MONITORING OF SUSPENDED LOADS IN WATERWAYS

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1 MONITORING NETWORK OF SUSPENDED LOAD IN GERMAN FEDERAL WATERWAYS

1.1 Existing Monitoring Network (since 1965)

The Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde) in cooperation with the local boards of the German Waterways and Shipping Administration maintain a permanent nationwide network of 67 stations in German federal waterways for measurements of suspended sediment concentration (Fig. 1). Bulk water samples of 5 liters are taken on every working day at a single point within the cross-section of a river. The samples are then filtered and dried and the filter residues are gravimetrically determined to yield the suspended sediment concentration. The data are archived in relational databases and small data gaps are filled by linear interpolation. The first measurement stations were established in 1964/65. In Western Germany, measurements at most stations are available since 1975, in Eastern Germany since 1992. Thus, there exist many long-term time-series of suspended sediment concentrations (SSC) in German rivers.

Figure 1 Monitoring network of suspended sediment concentrations in German federal waterways.

The time-series are used to calculate daily, monthly or annual loads and analyzed for statistical characteristics, such as seasonal trends, long-term trends, frequency distribution, correlation to discharges, catchment characteristics etc.

As an example, Figure 2 illustrates results of a trend analysis of annual suspended loads at the Maxau measuring station at Rhine-km 362.3 in million tonnes per year plotted against the time span since the mid-1960s. The figure shows a significant decrease ($p < 0.05$) in the loads up to the completion of the construction of the barrages at the Upper Rhine which is illustrated by a linear regression. The time series after the last barrage at Iffezheim was put into operation in 1977, however, shows no significant trend in the statistical test which is symbolized in the figure by a blue dashed line representing the averaged value of all annual loads after 1977.

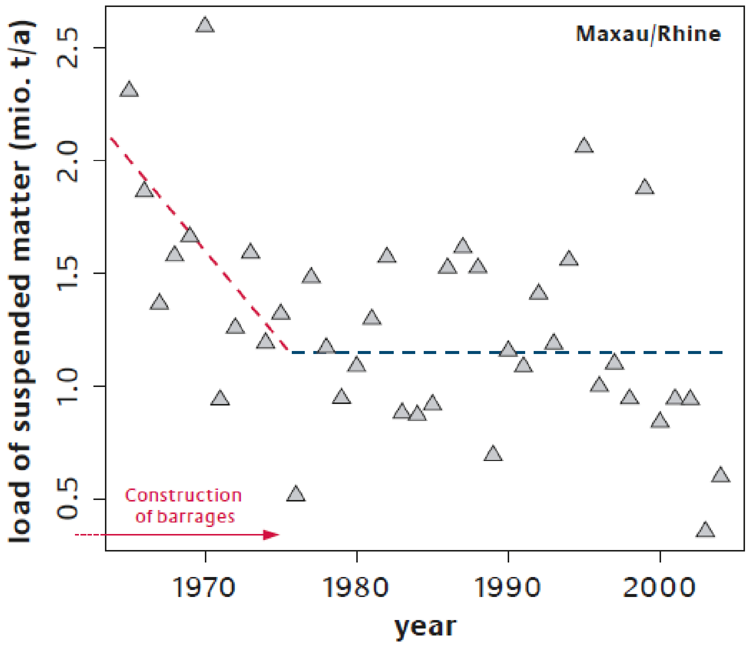


Figure 2 Annual suspended loads at the Maxau measuring station (Rhine km 362.3) (Hillebrand et al. 2012).

The figure also demonstrates the considerable range of natural fluctuation in the annual suspended solids loads. In the years 1995 and 1999, when the discharge of the Upper Rhine was high, the annual loads were above average, whereas a low annual load can be observed for the low-discharge year 2003 (about one quarter of the annual load in 1999).

1.2 Pilot operation phase of remodeled stations (since 2009)

Advantages of the existing monitoring network were the robustness of the procedure, making use of existing infrastructure, easy transport of samples (sent by mail) and low operating expenses in the laboratory allowing for high throughput of samples.

The main disadvantage of the current operation is that there is only one sample per day and none during holidays or the weekend, so peaks of suspended loads during flood events are often missed. Additionally, in recent years, reduced personnel along the rivers has led to increasing gaps in measurements up to inactiveness of several measuring stations.

Therefore, in 2009, a pilot phase was started where several measuring stations in the Rhine catchment were equipped with turbidity probes. Water samples are taken regularly next to the probe (twice a week, up to twice a day during floods), sent to the laboratory where they are analyzed for the SSC to calibrate the probes.

Preliminary results show that the deployed turbidity probes cover the necessary range of SSC in the inland waters and give very reasonable results in a high temporal resolution. The comparison to the traditional monitoring network shows that discrete values are similar, but loads are often underestimated by up to 20 to 40 % in the traditional operation compared to the automated probe system depending on the hydrologic conditions. This is illustrated by an example of the measuring station Cochem at the river Mosel in Fig. 3. The graph shows missing values in the traditional procedure during Christmas season (missing a flood event) and interpolated weekend values in early February 2010 during another sediment peak caused by elevated discharges.

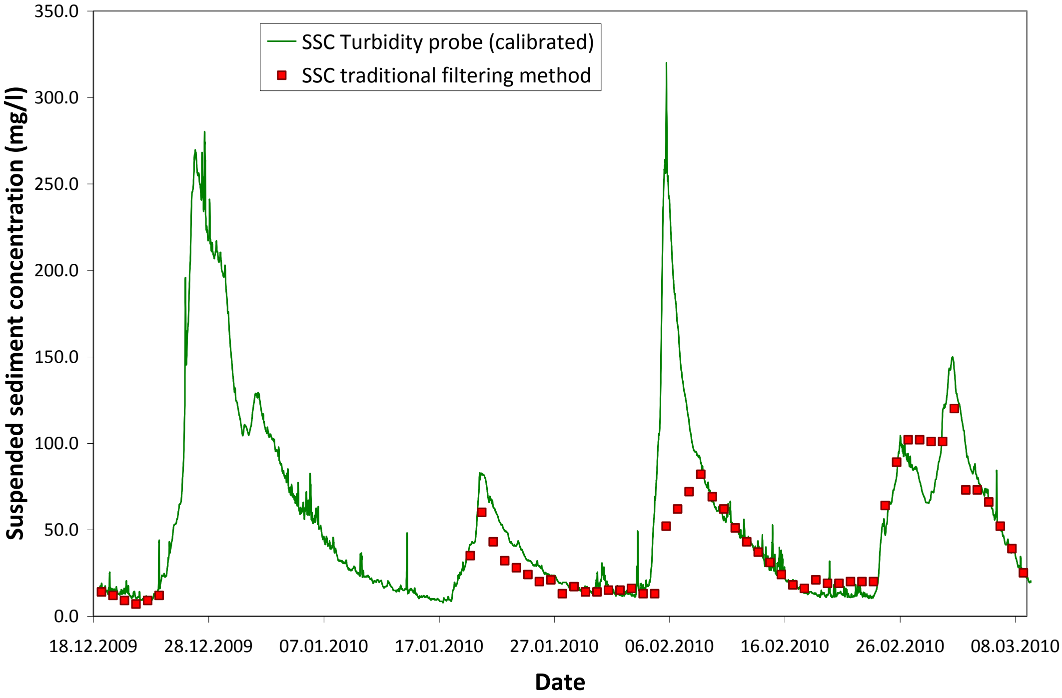


Figure 3 Suspended sediment concentrations at the Cochem measuring station (Mosel km 50.2).

2 SUPPLEMENTARY MEASURING STRATEGIES

2.1 Cross-sectional measurements of suspended loads

The permanent monitoring network for suspended sediment concentrations yields time-series at single points in rivers, for practical reasons typically at a point about 1 m below the water surface. However, suspended sediments are not distributed uniformly across cross-sections. Due to the self-weight of the particles, there is generally a vertical gradient with low concentrations near the surface and high concentrations near the river bed. In addition, there may be lateral gradients, e. g. due to tributaries or secondary currents in river bends. It is therefore necessary to get information of the cross-sectional distribution of SSC in relation to the point measurements in order to get correct information on suspended loads. Traditionally, manual multipoint measurements are done twice a year at about 70 cross-sections in the free-flowing sections of the federal waterways.

In recent years, Acoustic Doppler Current profiler (ADCP) measurements have been regularly used to provide high resolution velocity measurements in river cross-sections. Echo intensities of the ADCP back-scatter signals correlate with SSC. By analyzing water samples and comparing them to measured back-scatter intensities, it is possible to derive distributions of SSC. Fig. 4 gives an example of cross-sectional SSC derived from ADCP back-scatter signals that illustrates lateral and vertical SSC gradients.

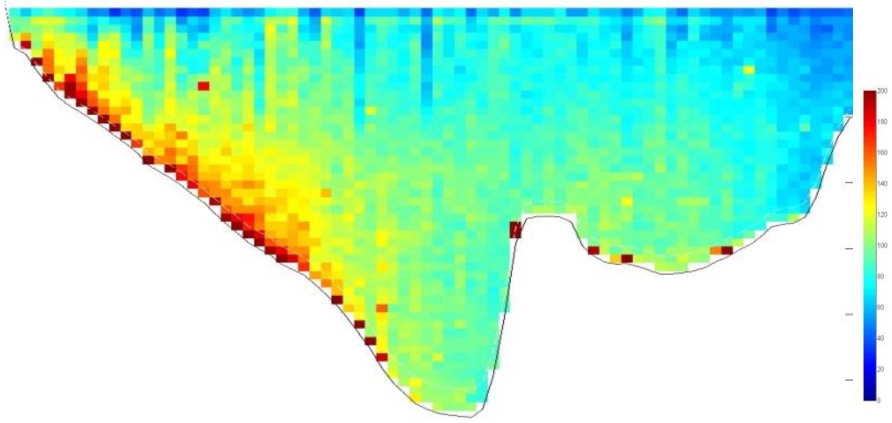


Figure 4 ADCP-measured suspended sediment concentrations at a cross-section at Rhine km 332.9 (range of color bar 0 to 200 mg/l).

2.2 Grain size distribution of suspended sediments

Grain size distribution of suspended sediments is not measured regularly in German waterways. In the abovementioned multipoint measurements the portion of suspended sand is determined, but otherwise little data is available on grain sizes of the suspended load. With increasing debates on particle-bound contaminant transport and settling behavior of fines, the need for information on primary particle sizes as well as floc sizes, i. e. sizes of agglomerated particles in situ, has risen.

Fig. 5 illustrates two methods for determining particle sizes in situ. On the left-hand side, a digital image is shown taken in situ by a microscope probe (Klassen & Lehmann 2011). Multiple images are then analyzed for the grain size distribution by image recognition algorithms. On the right-hand side of Fig. 5, the result of an in-situ measurement of particle sizes by laser scattering and transmittance is shown.

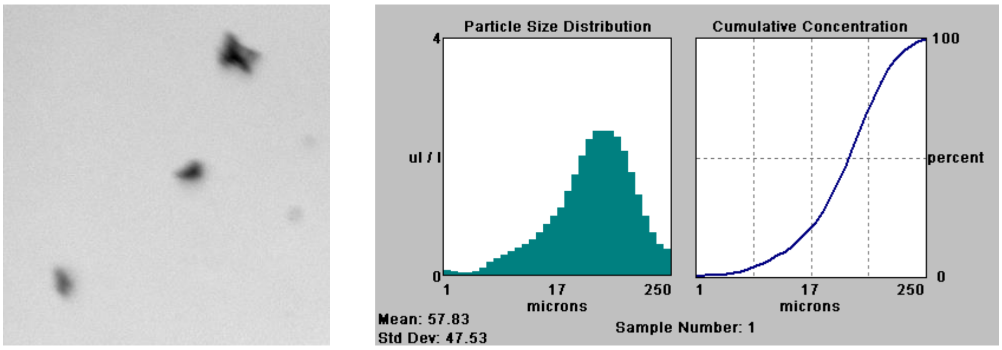


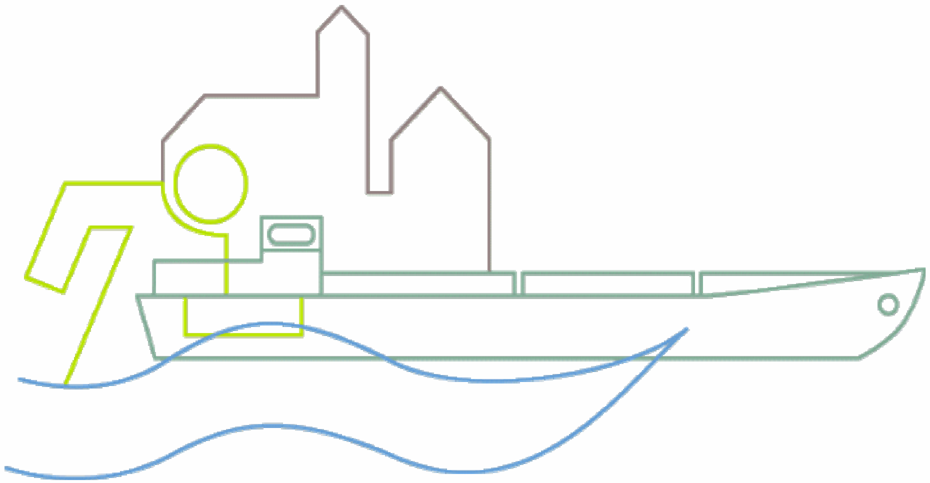
Figure 5 Left: In-situ particle imaging by in-line microscope (AELLO). Right: In-situ particle sizing by laser scattering and transmissometry (LISST).

The comparison of particle size distributions determined in situ to those determined from water samples in the laboratory (e. g. by laser analyzer) may show significant differences, especially after pre-treatment of the water samples, in that treated samples better reflect the primary particles and dense flocs. In-situ grain size distributions, however, give an impression of actual floc sizes determining transport processes like settling in the field. The two data sets should be seen as complementary and are useful for understanding transport processes and necessary for a physically based calibration of numerical models.

3 REFERENCES

Hillebrand, G., Pohlert, T., Vollmer, S. (2012): Past and Future Development of Suspended Loads in the Rhine. Conference Proceedings of the 2nd KLIWAS Status Conference, 25 and 26 October 2011, Federal Ministry of Transport, Building and Urban Development, Berlin. pp. 75-78.

Klassen, I., Lehmann, B. (2011): In-situ-Messung von Flockengrößen am Oberrhein in der Staustufe Iffezheim. Sachstandsbericht zu den Messungen in 2011.



Monitoring of suspended loads in waterways

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Outline

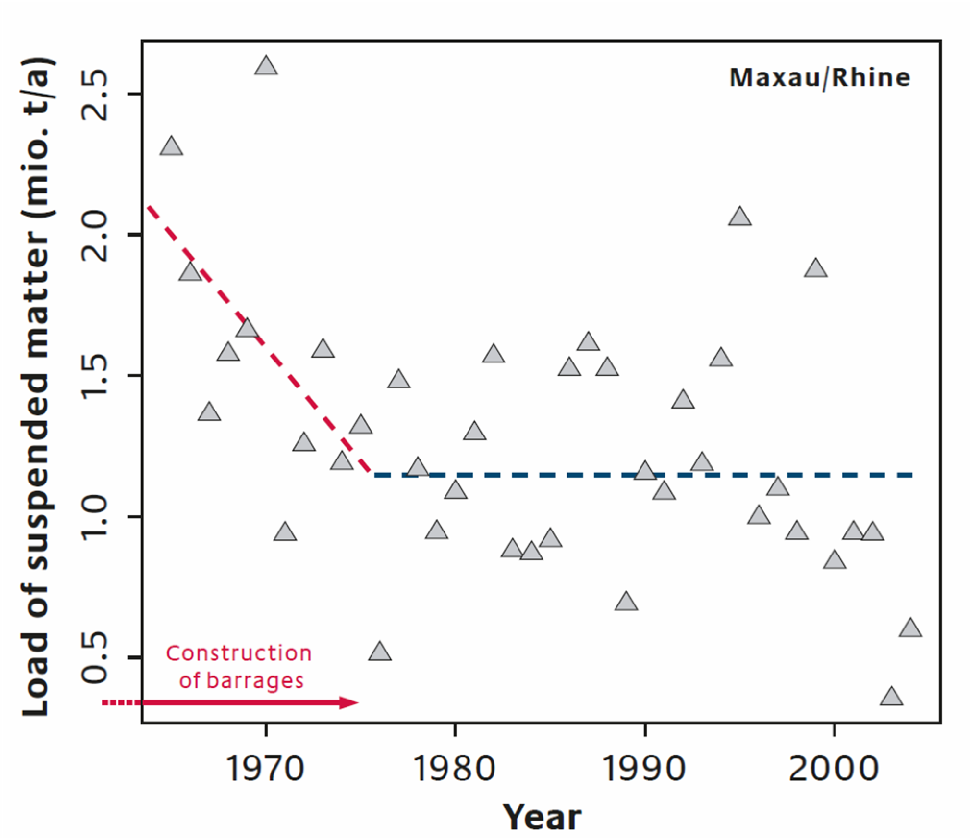
- Existing Monitoring Network in German Federal Waterways
- Pilot operation phase of remodeled stations
- Cross-sectional measurements of suspended loads
  - traditional method
  - ADCP
- Grain size distribution of suspended sediments
  - samples
  - in situ

Existing Monitoring Network

- started in 1965
- up to 67 stations in German federal waterways
- 5 liter bucket samples
- each workday (mo to fr)
- filtered, dried, weighed
  → suspended sediment concentration
- small gaps (e.g. weekend) are filled by linear interpolation

Example: Annual load at Maxau/Rhine

- daily SSC are used to calculate daily loads and aggregated values
- analyzed for seasonal trends, long-term trends, correlation to discharge, catchment characteristics etc.



Evaluation of existing monitoring network

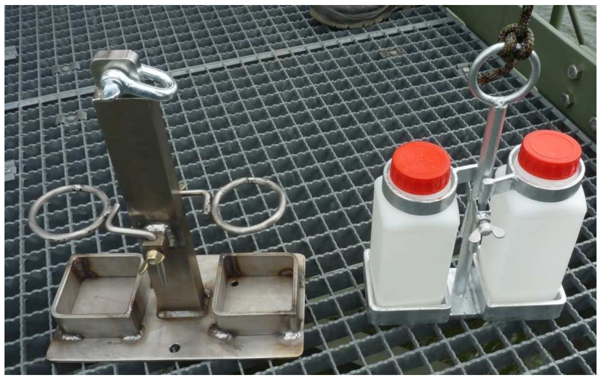
- advantages of existing network:
  - robust procedure
  - use of existing infrastructure
  - easy transport of samples (sent by mail)
  - low operating expanses in laboratory → high throughput of samples possible
- disadvantages:
  - only one sample per day and none during weekend, holidays etc. → missing peak concentrations
  - reduced personnel along the rivers → increasing gaps in measurements

⇨ try to get rid of the disadvantages by continuous measurements and reduced use in personnel in taking samples

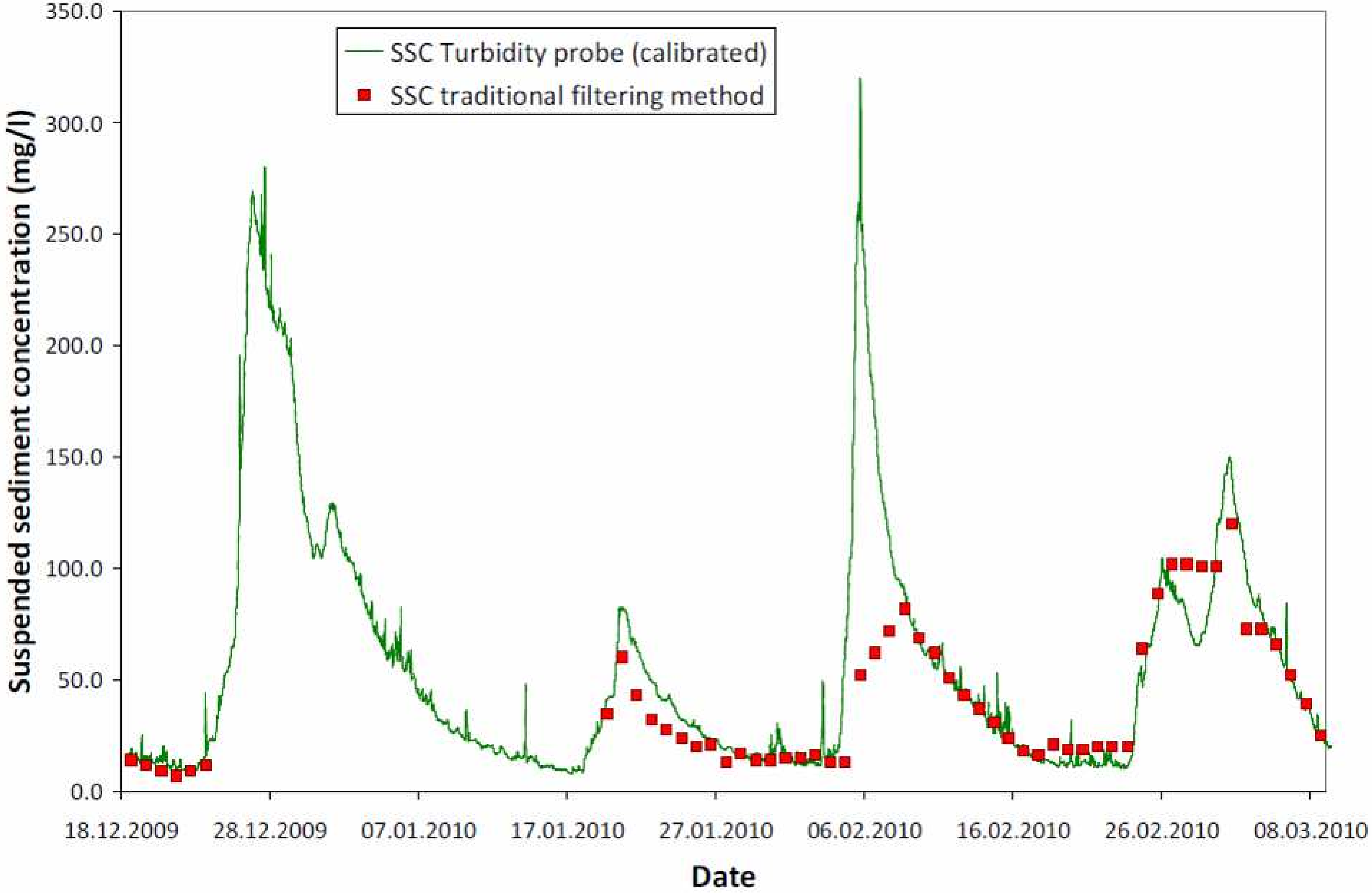
Pilot operation phase of remodeled stations

- started in 2009
- stations were equipped with turbidity probes
- samples only twice a week, up to twice a day during floods
- water samples are sent to the lab where they are filtered etc.





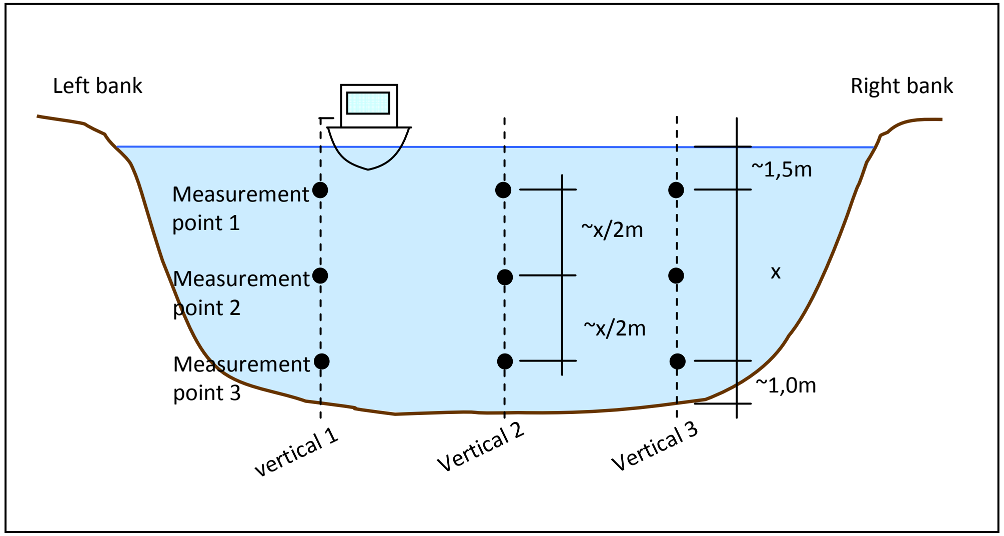
Example: SSC at Cochem/Moselle

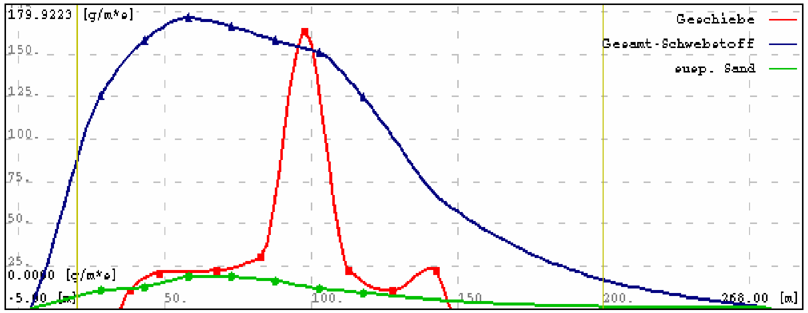


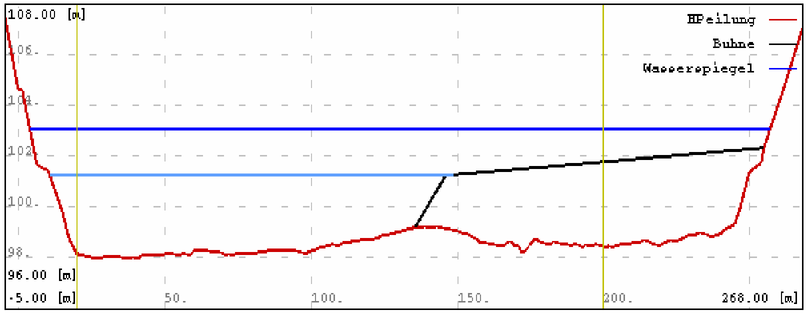
⇨ annual loads are sometimes underestimated by up to 20 to 40 % in the traditional operation compared to the automated probe system depending on hydrology

Cross-sectional measurements

- Traditional method: multipoint measurements
- flow velocity and suspended sediment concentration (from samples)
- twice a year at ca. 70 cross-sections in the free-flowing river sections

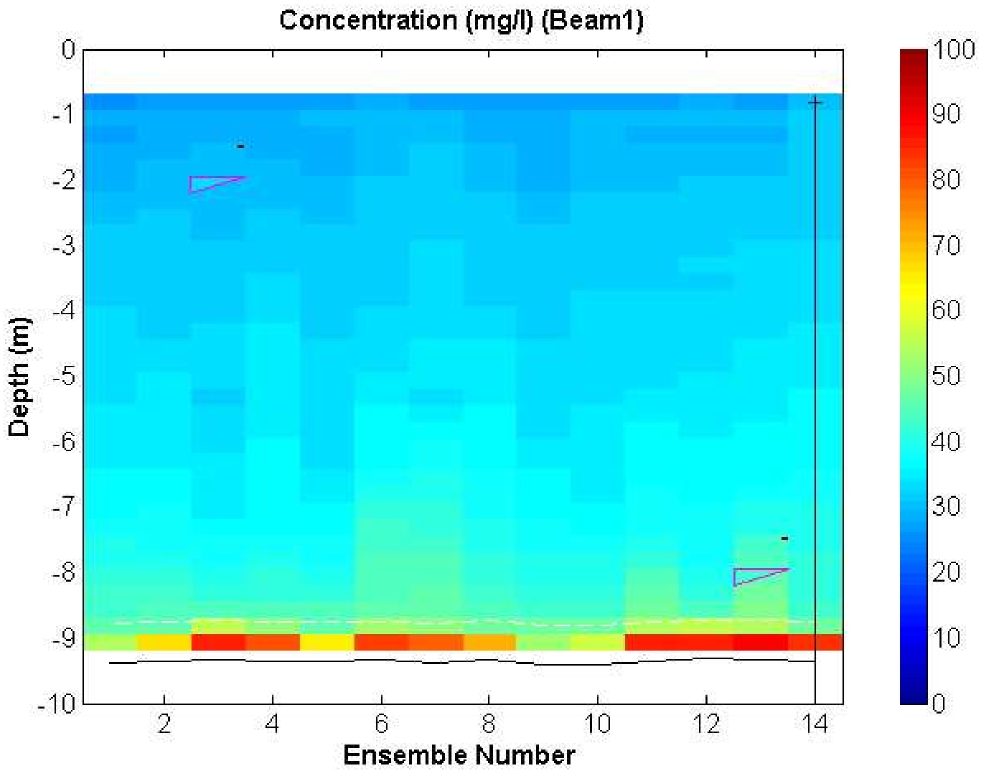






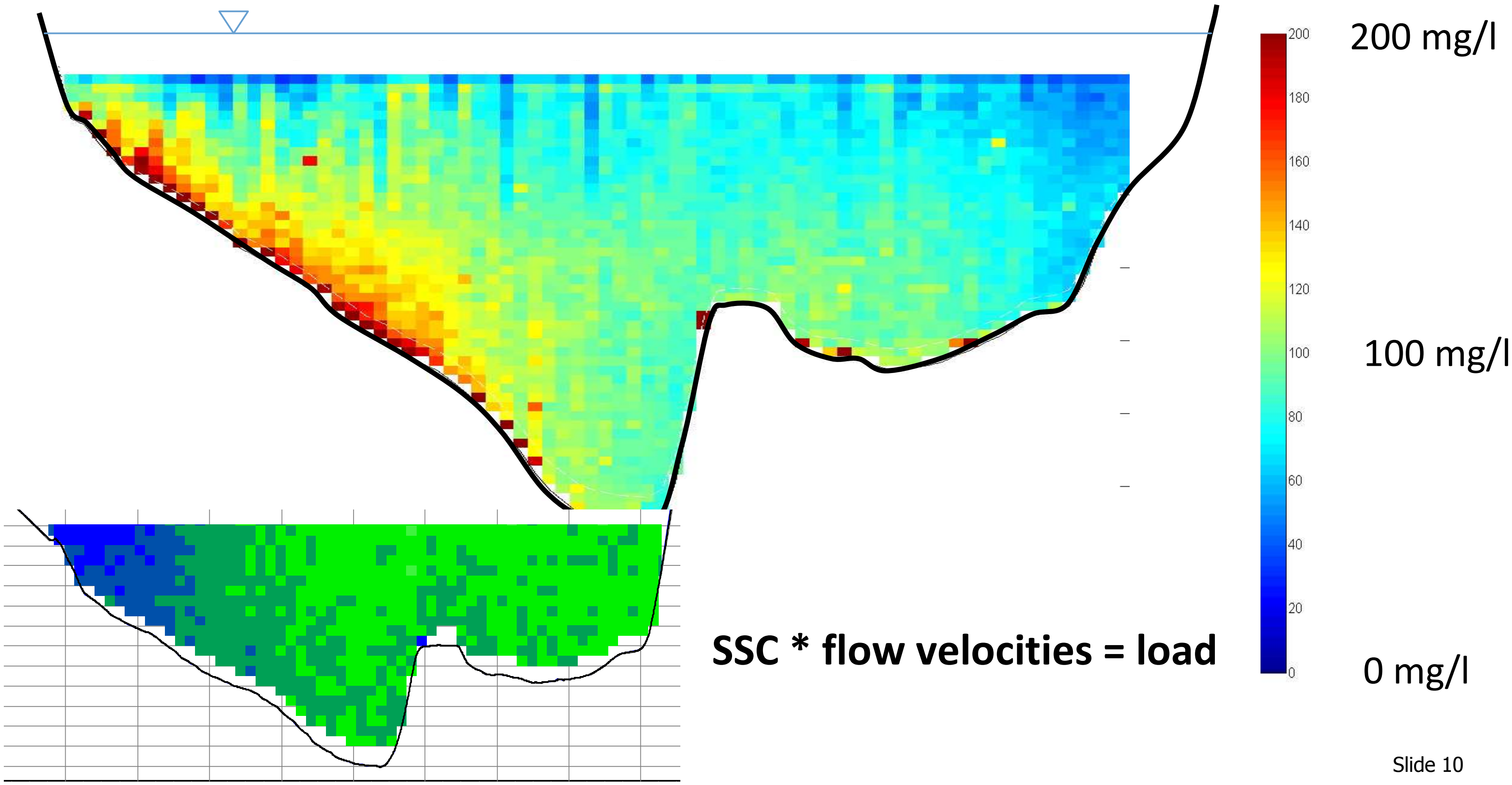
Cross-sectional measurements: ADCP

- calibration of back-scatter signal by ≥ 6 water samples per cross-section

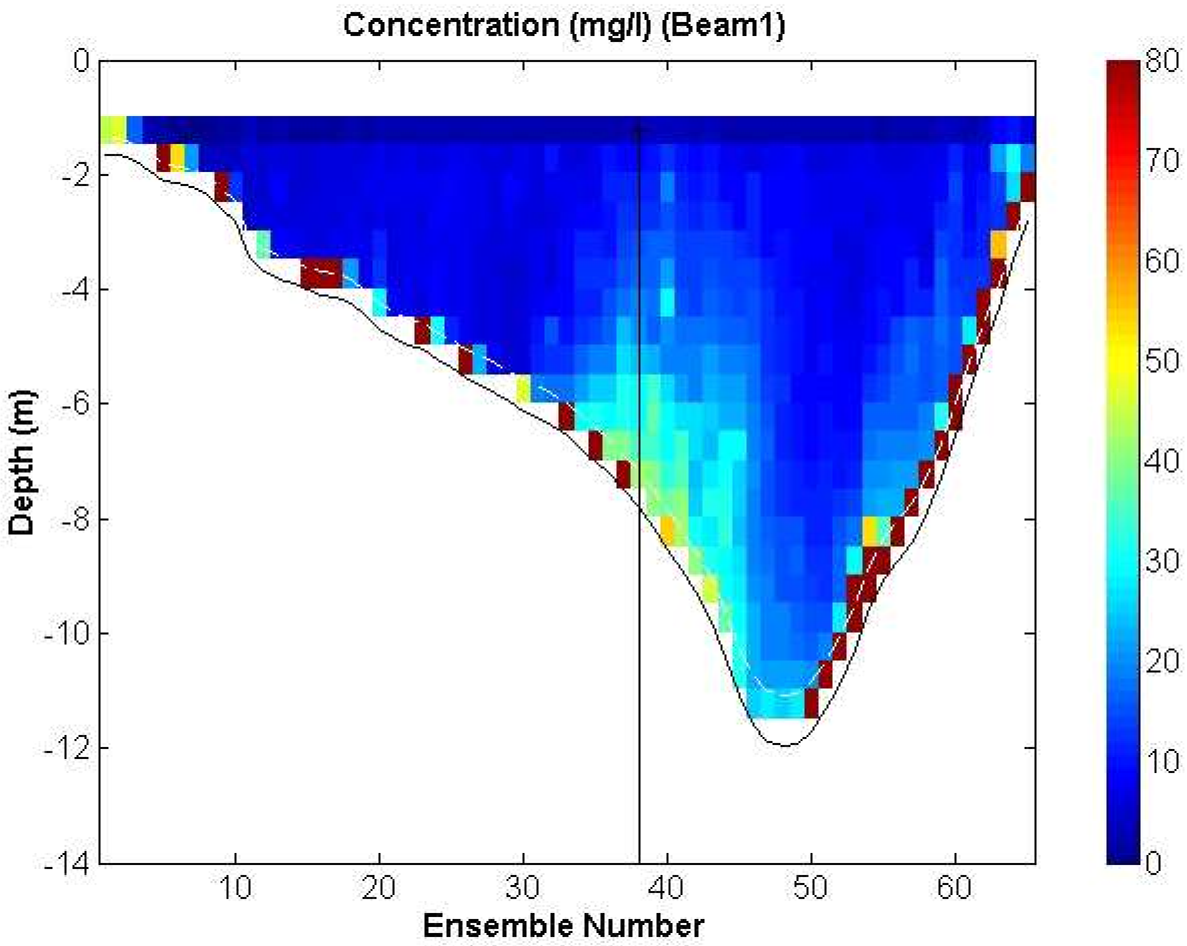


Cross-sectional measurements: ADCP

- ADCP-measured suspended sediment concentrations at Rhine-km 332.9

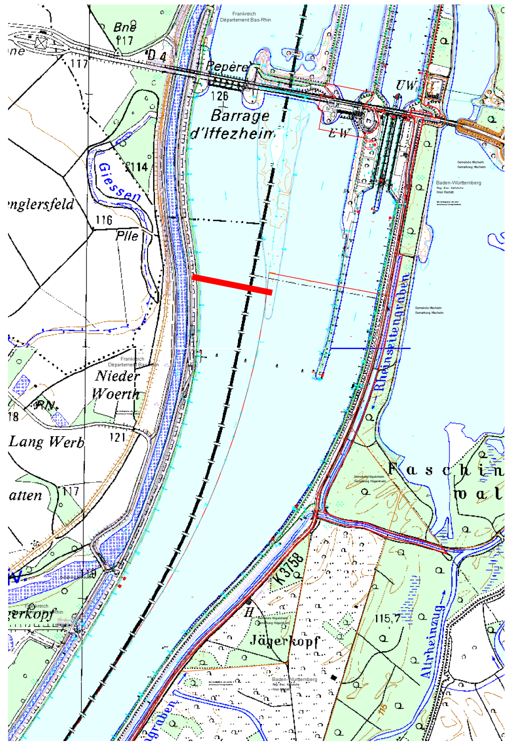


ADCP weir channel Iffezheim 15-05-2012



km 333.200

Cm = 15.4 mg/l



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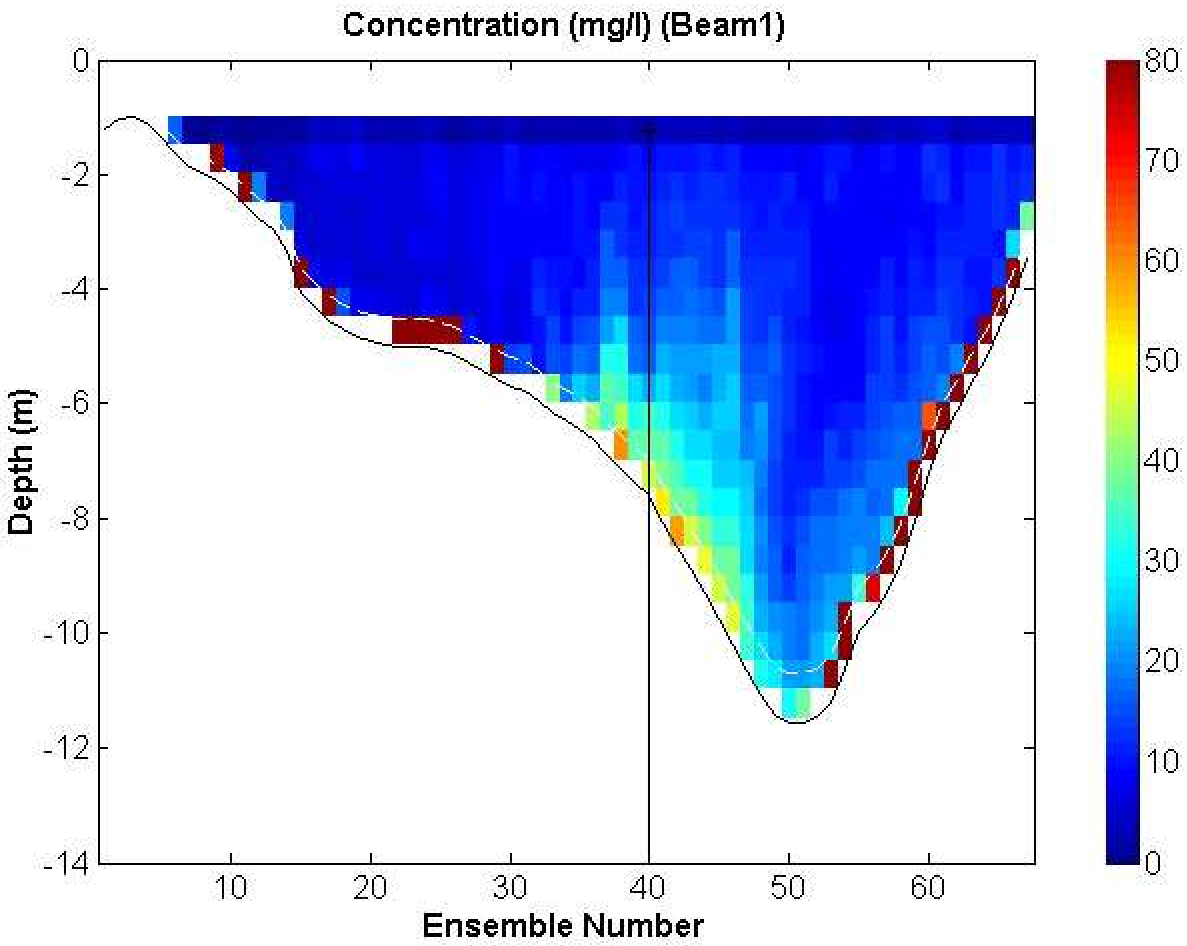
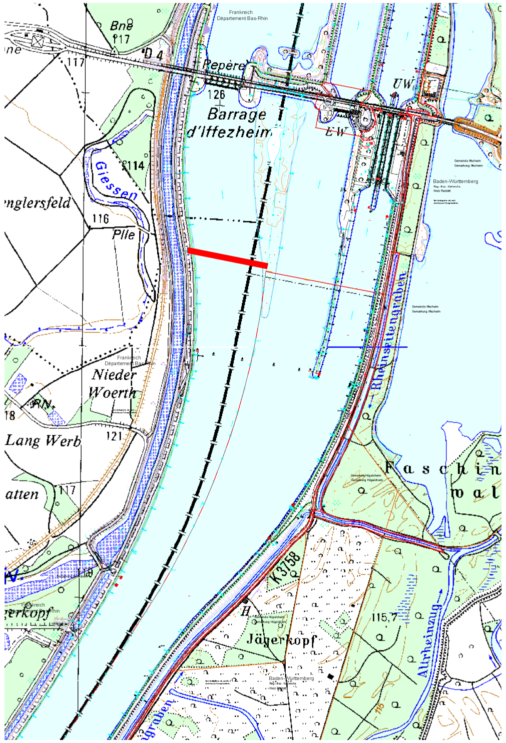


km 333.300

Cm = 13.4 mg/l



ADCP weir channel Iffezheim 15-05-2012

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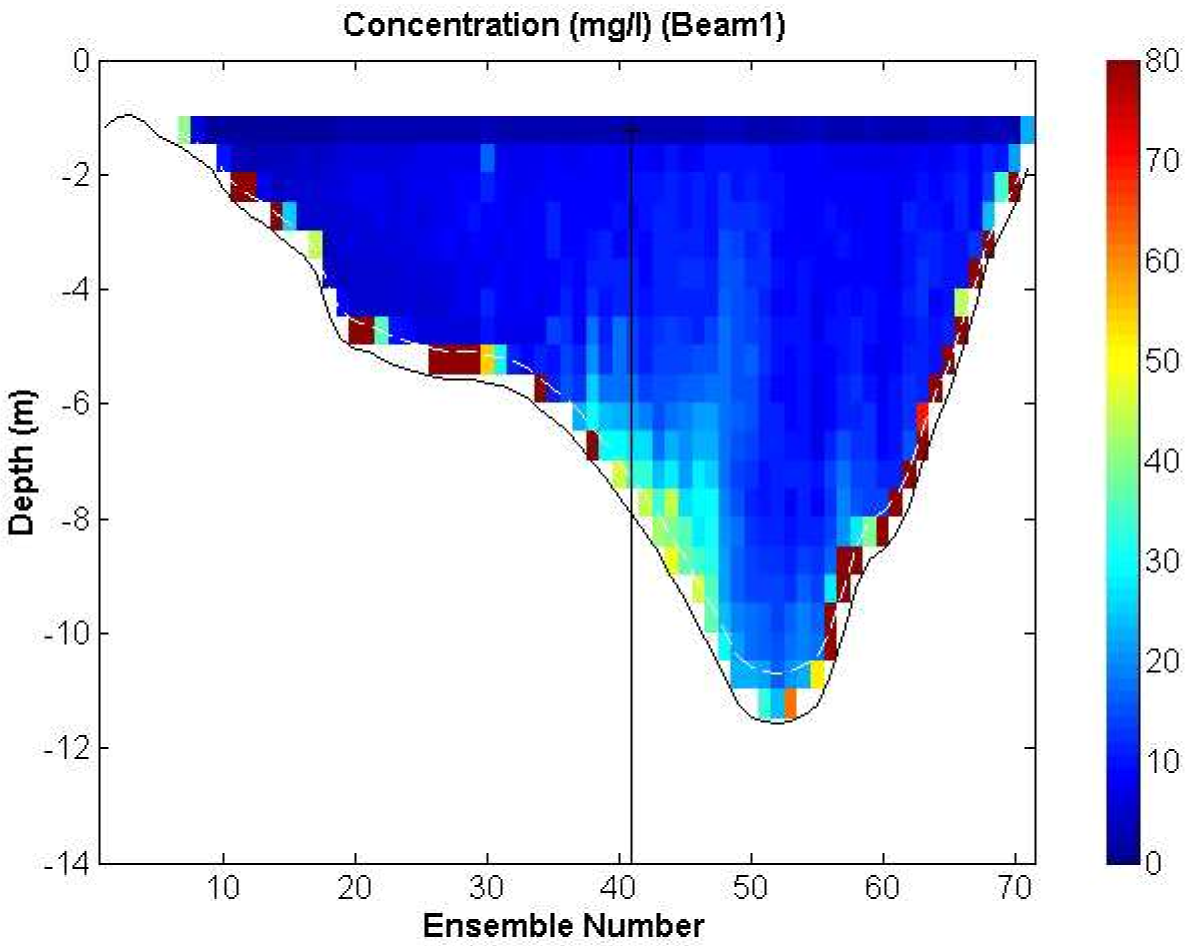
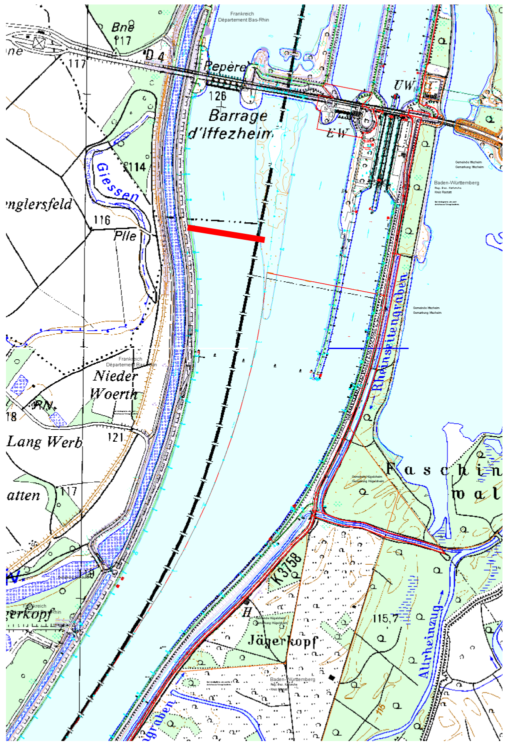
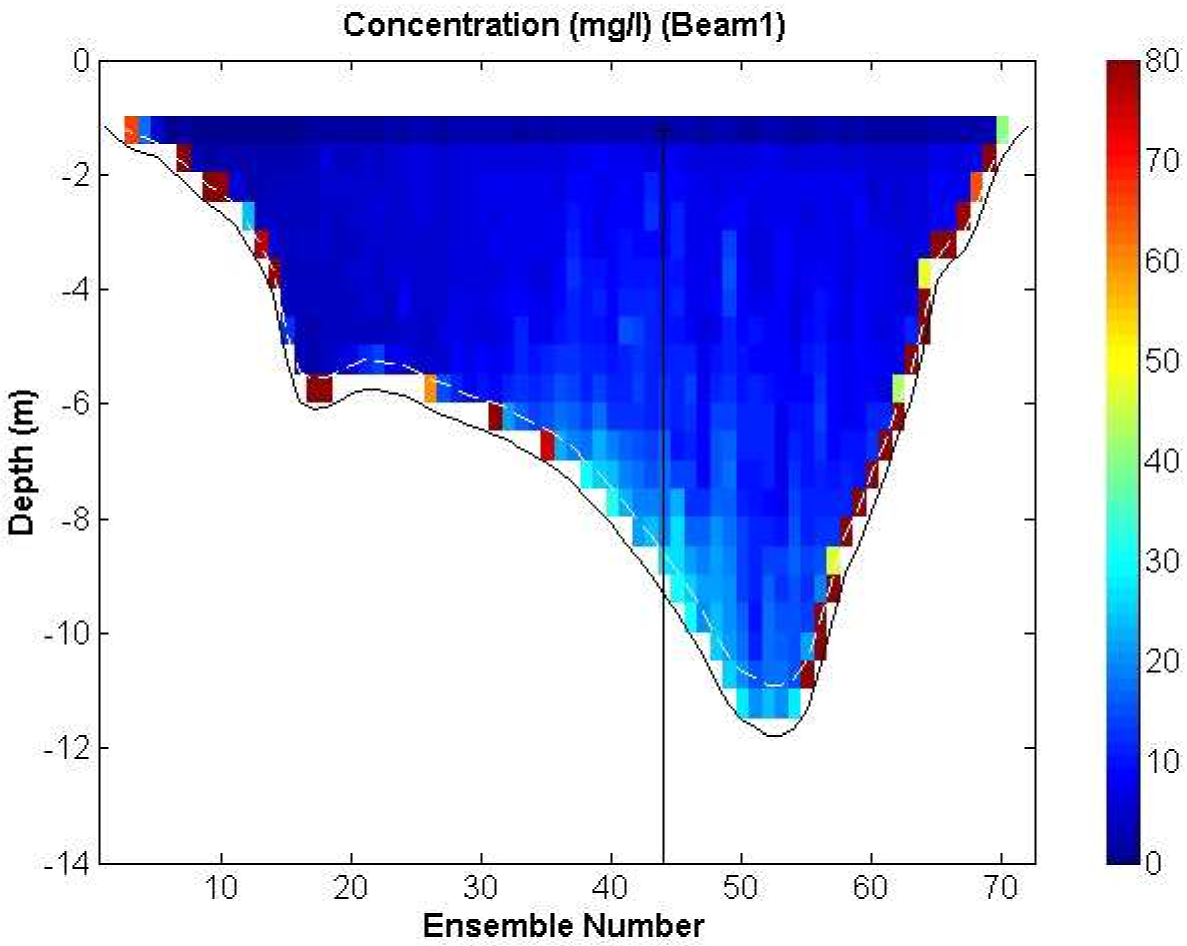


km 333.400

Cm = 13.0 mg/l

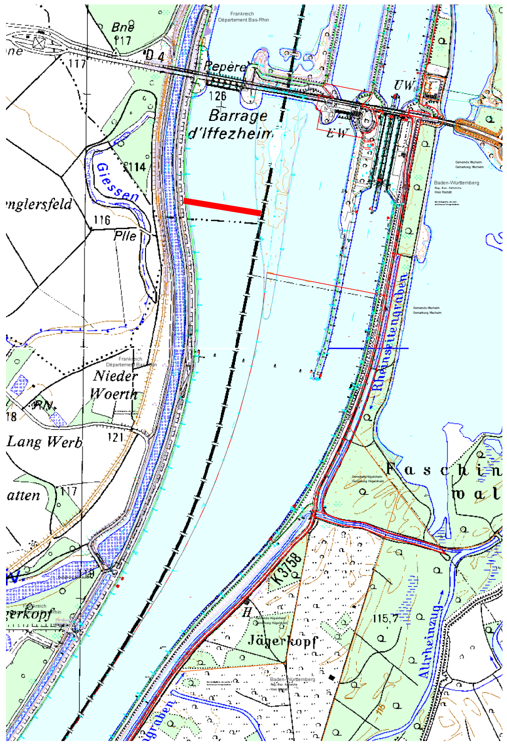


ADCP weir channel Iffezheim 15-05-2012



km 333.500

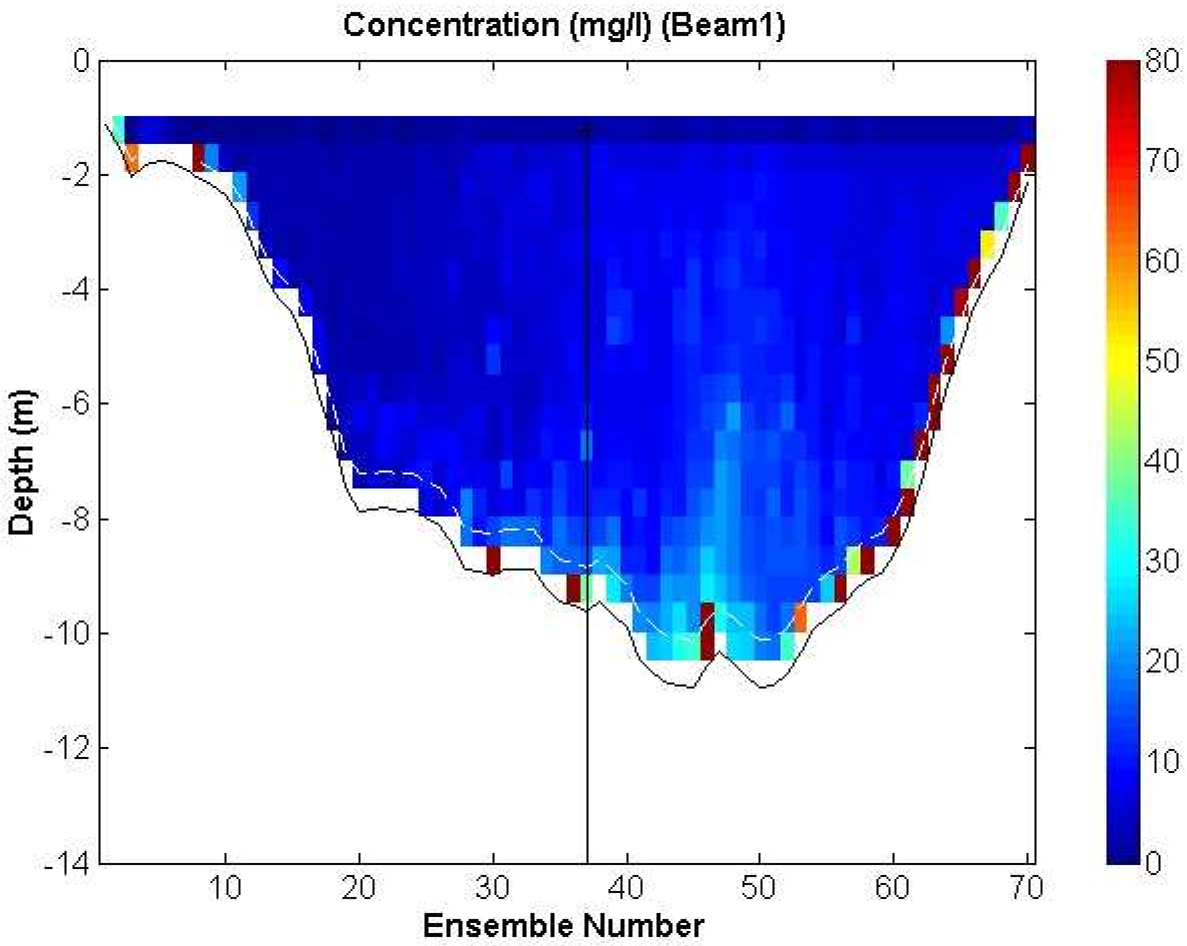
Cm = 9.8 mg/l

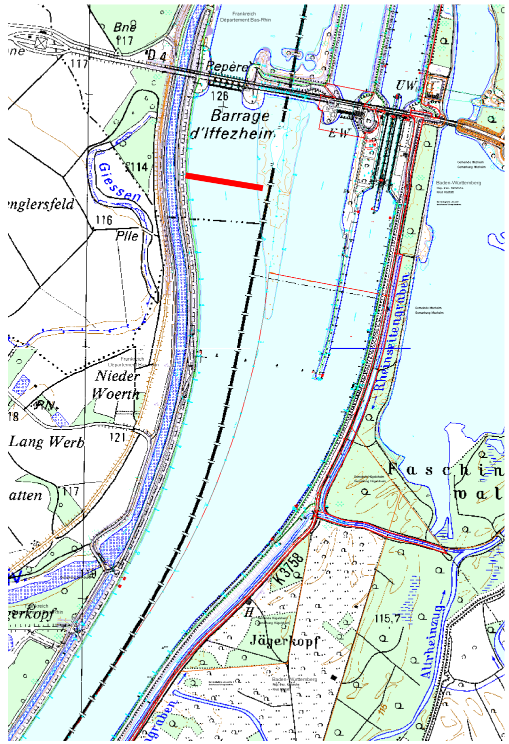


ADCP weir channel Iffezheim 15-05-2012

km 333.600

Cm = 8.9 mg/l



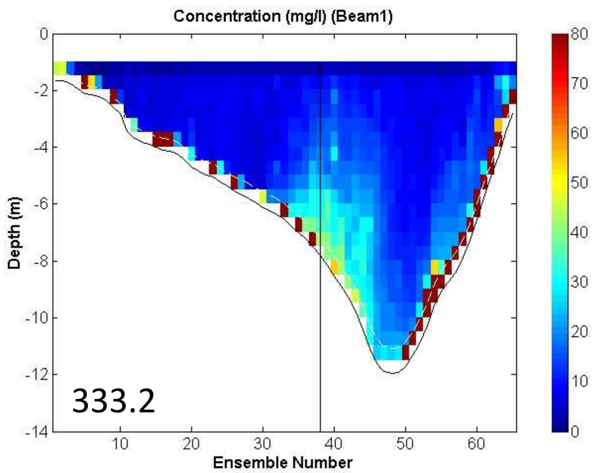


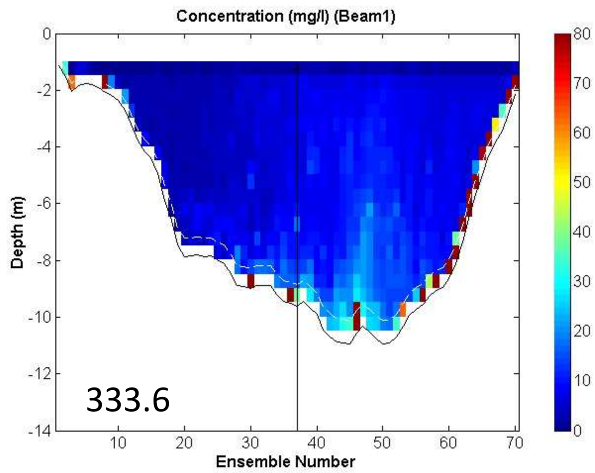
loss in suspended load from ADCP

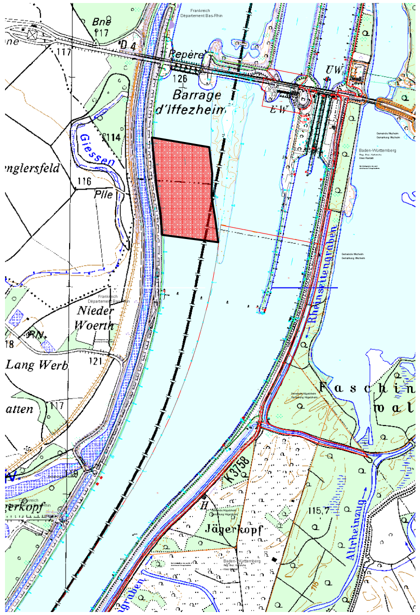
Rhine-km	Location	Date	discharge	load	load
			[m^3 / s]	[kg /s]	[t /d]
333.200	OW Wehr	15.05.2012	377	5,8	502
333.300	OW Wehr	15.05.2012	371	5,0	431
333.400	OW Wehr	15.05.2012	362	4,7	406
333.500	OW Wehr	15.05.2012	371	3,6	313
333.600	OW Wehr	15.05.2012	365	3,2	282

– 220 t/d

≈ 160 m^3/d

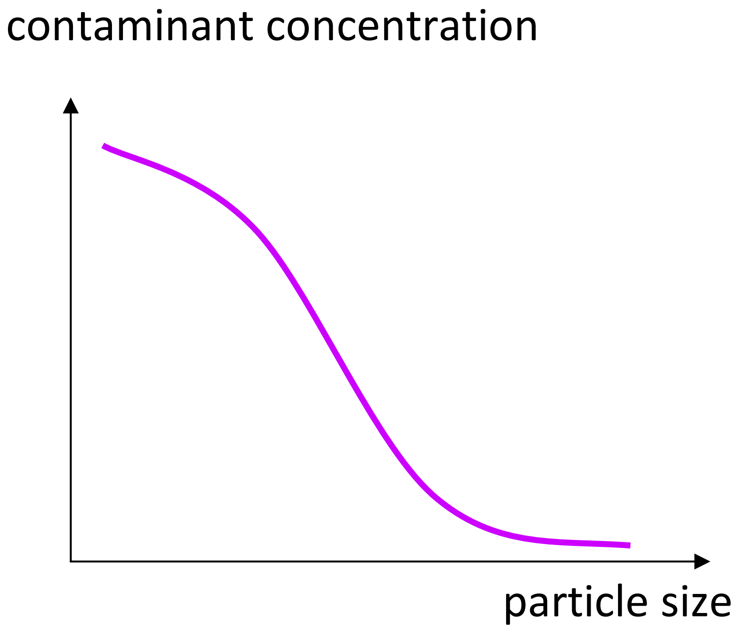


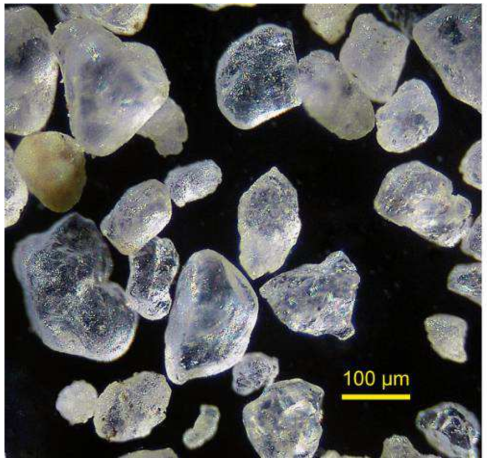


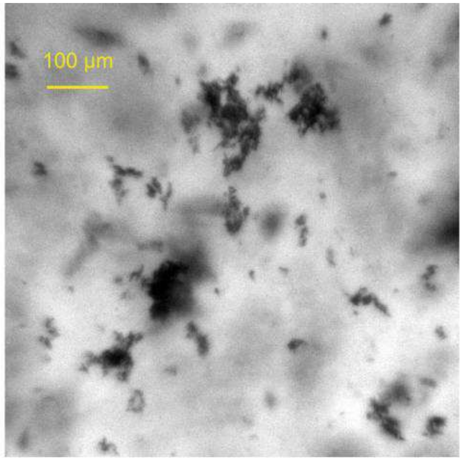


Grain size distribution

- Calculate characteristic grain size from concentration profile
- analysis of water samples (e.g. laser analyzer)
- in situ methods







in situ measurement of grain size: AELLO

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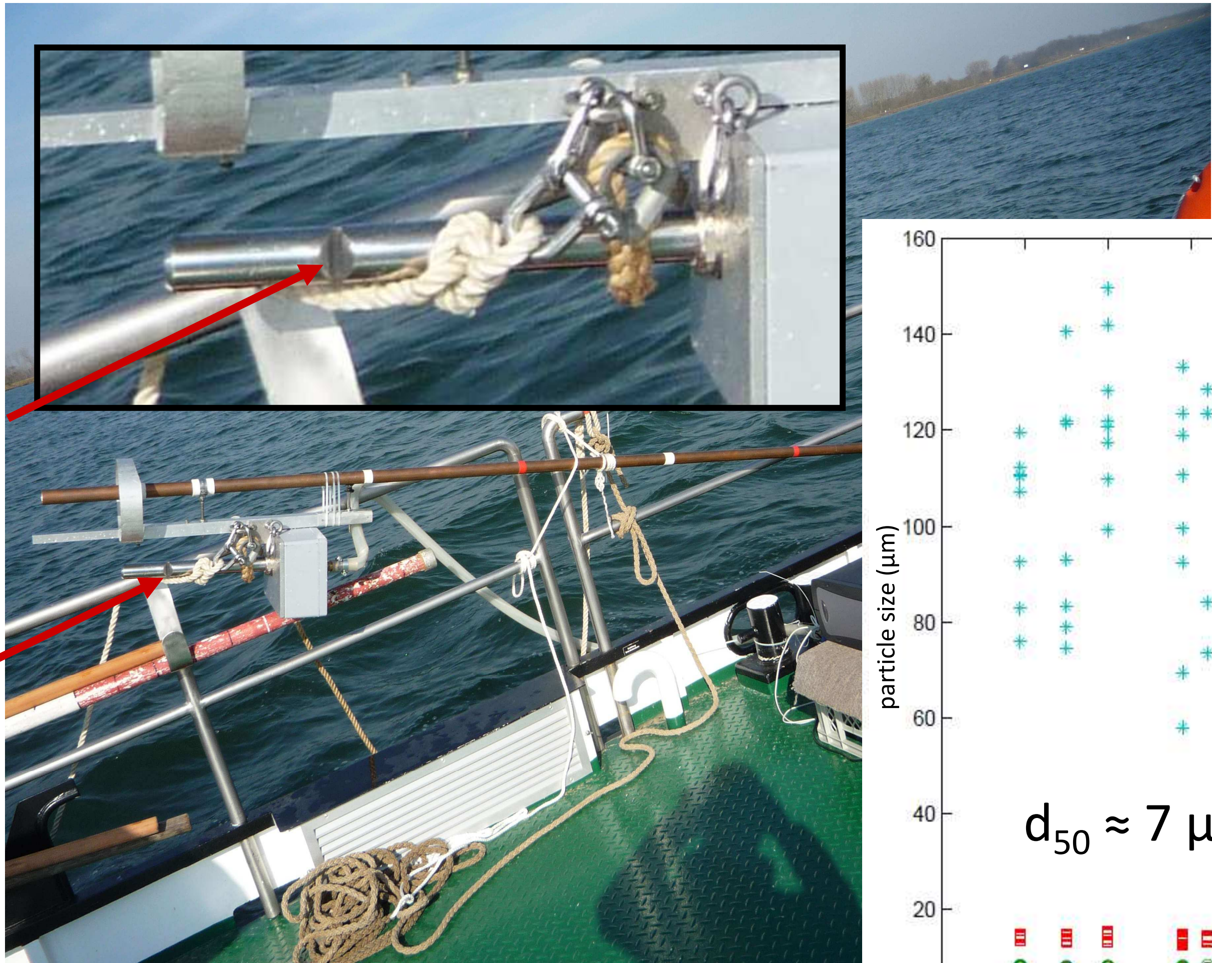
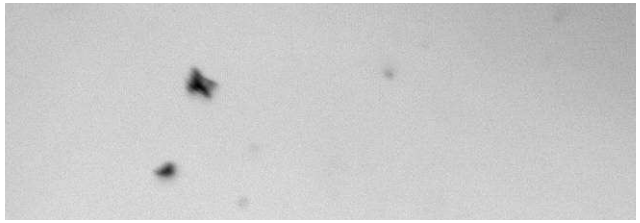
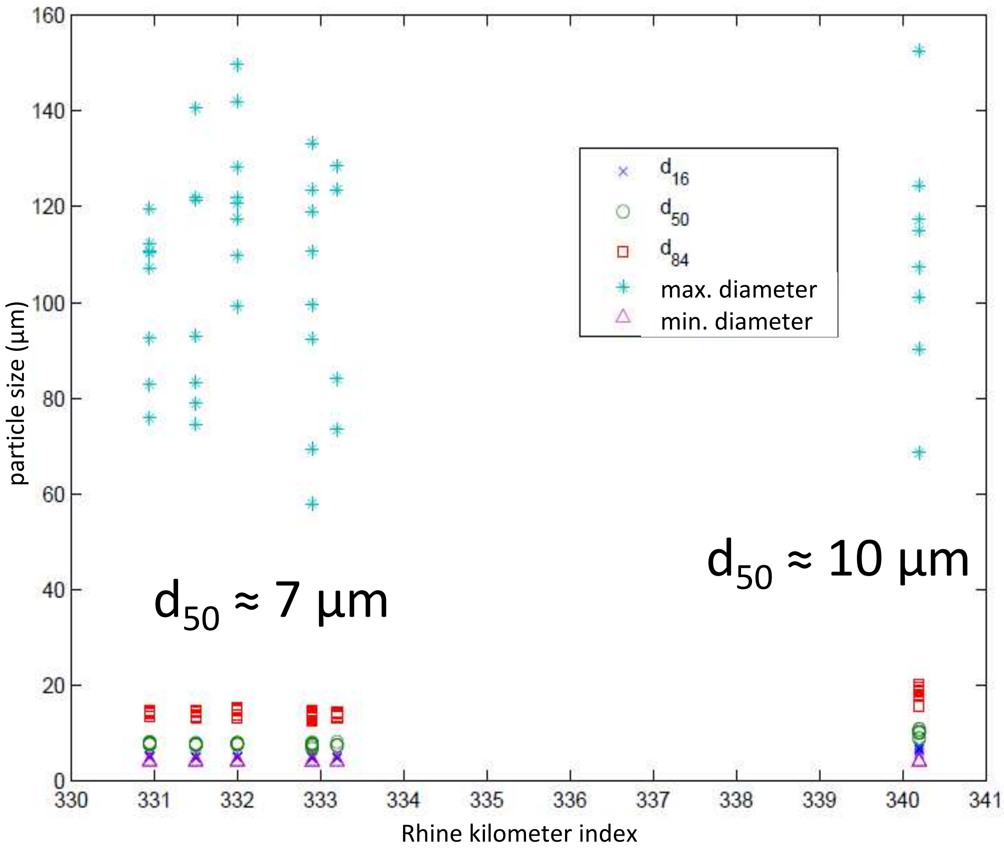
- field campaign during low flow conditions in March 2011



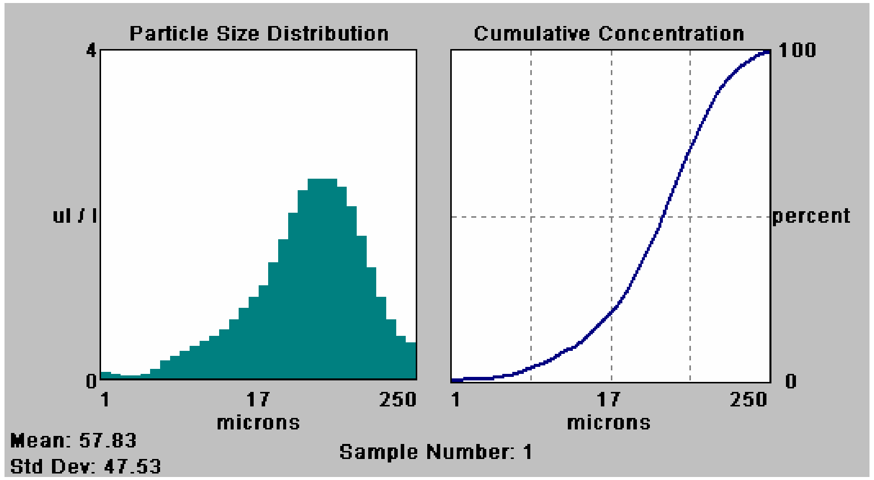




source: Irina Klassen, KIT

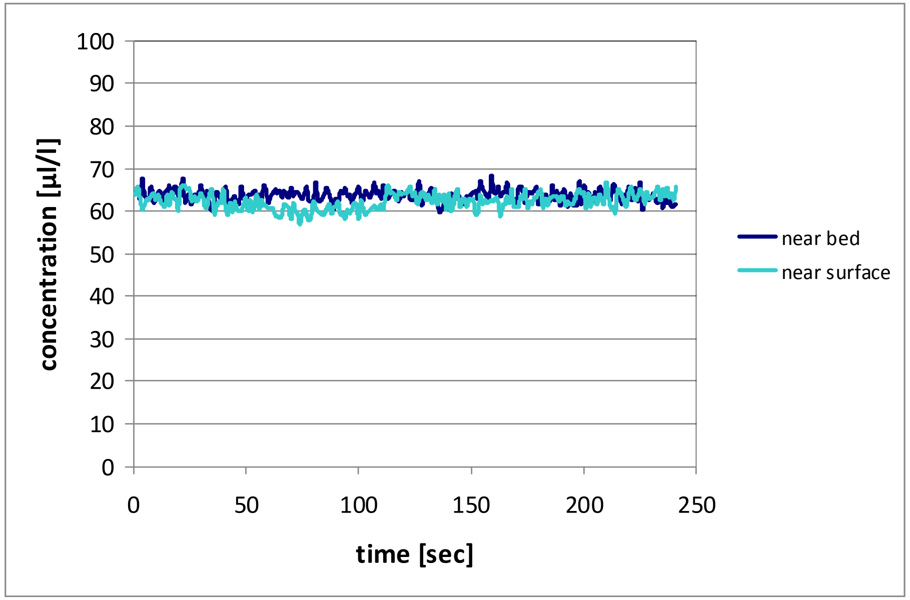
in situ measurement of grain size: LISST

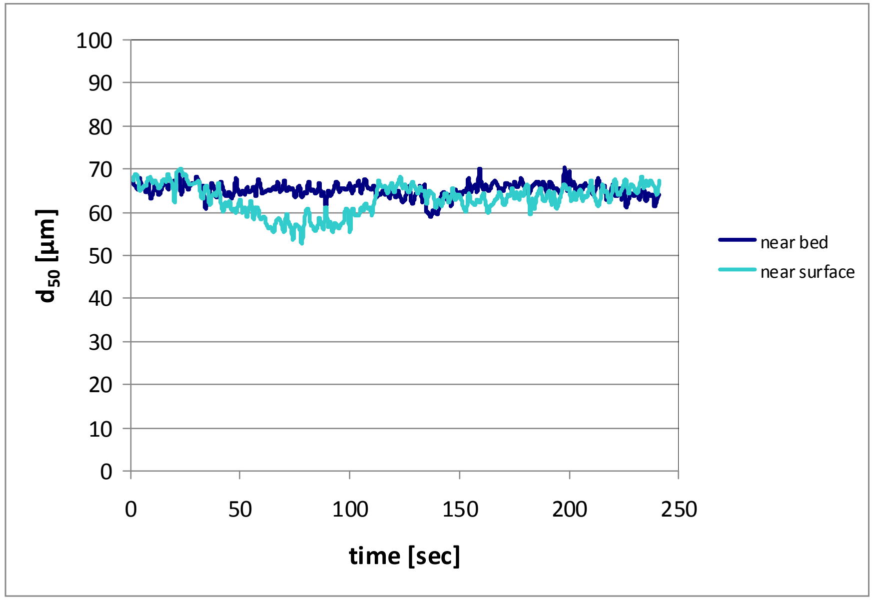
- laser scattering
- volumetric SSC and grain size distribution

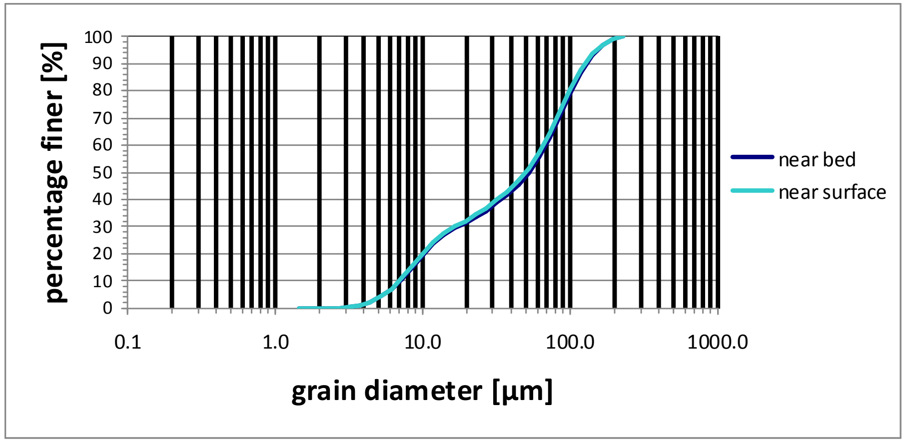


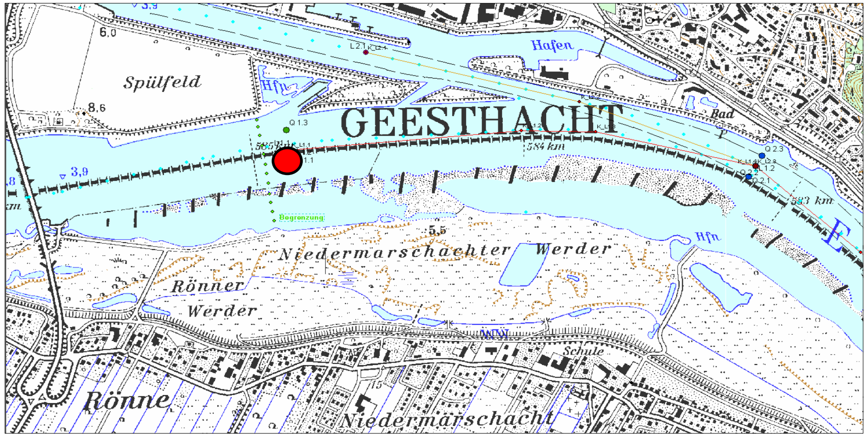
Time series of grain sizes, example Geesthacht

- LISST: measured at one point in two depths









source: Stefan Haun, NTNU

Thanks to

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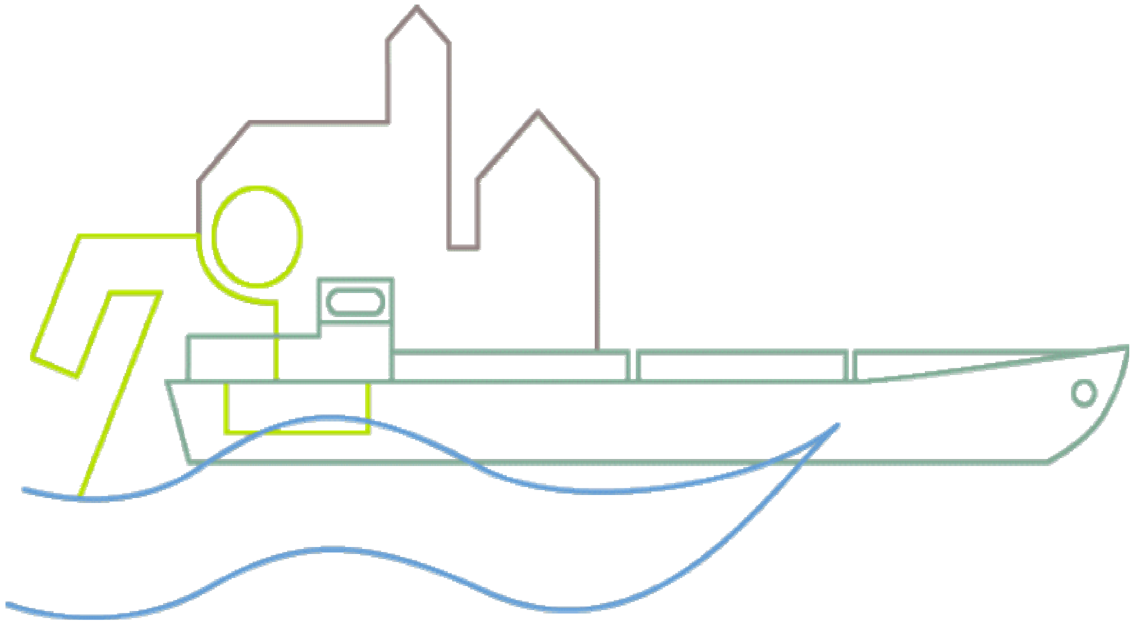
...

bfg Bundesanstalt für Gewässerkunde

WSV.de Wasser- und Schifffahrtsverwaltung des Bundes

NTNU

KIT Karlsruhe Institute of Technology



Thank you for your attention!

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