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Hydrologie und Glaziologie

Riverbed and surface composition adjustments in a gravel bed river subject to repeated sediment bypass tunnel

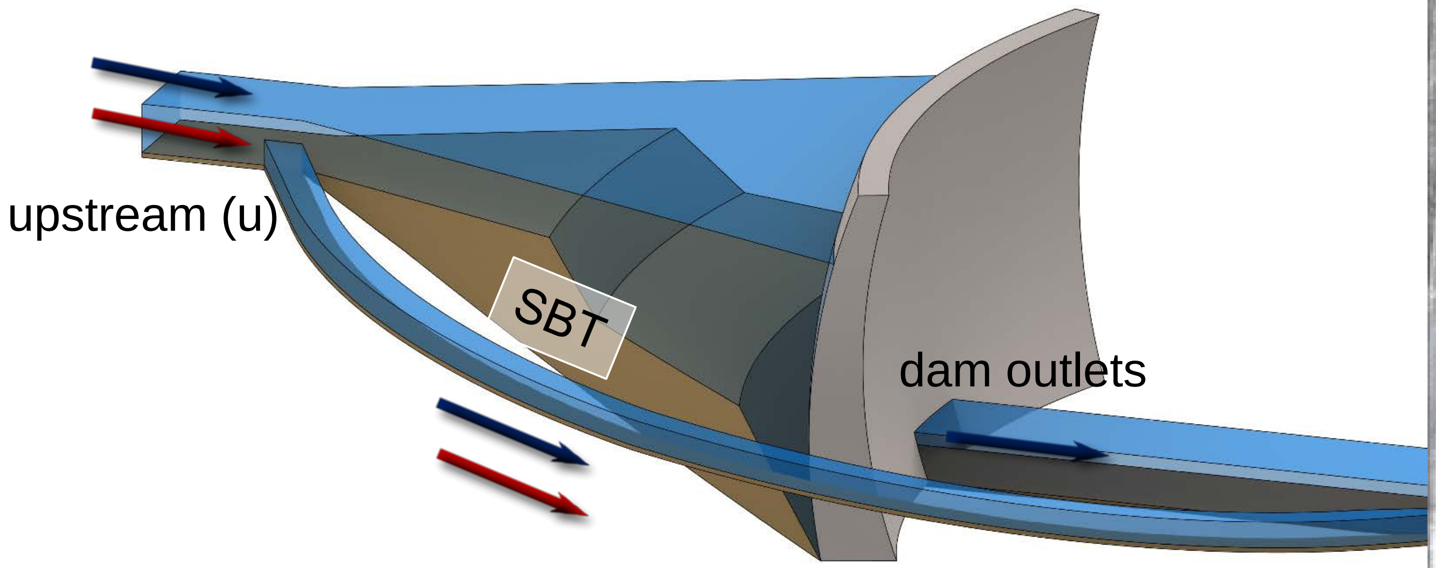
SCCER SoE Annual Conference 2018

14.09.2018

Sediment Bypass Tunnels (SBTs)

<u>Main aim of SBT's:</u>

- Route sediments around or through dams



Water discharge, Q_w

Bedload discharge, Q_b

Outlet structure of the Solis SBT (canton Grisons)

(Videos VAW)

Goals of this work

G1. Determine how much sediment and water are released by the SBT to the downstream reach.

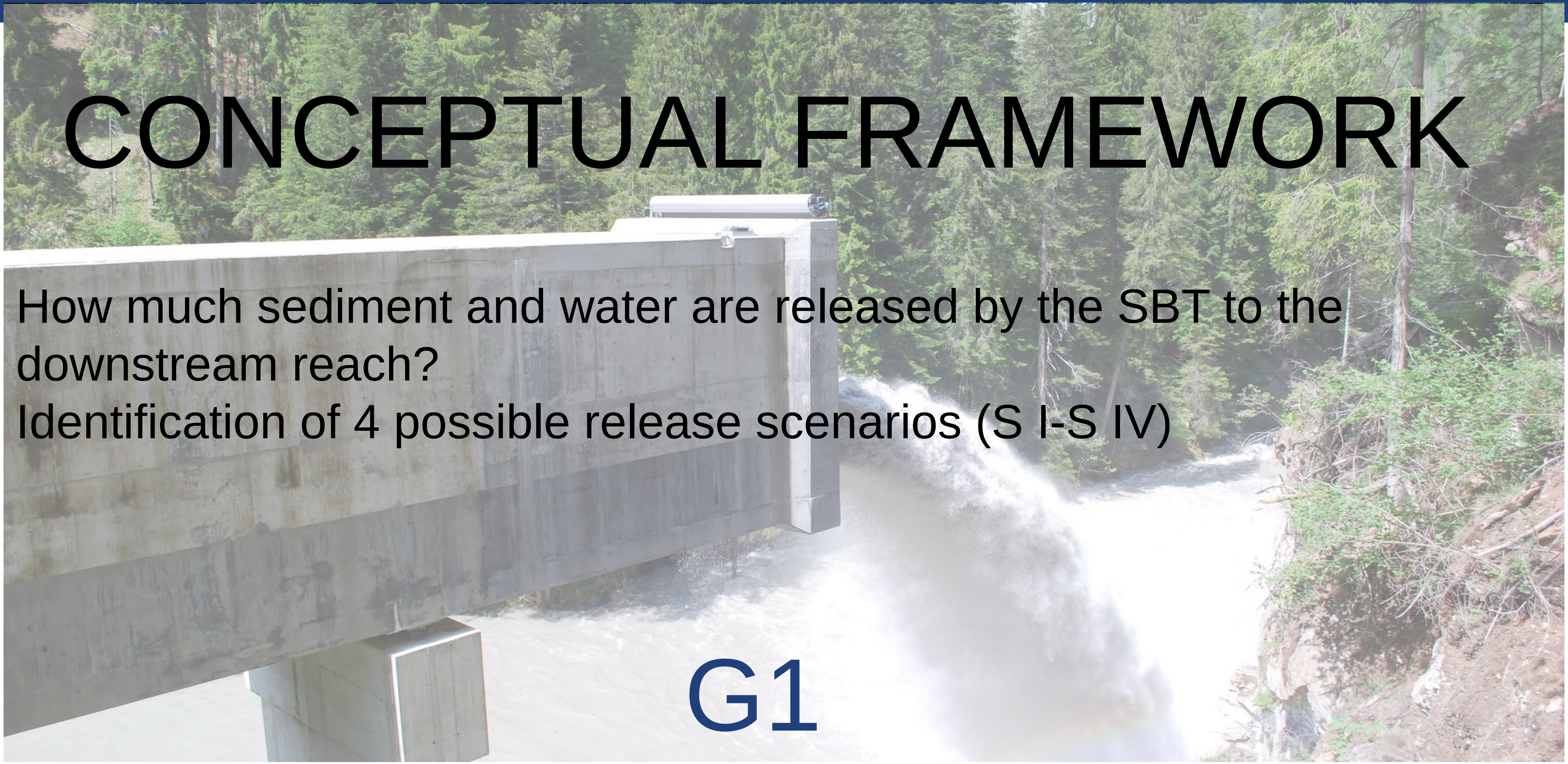
Development of a **conceptual framework** for the identification of possible release scenarios

G2. Quantify morphological variations in terms of riverbed and surface grain size distribution (GSD) in the downstream reach after repeated SBT operations on both short and long temporal scales.

CONCEPTUAL FRAMEWORK

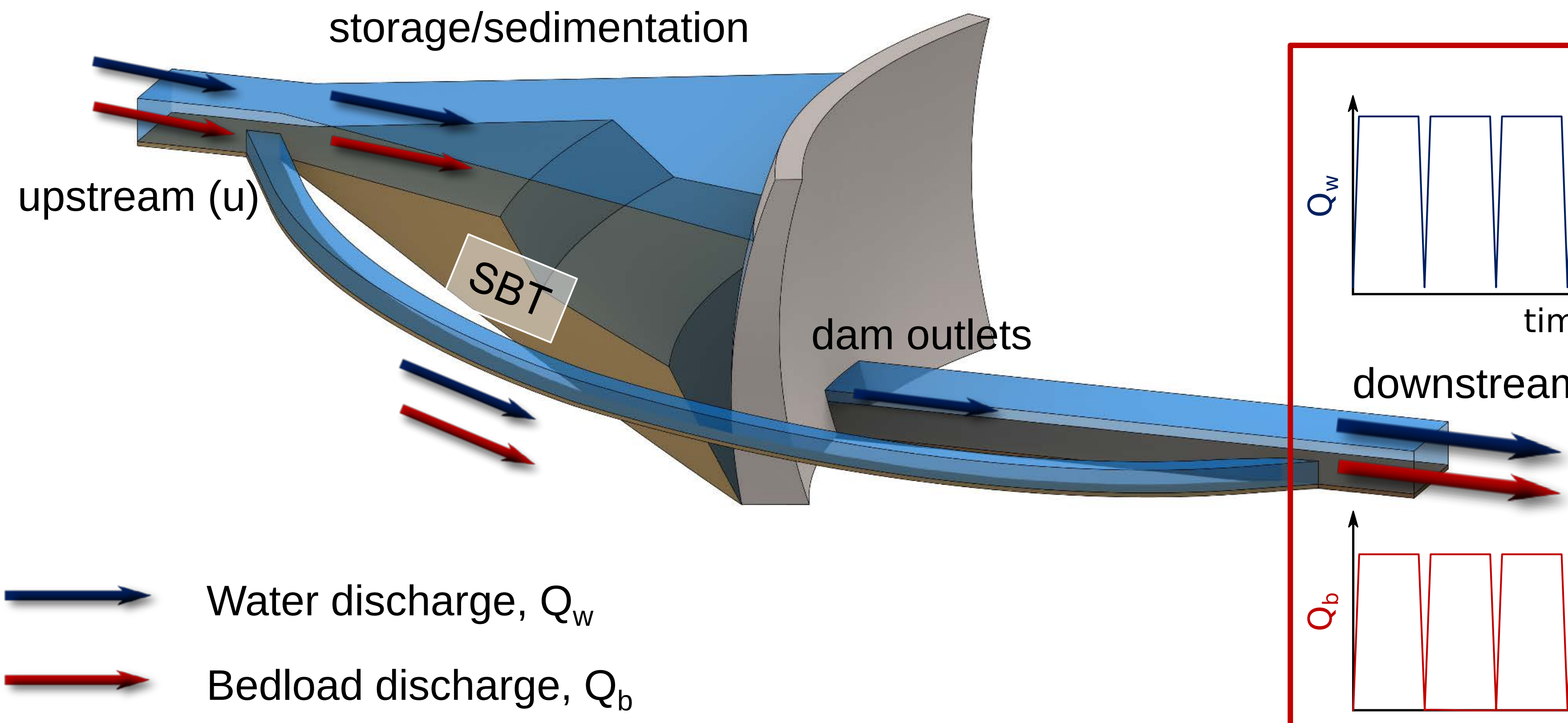
How much sediment and water are released by the SBT to the downstream reach?

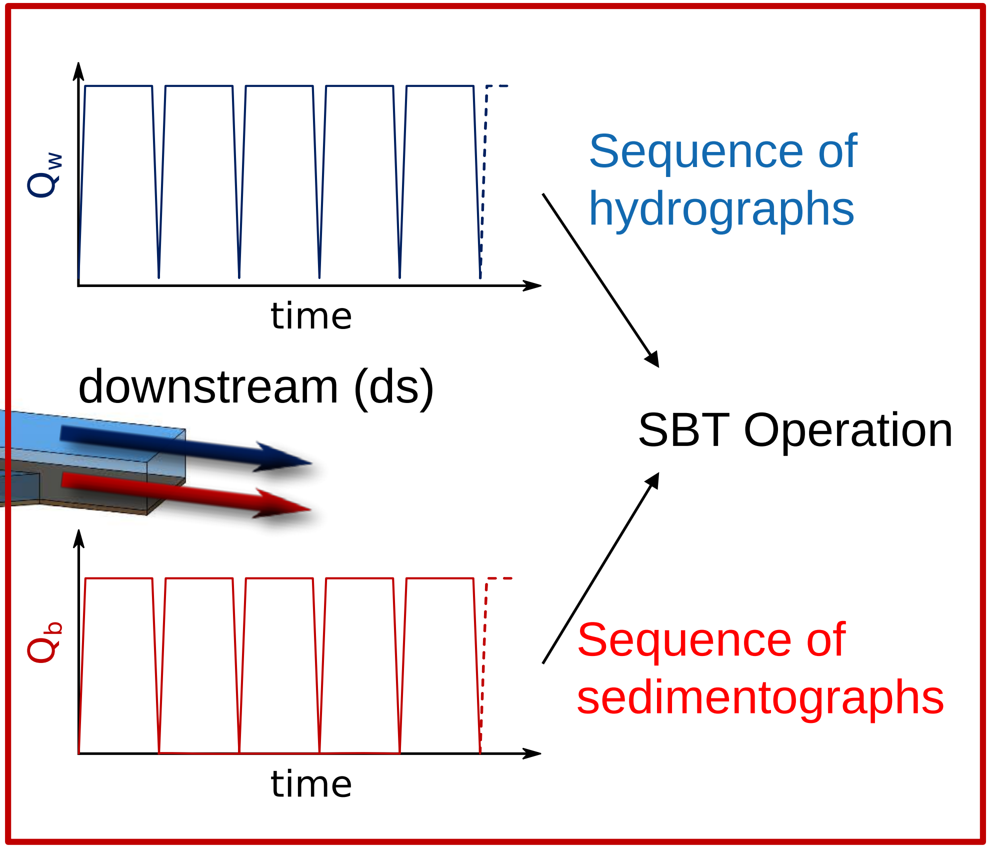
Identification of 4 possible release scenarios (S I-S IV)



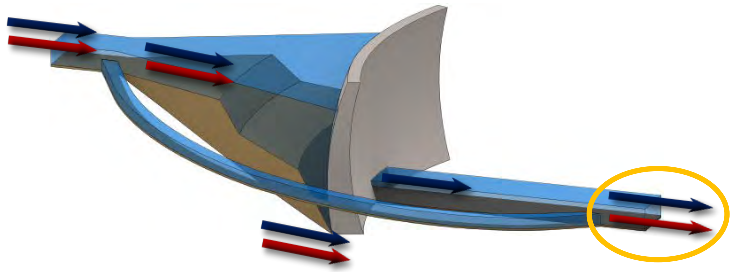
G1

Sediment Bypass Tunnels (SBTs) – conceptual framework (functioning scheme)

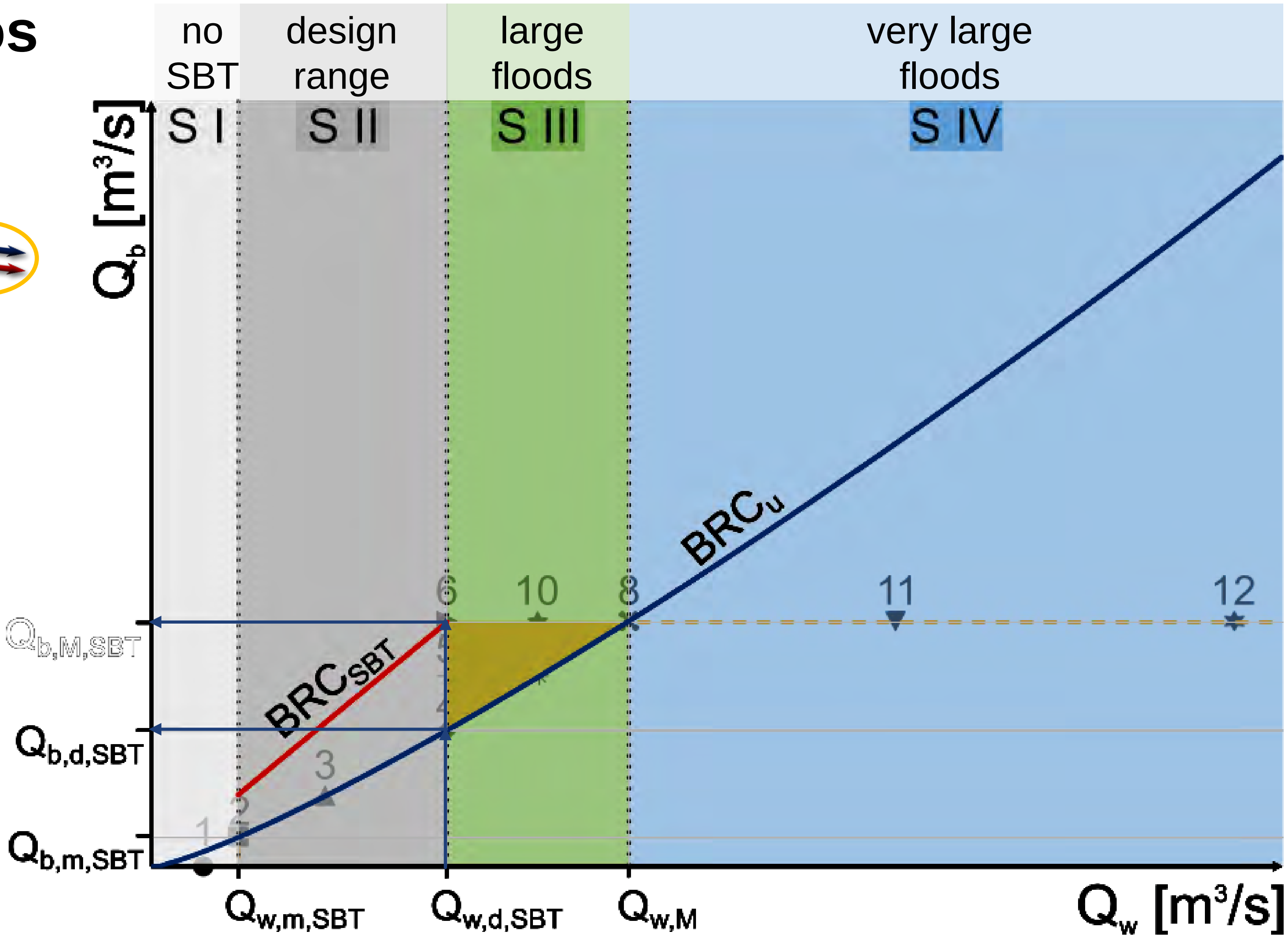




SBT release scenarios

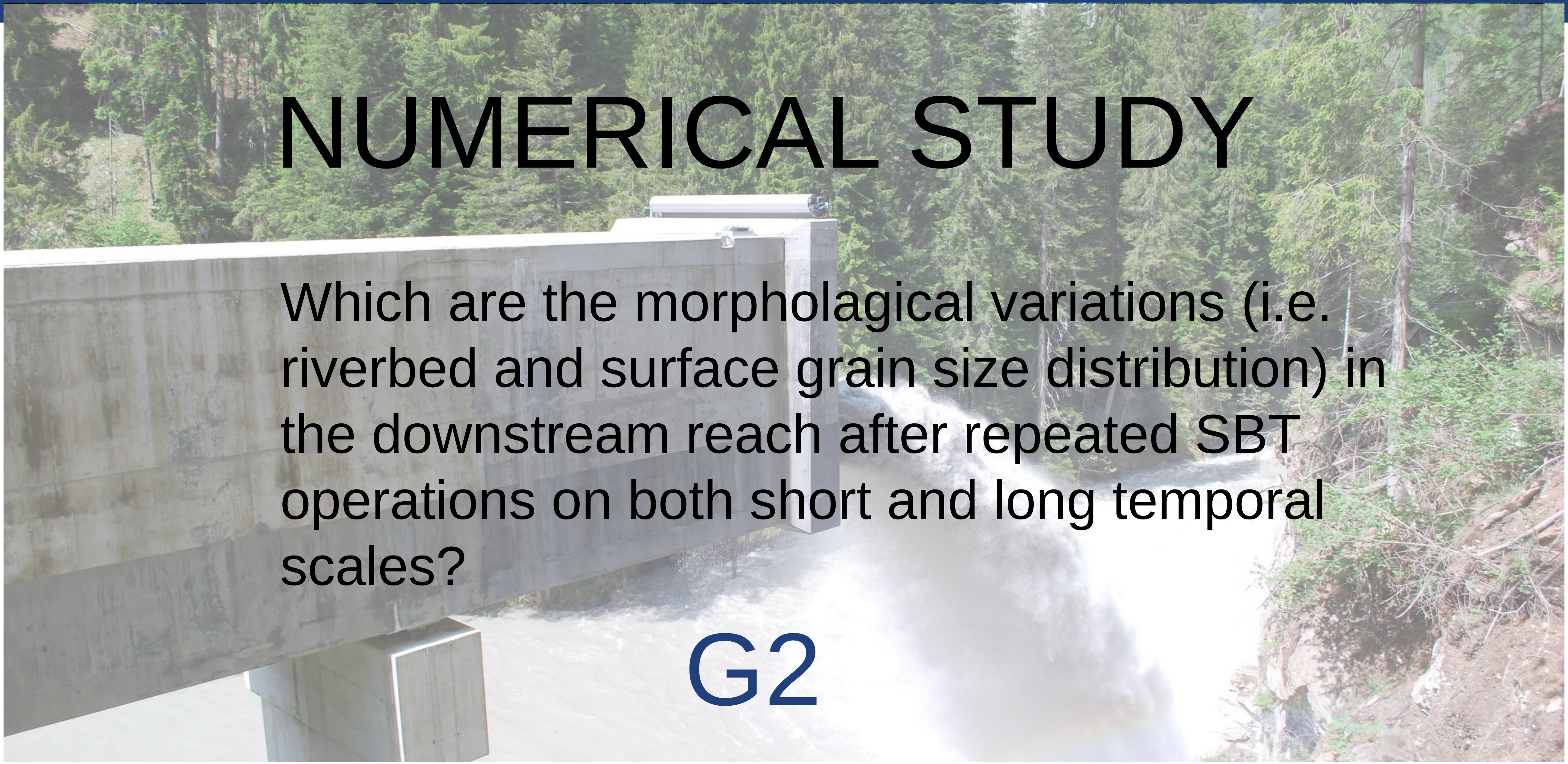


sediment discharge values.



Water discharge, Q_w

Bedload discharge, Q_b



NUMERICAL STUDY

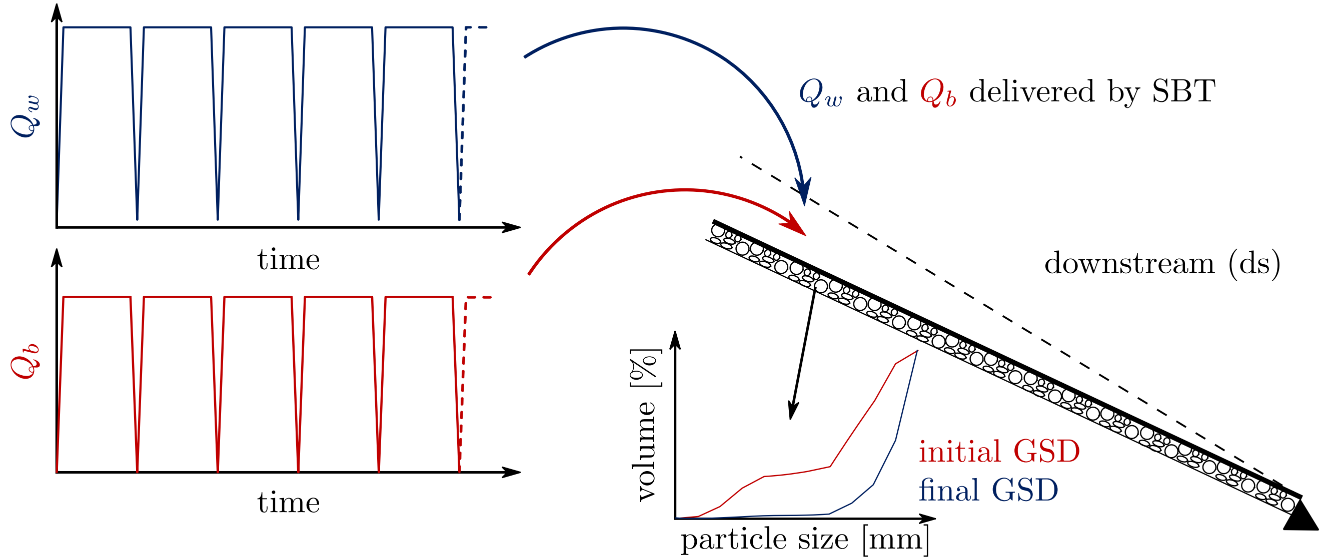
Which are the morpholagical variations (i.e. riverbed and surface grain size distribution) in the downstream reach after repeated SBT operations on both short and long temporal scales?

G2

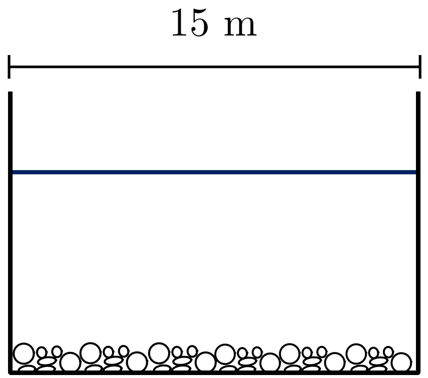
1D numerical modeling – simulations setup

simulations performed with BASEMENT (www.basement.ethz.ch)

Simplified Domain geometry and characteristics
→ Solis downstream reach



Parameter	Value
Channel Length [m]	10000
Channel width [m]	15
Initial bed slope [-]	0.014
Strickler parameter [$m^{1/3}$ s^{-1}]	32

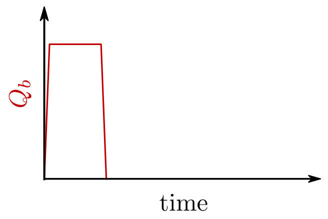


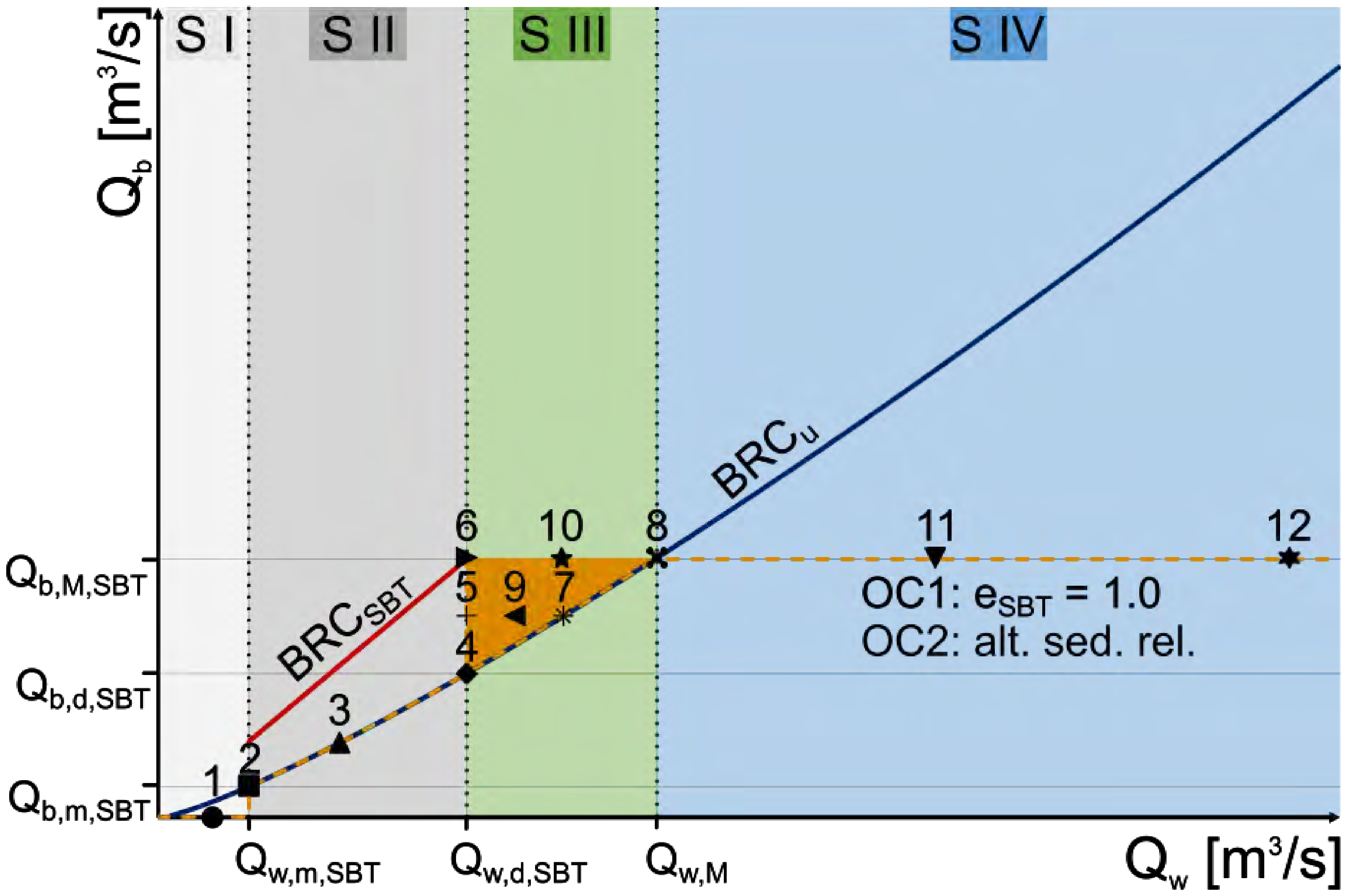
1D numerical modeling – boundary and initial conditions

<u>Operational Conditions:</u>

- OC1: SBT bypassing efficiency e_{SBT} = 1.0
- OC2: Alternate sediment-laden and clear water releases

OC1

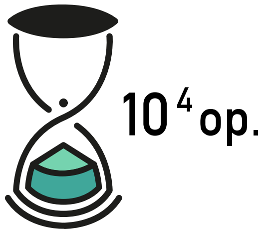




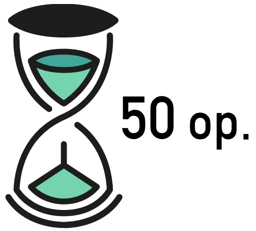
1D numerical modeling – results

We study the effects of SBT operations at different time scales:

- On the long-term → mobile-bed equilibrium

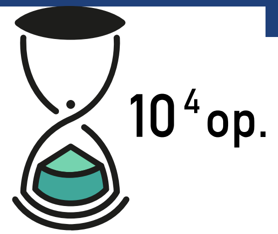


- On the mid-term → SBT (dam) lifespan



- On the short-term → event time-scale

1D numerical modeling – results at mobile-bed equilibrium

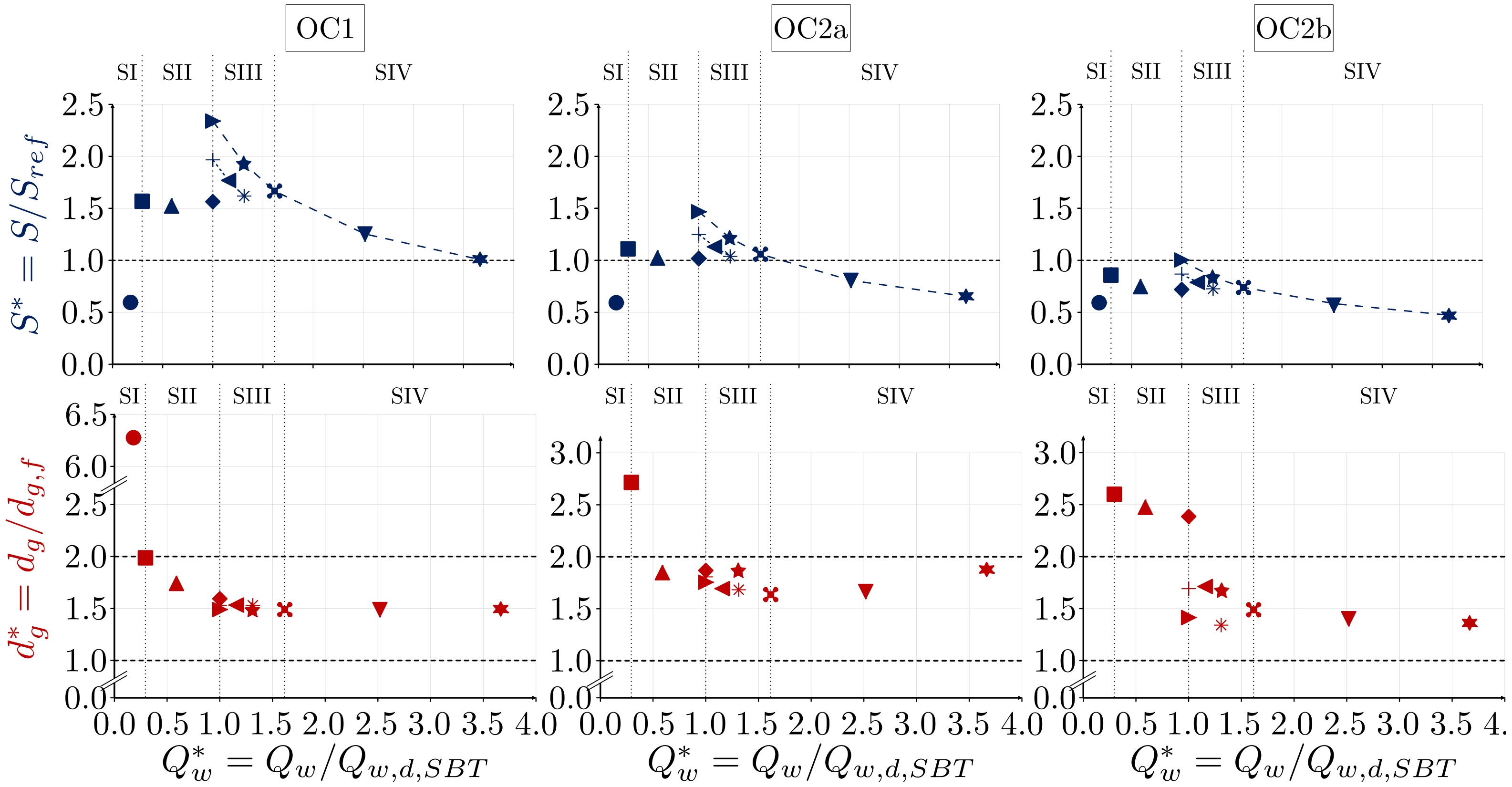


S: riverbed slope

d_g: mean geometric size of the surface layer GSD

S^* = non-dimensional slope, reference (S_{ref}) is the upstream reach

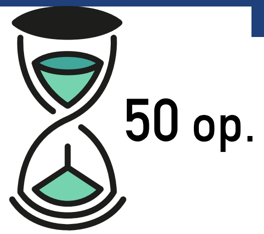
d^*_g = armoring ratio
d^*_g = 1.0
→ unarmored
1.0 < d^*_g < 2.0
→ mobile ar.
d^*_g = 10.7
→ static armor



Q_w^* = non-dimensional water discharge

Less sediment → $S^* < 1.0$,
Riverbed composition→ mobile armor

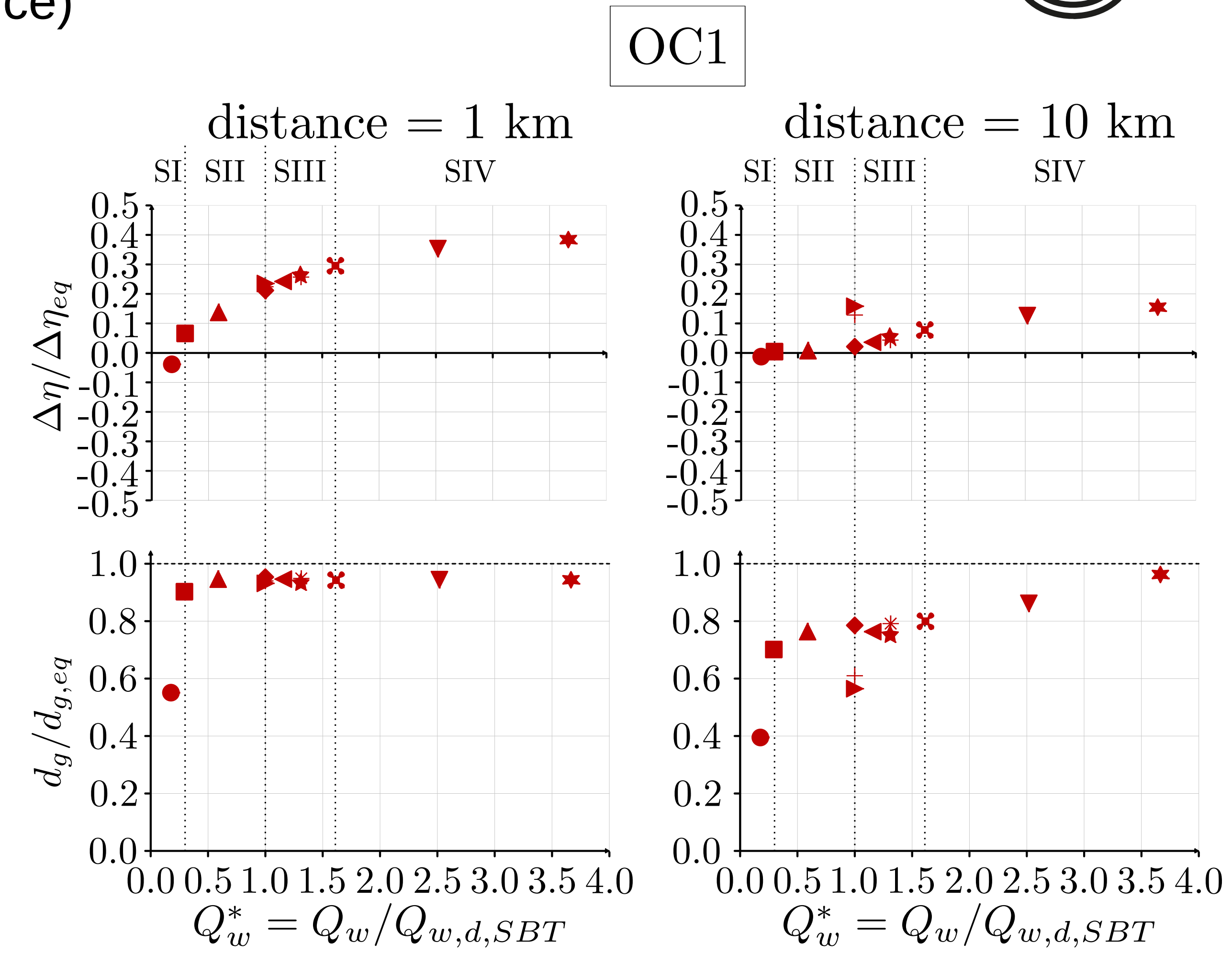
1D numerical modeling – results after 50 SBT operations



Δη: deviatoric riverbed level (elevation difference)
d_g: mean geometric size

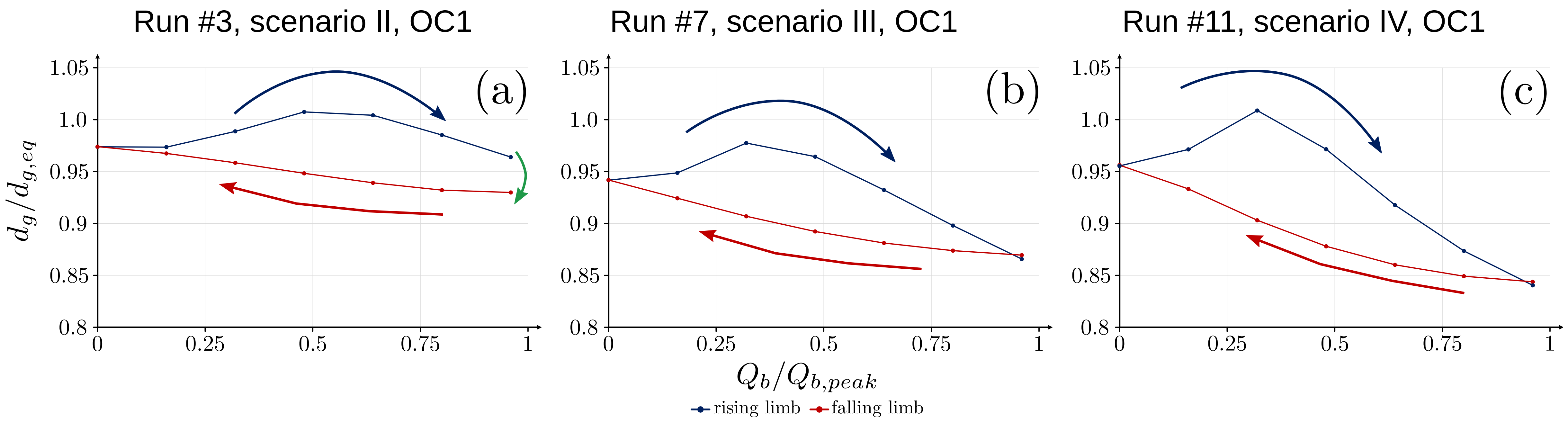
- $\Delta\eta = \Delta\eta(t = 50\ op.)$
  $\Delta\eta_{eq} = \Delta\eta(t > 10^4\ op.)$
- $d_g = d_g(t = 50\ op.)$
  $d_{g,eq} = d_g(t > 10^4\ op.)$

- Riverbed level
  → far from the equilibrium
- Riverbed GSD
  → close to the equilibrium



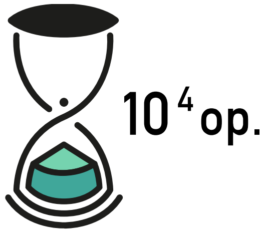
1D numerical modeling – results at event-scale, GSD hysteresis

Distance: 1km downstream

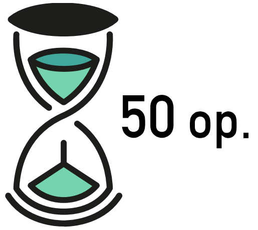


Conclusions

- We develop a conceptual framework to predict the amount of volume of water and sediments release from the SBT.
- At mobile-bed equilibrium:
  - $S < S_{ref}$ the more water is released
  - Riverbed surface → mobile armor



- After 50 SBT operations:
  - Riverbed level far from equilibrium
  - Riverbed GSD close to equilibrium



- At event-scale:
  - Fast reworking of the GSD

Thank you for your attention!

Special thanks to:

- the Federal Office of Environment of Switzerland (FOEN) for their financial support of the project *Bed load and habitat dynamics* (Geschiebe- und Habitatsdynamik) as part of the Swiss *Hydraulic engineering and Ecology* (Wasserbau und Ökologie) framework, and the Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE) to which the project is further affiliated.

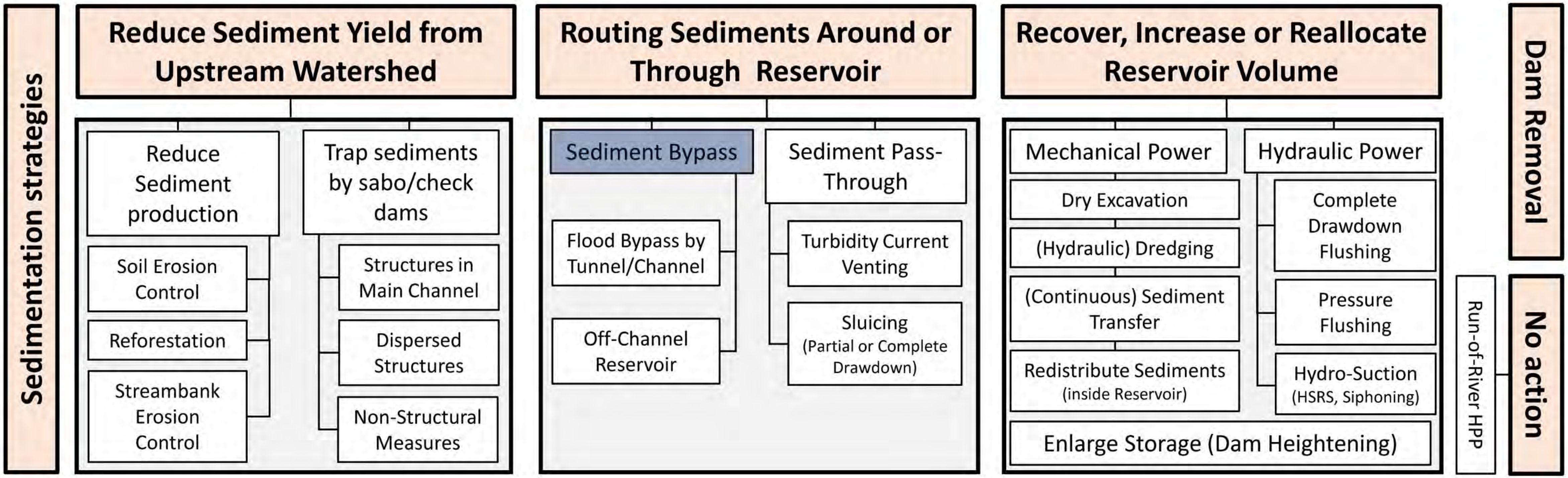
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Umwelt BAFU

Conclusions and outlook

- **Outlook**
  - regular morphological and ecological monitoring (effect of the tributaries)
  - more experience → keep framework up-to-date, introduce new OCs
  - 2D modeling → 2D morphological features (e.g. bars), river habitat modeling

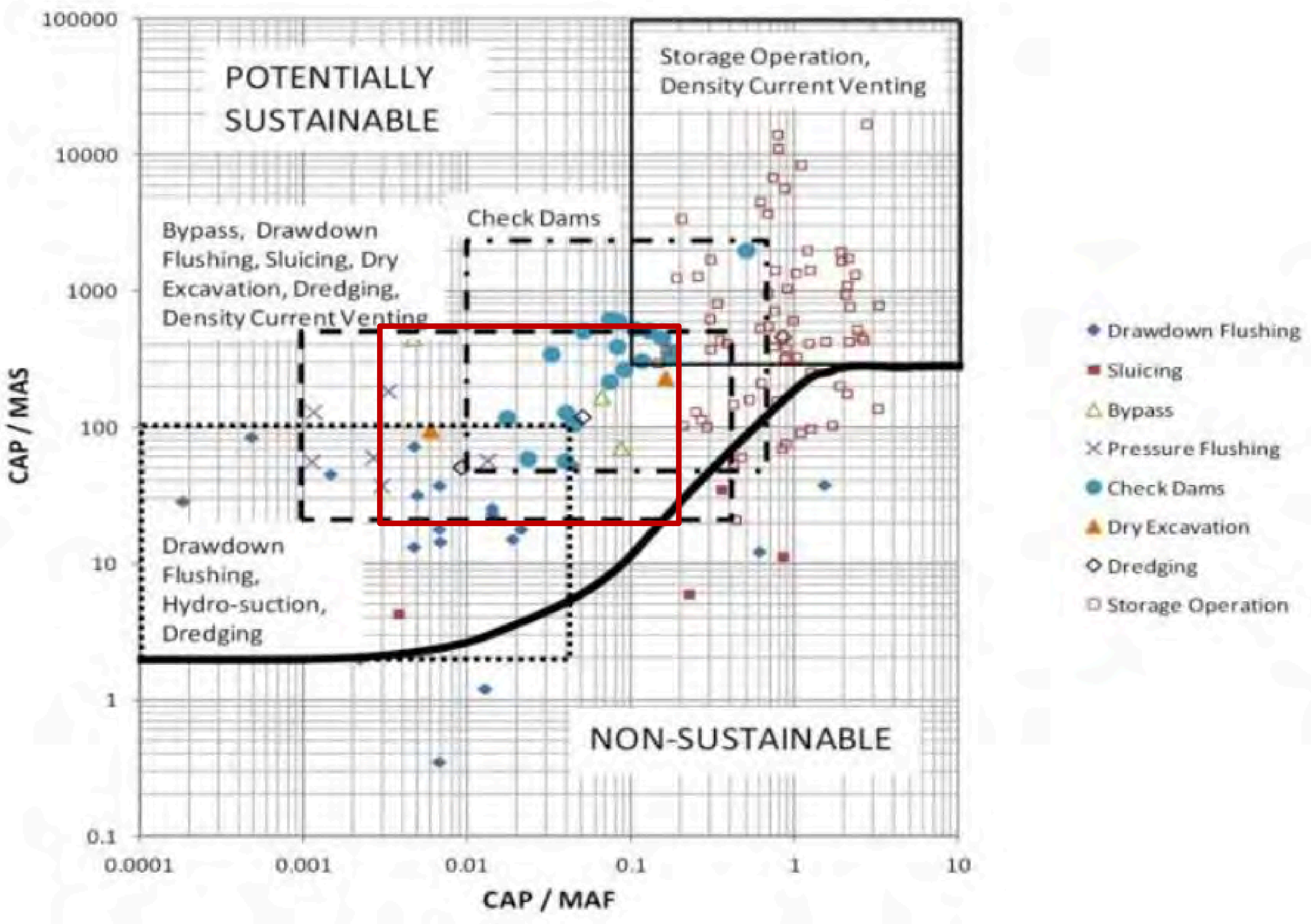
Reservoir sedimentation – countermeasures



(Auel et al., In Proc. 84th ICOLD Annual meeting, 2016)

Reservoir sedimentation – countermeasures classification

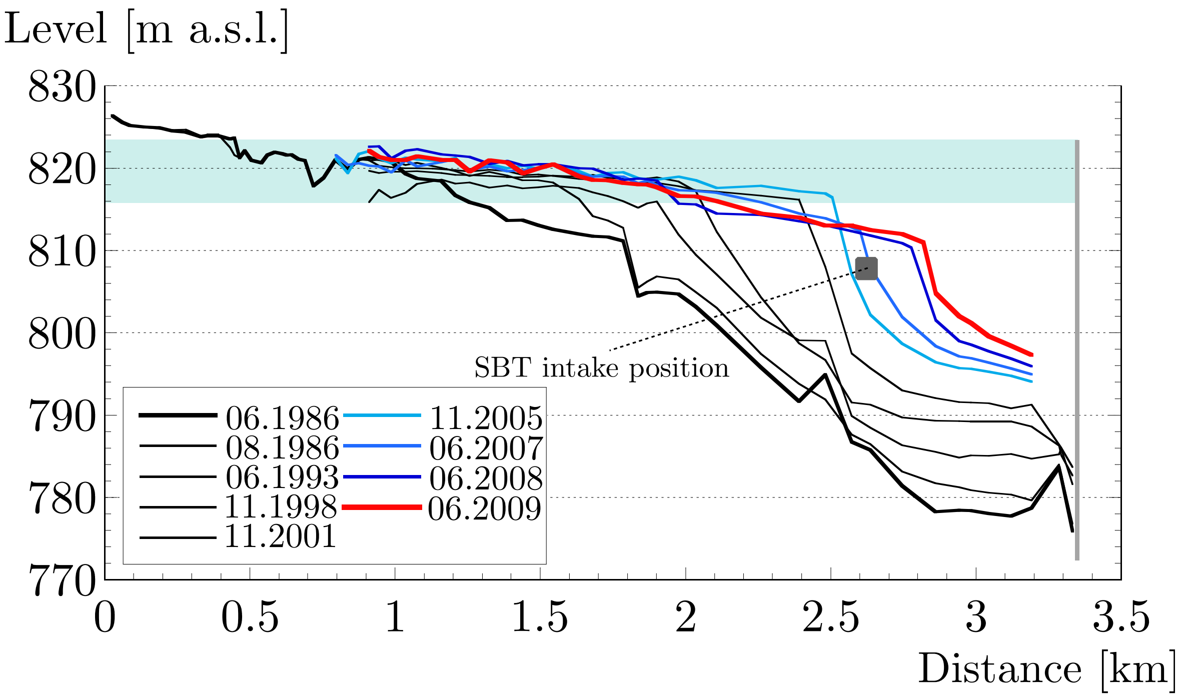
- CAP/MAS = reservoir volume / mean annual sediment inflow volume
- CAP/MAF = reservoir volume / annual water inflow volume
- Range of application for which SBTs are most effective



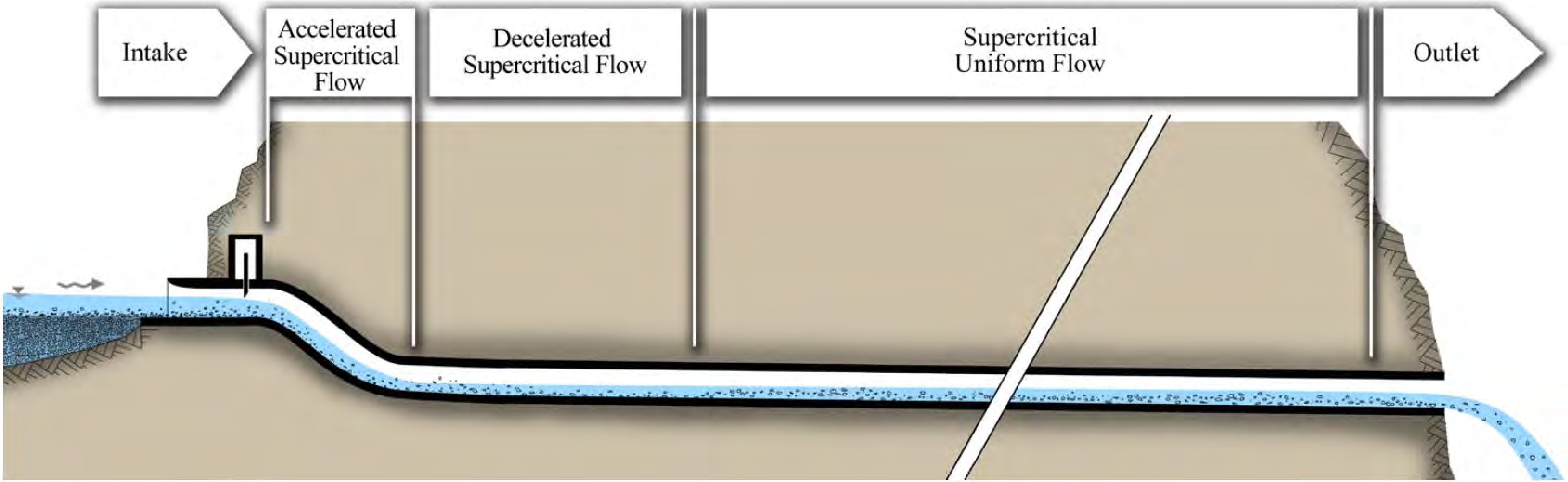
(Annandale, Createspace, 2003)

Reservoir sedimentation – loss of storage capacity

- More than 53% of the global sediment flux in regulated basins (28% of all river basins in the world) is potentially trapped in reservoirs → trapping rate = 4-5 billions tons of sediment per year (Vörösmarty et al., Glob. and Plan. Change, 2003)
- At the current rate the global storage capacity will be halved by 2050 (ICOLD, Tech. Rep., 2009)
- In Switzerland by 2050 around 20% of total reservoir capacity will be lost (Schleis et al., WEL, 2010)



SBT longitudinal profile



(Auel, PhD Thesis, 2014)

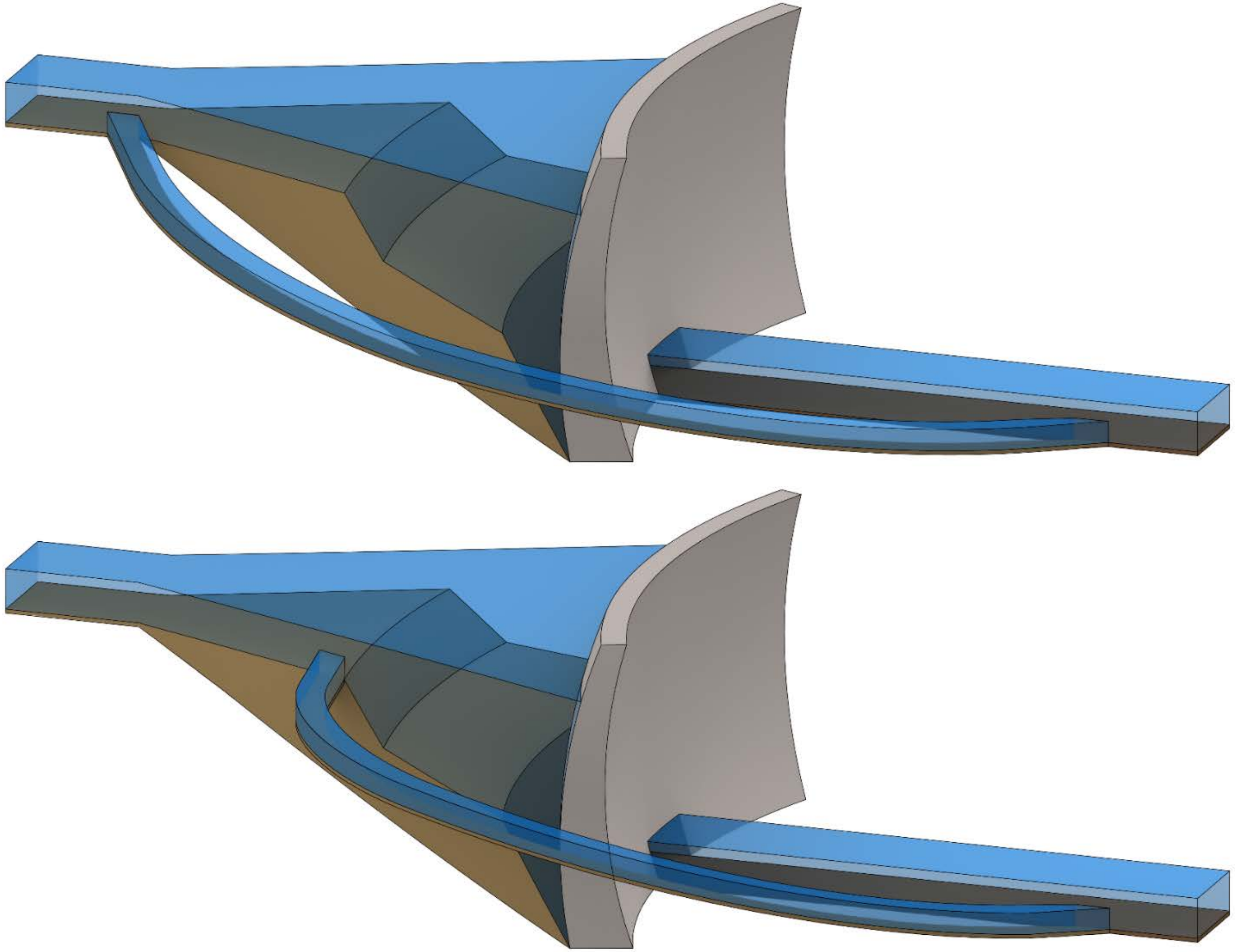
Sediment Bypass Tunnels (SBTs) – intake position

<u>Position of SBTs intake structure:</u>

- at the upstream end of the reservoir
- at the knickpoint of the aggradation body

<u>Other characteristics:</u>

- velocity values range between ca. 7 [m s^{-1}] and 15 [m s^{-1}] (supercritical flow conditions)
- outlet → uniform flow conditions
- intake → supercritical flow



SBTs in the world – Switzerland, Japan, Taiwan

Reservoir name	Country	Completion year	Cross-section shape	Intake position	b_t [m]	h_t or D_t [m]	L [m]	S [-]	$Q_{w,d}$ [m^3 s^{-1}]	Target grain size [mm]	Run time [days/a]	Reservoir purpose*
Egshi	CH	1976	Circular**	Midst.	1.20	2.80	360	0.026	50	d_m: 60	3–10	P
Hintersand	CH	2001	Arch	Upst.	3.25	3.20	1050	0.012	38	d_m: 20	n.s.	P
Palagnedra	CH	1977	Horseshoe	Upst.	3.70	6.20	1760	0.02	250	d_m: 74	5	P
Pfaffensprung	CH	1922	Horseshoe	Midst.	4.70	5.23	282	0.03	220	d_m: 250	100–200	W
Rempen	CH	1986	Horseshoe	Upst.	3.45	3.42	450	0.04	80	d_m: 60	1–5	P
Runcahez	CH	1962	Arch$^+$	Upst.	3.80	4.27	572	0.014	110	d_m: 230	4	P
Serra	CH	1952	Horseshoe	Upst.	2.80	2.80	425	0.0157	40	d_m: 50	1–10	P
Solis	CH	2012	Arch	Midst.	4.40	4.68	968	0.019	170	d_m: 60	1	P
Ual da Mulin	CH	1962	Horseshoe	Upst.	2.50	3.70	268	0.043	n.s.	d_m: 40	¿ 15	P
Val d'Ambra	CH	1967	Circular**	Upst.	3.60	3.60	512	0.02	85	d_m: 60	2–3	P
Nunobiki – Gohonmatsu	JP	1908	Arch	Upst.	2.90	2.90	258	0.013	39	n.s.	n.s.	W
Tachigahata	JP	1905	n.s.	Upst.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	W
Miwa	JP	2005	Horseshoe	Midst.	7.80	7.00	4308	0.01	300	washload	1–2	F/P
Asahi	JP	1998	Arch	Upst.	3.80	3.80	2350	0.029	140	d_m: 50	16	P
Koshibu	JP	2016	Horseshoe	Upst.	5.50	7.90	3999	0.02	370	d_m: 10	n.s.	F/A/P
Matsukawa	JP	2016	Arch	Upst.	5.20	5.20	1417	0.04	200	d_m: 10	n.s.	F/W
Shihmen	TWN	i.p.	Arch	Midst.	9.00	9.00	3685	0.0286	600	d_m: 0.04	n.s.	F/W/A
Nanhua	TWN	2018	Horseshoe	Midst.	9.50	9.50	1287	0.0185	1000	d_m: 0.02	n.s.	F/W
Tsengwen	TWN	2017	Horseshoe	At dam	9.50	9.50	1235	0.0532	995	d_m: 0.005	n.s.	F/W/A

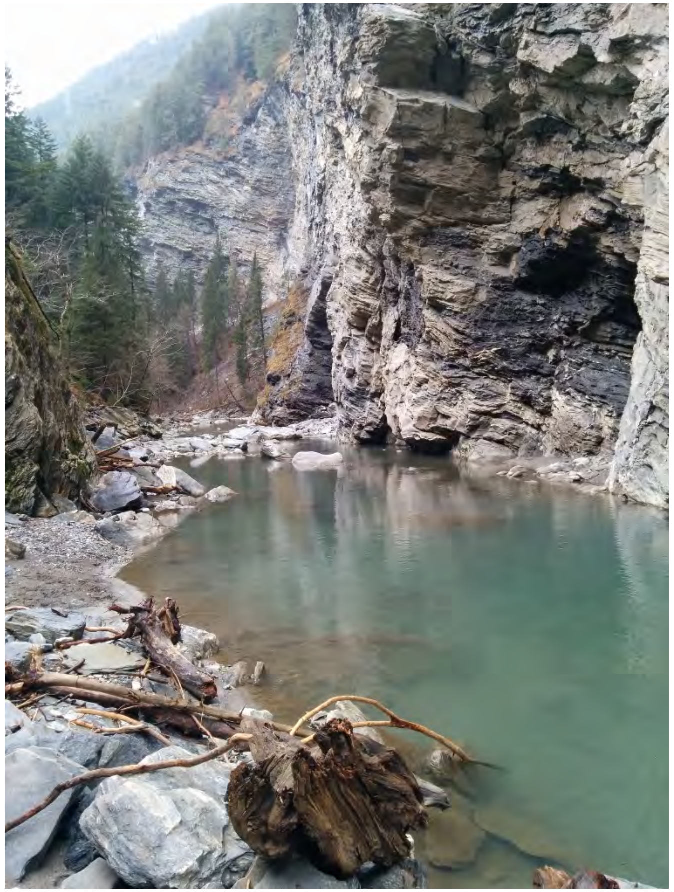
i.p.: in planning phase; n.s.: not specified
*: F: flood control; A: agriculture; W: water supply; P: hydropower production
**: circular shape with plain invert; $^+$: slightly concave invert

SBTs in the world – France, Ecuador, Iran, Pakistan, USA, South Africa

Reservoir name	Country	Commission-ing year	Cross-section shape	Intake position	b_t [m]	h_t or D_t [m]	L [m]	S [–]	$Q_{w,d}$ [m^3 s^{-1}]	Target grain size [mm]	Run time [days/a]	Reservoir purpose*
Jotty	FR	1949	n.s.	n.s.	n.s.	n.s.	118	0.006	n.s.	n.s.	n.s.	n.s.
Rizzanese	FR	2012	n.s.	n.s.	n.s.	n.s.	133	0.069	100	d_m: 0–18	n.s.	n.s.
Chespí – Palma Real	ECU	i.p.	n.s.	n.s.	n.s.	n.s.	2200	0.017	n.s.	n.s.	n.s.	n.s.
Delsitanisagua	ECU	u.c.	n.s.	n.s.	n.s.	n.s.	880	0.02	200	n.s.	n.s.	n.s.
Dez	IRN	i.p.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Patrind	PAK	2017	Arch	Midst.	7.50	8.50	180	0.0112	340	n.s.	n.s.	n.s.
Mud Mountain	USA	1940	Horseshoe	At dam	2.74	n.s.	505	0.0194	120	d_{50}: 62	$\sim$ 80	n.s.
Nagle Dam	ZAF	1950	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

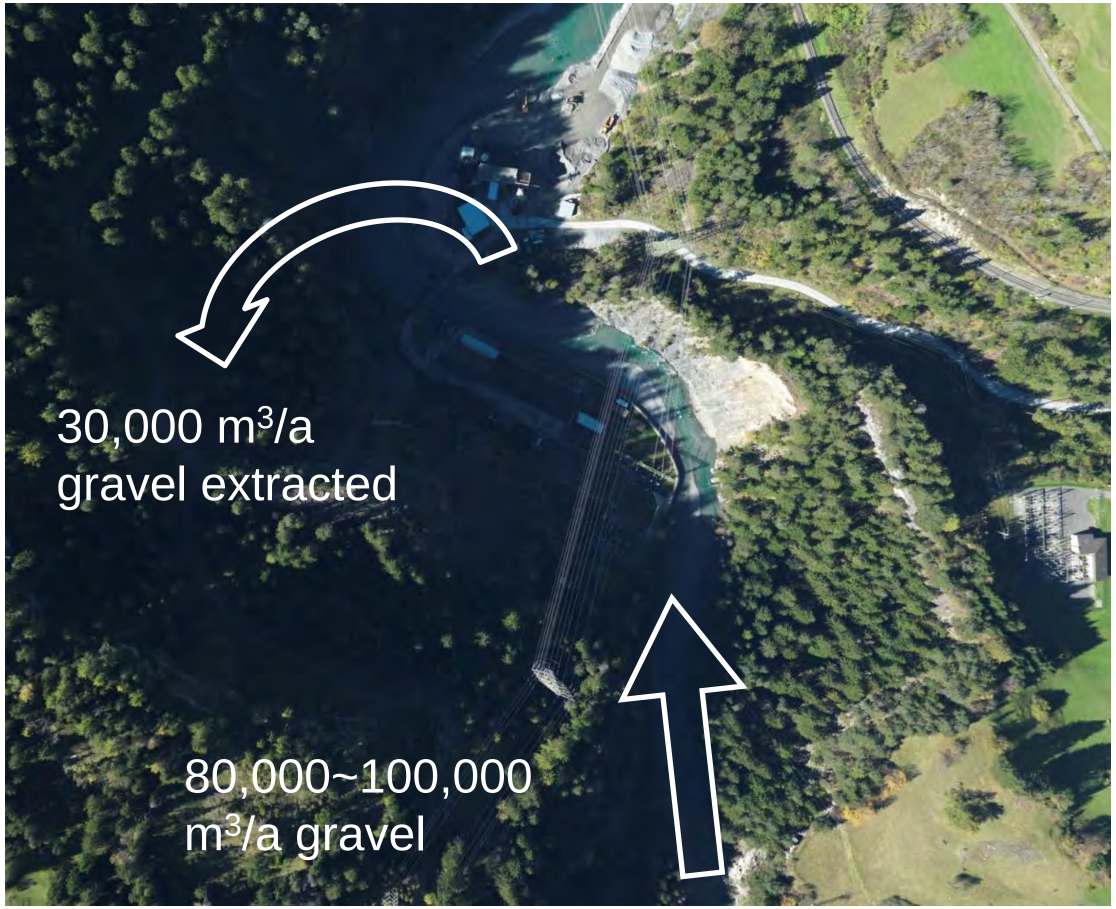
i.p.: in planning phase; u.c.: under construction; n.s.: not specified
*: F: flood control; A: agriculture; W: water supply; P: hydropower production

Schin canyon – morphology



Solis SBT – inlet/outlet structures

Solis SBT – reservoir upstream end and intersection with the Posterior Rhine

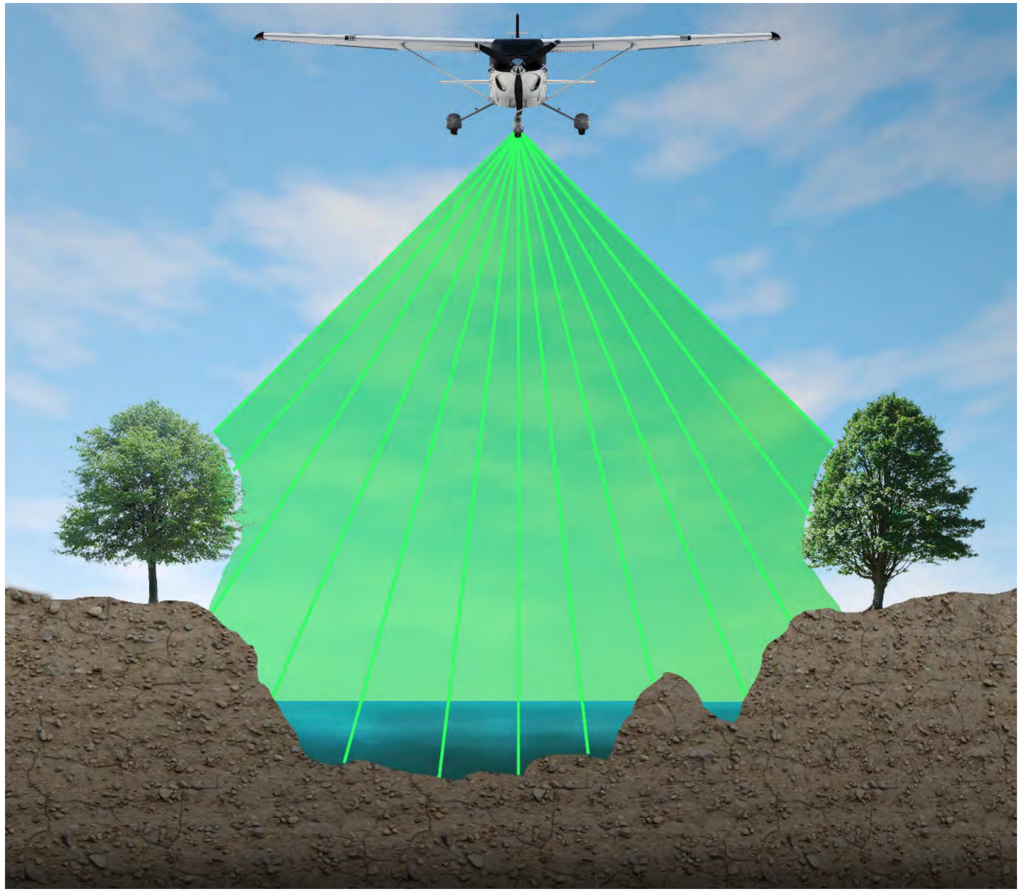


Study site – bathymetric LiDAR surveys at Solis

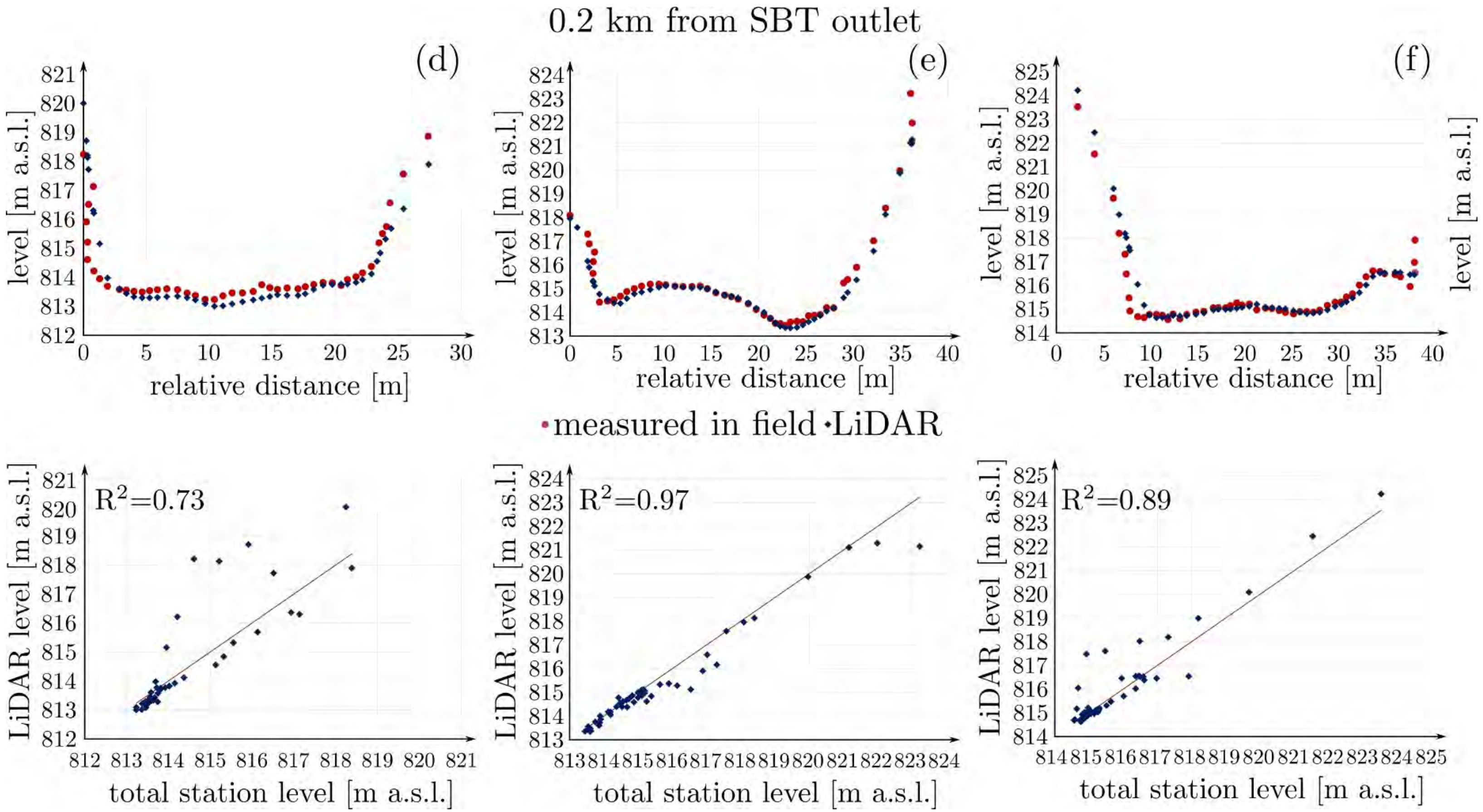
LiDAR = Light Detection And Ranging

Year	2014	2016
Operator	AHM[a]	AHM[a]
Flight date	Oct. 18	Oct. 17
ALS[b] system	VQ820-G	VQ880-G
Stripes	16	16
Point Density [pts/m^2]	20-30	50-60
ALS[b] accuracy [cm]	2.5[c]	2.5[d]
Georeferencing error [cm]	5	5
Stripes alignment error [cm]	6	8

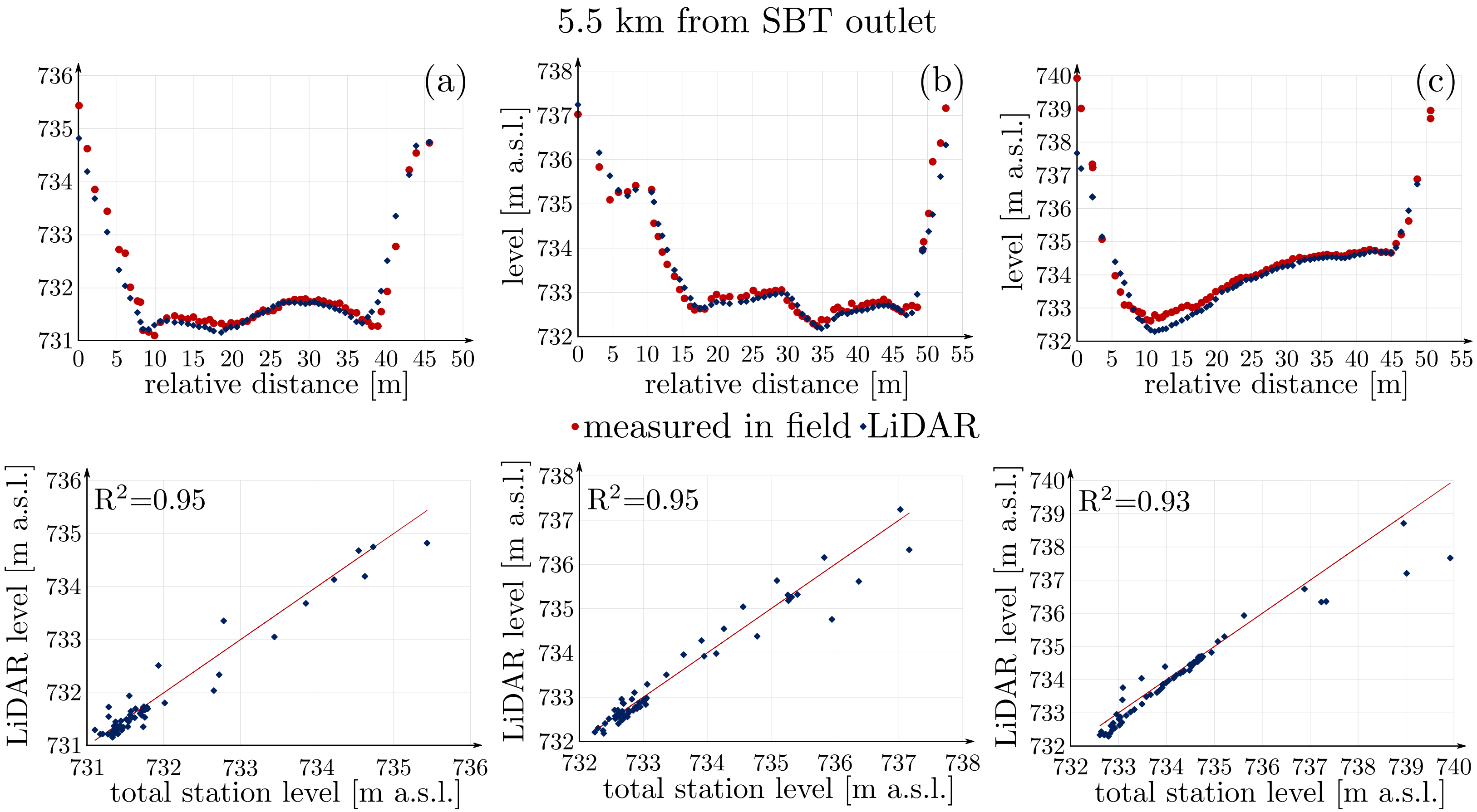
[a] AirborneHydroMapping GmbH, Innsbruck
[b] Airborne Laser Scanning
[c] at 1 Secchi depth
[d] at 1.5 Secchi depth



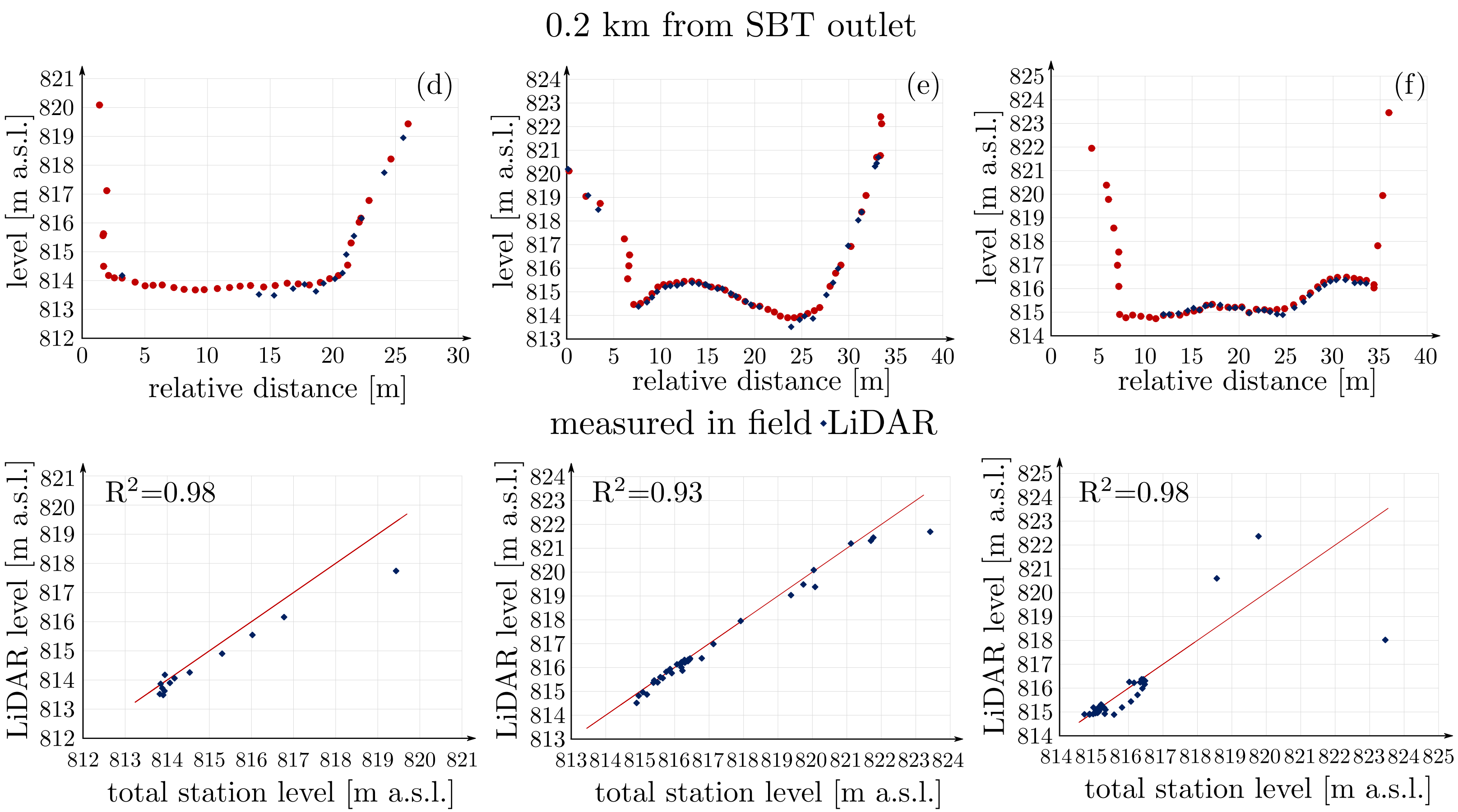
LiDAR Validation – 2014 Cross-Sections



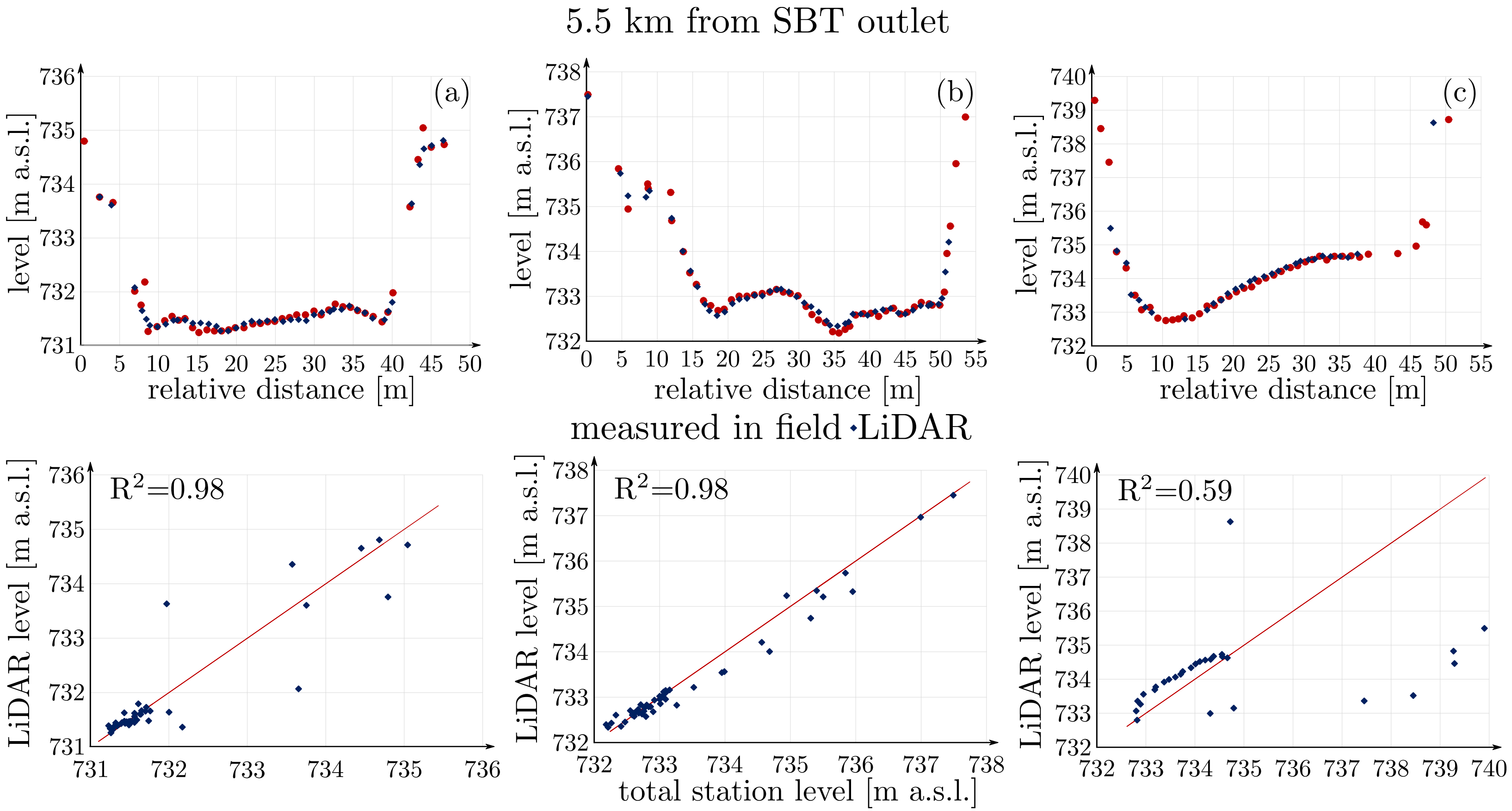
LiDAR Validation – 2014 Cross-Sections



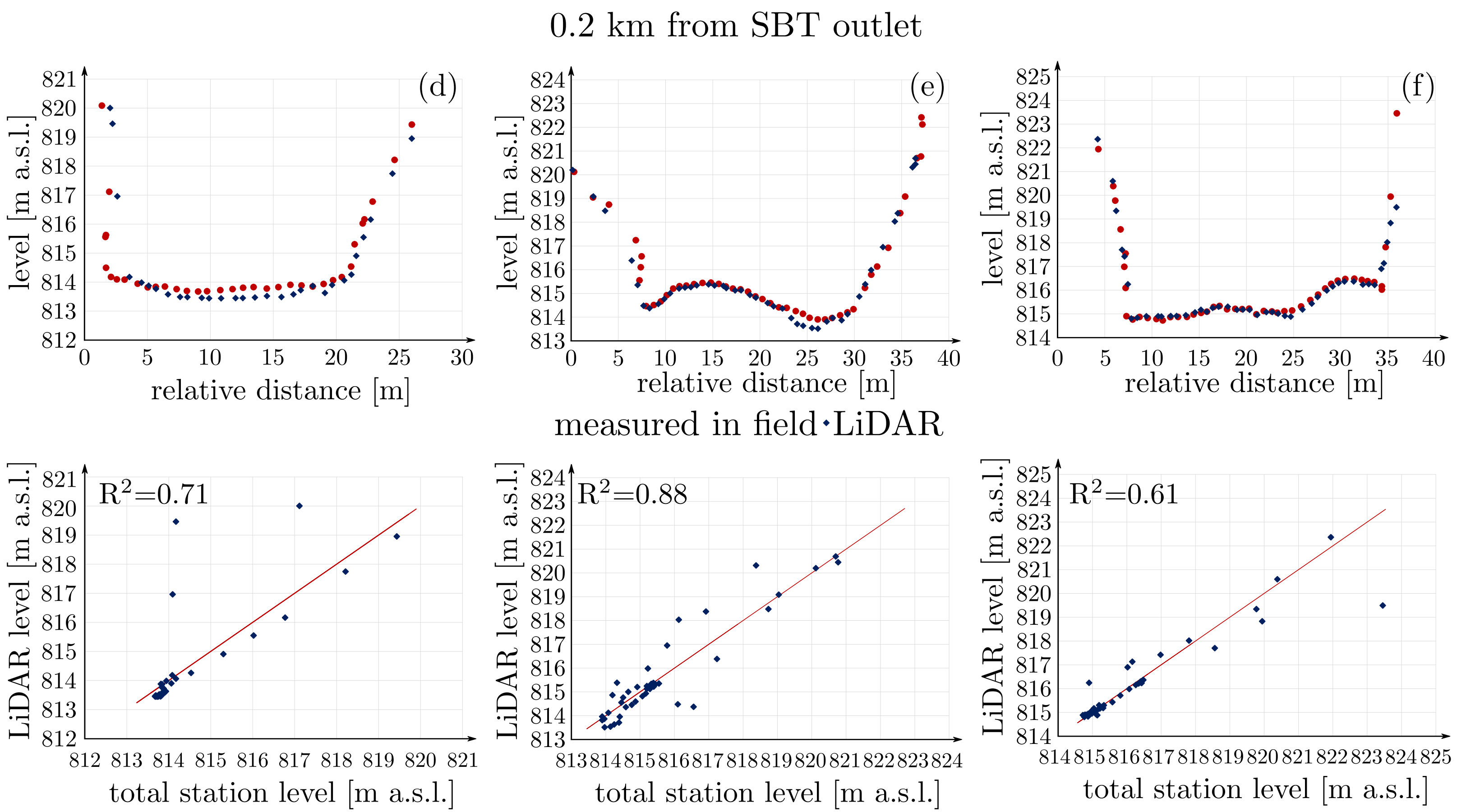
LiDAR Validation – 2016 Cross-Sections



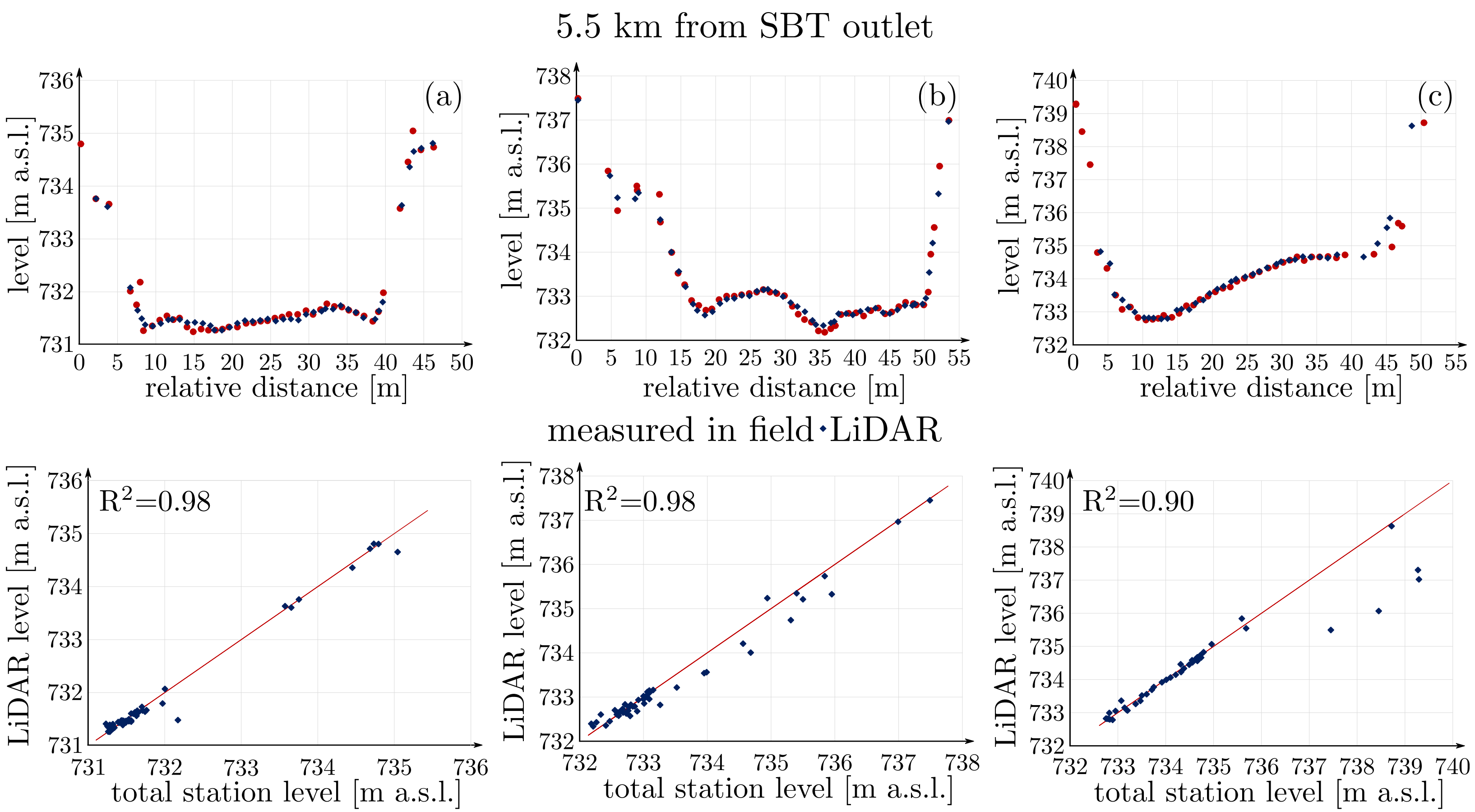
LiDAR Validation – 2016 Cross-Sections



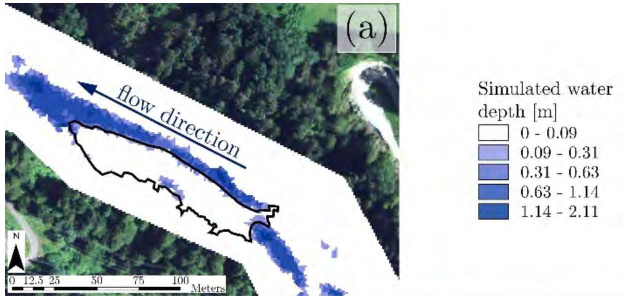
LiDAR Validation – Interpolated 2016 Cross-Sections



LiDAR Validation – Interpolated 2016 Cross-Sections



Digital Elevation Model (DEM) of Difference (DoD) – Method



- Bathymetric LiDAR data validation over the whole reach using:
  - 2D hydrodynamic modeling (a)
  - Return number of measured points (b) and (c)
  - Intensity of the measured points (d) and (e)

DoD - Fuzzy Inference System

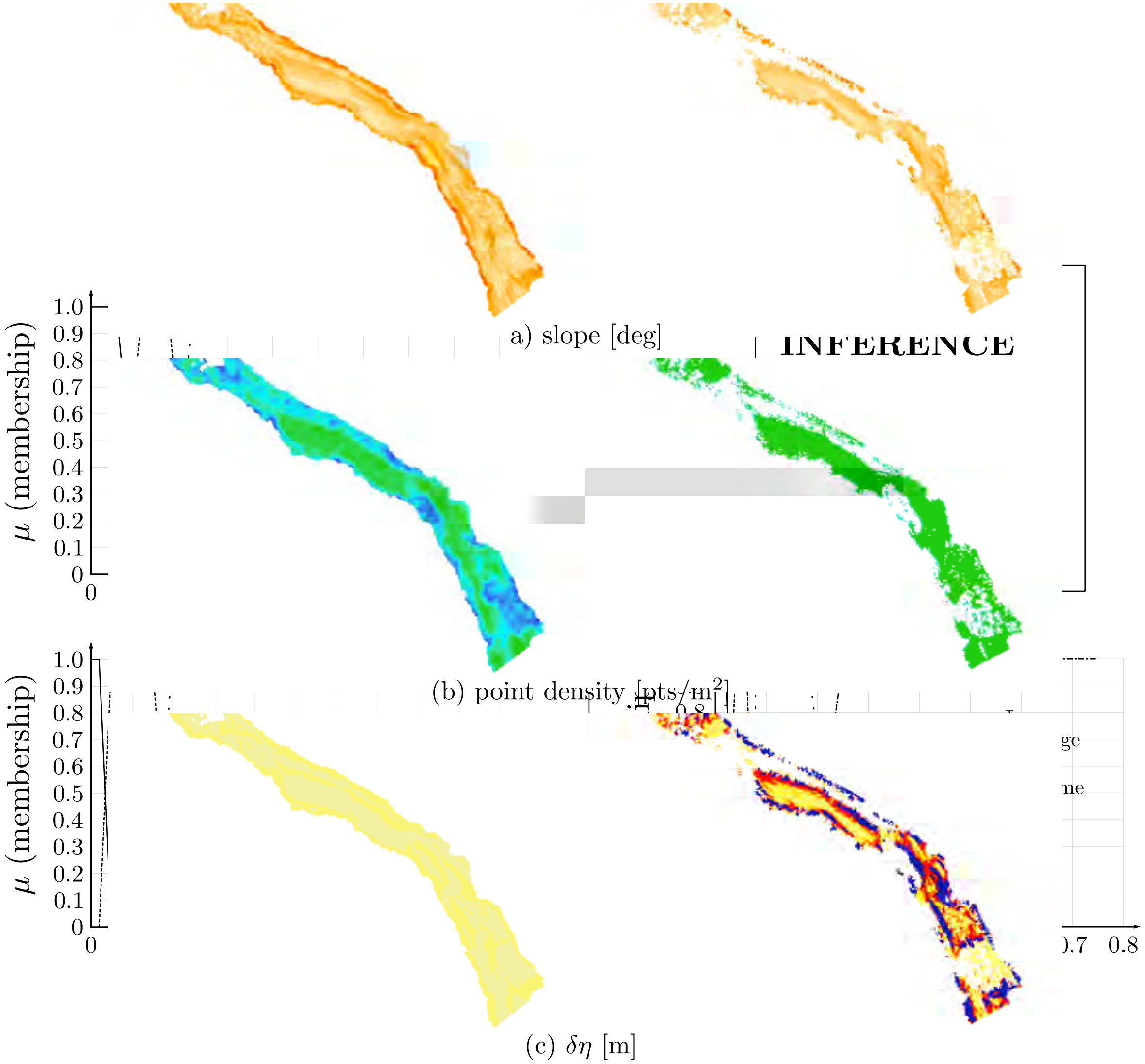
The estimation of the DEM uncertainties requires information beyond topographic data

- Steep areas: low survey point density and high slope
  → high elevation uncertainty
- Flat areas: high survey point density and low slope
  → low elevation uncertainty

components of elevation uncertainty: collinear variables which do not exhibit a simple monotonic relationship to elevation uncertainty

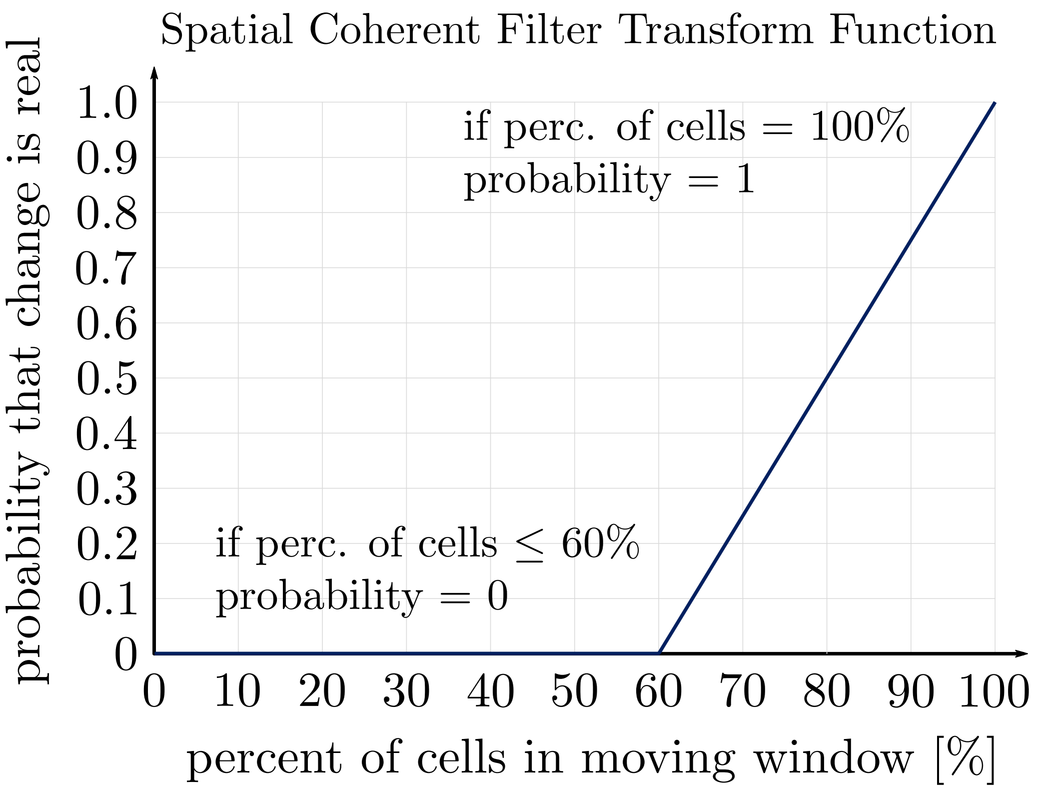
→ No deterministic model possible

Rule	Input		Output
	Slope [deg]	Pt. Density [pts/m^2]	$\delta\eta$ [m]
1	Low	Low	Average
2	Low	Medium	Low
3	Low	High	Low
4	Medium	Low	High
5	Medium	Medium	High
6	Medium	High	Average
7	High	Low	Extreme
8	High	Medium	High
9	High	High	High



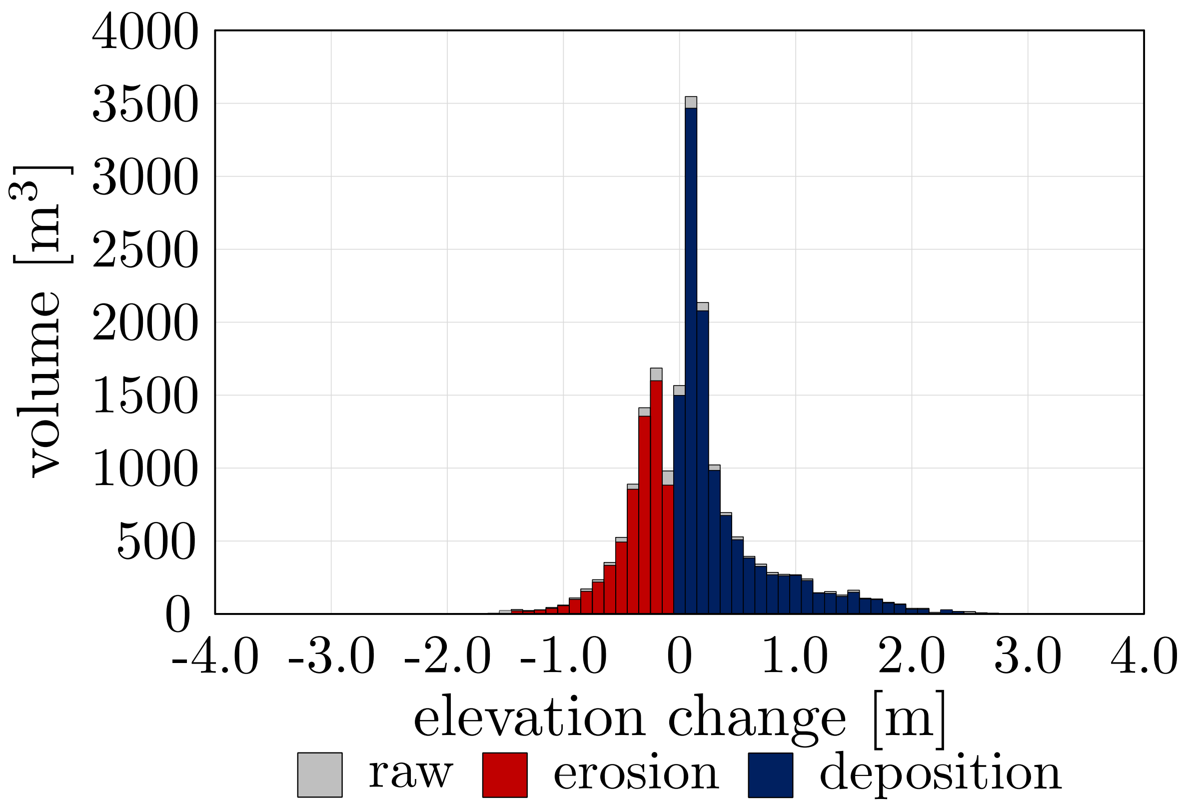
DoD – Spatial Contiguity Index (SCI)

On a movable 5x5 m window, the SCI expresses the probability of an elevation change falling inside the threshold interval to be true, given the number of surrounding cells being either in erosion or deposition



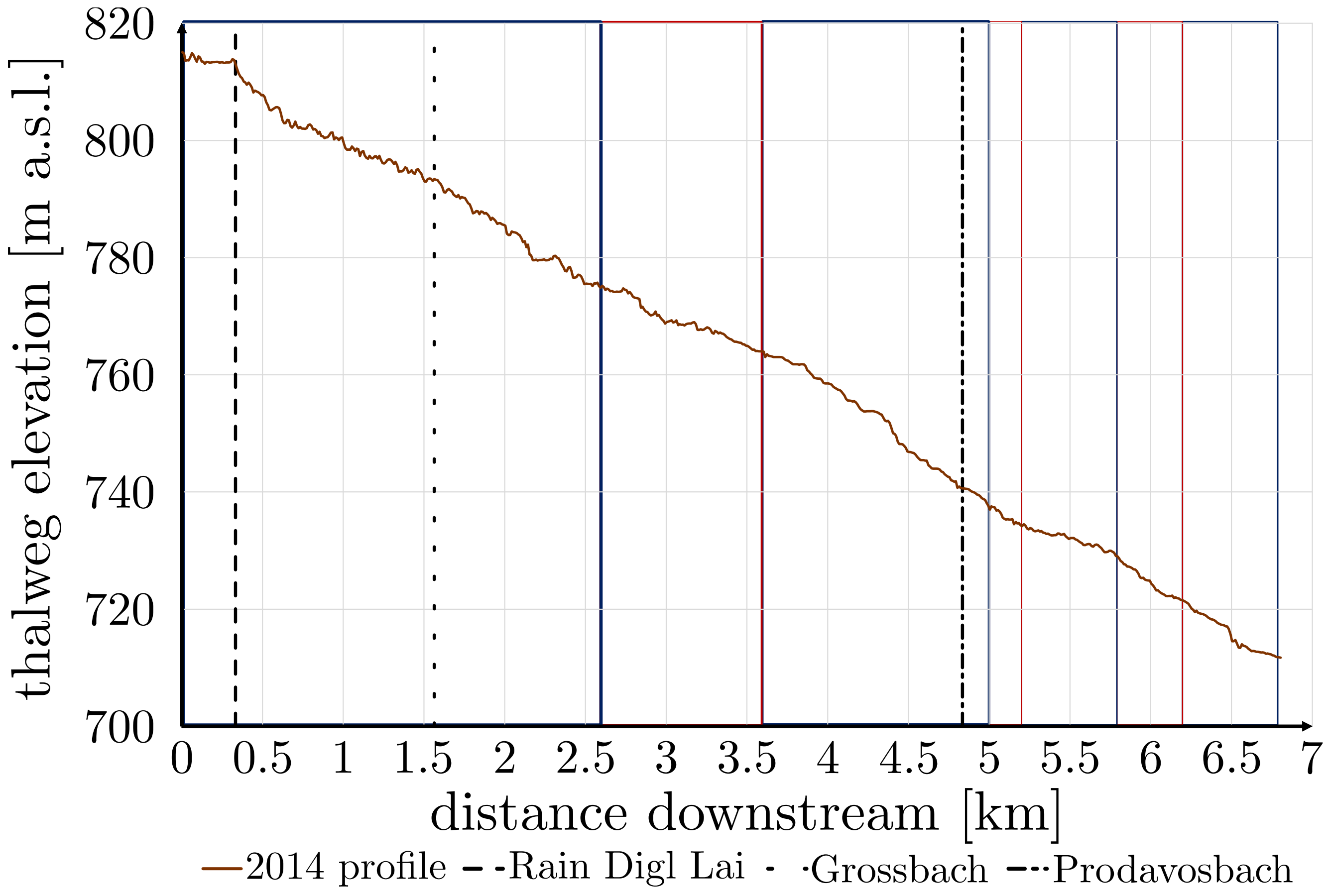
DoD – Results

Name	Eroded V [m³]	Deposited V [m³]	Net V [m³]
Raw	6593	12416	**5823**
U1P1 (a)	3085	5959	**2874**
U2P1 (b)	5171	10552	**5381**
U1P2 (c)	1103	3458	**2355**
U2P2 (d)	3373	8138	**4765**
U2P2SCI (e)	6182	11985	**5804**



DoD - Results

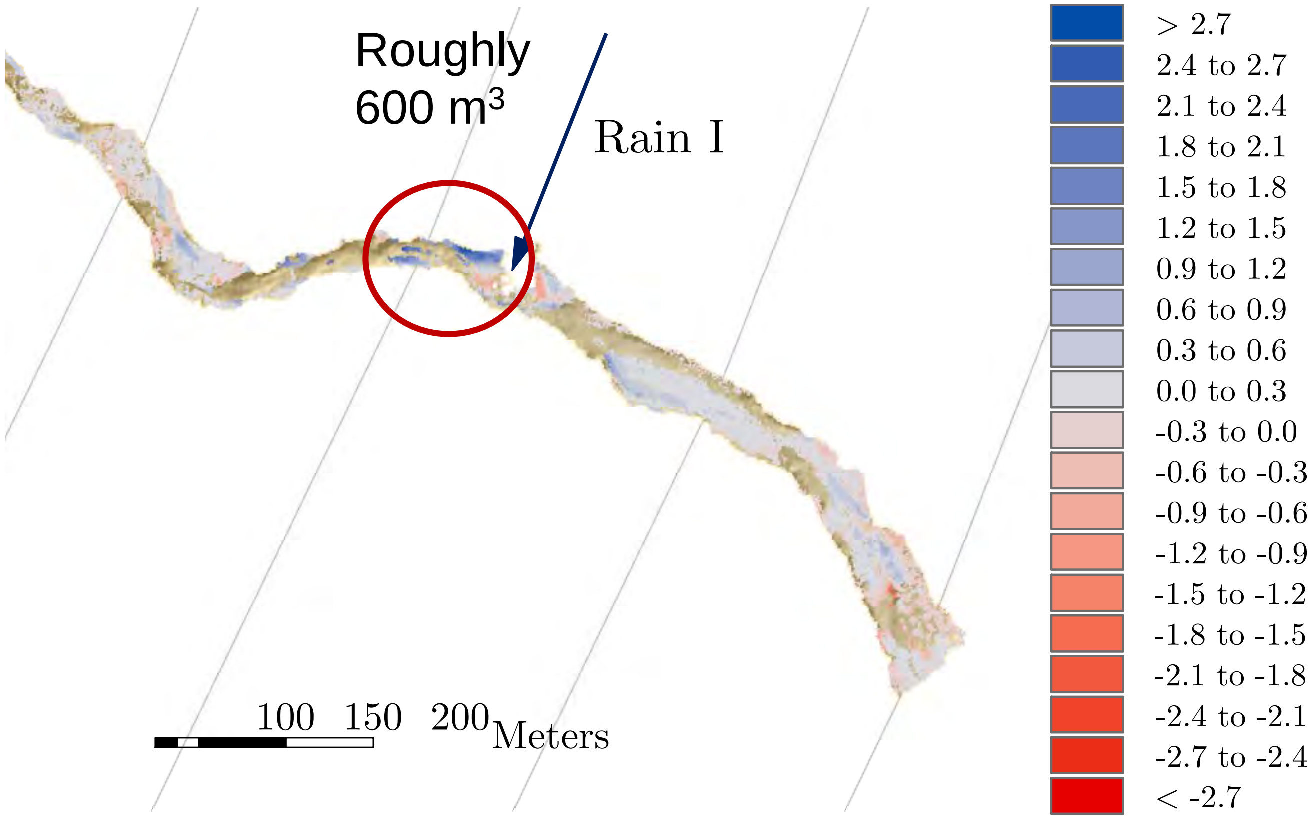
Erosion and deposition patterns with riverbed profile



DoD - Results

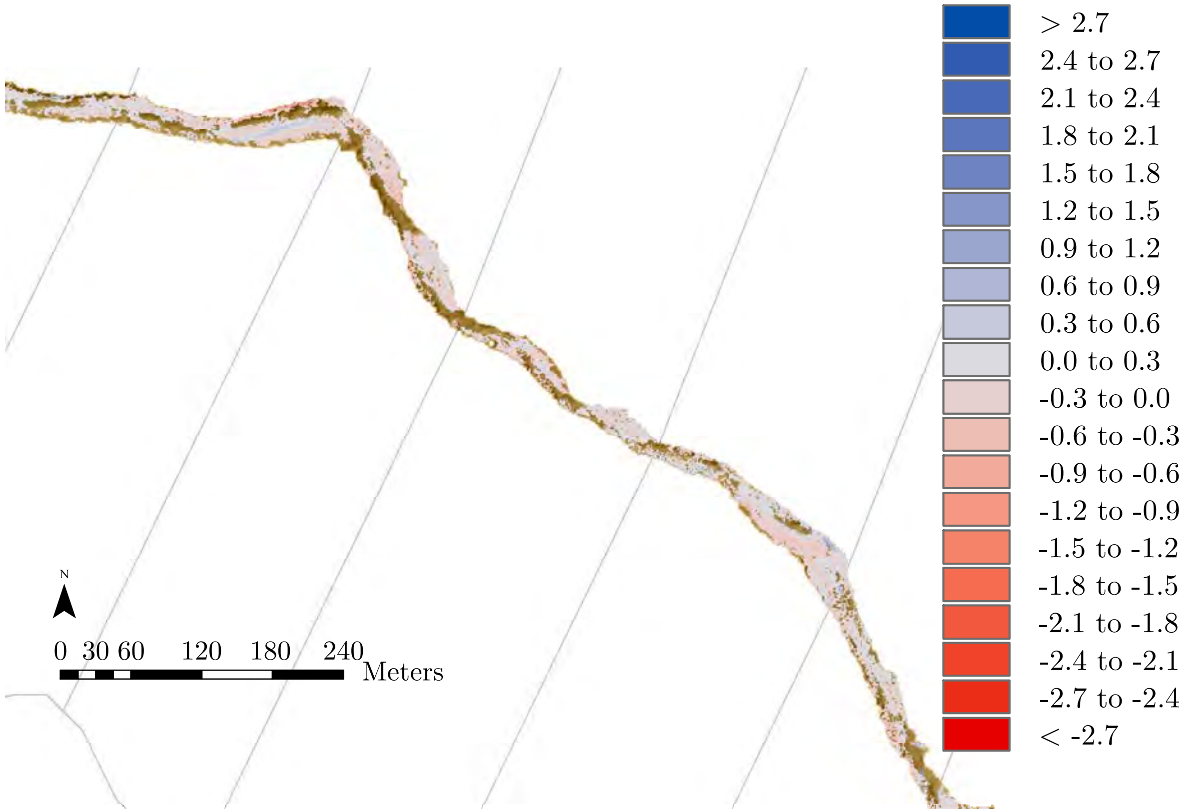
Big deposition upstream due to sediment transport from the tributary

Name	Net V [m^3]
Raw	**5223**
U1P1 (a)	**2274**
U2P1 (b)	**4781**
U1P2 (c)	**1755**
U2P2 (d)	**4165**
U2P2SCI (e)	**5204**



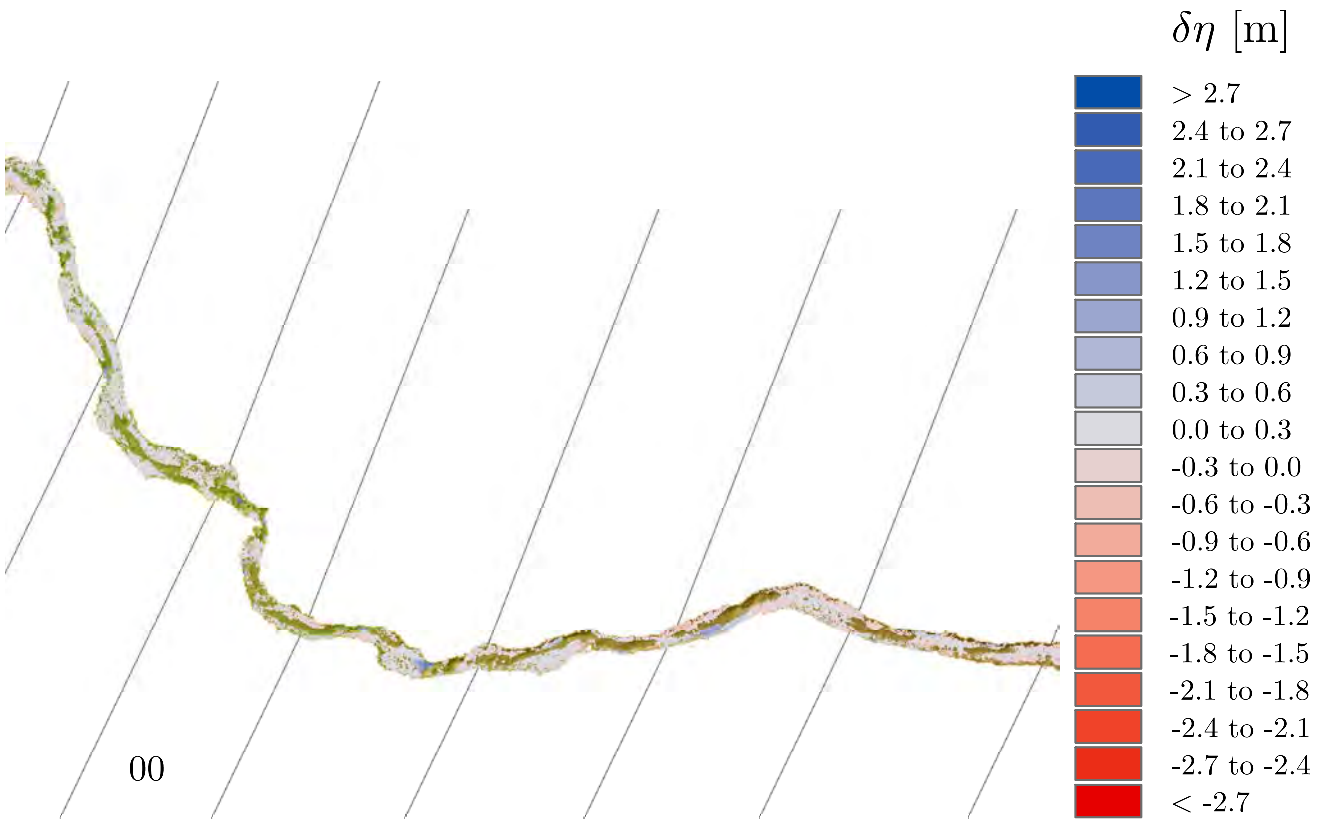
DoD - Results

Erosion trend in the middle reach



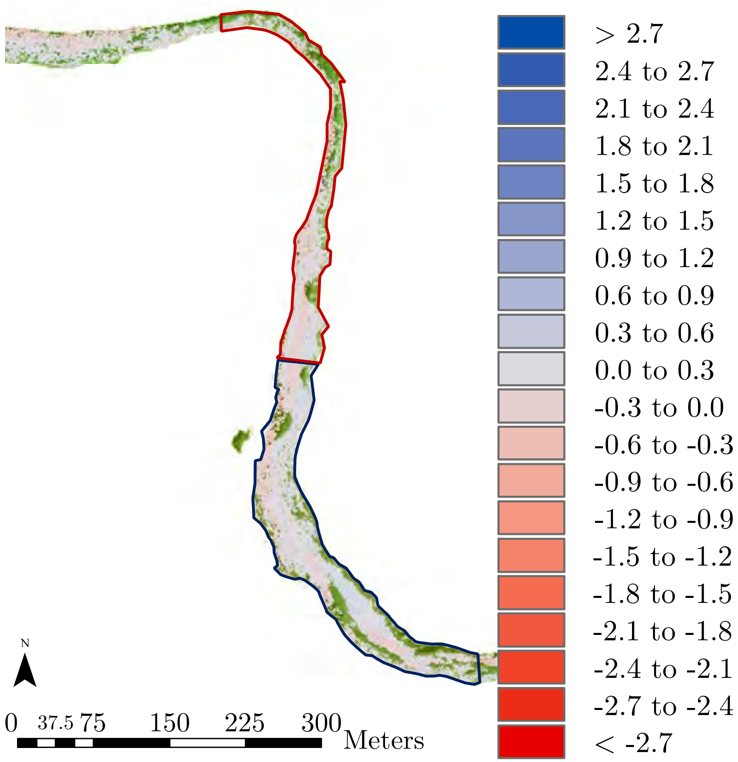
DoD - Results

Second depositional reach



DoD - Results

Fourth reach: mixed erosion and deposition



1D numerical modeling – Methods
Saint-Venant-Hirano model for mixed-sediment morphodynamics

We try to answer the research question with numerical simulations performed with BASEMENT

- BASEMENT uses the **Saint-Venant-Hirano model for mixed-sediment morphodynamics** to compute morphodynamic changes.
- Hydraulics

$$\frac{\partial h}{\partial t} + \frac{\partial q_w}{\partial x} = 0$$

Continuity equation

$$\frac{\partial q_w}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_w^2}{h} + \frac{1}{2} g h^2\right) + gh\frac{\partial \eta}{\partial x} = -ghS_f$$

Momentum principle

- Sediment transport

$$(1-\lambda_p)\frac{\partial \eta}{\partial t} + \frac{\partial q_{b,T}}{\partial x} = 0$$

Sediment mass continuity (Exner)

$$\frac{\partial M_{a,k}}{\partial t} + f_k^I \frac{\partial q_{b,T}}{\partial x} + \frac{\partial q_{b,k}}{\partial x} = 0$$

Mass conservation in the AL

$$\frac{\partial M_{s,k}}{\partial t} + f_k^I \frac{\partial q_{b,T}}{\partial x} = 0$$

Mass conservation in the substrate

$(2N_{gs} + 1)$ equations

Closure relations

- Gauckler-Strickler relation for the friction slope;
- Toro-Escobar et al. (JHR, 1996) for the grain size exchange between the substrate and the active layer;
- Wilcock and Crowe (JHE, 2003) surface-based transport model to compute bed-load transport.

1D numerical modeling – Methods

Saint-Venant-Hirano model for mixed-sediment morphodynamics

Closure relations:

$$L_a = n_a d_{s,90}$$

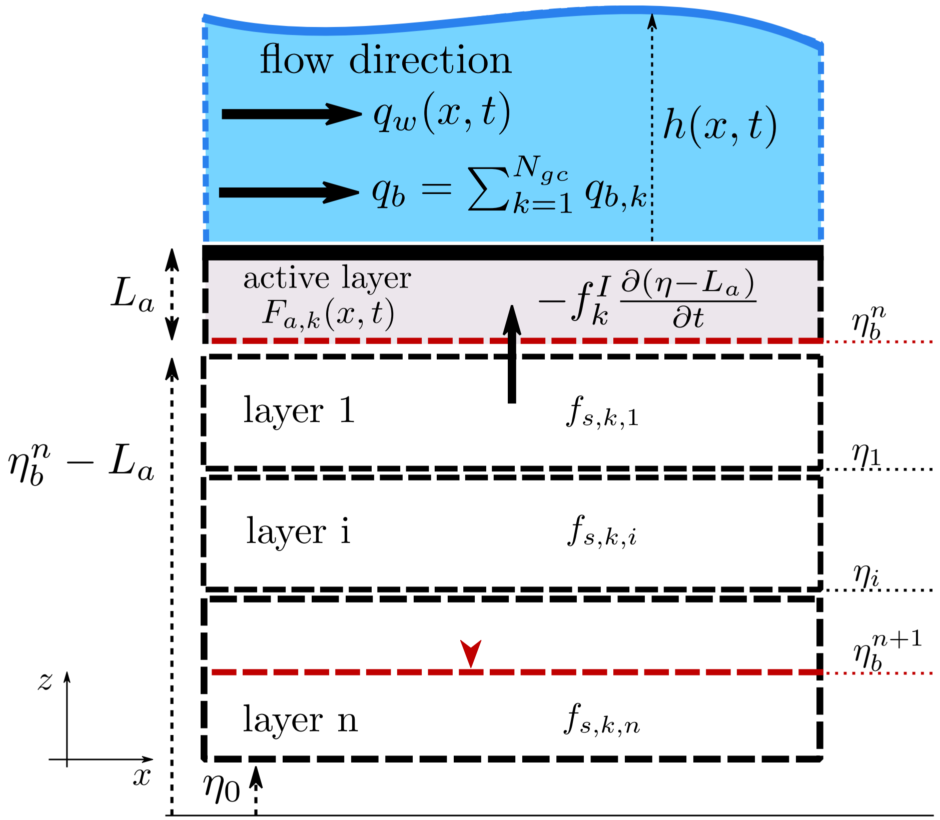
$$f_k^I = \begin{cases} f_{s,k}\Big|_{\eta=\eta-L_a}, & \dfrac{\partial}{\partial t}(\eta - L_a) < 0 \\ \alpha F_{a,k} + (1-\alpha) p_{b,k}, & \dfrac{\partial}{\partial t}(\eta - L_a) \geq 0 \end{cases}$$

(Toro-Escobar et al., JHR, 1996)

Definitions:

$$q_{b,T} = \sum_{k=1}^{N_{gs}} q_{b,k}$$

$$p_{b,k} = \frac{q_{b,k}}{q_{b,T}}$$



1D numerical modeling – Methods
Surface-based Transport Model by Wilcock and Crowe (JHE, 2003)

Computation of sediment discharge

$$q_{b,k} = F_{a,k} \frac{u_*^3}{\Delta g} W_k^*$$

$$W_k^* = G(\phi_k)$$

$$G(\phi_k) = \begin{cases} 0.002\phi_k^{7.5}, & \phi_k < 1.35 \\ 14\left(1 - \frac{0.894}{\phi_k^{0.5}}\right)^{4.5}, & \phi_k \geq 1.35 \end{cases}$$

$$\phi_k = \frac{\tau_{sg}^*}{\tau_{ssrg}^*}\left(\frac{d_{s,k}}{d_{s,g}}\right)^{-b}$$

$$\tau_{sg}^* = \frac{u_*^2}{\Delta g d_{s,g}}$$

$$\tau_{ssrg}^* = 0.021 + 0.015\exp(-20F_s)$$

$$b = \frac{0.67}{1 + exp\left(1.5 - d_{s,k}/d_{s,g}\right)}$$

1D numerical modeling – Methods

Surface-based Transport Model by Wilcock and Crowe (JHE, 2003)

Prediction of the static armor composition

$$q_{b,k} = F_{a,k} \frac{u_*^3}{\Delta g} W_k^*$$

$$W_k^* = G(\phi_k)$$

$$G(\phi_k) = \begin{cases} 0.002\phi_k^{7.5}, & \phi_k < 1.35 \\ 14\left(1 - \frac{0.894}{\phi_k^{0.5}}\right)^{4.5}, & \phi_k \geq 1.35 \end{cases}$$

$$\phi_k = \frac{\tau_{sg}^*}{\tau_{ssrg}^*}\left(\frac{d_{s,k}}{d_{s,g}}\right)^{-b_k}$$

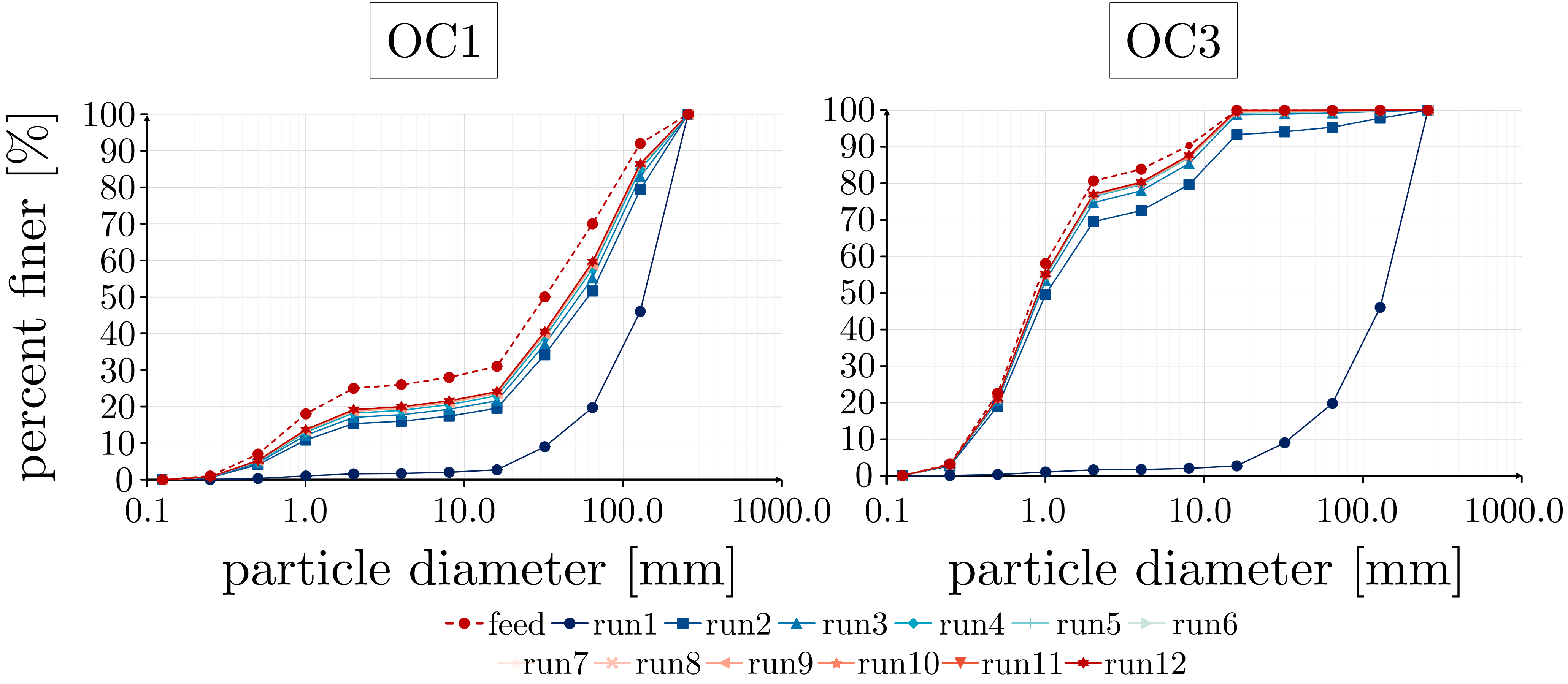
$$\tau_{sg}^* = \frac{u_*^2}{\Delta g d_{s,g}}$$

$$\tau_{ssrg}^* = 0.021 + 0.015\exp(-20F_s)$$

$$b_k = \frac{0.67}{1 + exp\left(1.5 - d_{s,k}/d_{s,g}\right)}$$

$$F_{a,k} = \frac{p_{b,k}\delta_k^{7.5b_k}}{\sum_{k=1}^{N_{gc}} p_{b,k}\delta_k^{7.5b_k}} \quad \delta_k = \frac{d_{s,k}}{d_{s,g}} \quad p_{b,k} = \frac{q_{b,k}}{q_{b,T}}$$

1D numerical modeling – results at mobile-bed equilibrium resulting GSD under OC1 and OC3



1D numerical modeling – results at mobile-bed equilibrium

Scenario II, OC2b

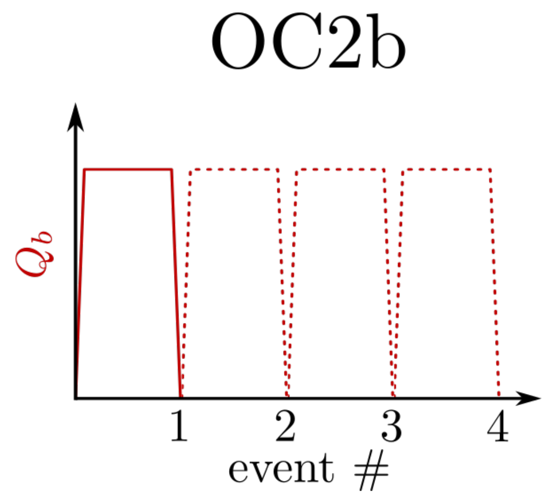
Δη: elevation difference

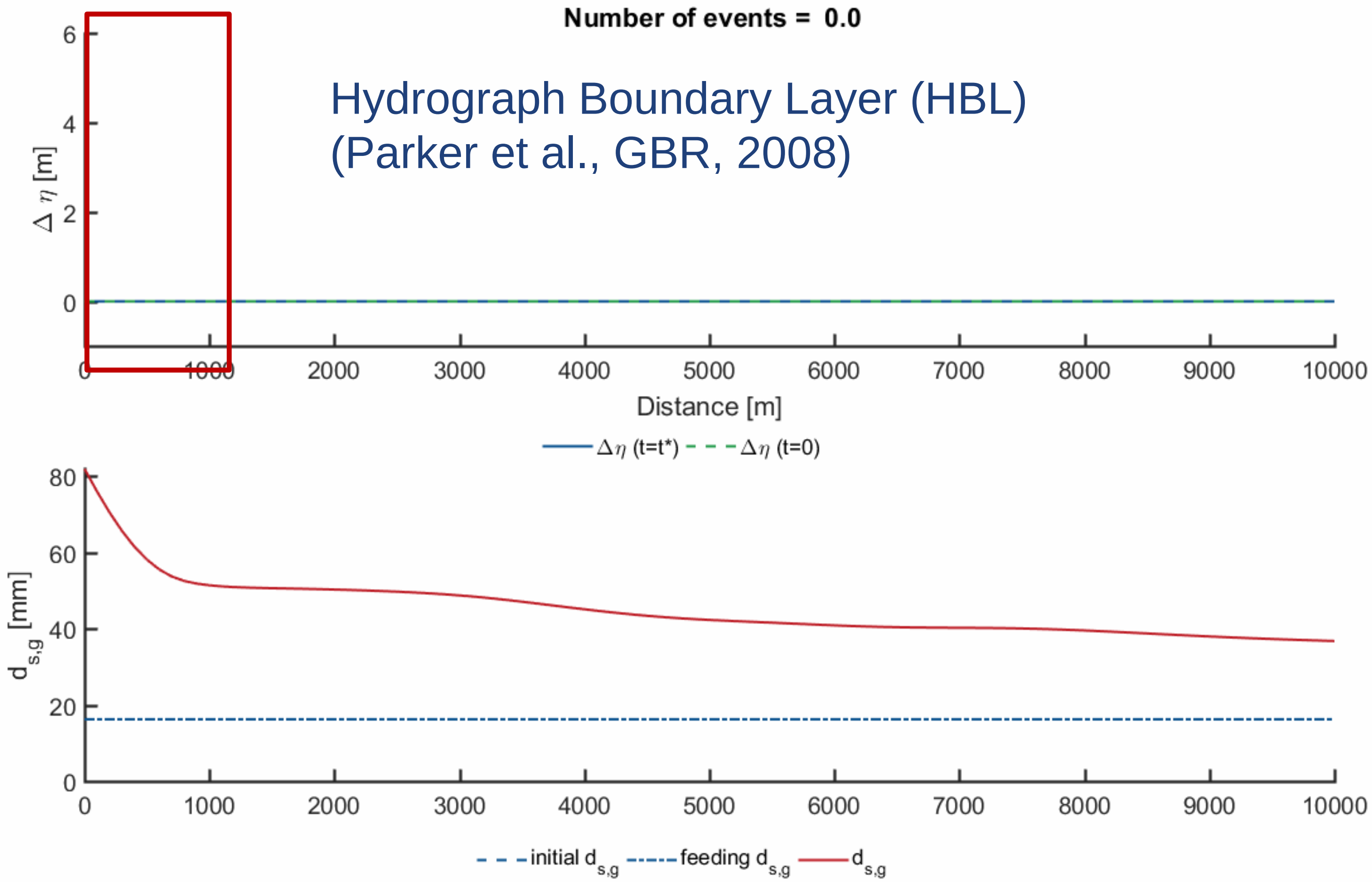
$$\Delta\eta = \eta(t = t^*) - \eta(t = 0)$$

$d_{s,g}$: mean geometric grain size of the riverbed surface

→ Dynamic situation

→ Δη changes confined

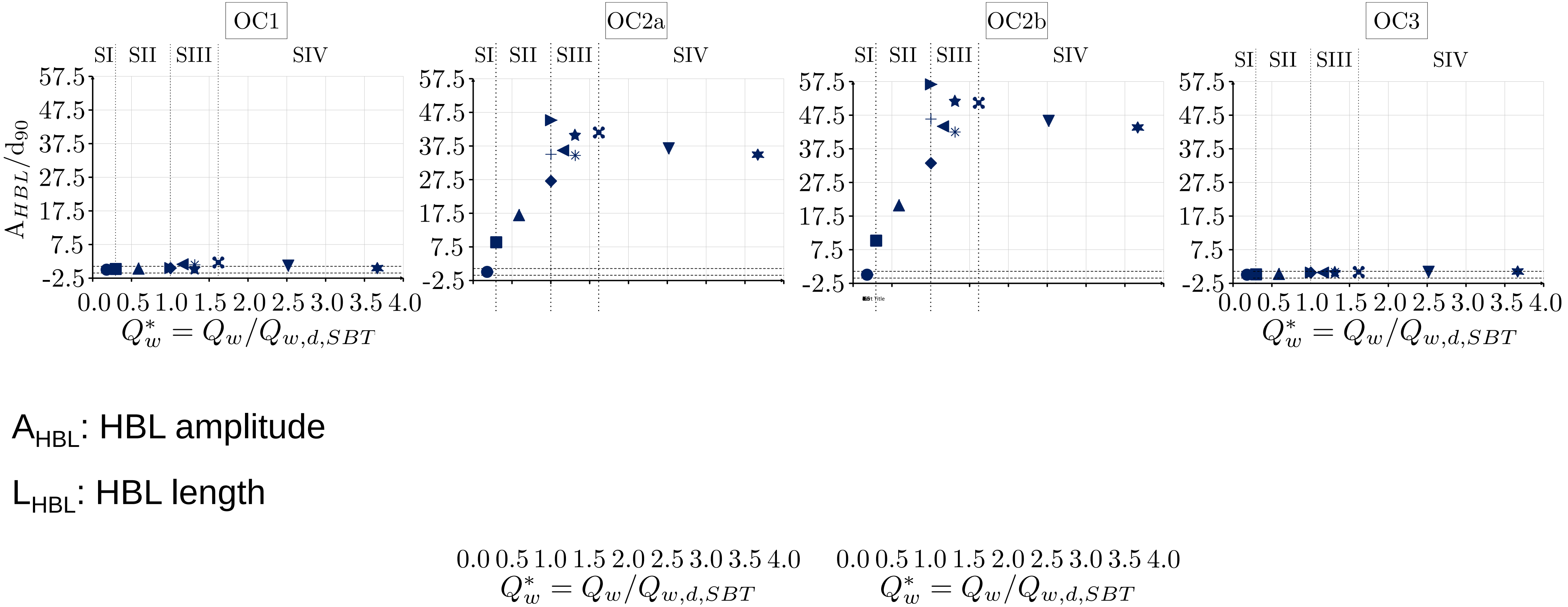




1D numerical modeling – results at mobile-bed equilibrium

HBL present only under OC2 → transport capacity / feeding unbalanced

HBL always confined upstream → less than 2 km from the upstream end



A_{HBL}: HBL amplitude

L_{HBL}: HBL length

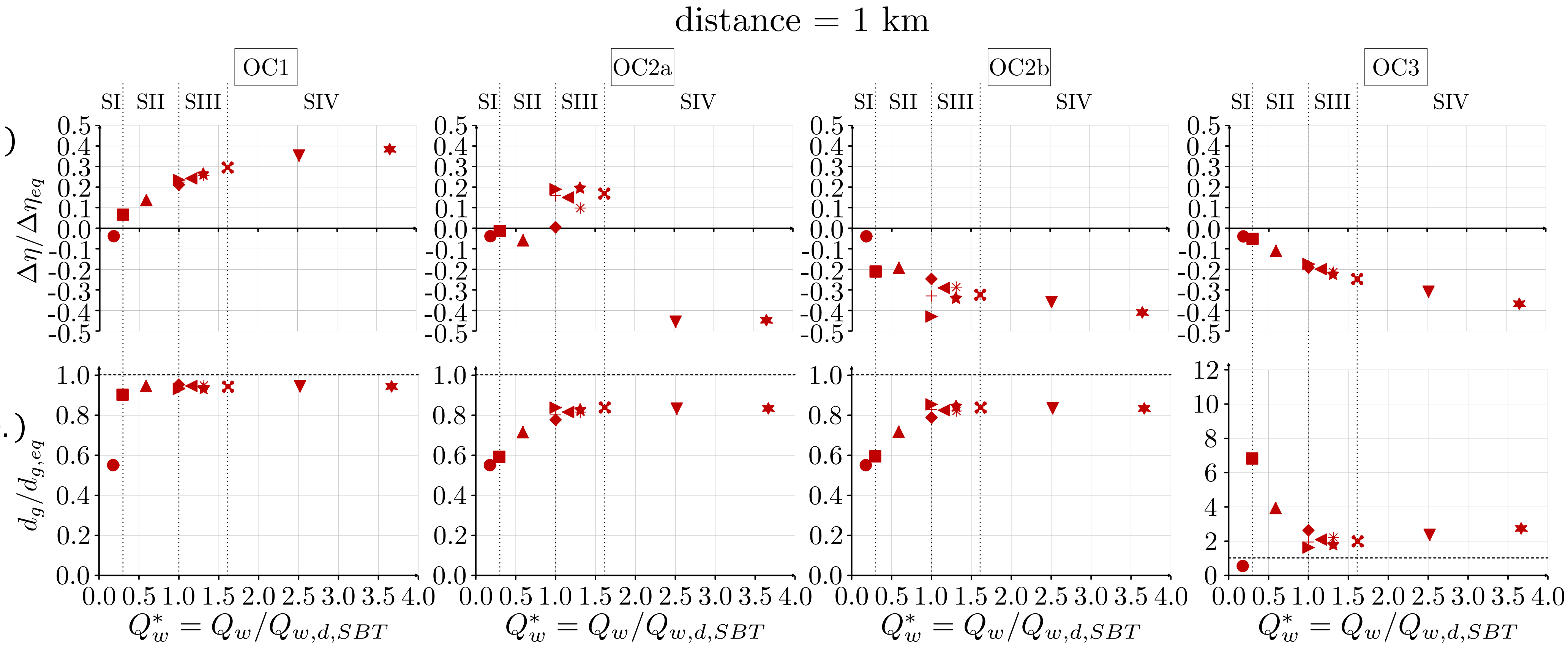
1D numerical modeling – results after 50 SBT operations, 1 km

$\Delta\eta = \Delta\eta(t = 50\ op.)$

$\Delta\eta_{eq} = \Delta\eta(t > 10^4\ op.)$

$d_g = d_g(t = 50\ op.)$

$d_{g,eq} = d_g(t > 10^4\ op.)$



Riverbed level → still far from the equilibrium

Riverbed GSD → close to the equilibrium

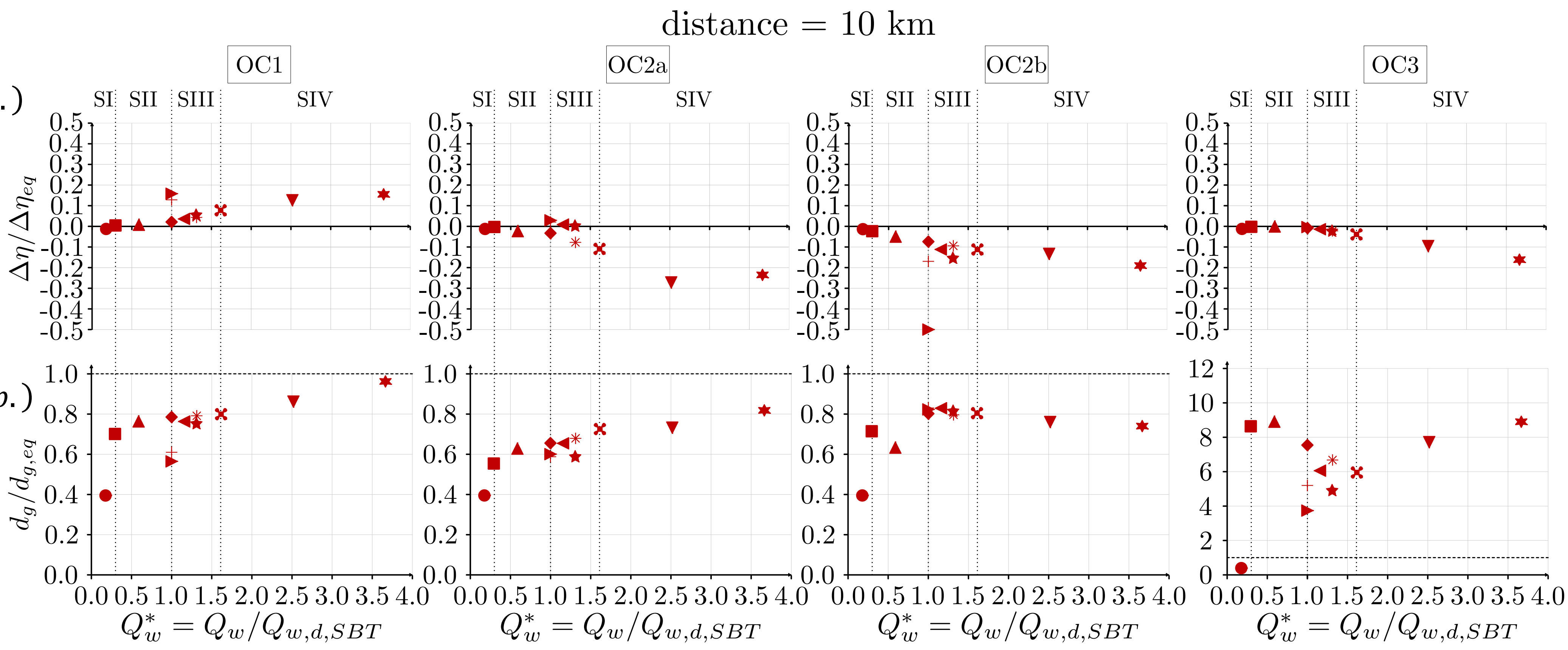
1D numerical modeling – results after 50 SBT operations, 10 km

$\Delta\eta = \Delta\eta(t = 50\ op.)$

$\Delta\eta_{eq} = \Delta\eta(t > 10^4\ op.)$

$d_g = d_g(t = 50\ op.)$

$d_{g,eq} = d_g(t > 10^4\ op.)$

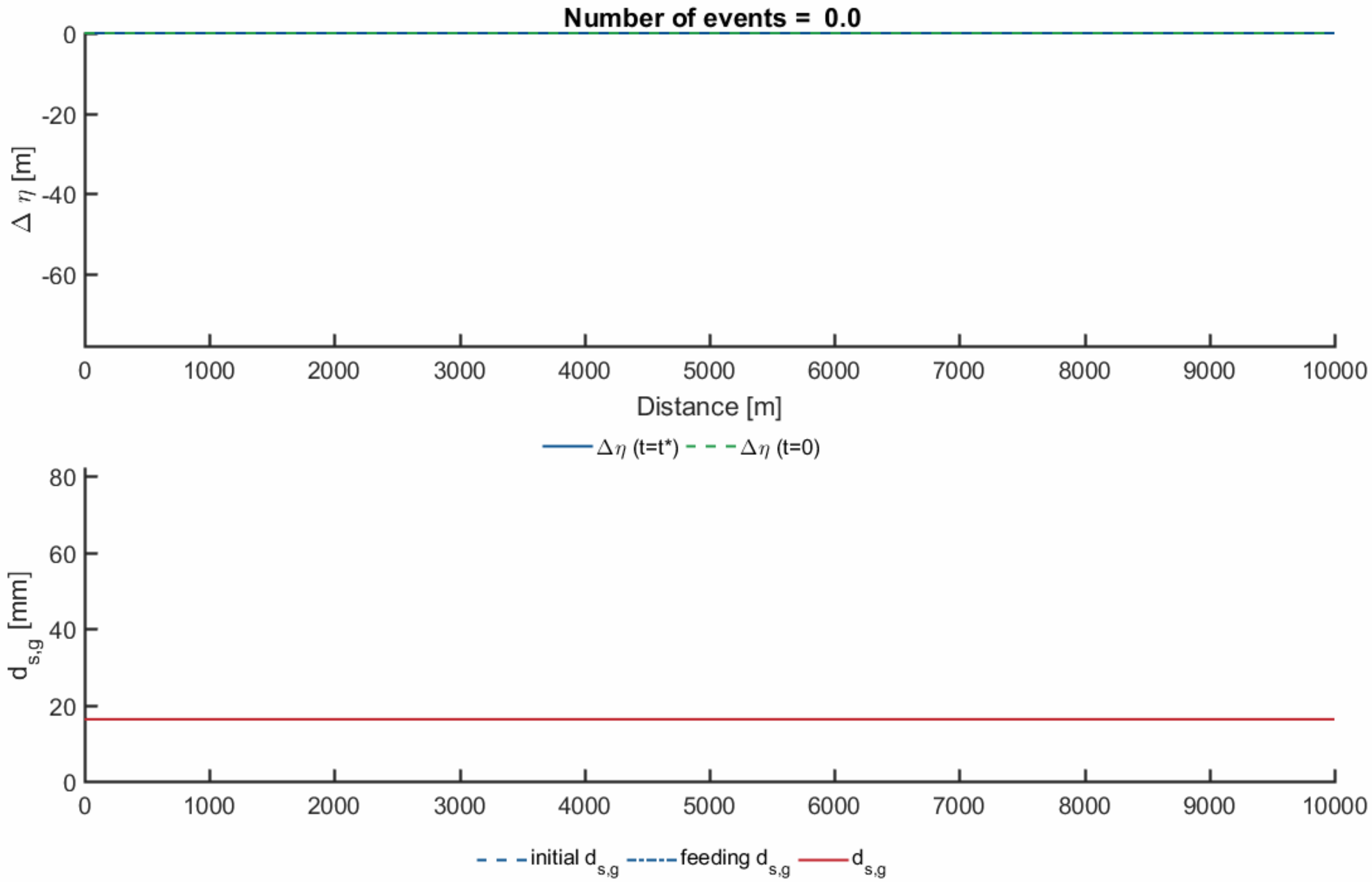


Riverbed level → even farther from the equilibrium

Riverbed GSD → the disturbance has arrived at the end of the domain

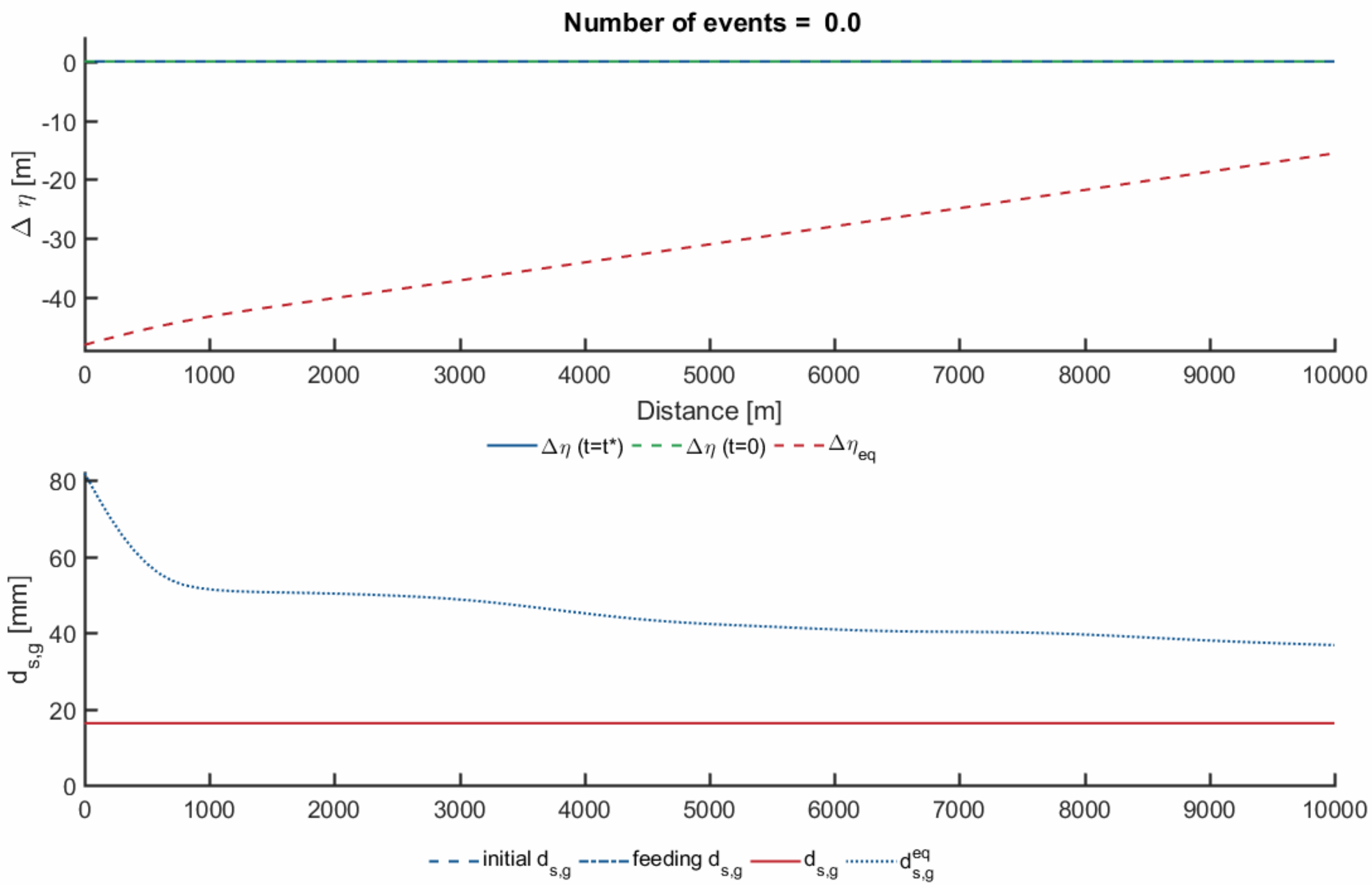
1D numerical modeling – results at mobile-bed equilibrium

Mobile-bed equilibrium reached under OC2b



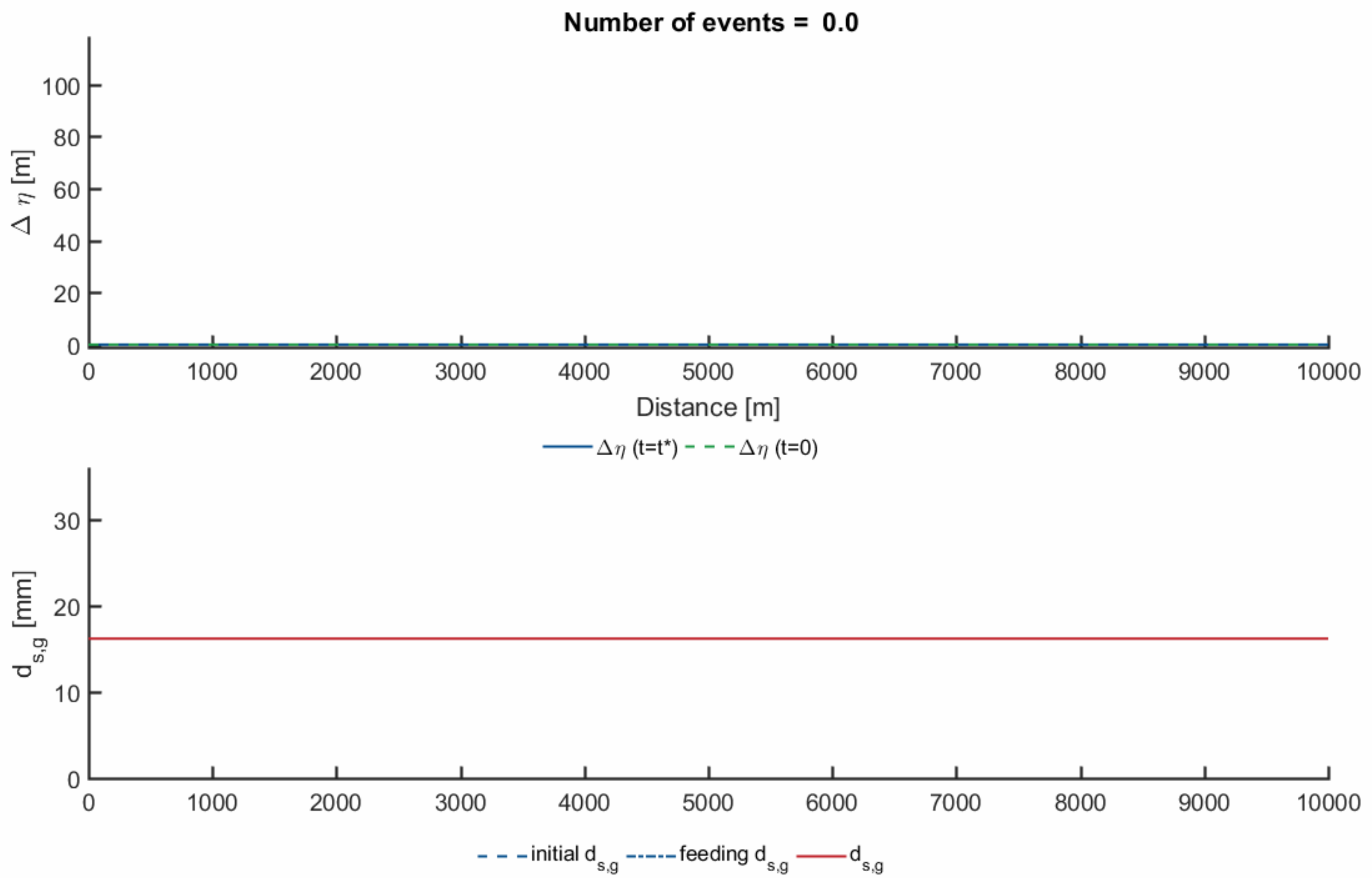
1D numerical modeling – results at mobile-bed equilibrium

First 50 SBT operation under OC2b



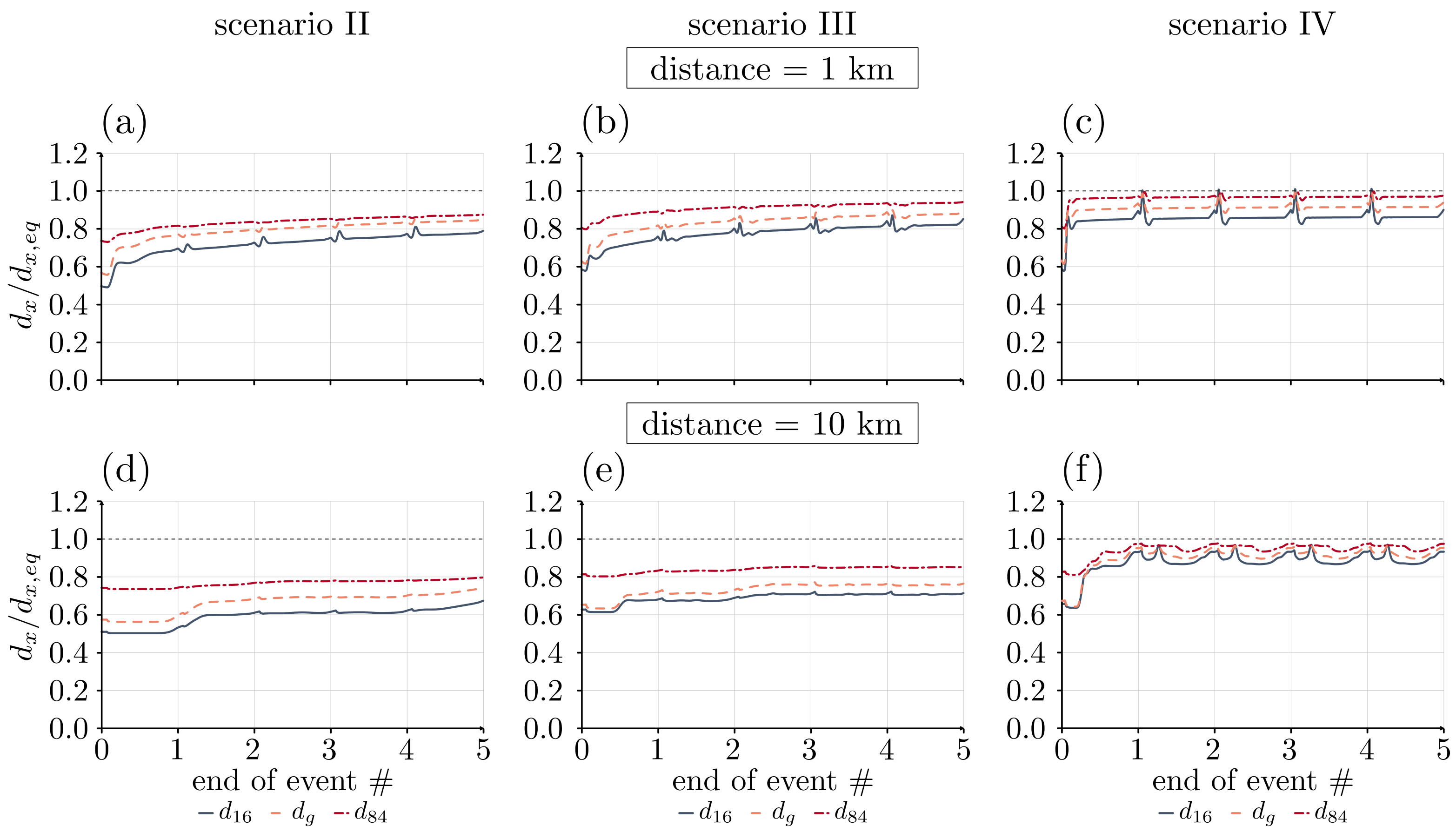
1D numerical modeling – results at mobile-bed equilibrium

Mobile-bed equilibrium reached under OC1



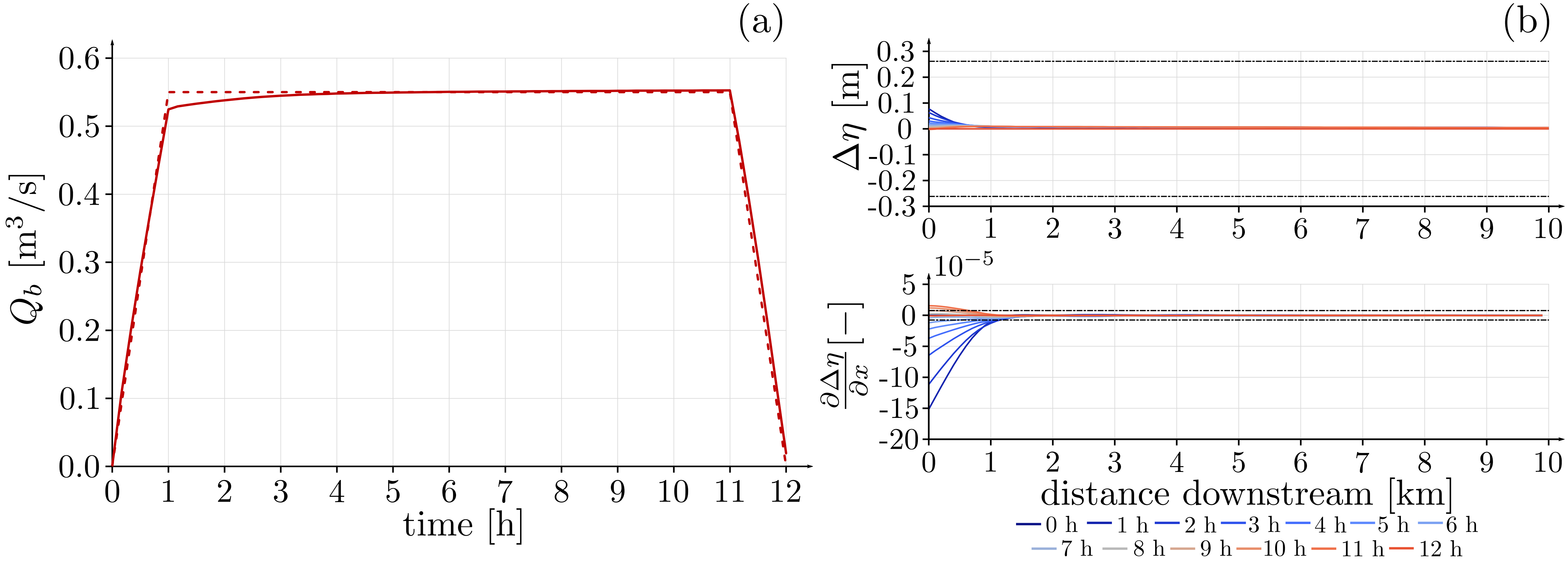
1D numerical modeling – results at event-scale, sorting waves

Run #3, scenario II, OC1



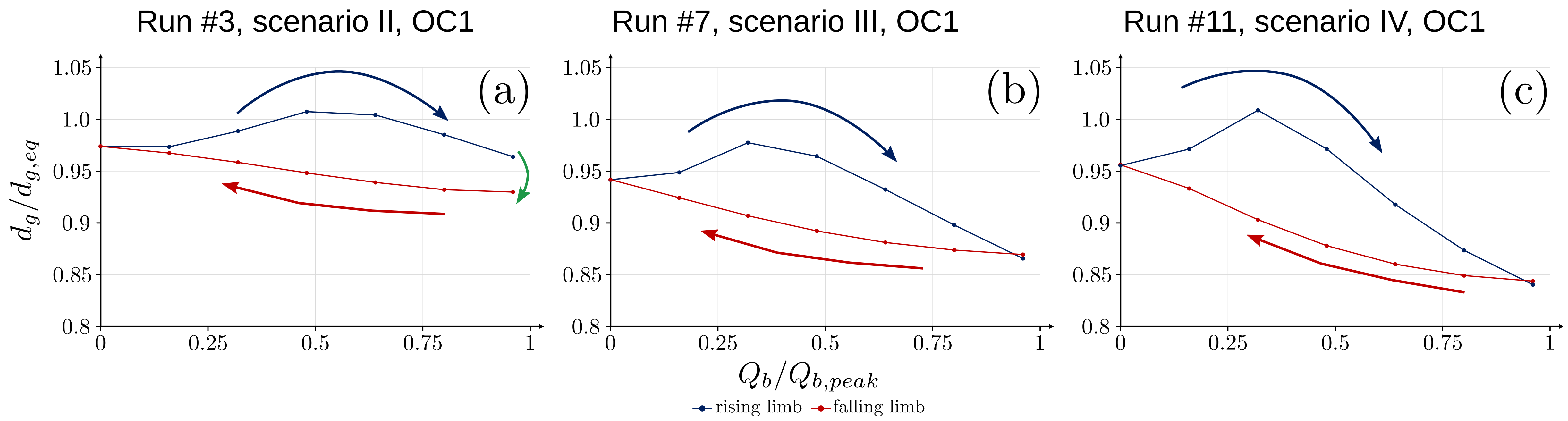
1D numerical modeling – results at event-scale, HBL thresholds

Run 03, scenario II, OC1
→ very small discrepancy between feeding and transport capacity



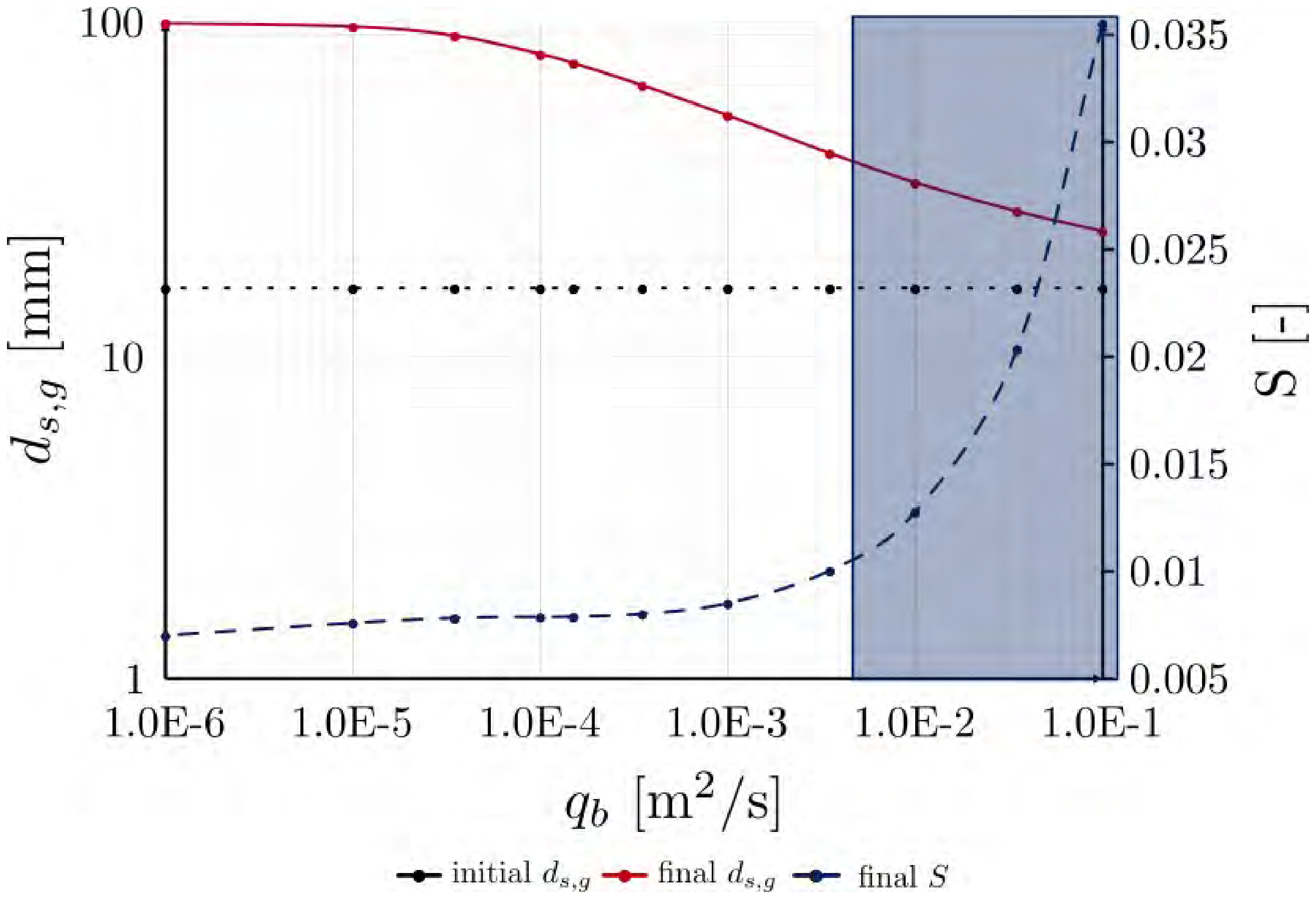
1D numerical modeling – results at event-scale, GSD hysteresis

Released sediment volume >> transport capacity volume → cycle not closed



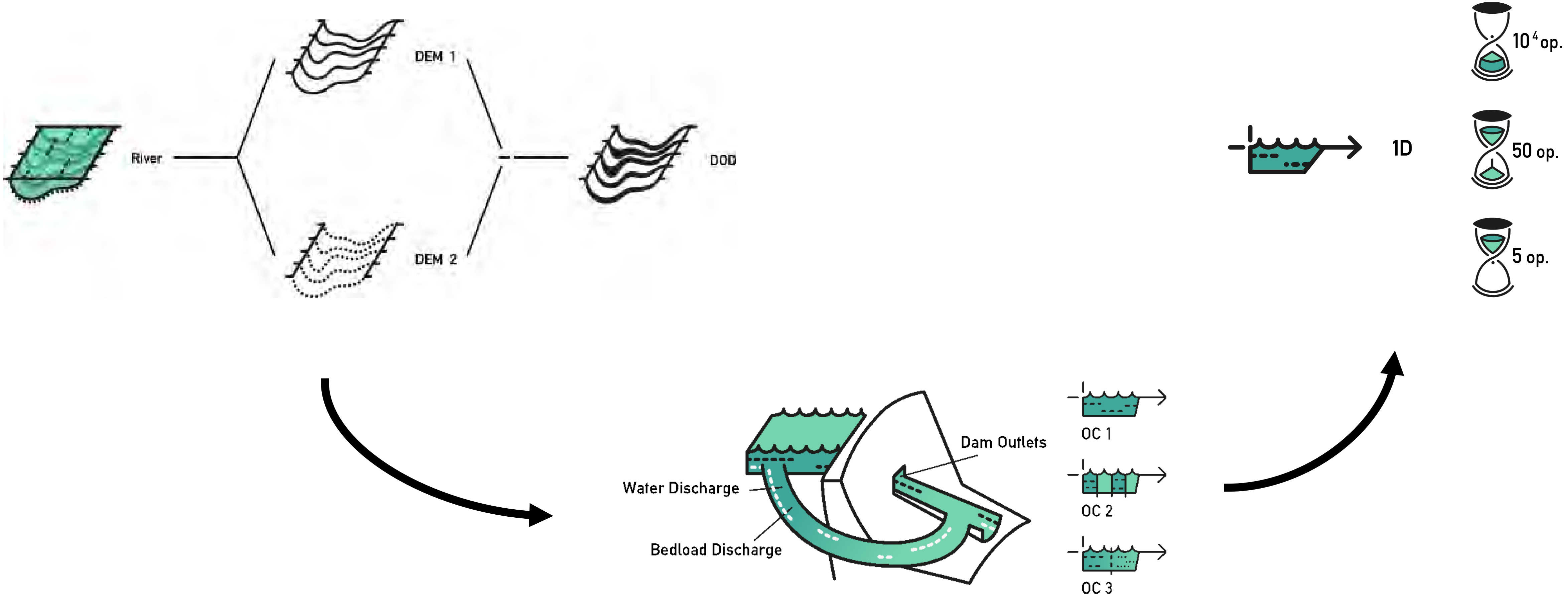
1D numerical modeling – results at event-scale, HBL thresholds

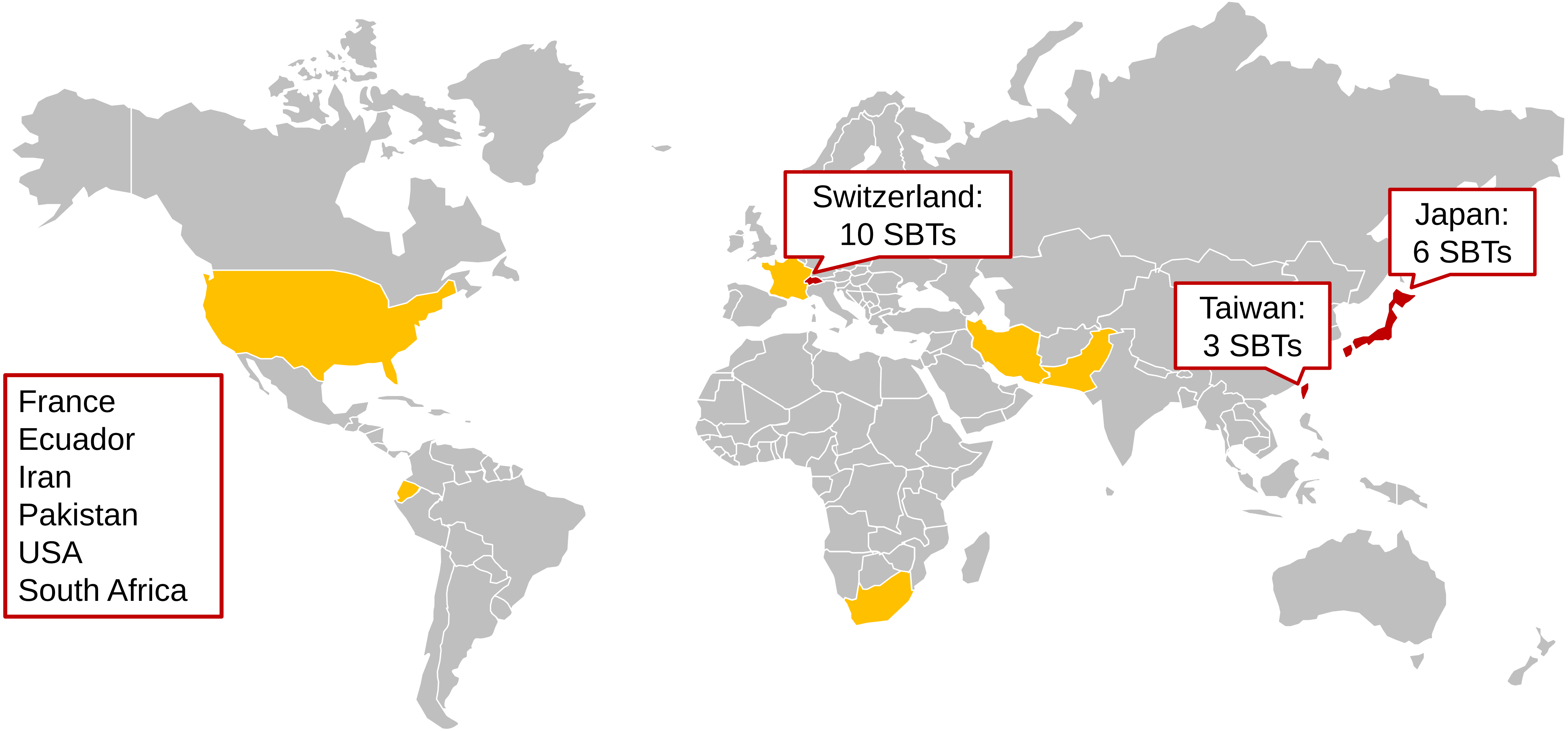
Q_b variations for SBT scenarios is in an area where there are huge slope variations and small GSD variations



Adapted from Parker et al., GBR 2008

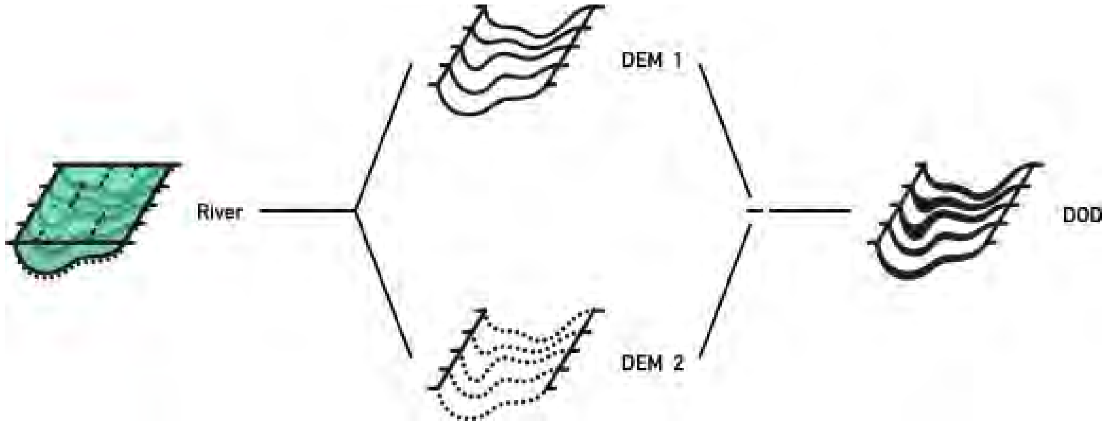
Real case study




Switzerland:
10 SBTs
Japan:
6 SBTs
Taiwan:
3 SBTs
France
Ecuador
Iran
Pakistan
USA
South Africa

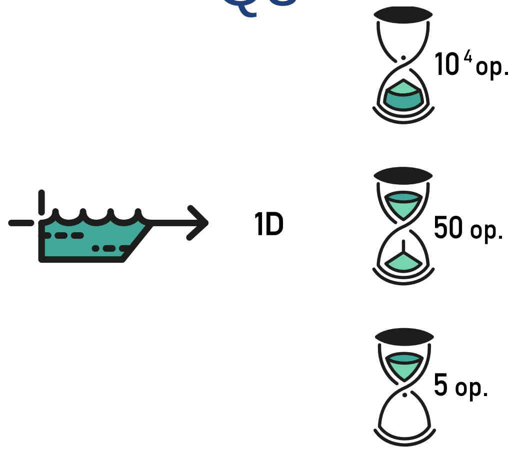
Workflow

Q1



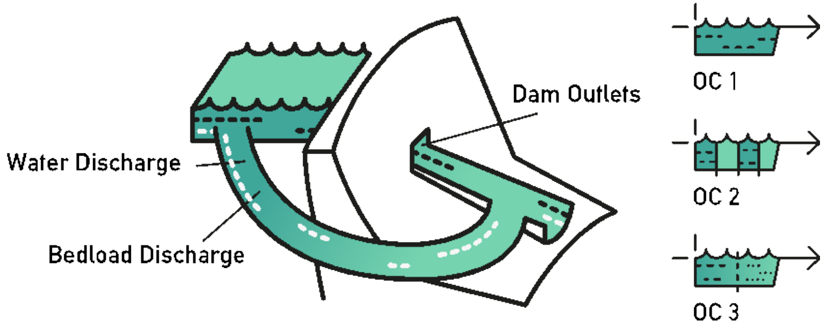
Real case study

Q3



Numerical study

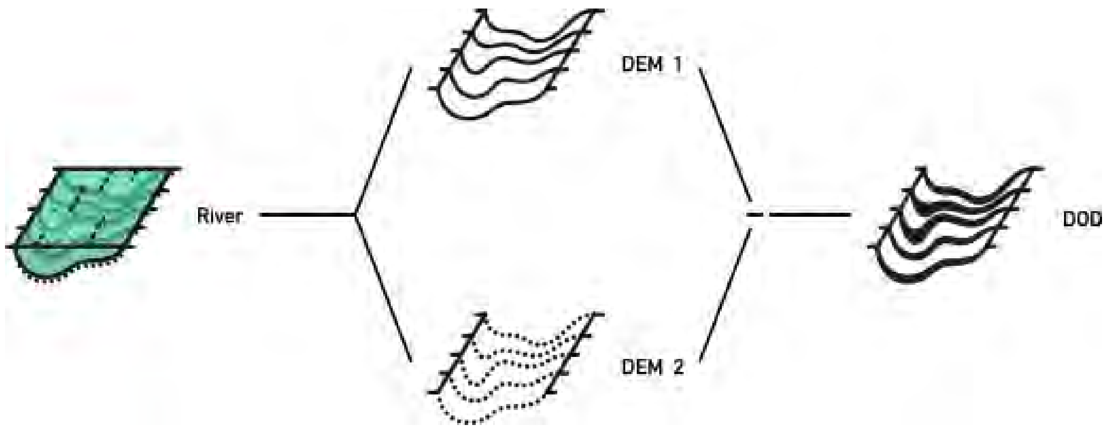
Q2



General framework

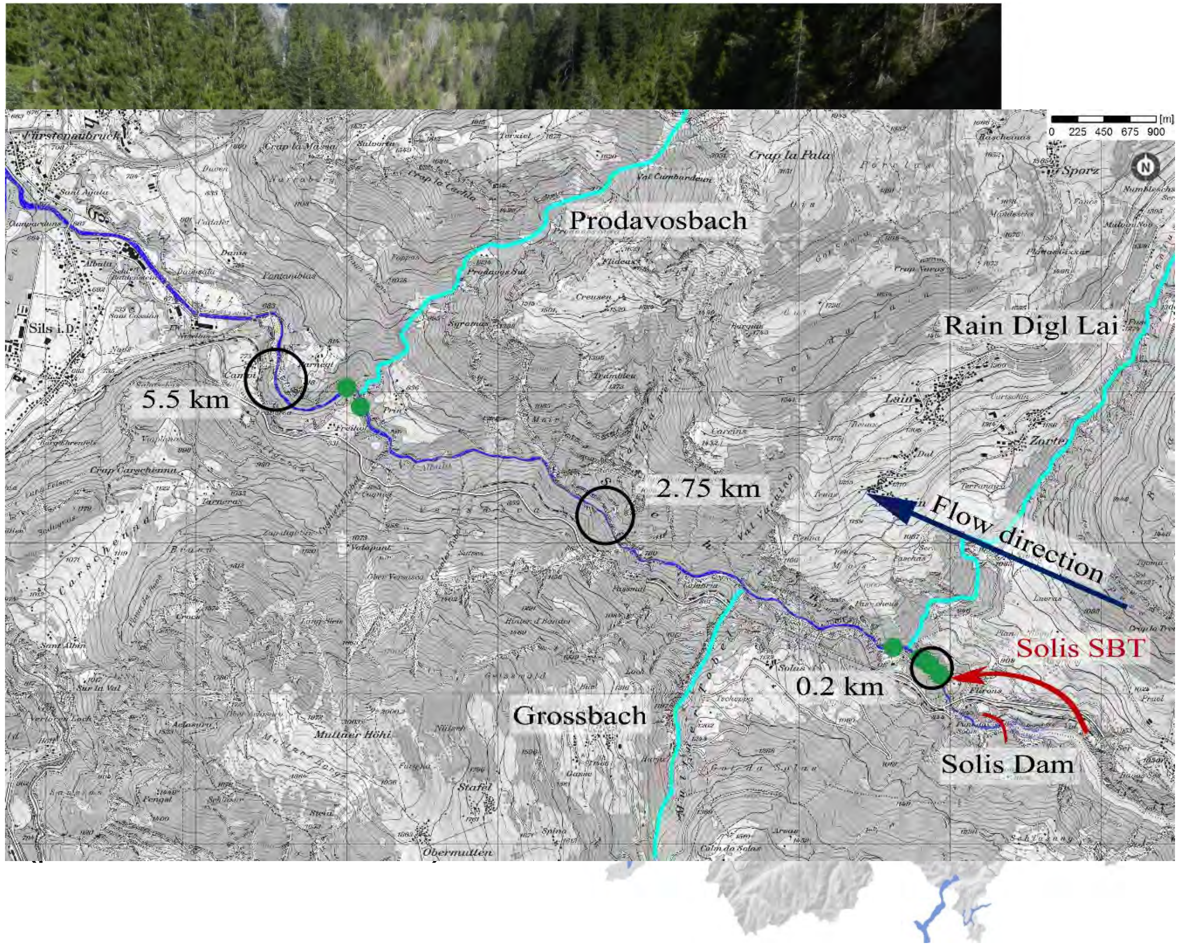
REAL CASE STUDY

Real case study



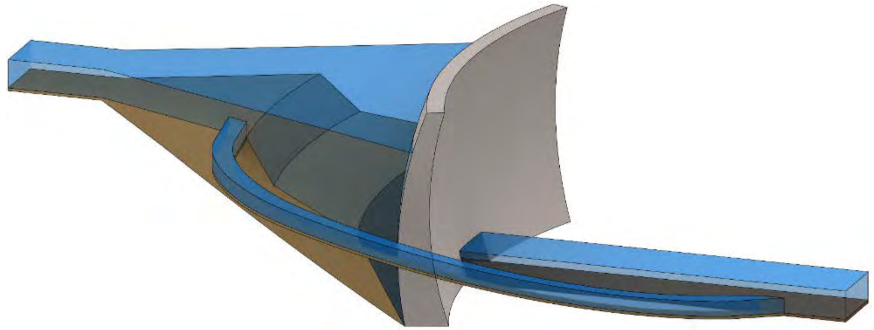
Q1. Which are the volumes mobilized by two years of SBT operations at the Solis SBT and how do they affect river morphology?

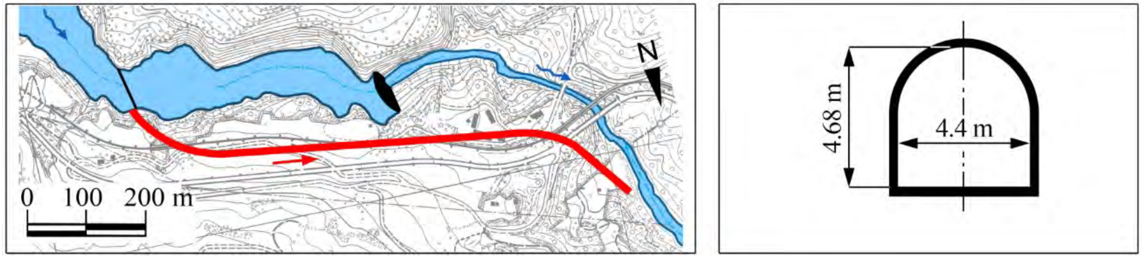
Study site – Reach of the Albula River



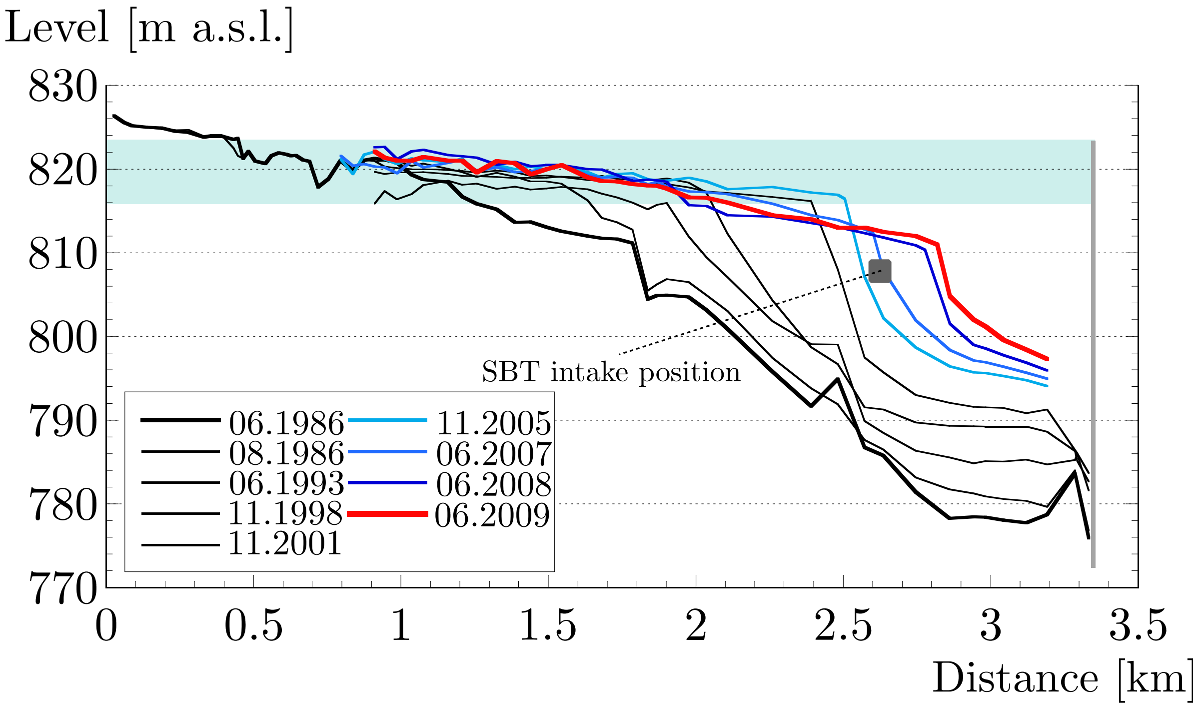
- **Location:**
  downstream of Tiefencastel,
  Canton of Grisons, Switzerland
- **Albula River:**
  950 km^2 drainage basin, 40 km long
- **Downstream Reach:**
  - ca. 7 km long
  - three main tributaries
  - cross-sections surveyed at three locations
  - ecological survey (eawag) at two locations

Study site – Solis SBT





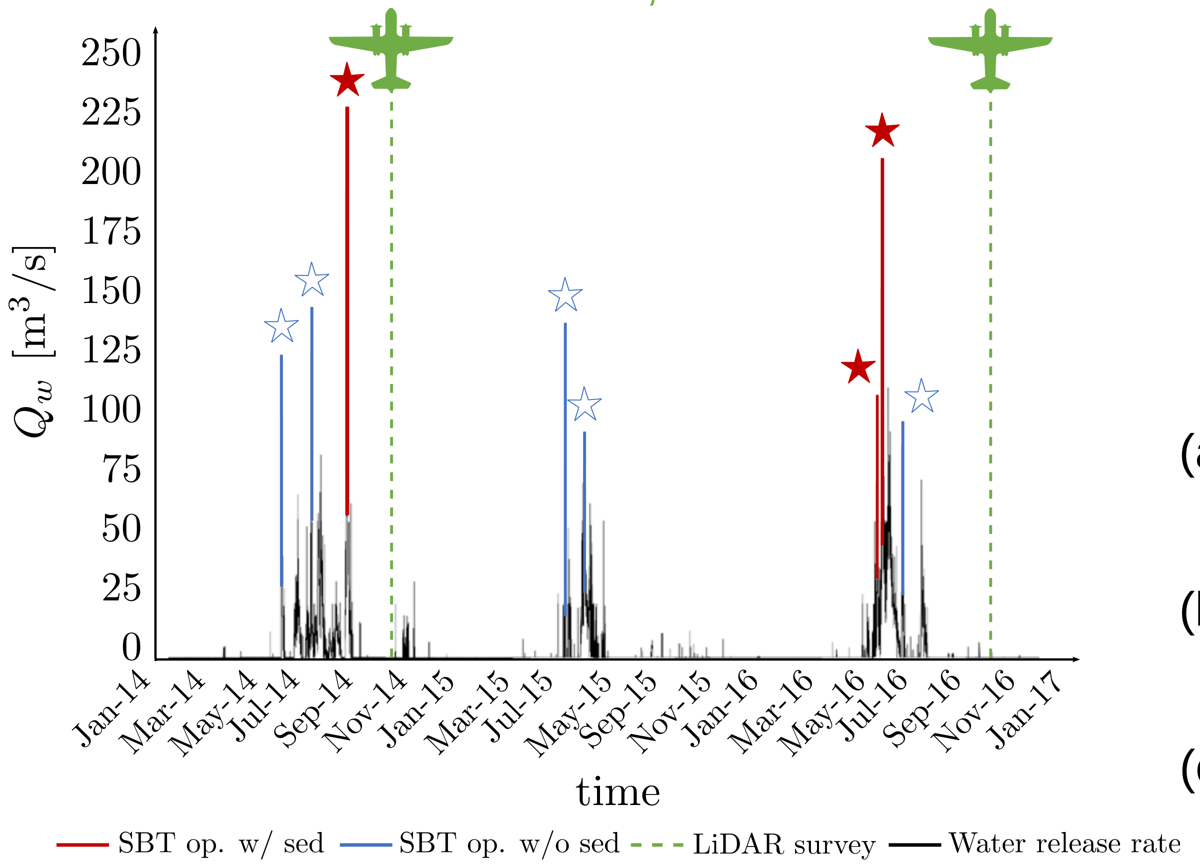
(courtesy of M. Müller-Hagman, VAW)



- **Solis SBT:**
  968 m long, 1.9% slope
- **Inflow section:**
  50 m long, 1% slope
- **Intake location:**
  at the knickpoint of the aggradation body
- **Cross-section shape:**
  horseshoe shape: 4.68 m high, 4.4 m wide

Study site – SBT operations at Solis

Bathymetric LiDAR surveys:
October 18, 2014
October 17, 2016



(a) August 13, 2014
30-year return period

(b) June 11, 2016
2-year return period

(c) June 16/17, 2016
10-year return period

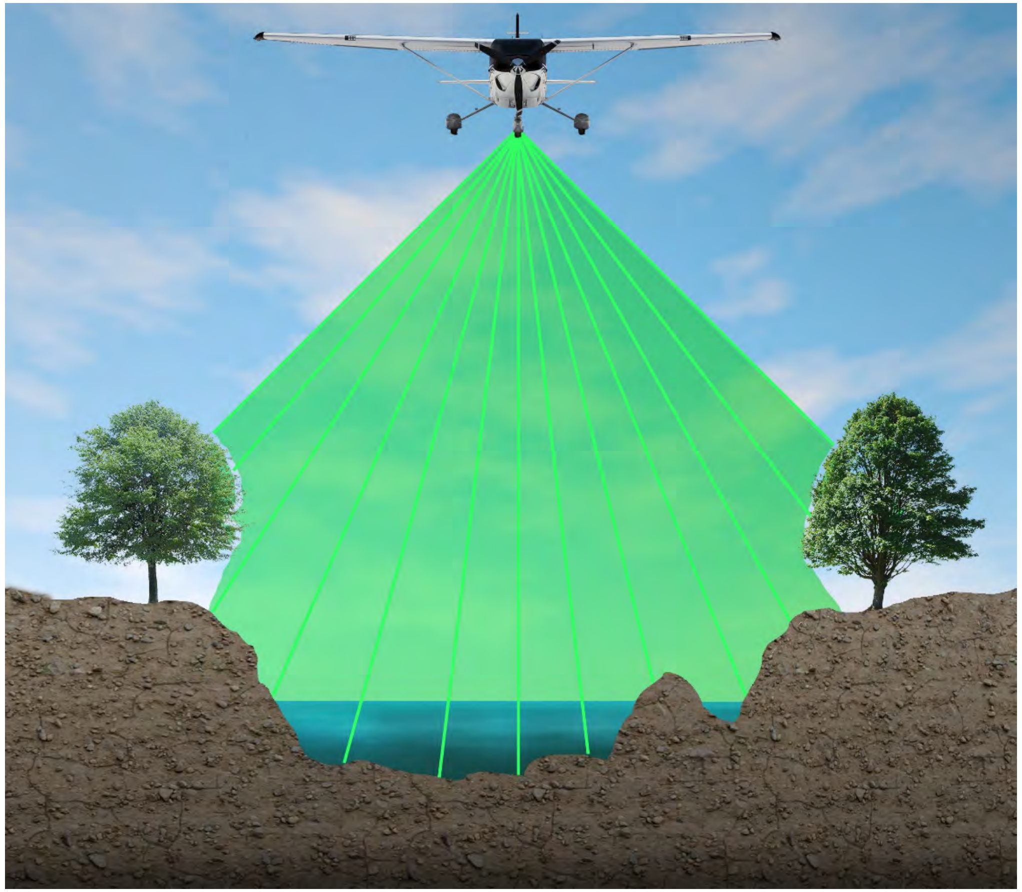
Study site – bathymetric LiDAR surveys at Solis

LiDAR = Light Detection And Ranging

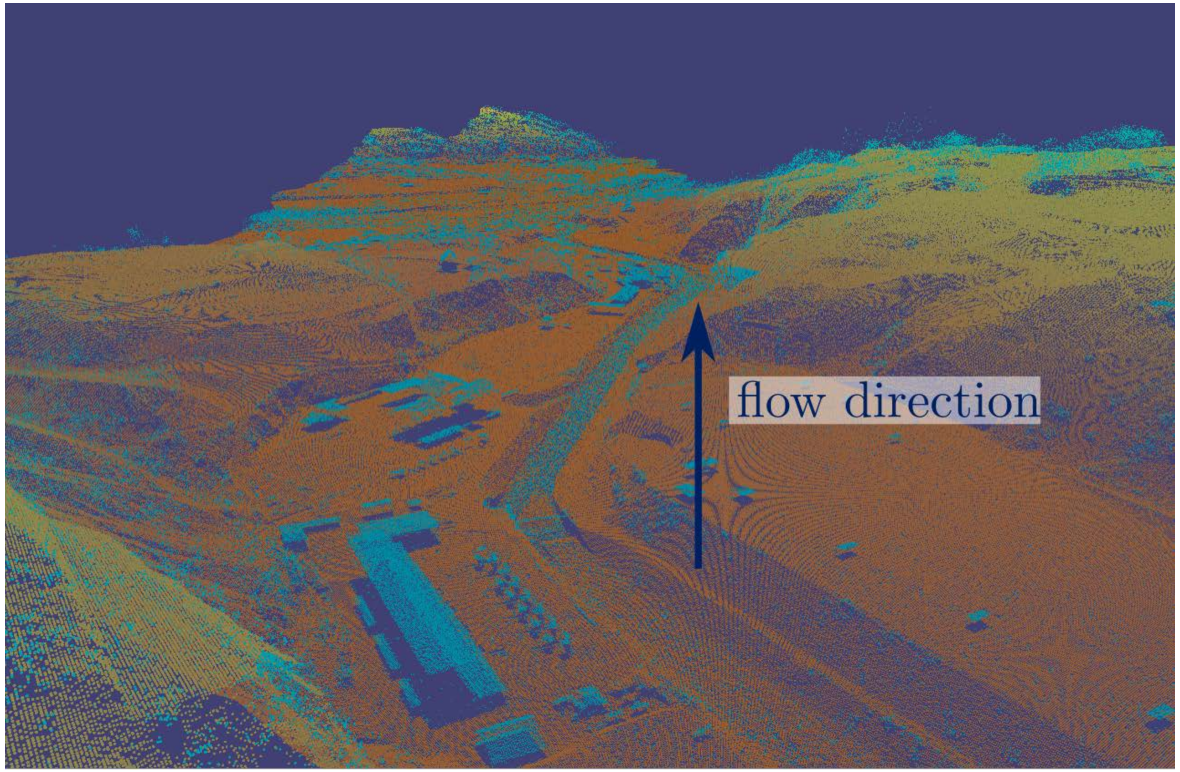
Bathymetric LiDAR → under water points

Year	2014	2016
Operator	AHM[a]	AHM[a]
Flight date	Oct. 18	Oct. 17
ALS[b] system	VQ820-G	VQ880-G
Point Density [pts/m^2]	20-30	50-60
ALS[b] accuracy [cm]	2.5	2.5

[a] AirborneHydroMapping GmbH, Innsbruck
[b] Airborne Laser Scanning



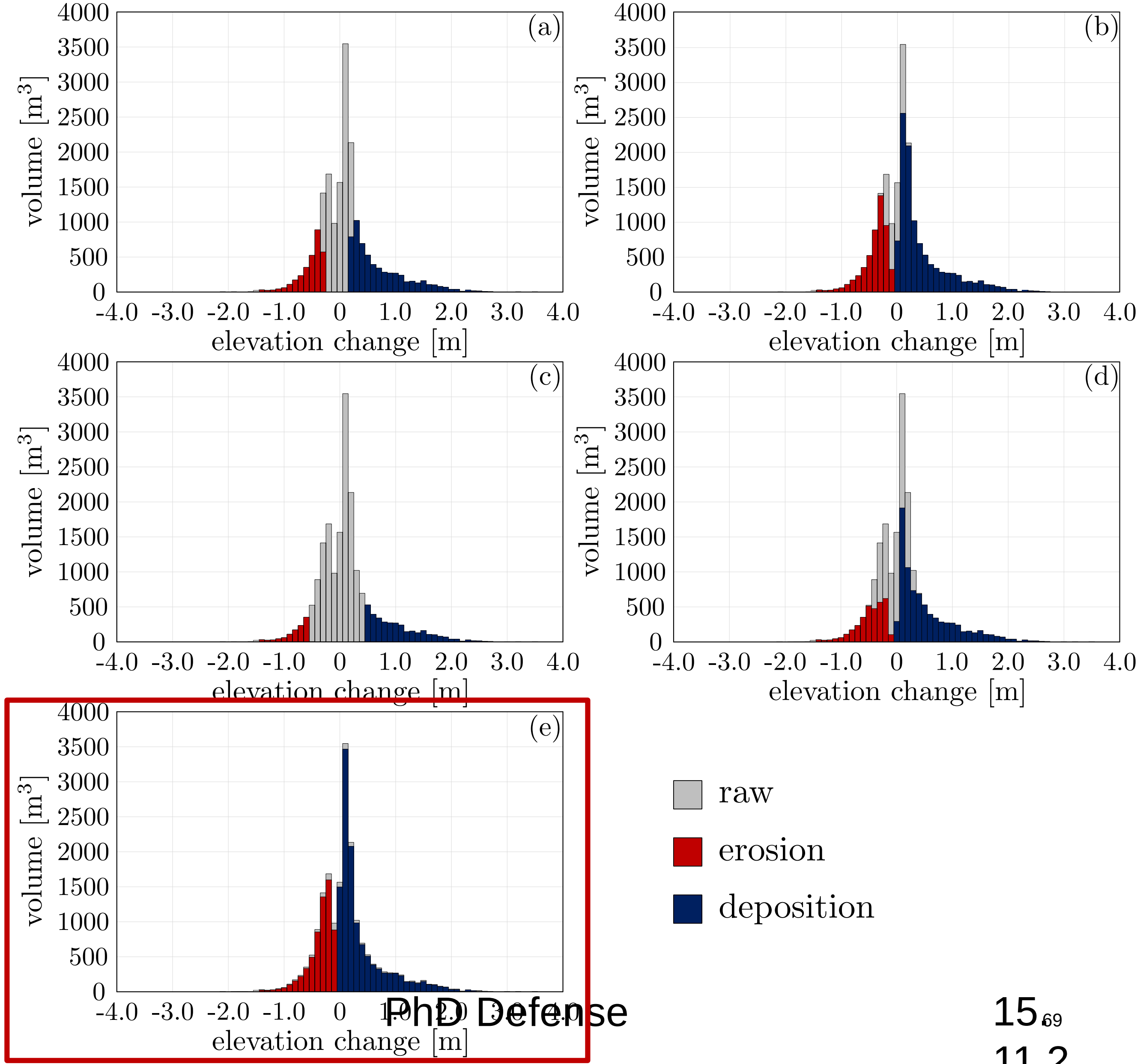
Digital Elevation Model (DEM) of Difference (DoD) – Method



- LiDAR data post processing to generate a DEM for each survey + validation
- DEM2016 – DEM2014 = DoD
  → volumes + erosion/deposition patterns
- Geomorphic Change Detection (GCD) tool by J. Wheaton (ESPL, 2010):
  - Quantification of single DEM uncertainties
    - Uniform error
    - Fuzzy Inference System (point density and slope)
  - Propagation of single DEM uncertainties into the DoD
    - Minimum level of detection
    - probabilistic representation of uncertainty (CI)
  - Spatial Contiguity Index (SCI)

DoD – Results

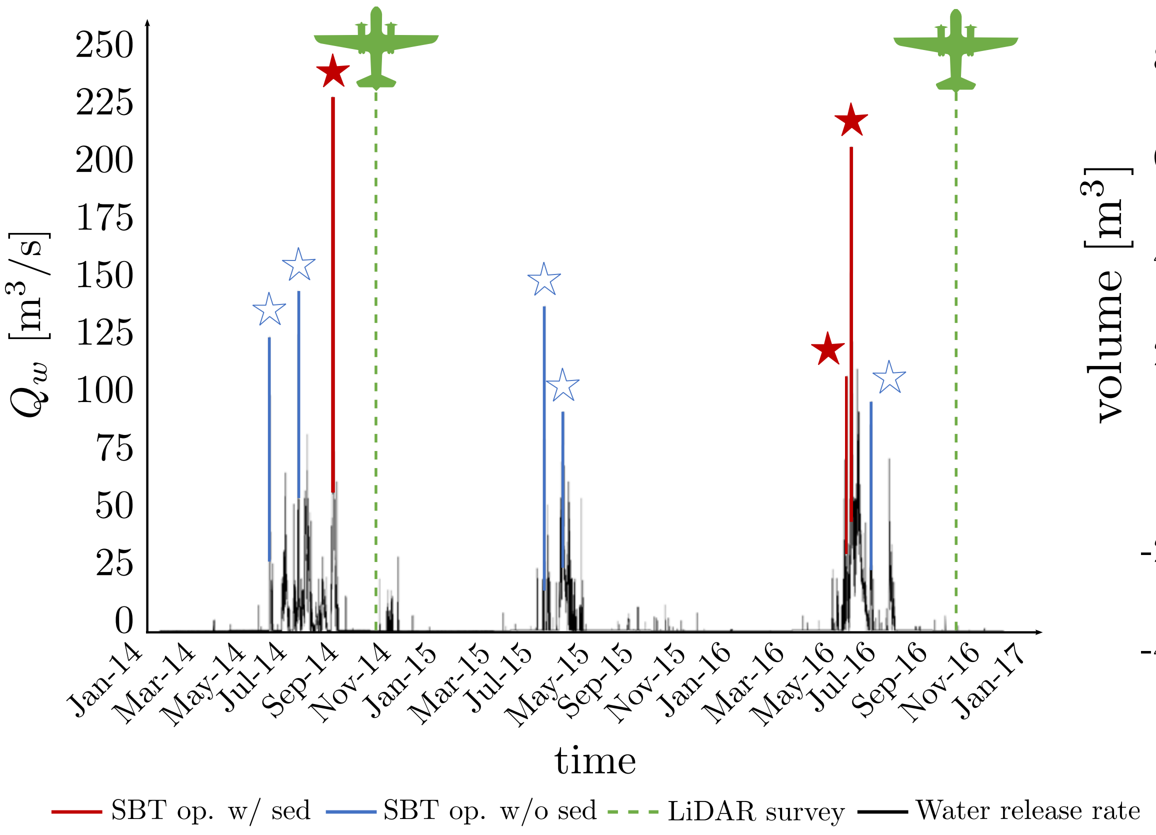
Name	Eroded V [m³]	Deposited V [m³]	Net V [m³]
Raw	6593	12416	**5823**
U1P1 (a)	3085	5959	**2874**
U2P1 (b)	5171	10552	**5381**
U1P2 (c)	1103	3458	**2355**
U2P2 (d)	3373	8138	**4765**
U2P2SCI (e)	6182	11985	**5804**

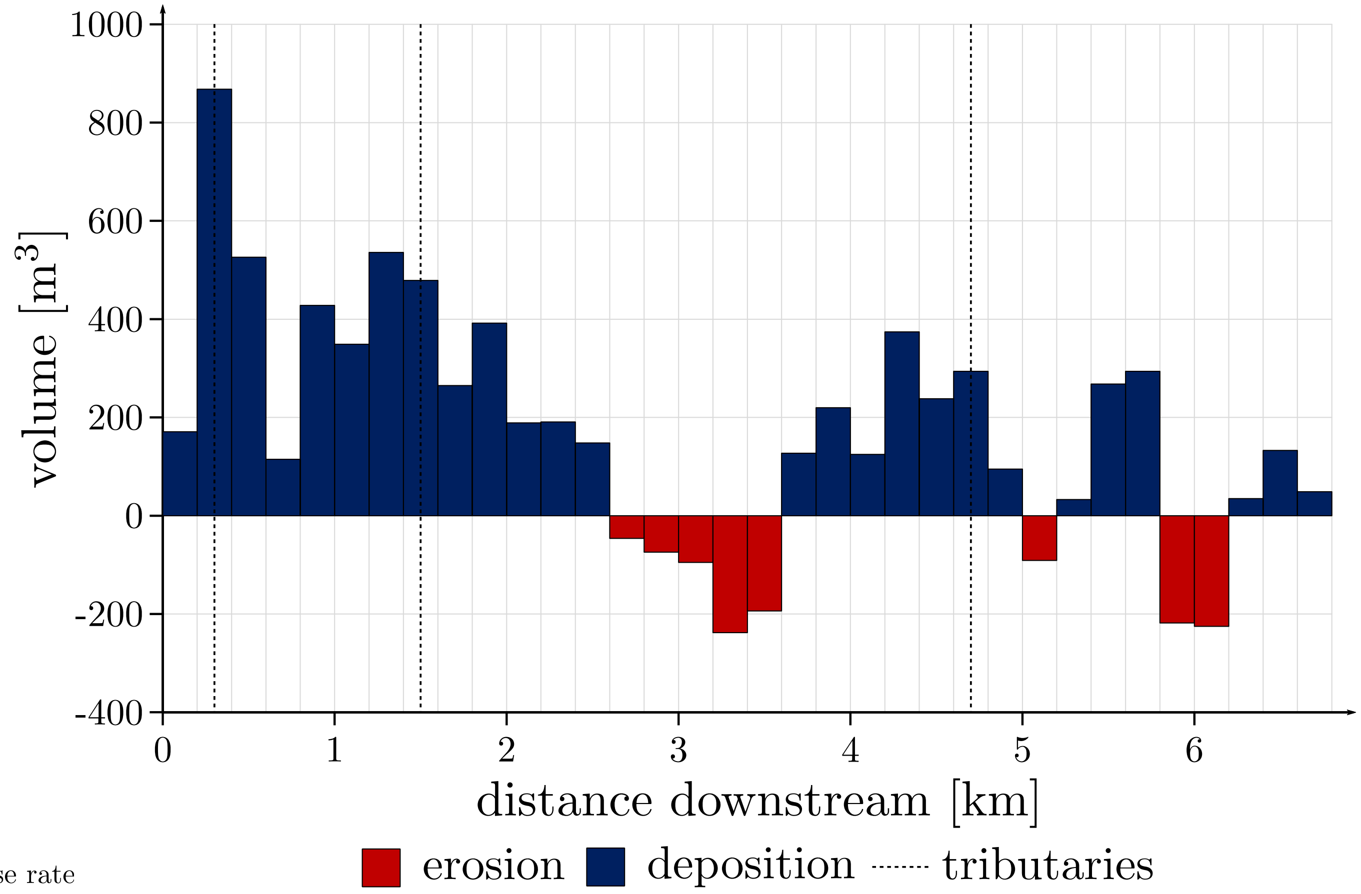


DoD - Results

Budget segregation (200 m reaches):

- deposition – erosion – deposition in the first 5 km
  - possible sediment pulse behavior





Conclusions

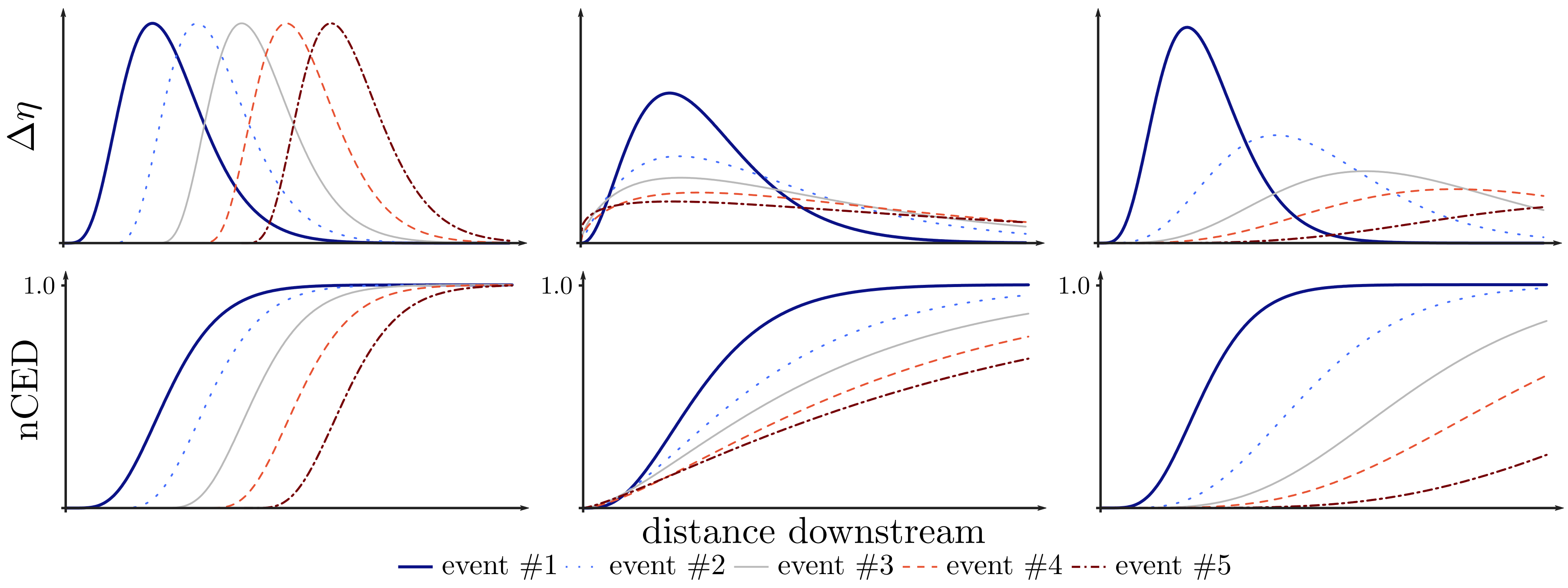
Q1. Which are the volumes mobilized by two years of SBT operations at the Solis SBT and how do they affect river morphology?

- Large volumes (2400~5800 m^3) of sediment mobilized
- Clear water releases → pulse advection

1D numerical modeling – results at event-scale

5 op.

Δη: deviatoric riverbed level (elevation difference)
nCED: normalized Cumulative Elevation Difference



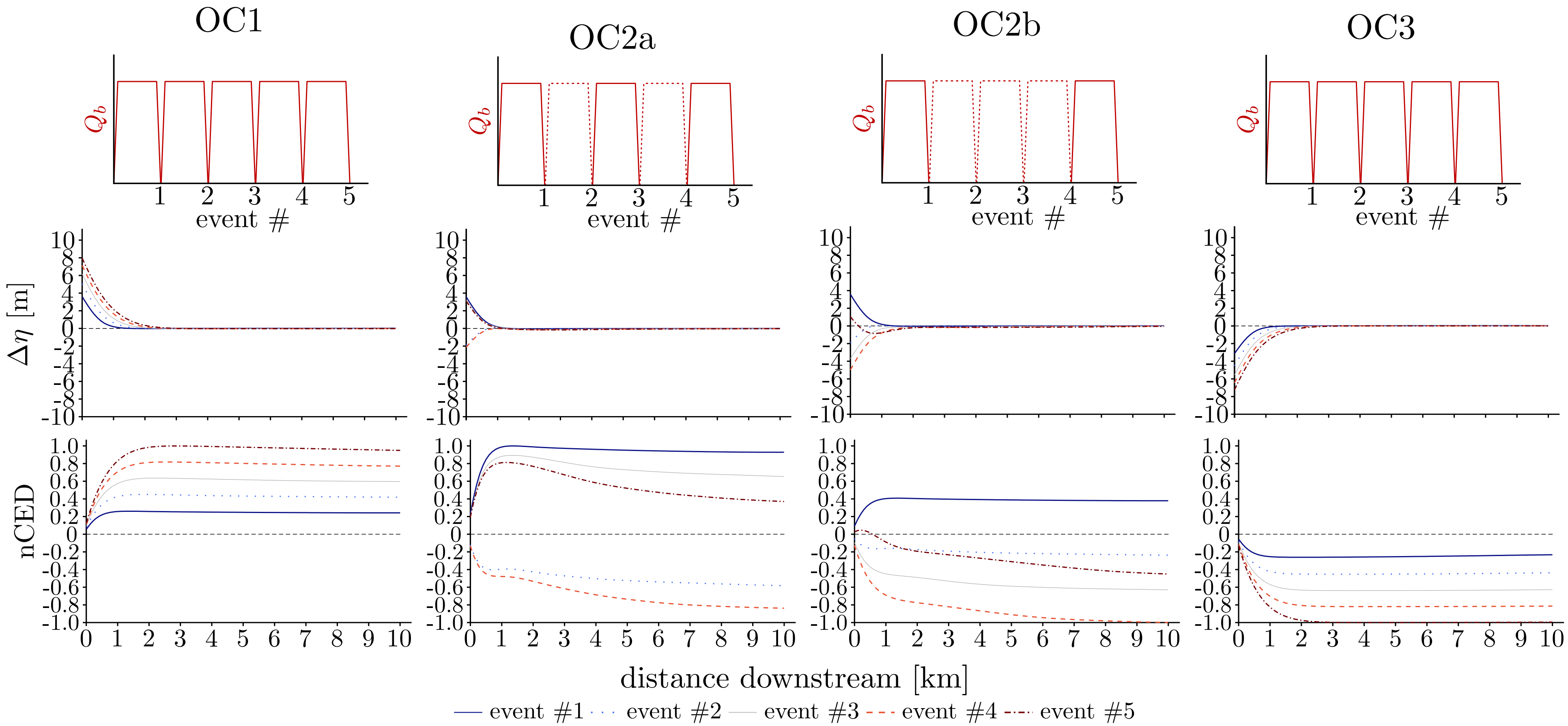
Adapted from Sklar et al., WRR, 2009

1D numerical modeling – results at event-scale

Scenario II (SBT design range)

- Clear water releases (OC2a and b) → pulse advection

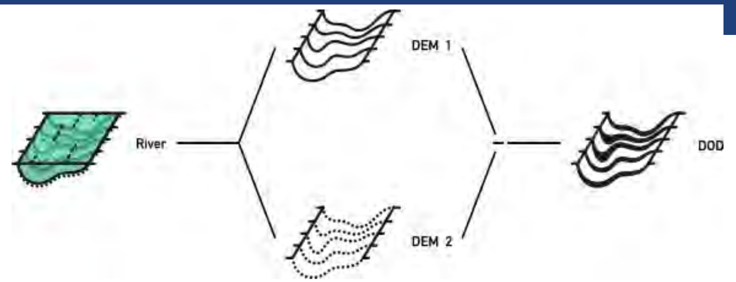
5 op.

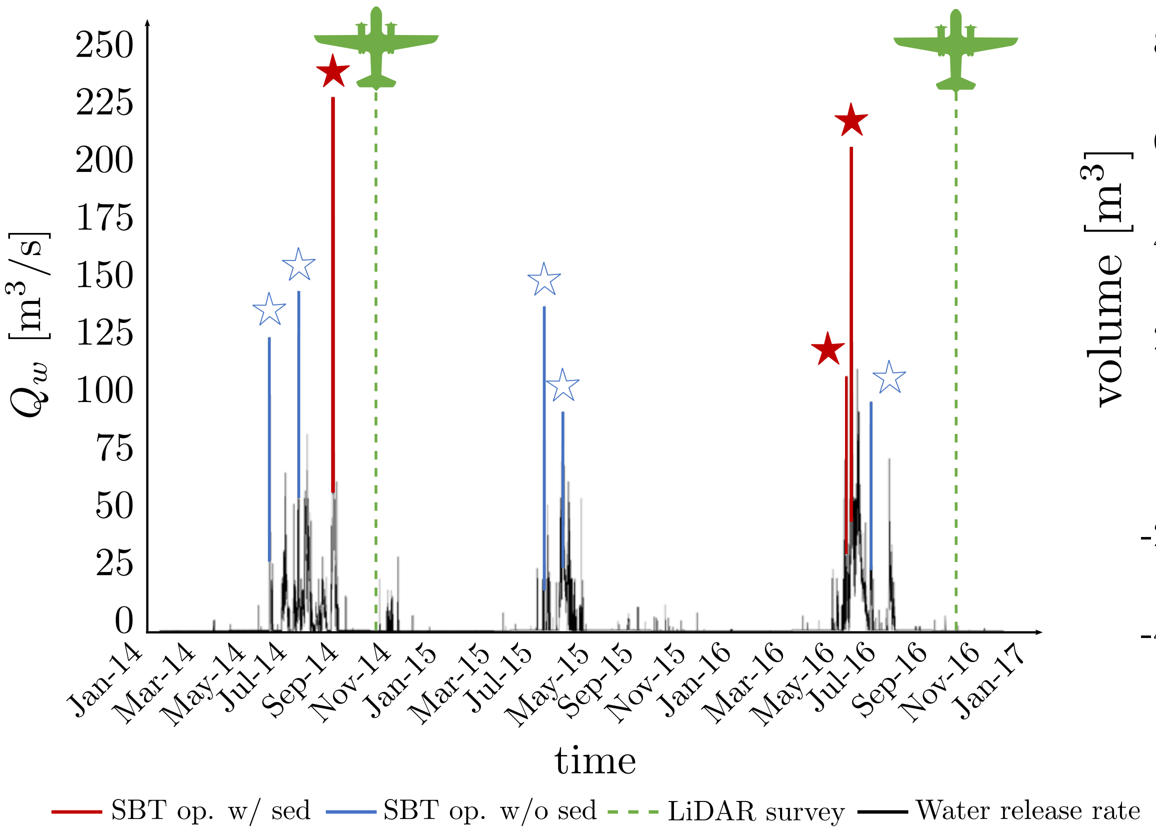


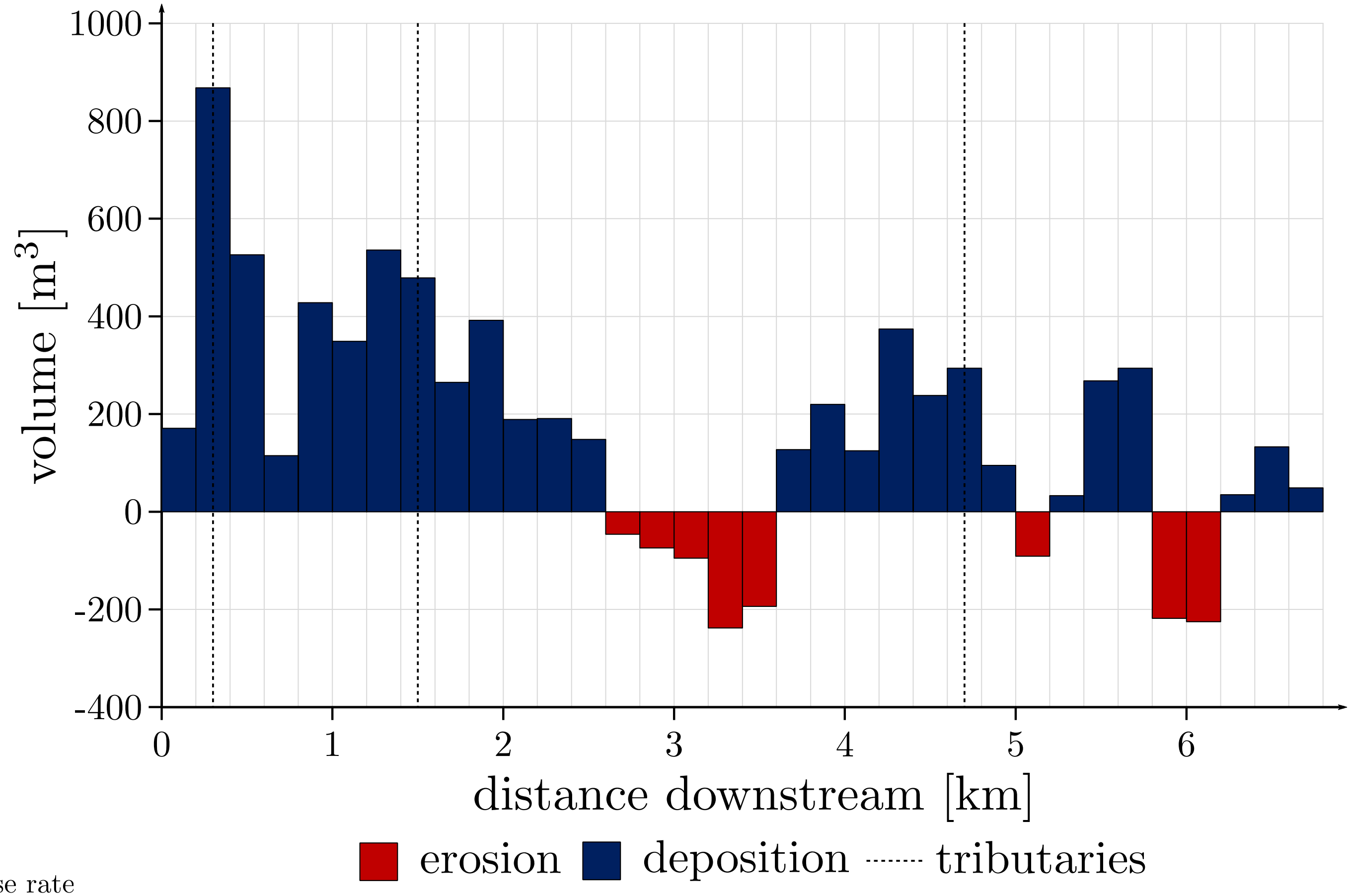
DoD - Results

Budget segregation (200 m reaches):

- deposition – erosion – deposition in the first 5 km
  - possible sediment pulse behavior







1D numerical modeling – results at event-scale

Scenario II (SBT design range), OC1

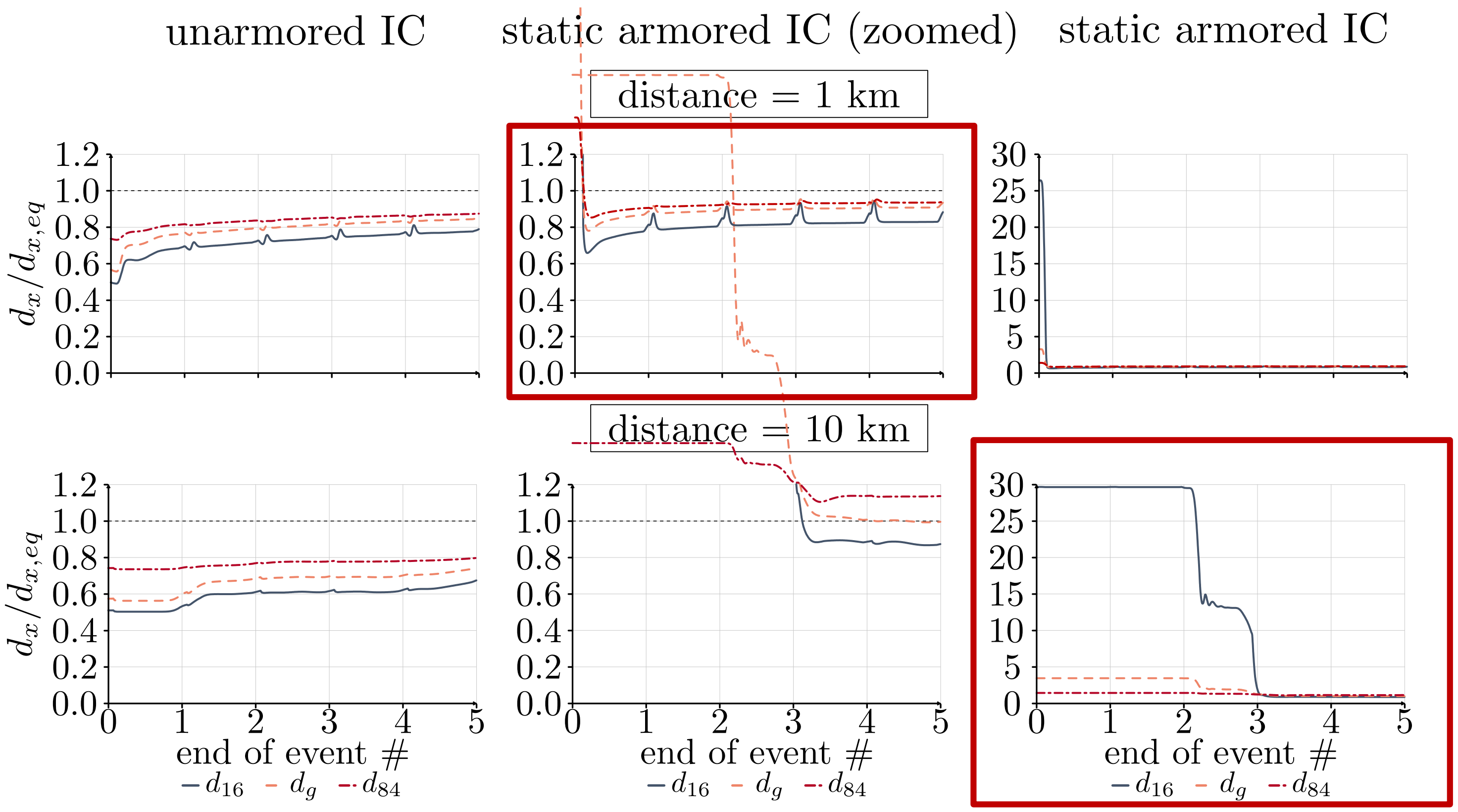
$\frac{d_x}{d_{x,eq}} < 1.0$ → finer

$\frac{d_x}{d_{x,eq}} > 1.0$ → coarser

$d_x = d_x(t = t^*), t^* < 5\ op.$

$d_{x,eq} = d_x(t > 10^4\ op.)$

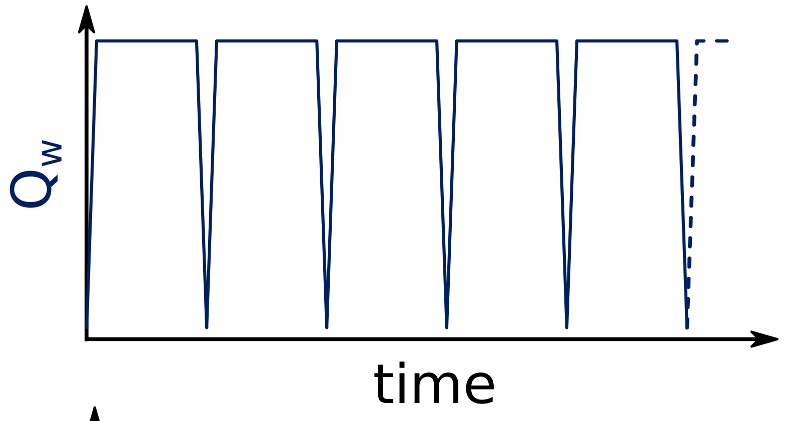
- 3 SBT operations
  → static armor broken
- GSD oscillations at each event

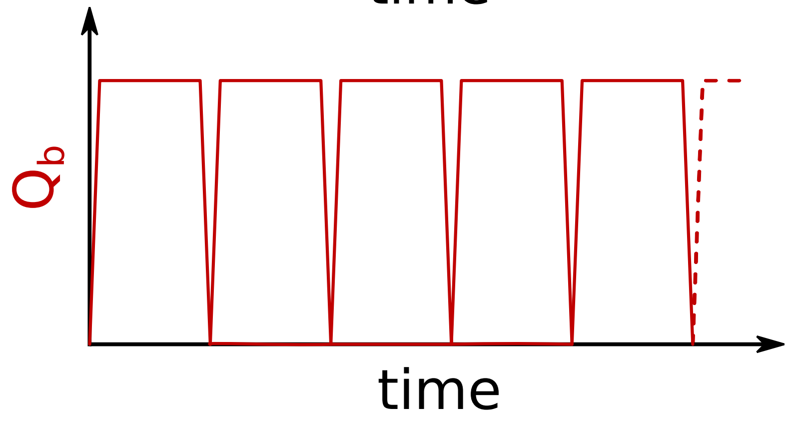


1D numerical modeling – simulations setup

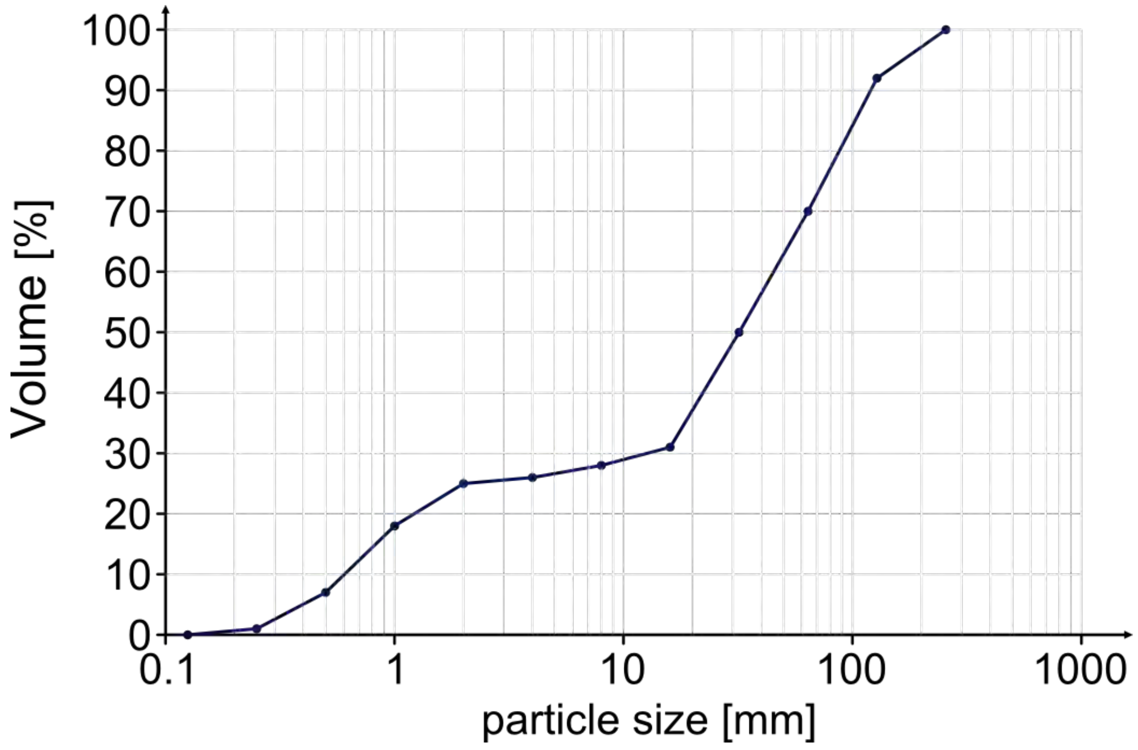
simulations performed with BASEMENT (www.basement.ethz.ch)

Water and sediment fed to the channel:
hydrograph and sedimentograph





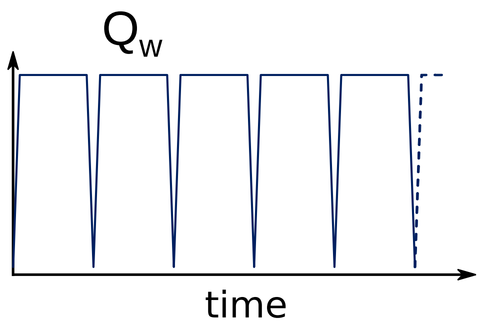
Feeding (reference) GSD:
geometric mean size $d_{s,g,f}$ = 16 mm,
sand percentage = 25%
grain classes: 11

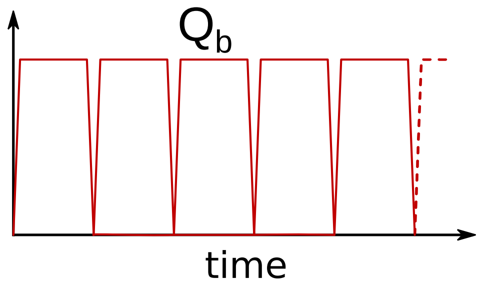


Conclusions

Q1. How much sediment and water are released by the SBT to the downstream reach, under <u>different operational conditions</u>?

- Q_w and Q_b dependent on upstream transport conditions





Sediment Bypass Tunnels (SBTs) – aims

- Route sediments around or through dams result in
  - the reduction of reservoir sedimentation
  - the re-establishment of water and sediment continuity

Outline

- Introduction
- Coceptual framework: identification of the possible operational conditions
- Numerical study: riverbed and surface composition adjustments
- Conclusions

INTRODUCTION

Sediment Bypass Tunnels (SBTs) – research

Research about SBTs

- Building materials and technologies (e.g. Müller-Hagmann, 2017 VAW)
- Bypassing efficiency (sedimentation reduction) (e.g. Auel et al., 2016 VAW)
- Downstream ecological effects (e.g. Martín et al., 2017, EAWAG)

Downstream morphological effects are mostly unexplored