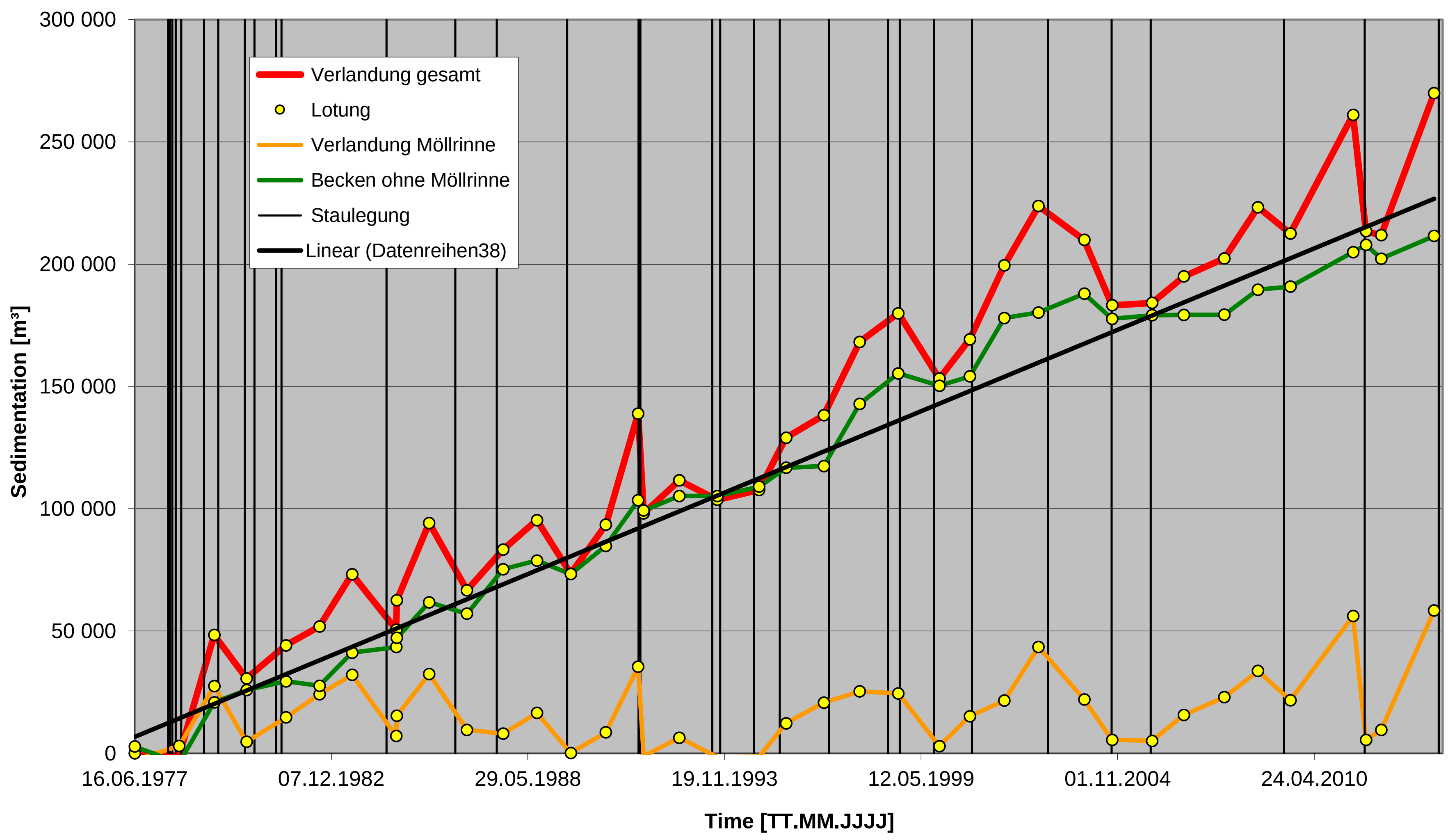
Suspended sediment concentrations per operation mode

Example Rottau

- Flushing
- Reservoir management



Sedimentation AB Rottau



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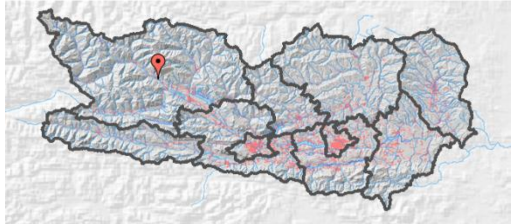
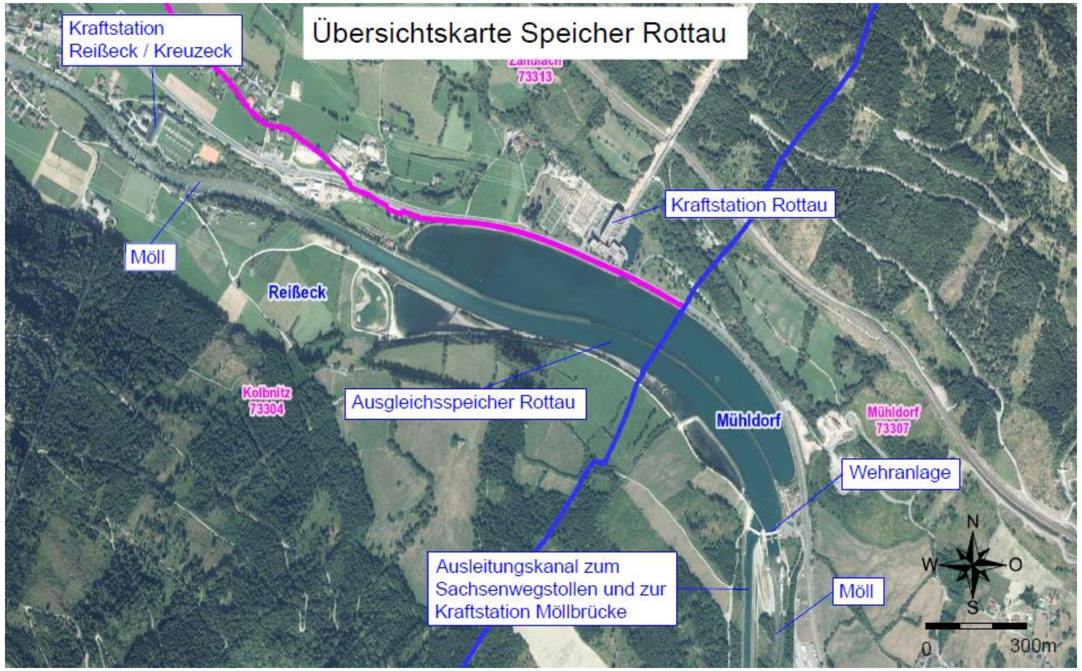
Model based study of flushing efficiency

Reservoir Rottau





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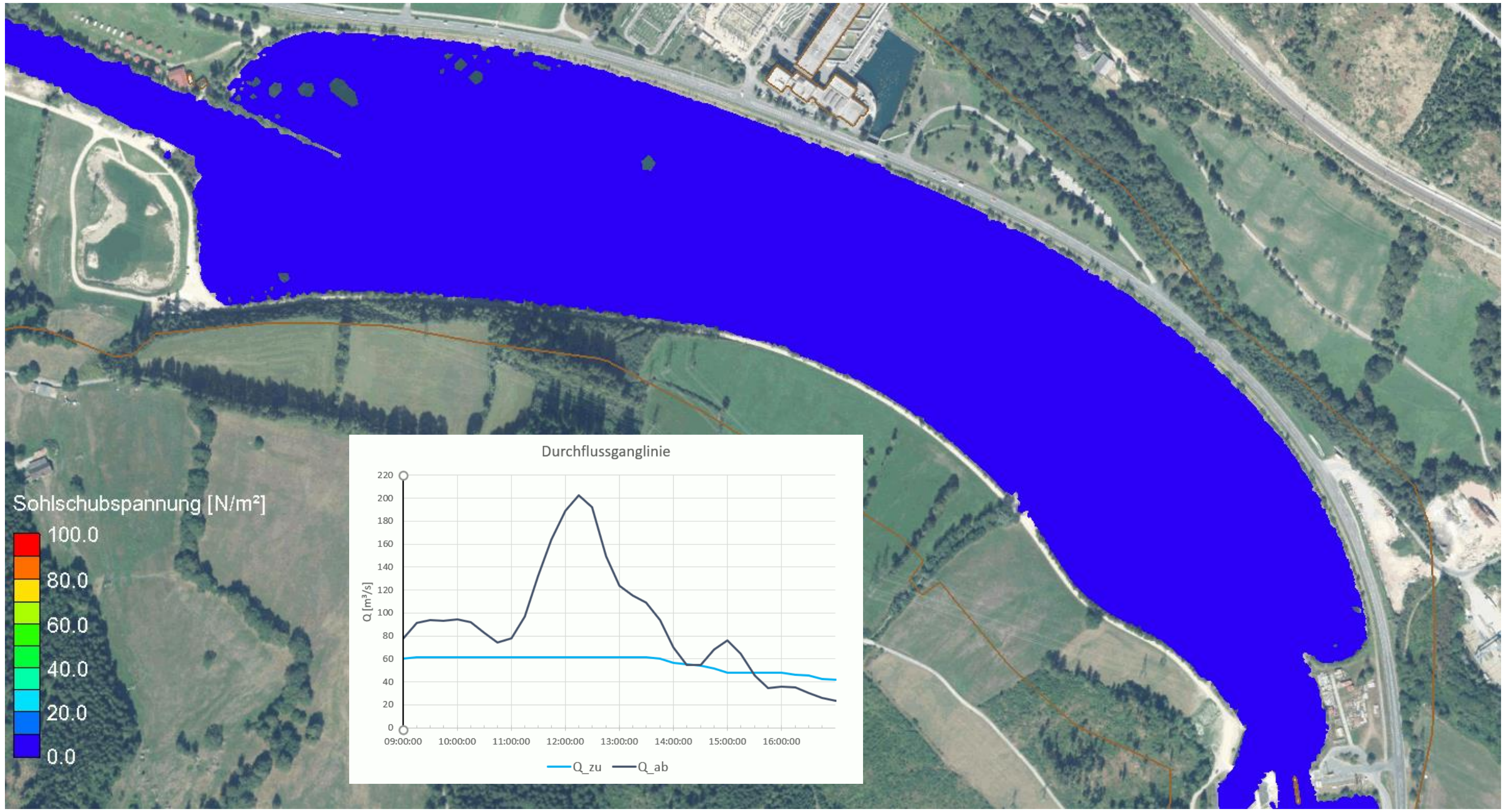
Model based study of flushing efficiency

Shear stress existing situation



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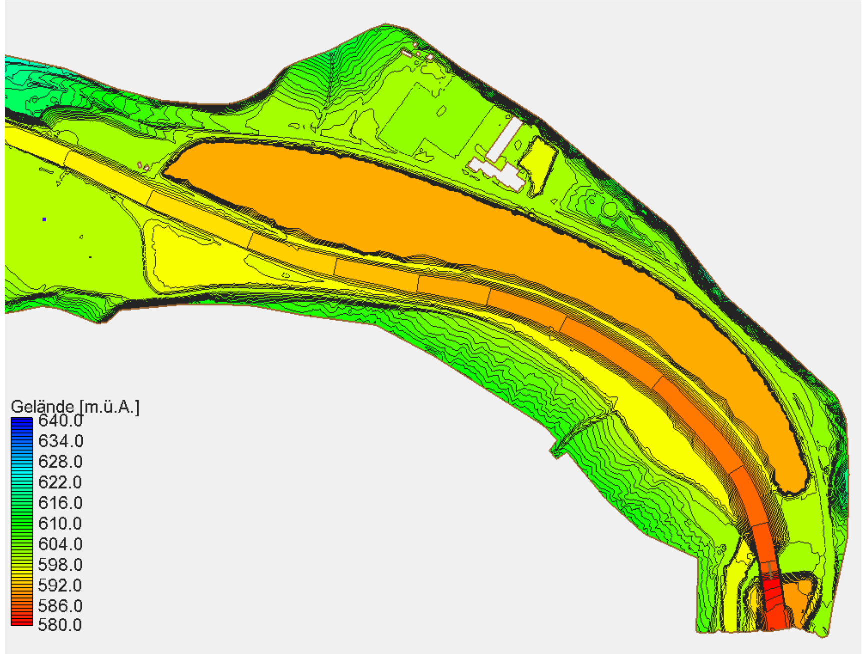
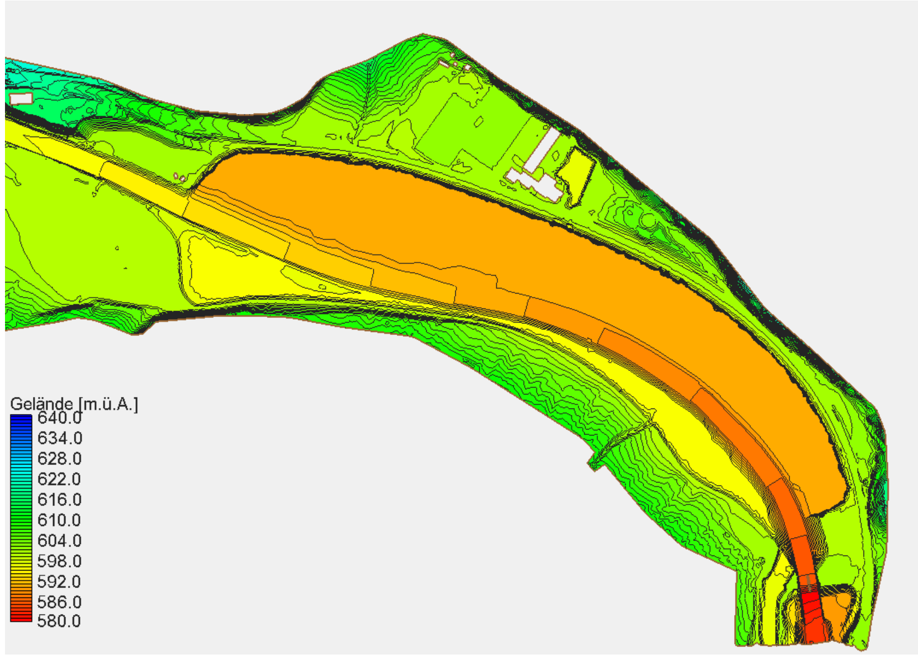
Model based study of flushing efficiency

Scenario 1: Taking out the guiding wall



With guiding wall

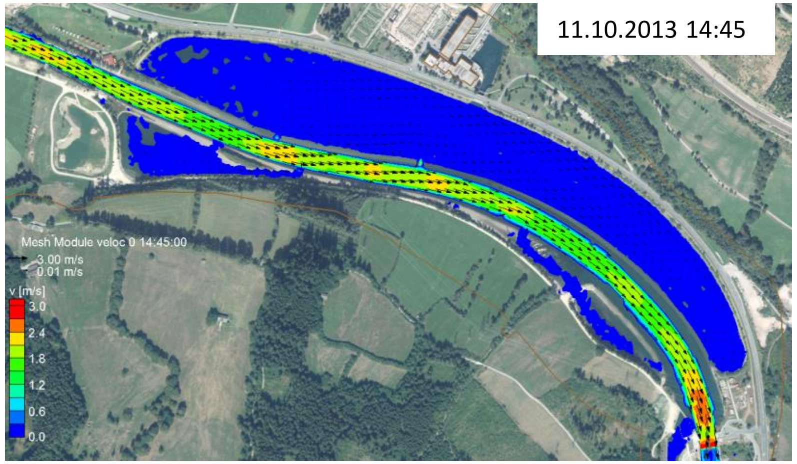


Without guiding wal

Model based study of flushing efficiency

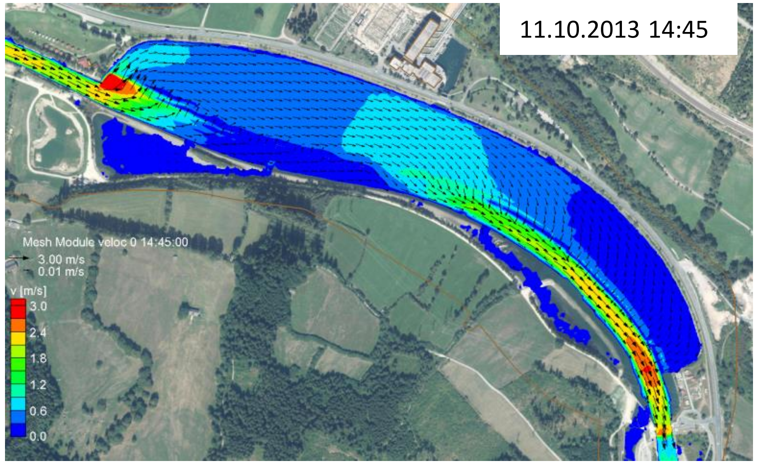
Comparison of existing situation with scenario 1

Model with guiding wall



- Flow velocities of 1.5 – 2.4 ms^{-1} at free flowing discharge in the river channel

Model without guiding wall, scenario 1



- Flow velocities of up to 0.9ms^{-1} in the reservoir
- Significant reduction of flow velocities in the upper part of the reservoir

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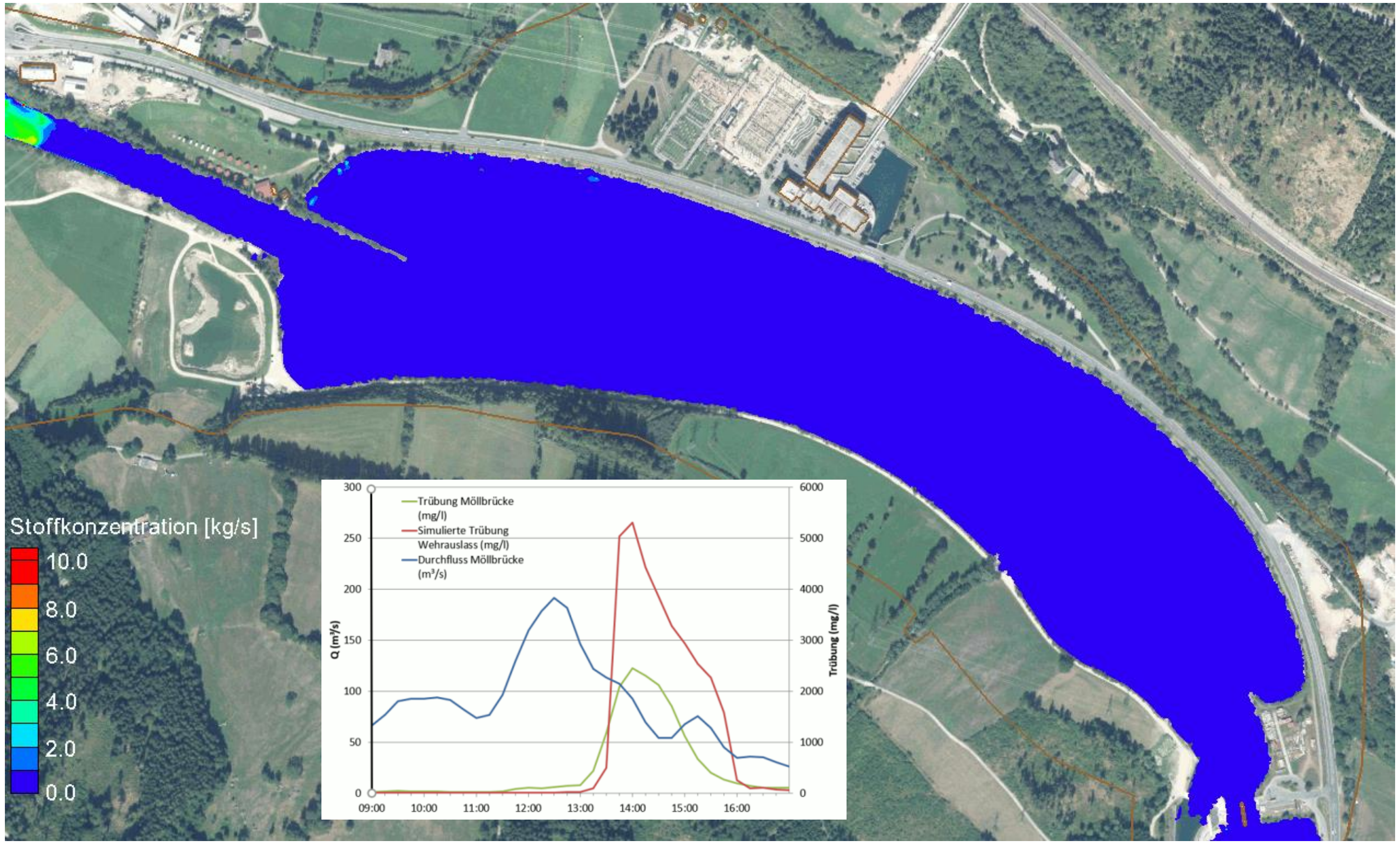
Model based study of flushing efficiency

Suspended sediment concentration in the existing condition 11.10.2013 09:00 – 16:15



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Summary

- Sediment management is essential for reservoirs but also the downstream free flowing sections → there is a high sensitivity e.g. in Asian river basins
- Modelling is a basic instrument for reservoir design, optimisation and management
- Sediment transport is still a demanding subject but essential
- Physical modelling of sediment transport forms the basis for understanding fundamental processes → the larger the scale the better the results
- In many complex reservoir configurations and detailled studies physical modelling is still needed in order to analyse sedimentation, sediment continuity and remobilisation
- Numerical modelling gains increasing importance and capabilities and is used to study the basic configurations and scenarios (the most promising scenarios often have to be tested and improved in physical models)
- Numerical models are only as good as the used formulas AND the data that are used
- In future hybrid models will become more important by combining eg long reach and long term numerical modelling with physical modelling of detailled scenarios and solutions

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Many thanks for your attention!

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1D - sediment transport models

	BASEMENT	CCHE1D	FLORIS2000	FLUVIAL-12	HEC-6	HEC-RAS4.1	MIKE11	MORMO	SETRAC	SOBEK-River	SRH-1D	WASPI-HEC6
Hersteller der Software												
Nichtkommerziell/Kommerziell	N	N	K	N	KN	N	K	N	N	K	N	K
Unterstützte Betriebssysteme												
UNIX												
Linux	x											
Windows (DOS)	x	x	x	x	x	x	x	x	x	x	x	x
OS/2												
Feststofftransport												
Schwebstoff	x	x	x	x	x		x	x		x	x	x
Geschiebe	x	x	x	x	x	x	x	x	x	x	x	x
Modellkoppelung												
Gekoppelt/Ungekoppelt	U	U	G	K	U	K	K	U	U	U	U	U
Grafische Ausgabemöglichkeit												
Lageplan		x					x		x			
Längenschnitt		x	x	x	x	x	x		x	x	x	x
Querprofil		x	x	x	x	x	x		x	x	x	x
Verknüpfung mit Software												
CAD						x			x			x
GIS		x				x	x	x		x		
Schwebstoff												
Kohäsives Sediment		x	x	x	x		x			x	x	x
Nichtkohäsives Sediment	x	x	x	x	x		x	x		x	x	x
Geschiebe												
Schwebstoff/Geschiebe getrennt	x		x		x	x	x		x		x	x
Gesamttransport (total load)		x		x				x		x	x	
Kornfraktionen der Sieblinie												
Maximale Anzahl (Unbegrenzt)	U	20	10	8	16	20	U	25	U	3	U	16
Gewässersohle												
Anzahl Schichten (Unbegrenzt)	U	U	2	2	2	2	U	50	2	2	U	2
Deckschichtbildung berücksichtigt	x	x	x	x	x	x	x	x	x		x	x
Raumdiskretisierung												
FDM/FEM/FVM	V	D	V	D	D	D	D	D	D	D	D	D

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2D - sediment transport models

	BASEMENT	CCHE-2D	FLO-2D	FLUMEN	Hydro_GS-2D	Hydro_SS-2D	iSed	MIKE21C	SED-2D	TELEMAC-2D
Hersteller der Software										
Nichtkommerziell/Kommerziell	N	N	K	K	K	K	N	K	K	KN
Unterstützte Betriebssysteme										
UNIX				x			x			x
Linux	x			x			x			
Windows	x	x	x		x	x	x	x	x	x
OS/2										
Feststofftransport										
Schwebstoff	(x)	x		x		x	x	x	x	x
Geschiebe	x	x	x	x	x		x	x		x
Modellkoppelung										
Gekoppelt/Ungekoppelt	U	U	U	U	K	K	U	K	U	K
Grafische Ausgabemöglichkeit										
Lageplan		x	x	x	x	x	x	x	x	x
Längenschnitt		x	x		x	x	x	x	x	x
Querprofil		x	x		x	x	x	x	x	x
Verknüpfung mit Software										
CAD			x	x	x	x			x	
GIS			x	x	x	x		x	x	
Schwebstoff										
Kohäsives Sediment		x				x			x	
Nichtkohäsives Sediment	(x)	x		x		x	x	x	x	x
Geschiebe										
Schwebstoff/Geschiebe getrennt	(x)						x			
Gesamttransport (total load)		x		x	x			x		x
Kornfraktionen der Sieblinie										
Maximale Anzahl (Unbegrenzt)	U	8	U	2	1	5	U	16	1	1
Gewässersohle										
Anzahl Schichten (Unbegrenzt)	U	U	2	1	1	1	U	1	1	U
Deckschichtbildung berücksichtigt	x	x		x			x			
Raumdiskretisierung										
FDM/FEM/FVM	V	V	D	V	V	V	V	D	E	E

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3D - sediment transport models

	CFX	Delft3D	FLOW-3D	FLUENT	iSed	RSim-3D	SSIIM	TELEMAC-3D
Hersteller der Software								
Nichtkommerziell/Kommerziell	K	K	K	K	N	N	N	KN
Unterstützte Betriebssysteme								
UNIX	x		x	x	x	x		x
Linux	x	x	x	x	x	x	x	
Windows	x	x	x	x	x	x	x	x
OS/2							x	
Feststofftransport								
Schwebstoff	x	x	x	x		x	x	x
Geschiebe		x			x		x	
Modellkoppelung								
Gekoppelt/Ungekoppelt	K	K	K	K	U	K	K	K
Grafische Ausgabemöglichkeit								
Lageplan	x	x	x	x	x	x	x	x
Längenschnitt	x	x	x	x	x	x	x	x
Querprofil	x	x	x	x	x	x	x	x
Verknüpfung mit Software								
CAD	x		x	x				
GIS		x				x		
Schwebstoff								
Kohäsives Sediment		x						x
Nichtkohäsives Sediment	x	x	x	x	x	x	x	
Geschiebe								
Schwebstoff/Geschiebe getrennt		x			x		x	
Gesamttransport (total load)		x						
Kornfraktionen der Sieblinie								
Maximale Anzahl (Unbegrenzt)	U	99	1	U	U	8	U	1
Gewässersohle								
Anzahl Schichten (Unbegrenzt)	1	U	1	1	U	1	2	U
Deckschichtbildung berücksichtigt					x			
Raumdiskretisierung								
FDM/FEM/FVM	V	D	D	V	V	V	V	E

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