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Good practices in suspended sediment monitoring: Continuous turbidity measurements

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Spatial and temporal variability

- Suspended sediments vary in space and time

Turbidity

↓

Concentration close to the sensor

↓

Mean concentration

↓

Suspended sediment transport

↓

Suspended sediment load

← Probe characteristic $s_k = a\ s_s$

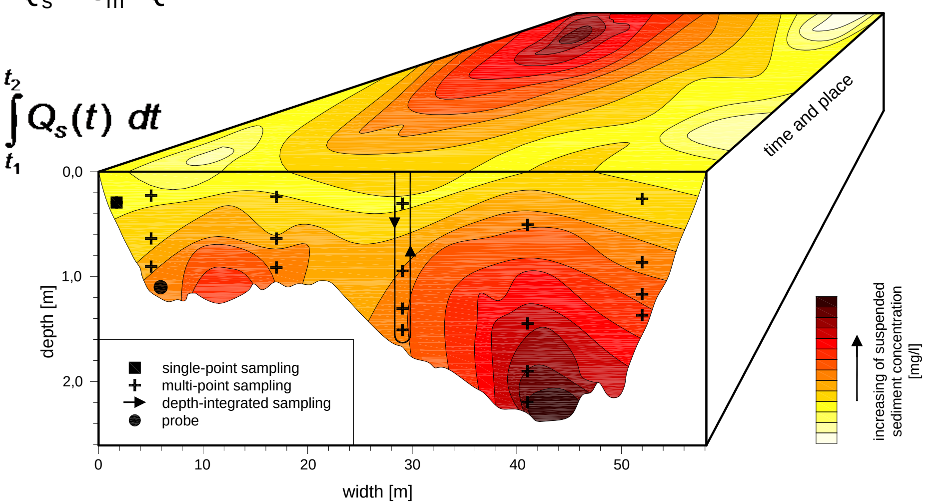
Probe factor $k_s = s_k/s_s$

← Cross-sectional characteristic

$s_m = a\ s_k$

← Discharge $Q_s = s_m\ Q$

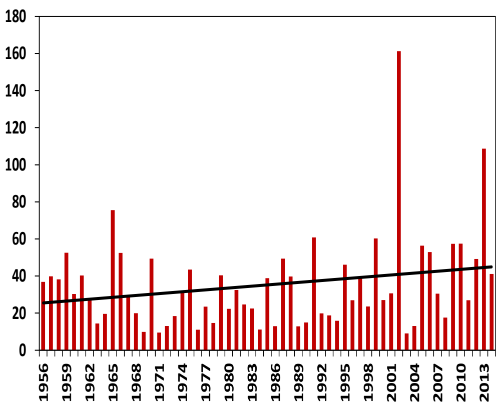
← Time $V_s = \int_{t_1}^{t_2} Q_s(t)\ dt$

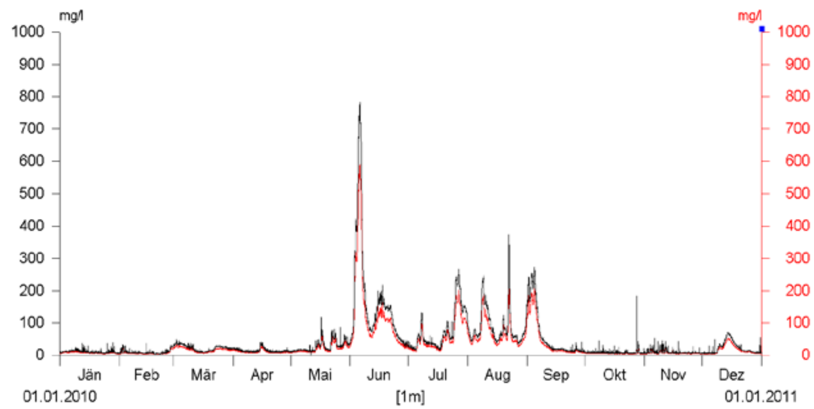


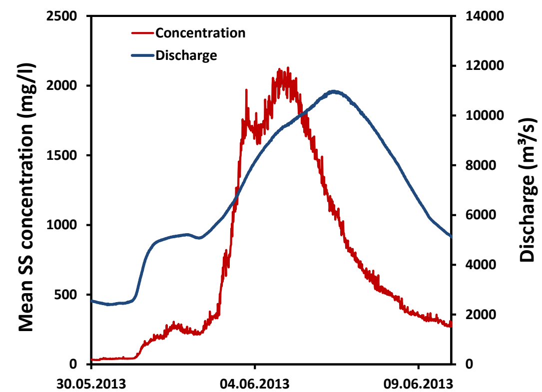
BMLFUW (2008; 2017): Schwebstoffe im Fließgewässer - Leitfaden zur Erfassung des Schwebstofftransports (Austrian Guideline of surveying suspended sediment transport) https://www.bmnt.gv.at/wasser/wasser-oesterreich/wasserkreislauf/Schwebstoffe_LF.html

Variability of suspended sediments

- Variation of suspended sediments with time







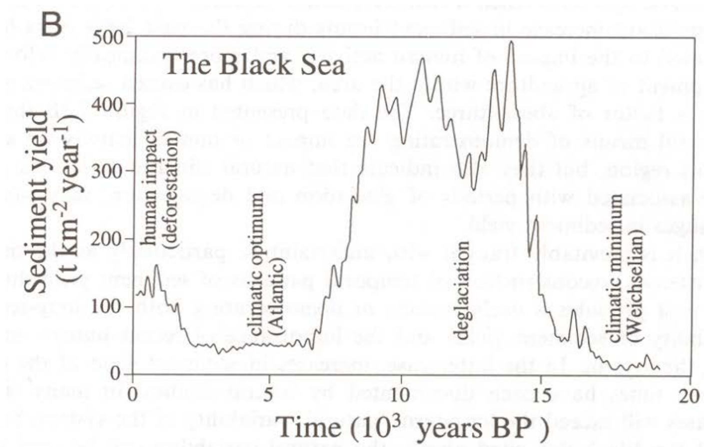
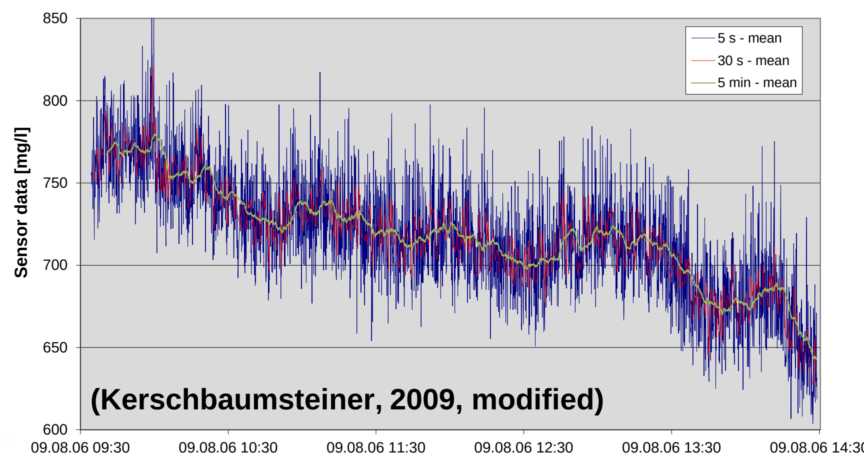


Figure 7.2 Variations of sediment yield over geological time. Based (A) on Tardy *et al.* (1989) and (B) on Degens *et al.* (1991)

(Walling, 1999)



Temporal variability

- Often measured by instantaneous samples
- Many methods available to calculate suspended sediment loads based on these samples

Temporal variability

Interpolation methods

- Linear interpolation
- Averaging estimator

$$L = \sum_{m=1}^{M} \frac{C_m^{\mathrm{int}} Q_m}{M} n$$

$$L = \frac{\sum_{i=1}^{n} A_i C_i}{\sum_{i=1}^{n} A_i} \frac{\sum_{i=1}^{n} A_i Q_i}{\sum_{i=1}^{n} A_i} n = \overline{C} \cdot \overline{Q} \cdot n$$

$$L = \frac{\sum_{i=1}^{n} A_i C_i}{\sum_{i=1}^{n} A_i} \frac{\sum_{i=1}^{n} Q_i}{n} n = \overline{C} \cdot \mu_q \cdot n$$

$$L = \frac{\sum A_i C_i Q_i}{\sum_{i=1}^{n} A_i} n = \overline{CQ} \cdot n$$

$$L = \frac{\dfrac{\sum_{i=1}^{n} A_i C_i Q_i}{\sum_{i=1}^{n} A_{i1}}}{\dfrac{\sum_{i=1}^{n} A_i Q_i}{\sum_{i=1}^{n} A_i}} \frac{\sum_{i=1}^{n} Q_i}{n} n = \overline{CQ} \frac{\mu_q}{\overline{Q}} n$$

Delmas M., Cerdan O., Cheviron B., Mouchel J. M. 2011, River basin sediment flux assesments. Hydrological Processes, 25, pp. 1587-1596.

Phillips J. M., Webb B. W., Walling D. E., Leeks G. J. L. 1999, Estimating the suspended sediment loads of rivers in the LOIS study area using infrequent samples. Hydrological Processes, 13, pp. 1035-1050.

Quilbé R., Rousseau A. N., Duchemin M., Poulin A., Gangbazo G., Villeneuve J.-P. 2006, Selecting a calculation method to estimate sediment and nutrient loads in streams: Application to the Beaurivage River (Québec, Canada). Journal of Hydrology, 326, pp. 295-310.

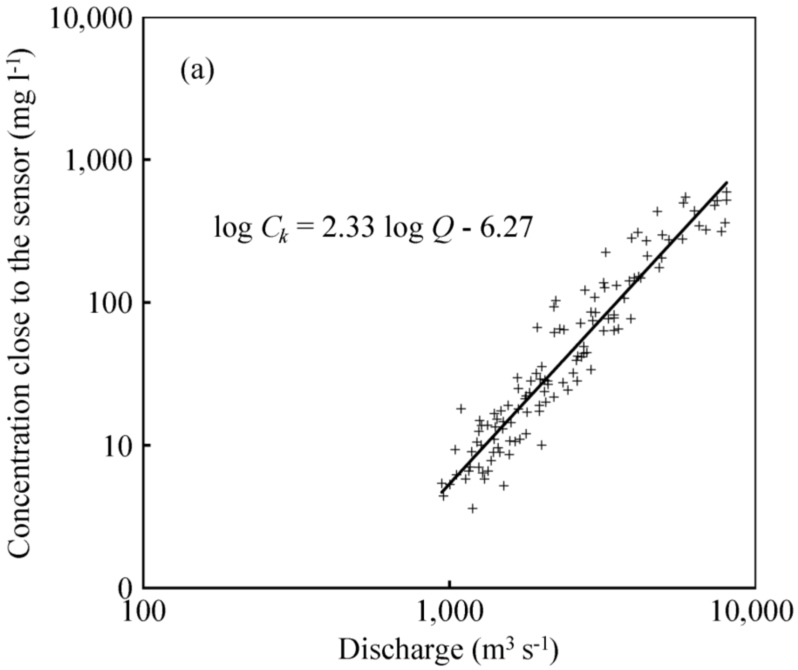
Walling D. E., Webb B. W. 1981, The reliability of suspended sediment load data. Erosion and Sediment Transport Measurement (Proceeding of the Florence Symposium, June 1981). IAHS Publ. no. 133., pp. 177-194.

Zamyadi A., Gallichand J., Duchemin M. 2007, Comparison of methods for estimating sediment and nitrogen loads from a small agricultural watershed. Canadian biosystems engineering, Vol. 49, pp. 1.27-1.36.

Temporal variability

Extrapolation methods

$$C = aQ^{b}$$



(Haimann et al., 2014)

Asselman N. E. M. 2000, Fitting and interpreting of sediment rating curves. Journal of Hydrology, 234, pp. 228-248.

Doomen A. M. C, Wijma E., Zwolsman J. J. G., Middelkoop H. 2008, Predicting suspended sediment concentrations in the Meuse River using a supply-based rating curve. Hydrological Processes, 22, pp. 1846-1856.

Horowitz A. J. 2003, An evaluation of sediment rating curves for estimating suspended sediment concentrations for subsequent flux calculations. Hydrological Processes, 17, pp. 3387-3409.

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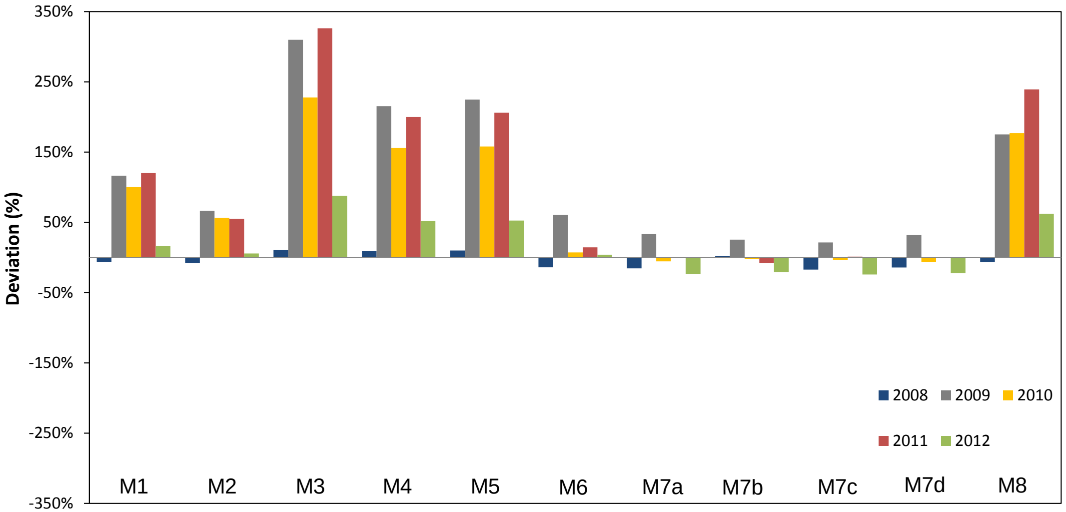
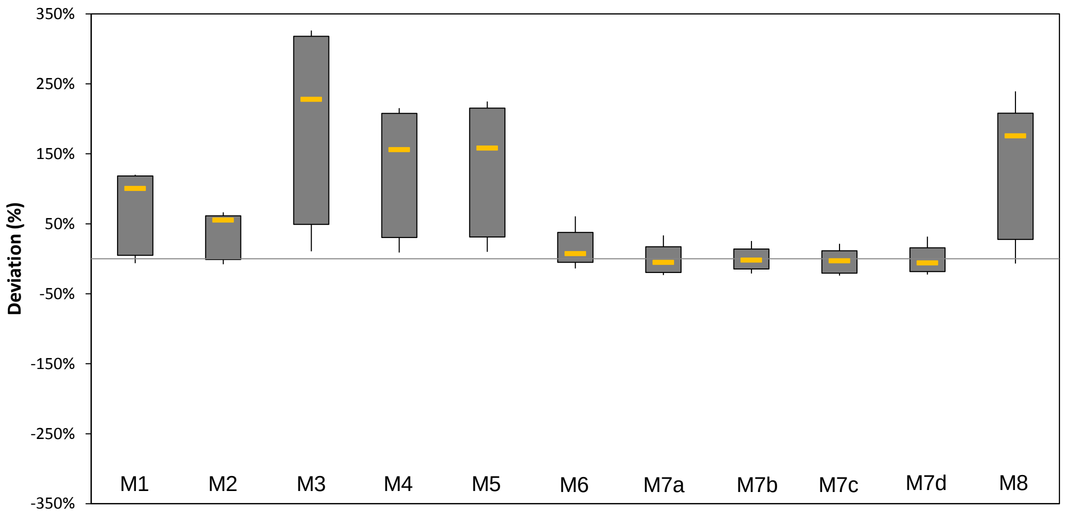
Temporal variability

- Often measured by instantaneous samples
- Many methods available to calculate suspended sediment loads based on these samples
- Based on the applied method the results can differ substantially

Temporal variability





M1	Averaging estimator	M7a	Rating curve all 5 years
M2	Averaging estimator	M7b	Rating curve only 1 year
M3	Averaging estimator	M7c	Rating curve season
M4	Averaging estimator	M7d	Rating curve discharge
M5	Ratio estimator	M8	Method “Switzerland”
M6	Linear Interpolation		

(Haimann, 2015)

Temporal variability

- Often measured by instantaneous samples
- Many methods available to calculate suspended sediment loads based on these samples
- Based on the applied method the results can differ substantially

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Temporal variability

- Often measured by instantaneous samples
- Many methods available to calculate suspended sediment loads based on these samples
- Based on the applied method the results can differ substantially
- No information on e.g. maximum concentration

Surrogate technology

- Optical sensors

backscatter

Solitax ts-line

(https://at.hach.com)

transmission

(Bittner, 2008)

S::can

- Acoustic sensors

Single frequency

(https://www.sequoiasci.com)

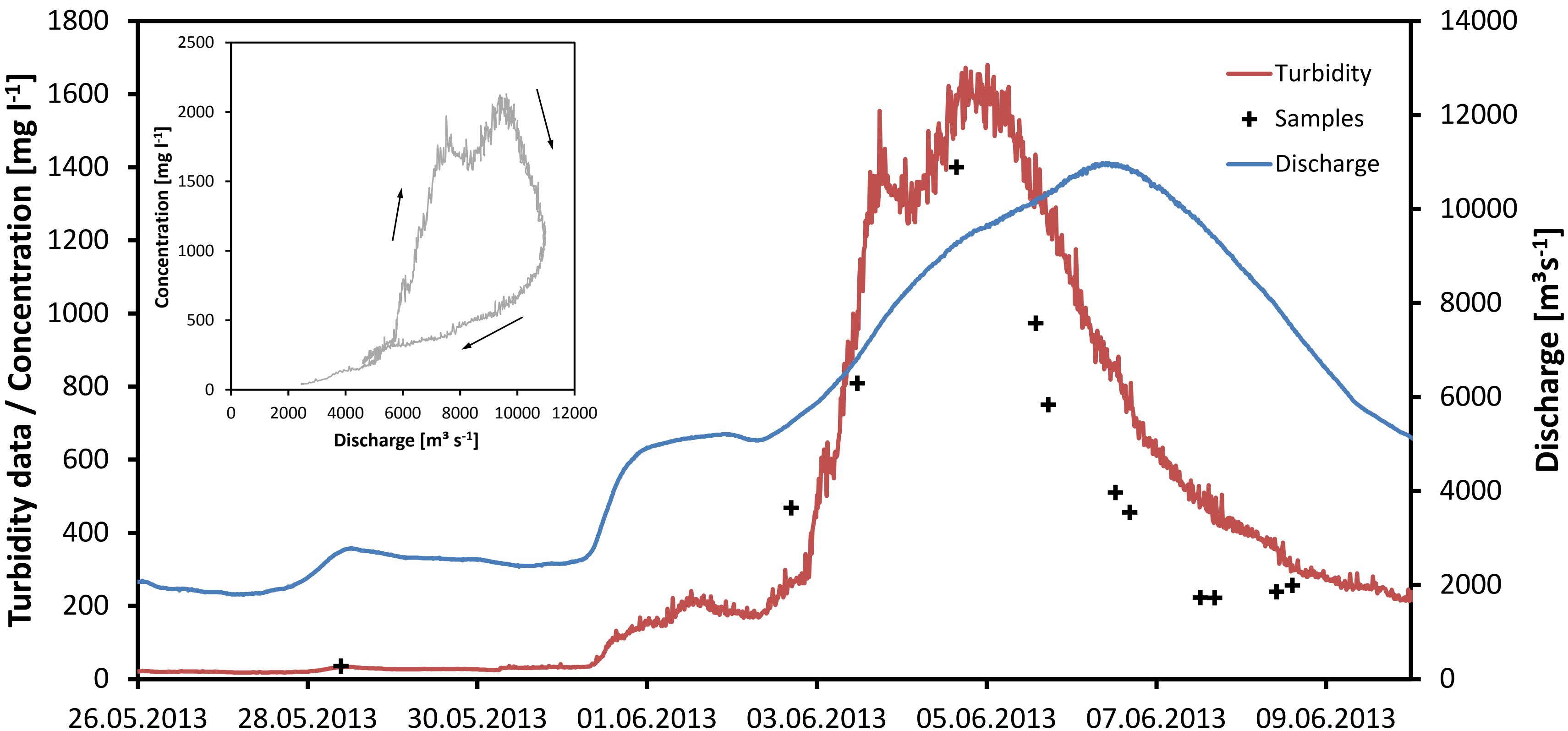
Multi frequency

SediScat™ Pro

(http://www.hydrovision.de/)

Advantages of turbidity sensors

- Suspended sediment concentration correlates much better with turbidity than with water level / discharge



(Gmeiner et al., 2016, modified)

Advantages of turbidity sensors

- Suspended sediment concentration correlates much better with turbidity than with water level / discharge
- Continuous information (e.g. 15 min interval)
- Easy to handle
- Can be connected to online monitoring system
- Turbidity sensors are comparatively cheap
- Optical sensors already used in many countries at the Danube River

Disadvantages of turbidity sensors

- Turbidity sensors are not only dependent on concentration but also e.g. on the size of the reflecting particles --> have to be calibrated by water samples
- Point measurement only
- (Bio-) Fouling can occur

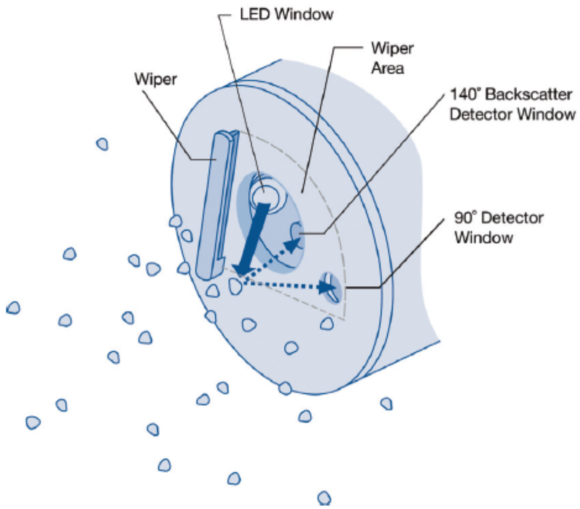
(Photo: HD Tirol)

(Photos: BMLFUW, 2008; 2017)

Turbidity sensors

What has to considered when using turbidity sensors?

- Measurement range suitable for the river
- Cleaning system (e.g. wiper)



(https://at.hach.com/)

(Photo: viadonau)

Turbidity sensors

What has to considered when using turbidity sensors?

- Measurement range suitable for the river
- Cleaning system (e.g. wiper)
- Installation height: varying with water level or fixed
- Enough water cover during low flow but not to close to the river bed

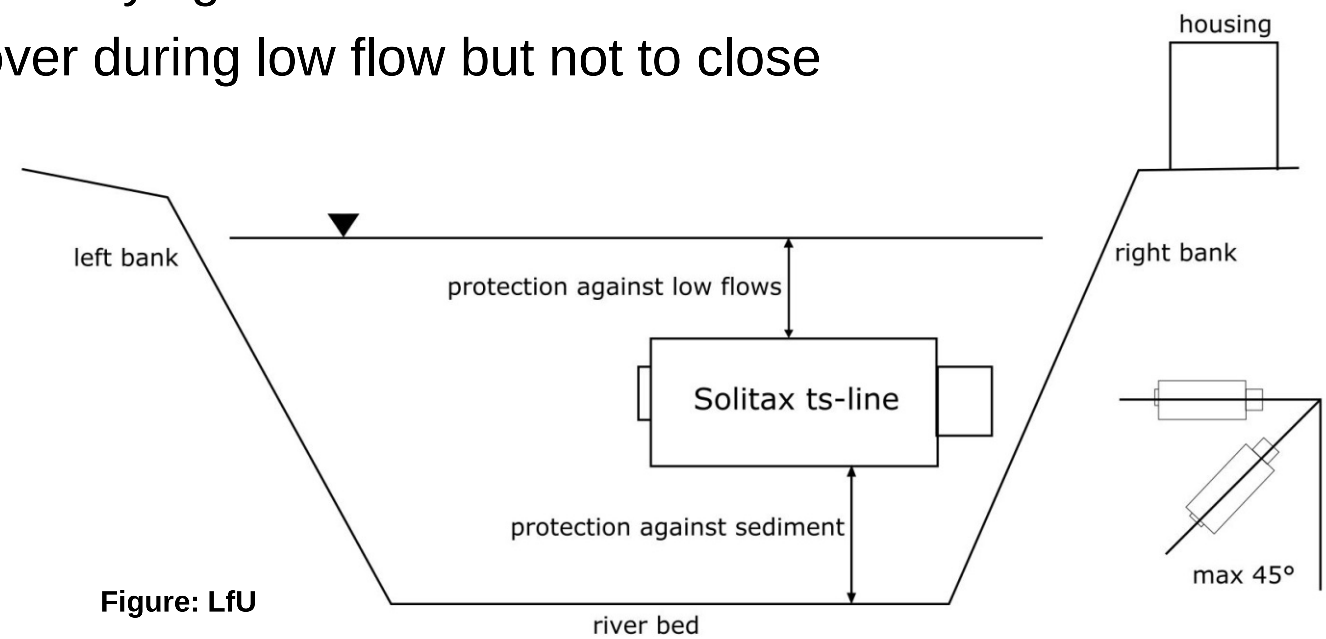


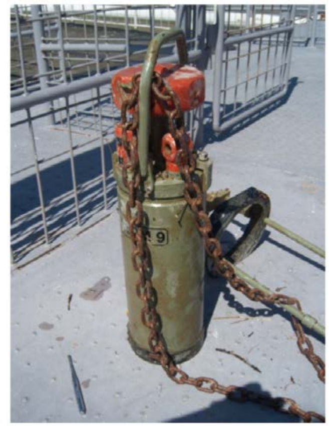
Figure: LfU

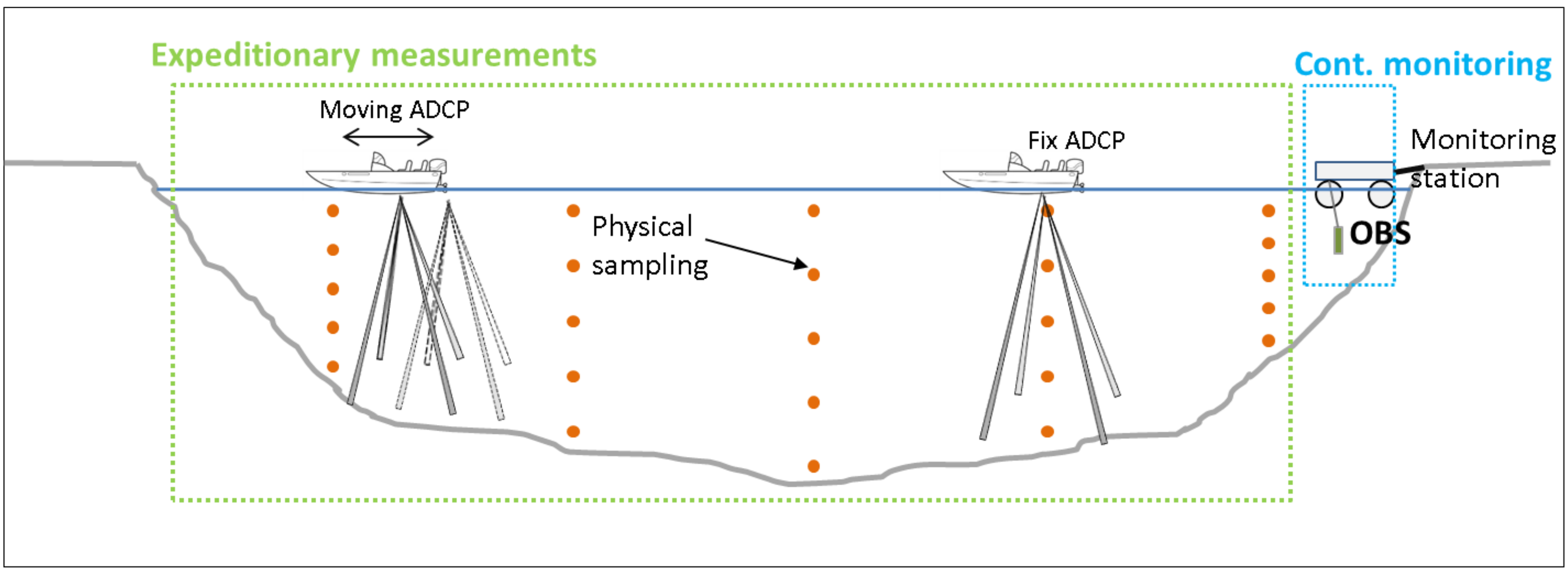
Turbidity sensors

What has to considered when using turbidity sensors?

- Measurement range suitable for the river
- Cleaning system (e.g. wiper)
- Installation height: varying with water level or fixed
- Enough water cover during low flow but not to close to the river bed
- Retrieving the sensor should be possible at any water level for e.g. maintenance reason

Installation of turbidity sensors





(Figures: BME)

Installation of turbidity sensors

Calibration of turbidity sensors

Why is calibration necessary?

- Turbidity sensors are not only dependent on concentration but also e.g. on the size of the reflecting particles
- Thus samples have to be taken close to the sensor to correct the data

(Bacher, 2008)

(Hauer, 2007)

Method	Frequency
Turbidity sensor	Continuously
Single point samples close to the sensor	High sediment discharge: min. daily Med. sediment discharge: min. 1-2 / week Low sediment discharge: rare

(BMLFUW, 2008; 2017)

Data Processing

Turbidity

↓ ← Probe characteristic $s_k = a\ s_s$

Probe factor $k_s = s_k / s_s$

Concentration close to the sensor

↓ ← Cross-sectional characteristic $s_m = a\ s_k$

Mean concentration

↓ ← Discharge $Q_s = s_m\ Q$

Suspended sediment transport

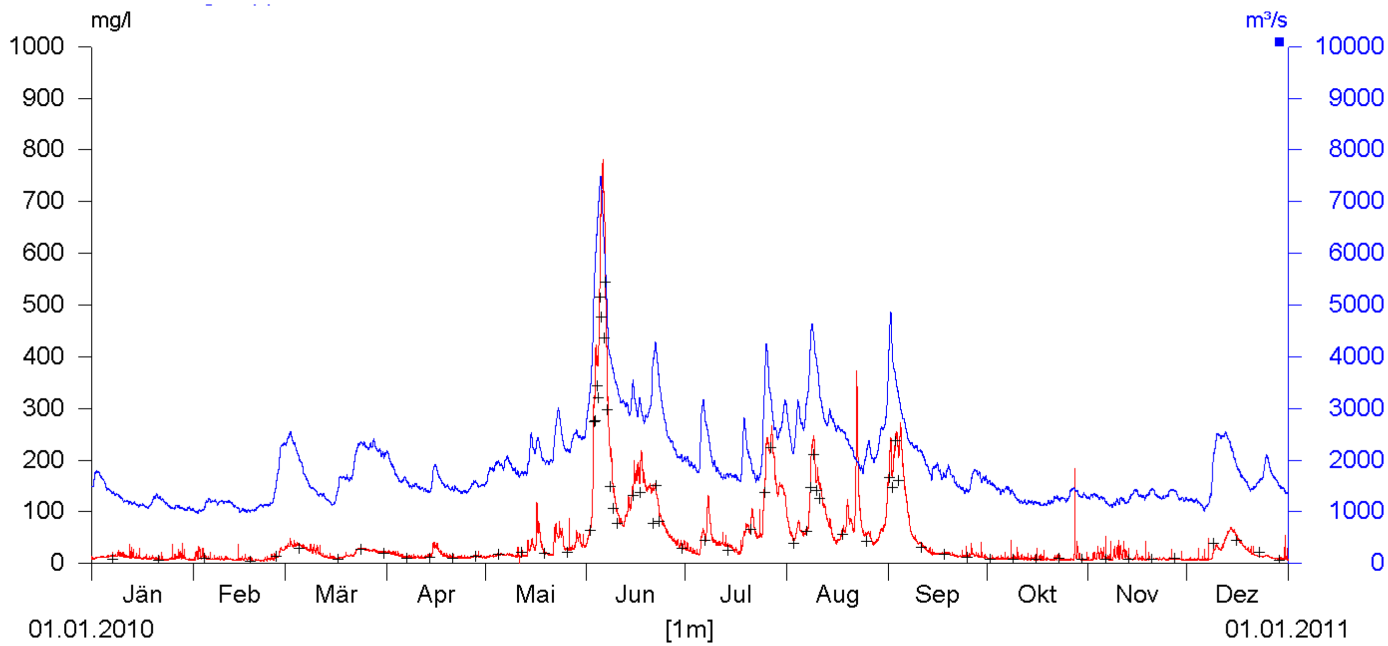
↓ ← Time $V_s = \int_{t_1}^{t_2} Q_s(t)\ dt$

Suspended sediment load

Data processing

Plausibility check

- Natural processes: e.g. heavy rainfall, flood event, snow melt
- Anthropogenic influences: e.g. dredging, construction works in the river
- Other influences: e.g. fouling, debris



Discharge (blue), turbidity data (red) and samples close to the sensor (black) (data source: viadonau)

Data Processing

Turbidity

Concentration close to the sensor

Mean concentration

Suspended sediment transport

Suspended sediment load

Probe characteristic s_k=a s_s

Probe factor $k_s=s_k/s_s$

Cross-sectional characteristic s_m=a s_k

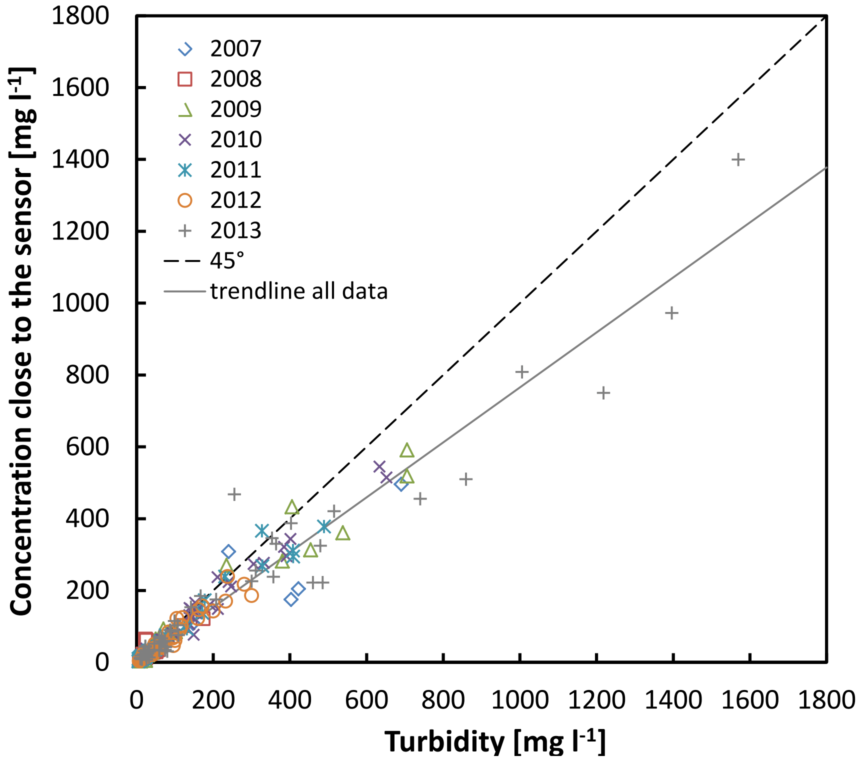
Discharge $Q_s = s_m \; Q$

Time $V_s = \int_{t_1}^{t_2} Q_s(t)\, dt$

Data processing

How is the data calibrated?

- Two different methods are applied:
  - Statistical regression:



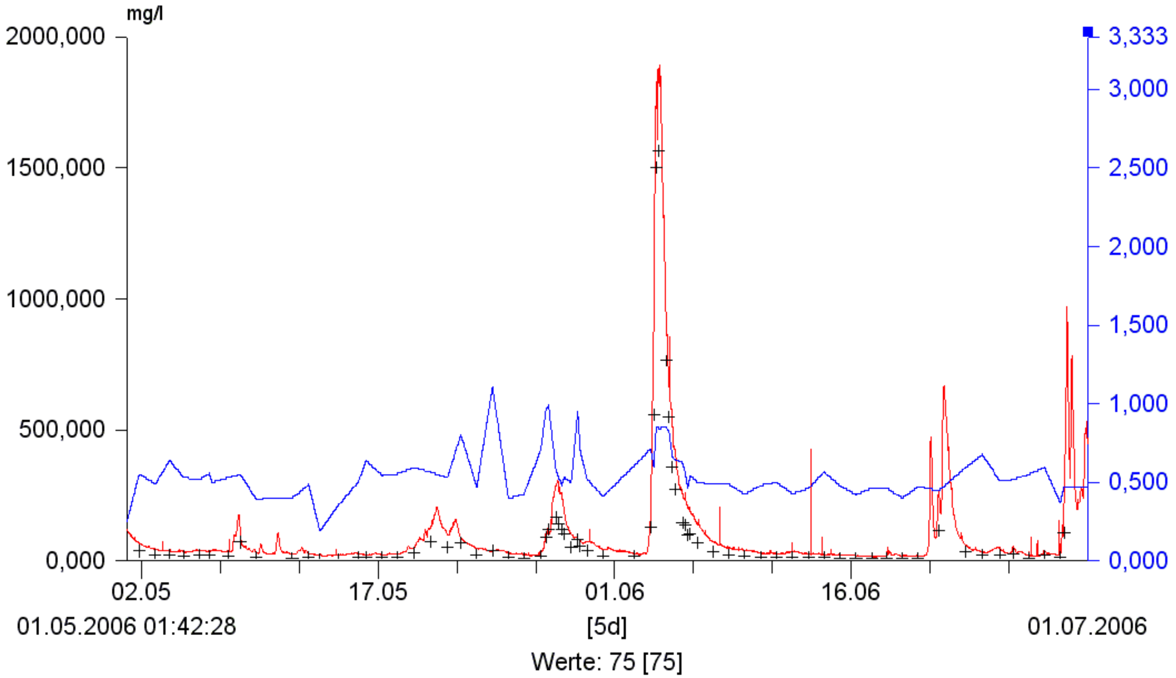
(Habersack et al., 2015)

Data processing

How is the data calibrated?

- Two different methods are applied:
  - Statistical regression:
  - Correction factor:

    $k_s = s_k / s_s$



Turbidity sensor (red), samples (black), correction factor (blue)
(data source: Hydrographic service Upper Austria)

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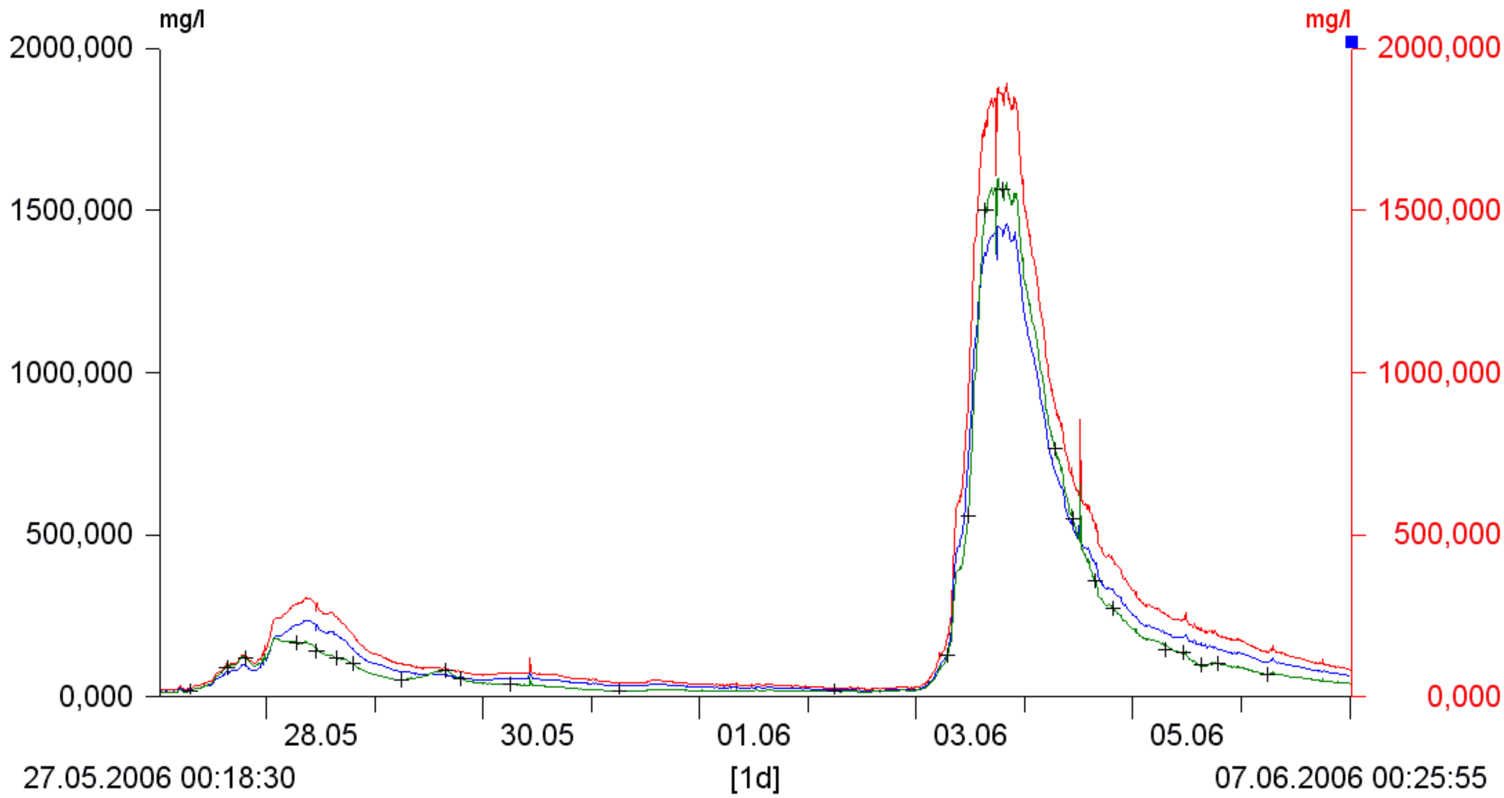
Calibration of turbidity sensors

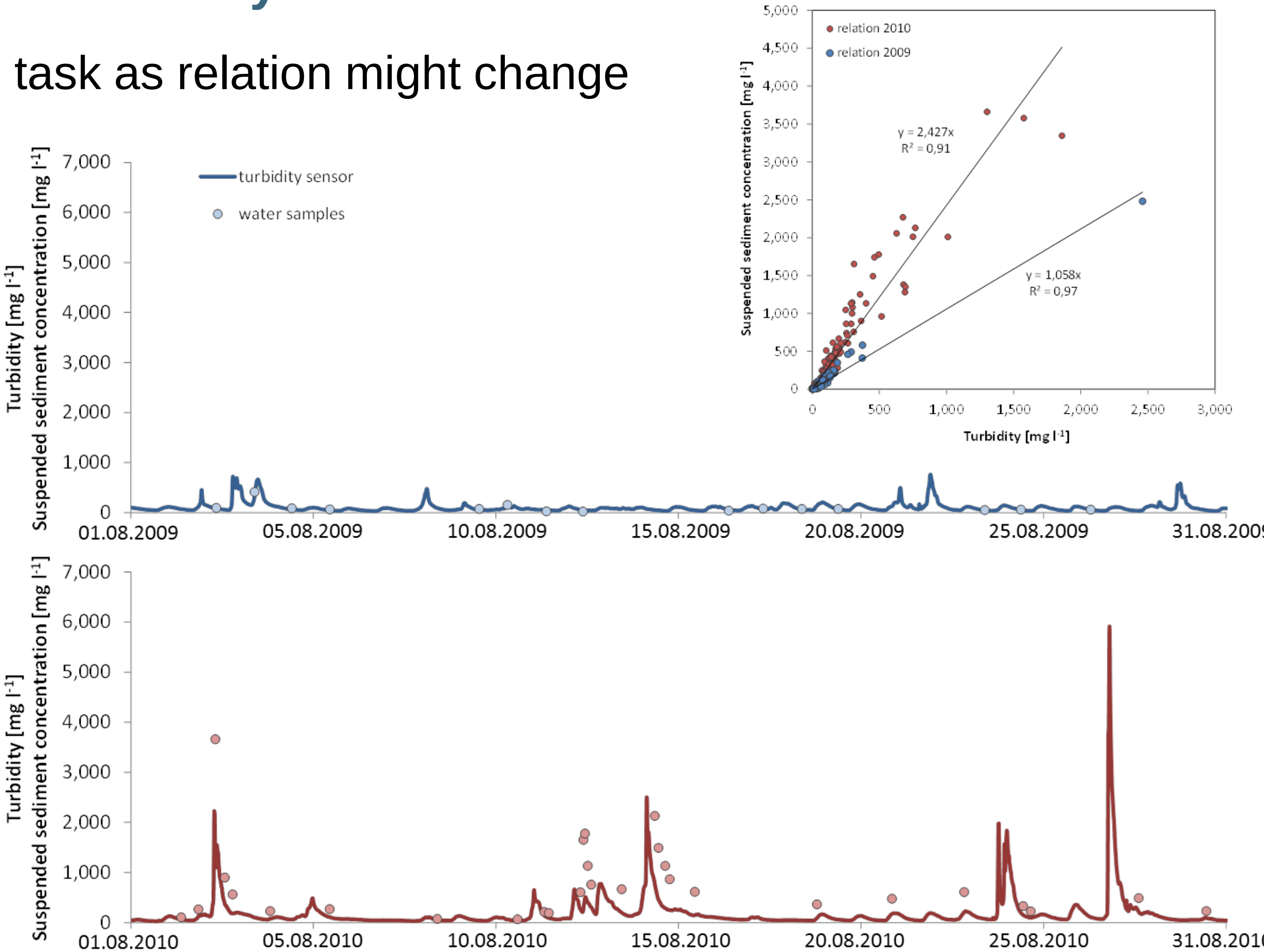


Turbidity sensor (red), samples (black), suspended sediment concentration close to the sensor - linear regression (blue), suspended sediment concentration close to the sensor probe factor (green)

(BMLFUW, 2008; 2017)

Calibration of turbidity sensors

Continuous task as relation might change



(Lalk et al., 2014, modified)

Data Processing

Turbidity

↓

Concentration close to the sensor

↓

Mean concentration

↓

Suspended sediment transport

↓

Suspended sediment load

Probe characteristic $s_k = a\ s_s$

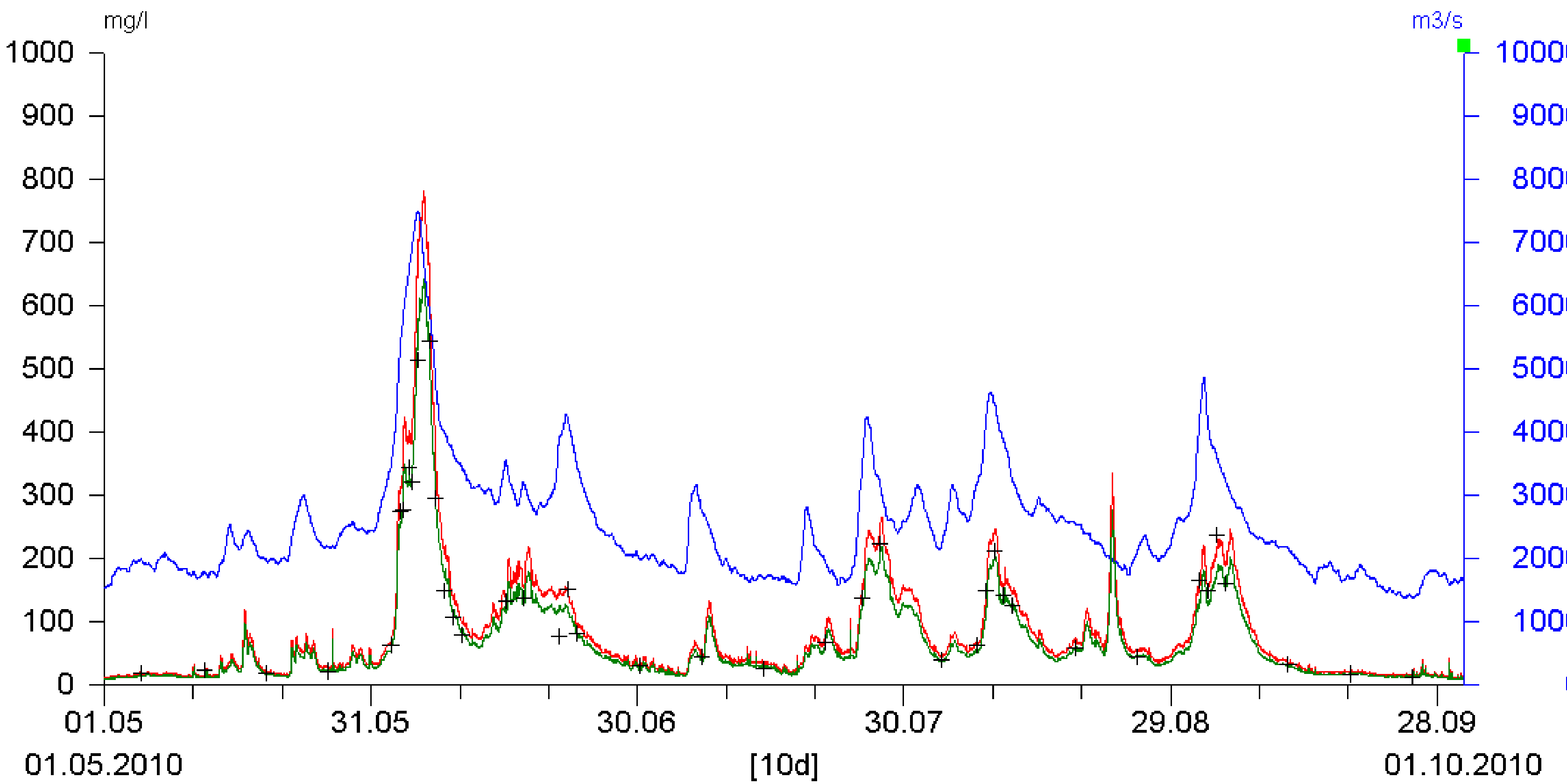
Probe factor $k_s = s_k / s_s$

Cross-sectional characteristic $s_m = a\ s_k$

Discharge $Q_s = s_m\ Q$

Time $V_s = \int_{t_1}^{t_2} Q_s(t)\ dt$

Calibration of turbidity sensors



Discharge (blue), turbidity data (red), samples (black), concentration close to the sensor (green)
(data source: viadonau)

Data Processing

Turbidity

Concentration close to the sensor

Mean concentration

Suspended sediment transport

Suspended sediment load

Probe characteristic $s_k = a\ s_s$

Probe factor $k_s = s_k / s_s$

Cross-sectional characteristic $s_m = a\ s_k$

Discharge $Q_s = s_m\ Q$

Time $V_s = \int_{t_1}^{t_2} Q_s(t)\ dt$

Conclusions

- Continuous turbidity monitoring with OBS (or ABS) sensors mounted on the river bank
- If possible, automatized and connected to online monitoring system
- Calibration of sensors with samples taken close to the sensor

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Thank you for your attention!

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